A More Sustainable Transport Future

The Effectiveness of Personal Rapid Transport in Edge Cities

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Submitted for the award of
Master of Built Environment (Research)

2012

To my lovely daughter Clara Teodora who wouldn’t be afraid to bungee jump from a bridge, but strongly refuses to get behind the wheel and drive over that bridge.

Certificate
of
Authorship / Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Monica Elena Zarafu

Acknowledgements

First and foremost, I would like to thank my supervisor, Associate Professor Heather MacDonald for her continuous support and guidance throughout the course of my candidature. Her invaluable help and carefully considered suggestions on much of my writing helped me finish this thesis in time. I am also particularly indebted to my co-supervisor, Dr Garry Glazebrook, who accepted me as an international student and without whom I would have not carried out this research at University of Technology, Sydney. His kind support, encouragement and assistance continued even after he left the University for a position within City of Sydney.

I am also sincerely grateful to Professor Peter Newman and Professor Anthony Capon for the opportunity to be part of the collaborative research program under the CSIRO Climate Change Adaptation flagship cluster. I would like to express my gratitude towards UTS, Curtin University and CSIRO, who provided the funding for my research. I would also like to give my thanks to Research Fellow Katrina Proust and Associate Professor Barry Newell, who welcomed me and helped me integrate within a great team of valuable scholars.

Professor Martin Lowson from University of Bristol, founder and president of ULTra PRT was generous with his time during my visit in London. A sincere thank you to Martin and Mark Griffiths who facilitated my visit to ULTra PRT at Heathrow, and many thanks to all the staff who spent time answering all my questions about PRT. I would also like to acknowledge Robbert Lohmann from 2getthere and Martin Pemberton from Vectus, and thank them for their helpful information and insights into the PRT concept and technology. Special thanks to Richard Lowson, who was always there to ensure that Martin would make time to answer all my questions. Many thanks are also directed towards John Lees-Miller who provided the expert version of the ATS City Mobil software.

I would also like to acknowledge the great assistance given to me by Evelyn Karantonis and Blake Xu from the Bureau of Transport statistics, who provided large amounts of data on request although they were overwhelmed with ministerial and departmental work.

Thanks are owed to Charlie Lin who assisted me with patronage data for rail stations. Genuine thanks to Anthony Ogle from City of Ryde for his time spent guiding me through the politics, rules and regulations applicable to the area. I still owe him a coffee and my gratitude for influencing me to think differently.

I would also like to send thanks to Dr Peter Rickwood, Dr Sumita Ghosh and Dr Janet Ge for their helpful feedbacks from my Master's assessment, and thanks to Peter McNeil and Ann Hobson for organising very helpful workshops. My thanks also go to Nick Chapman, who has promised to be the first person to try the "flying cars", as he calls them. Thanks to the occupants of our "Active Brains" office for a quiet and stimulating environment. A great thank you to Alejandra for her help in integrating me into the postgrad world and for always having an answer to my questions.

And last, but surely not least, thanks to my great and lovely family. To my husband Marius who did a great job in editing the thesis even in the long night of the culmination of my work with the writing of these thanks, and thank you to my daughter Clara who gave up her time with friends and many potentially early nights to correct my writing errors. Thanks to my parents and my brother in Romania who supported any decision in my life, even if it meant a very painful separation.

Lastly, a big thank you to all those who have witnessed the progression of my work and provided their encouragement and support when it was most needed.

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Abstract

This thesis investigates how effective a Personal Rapid Transit (PRT) system could be in addressing sustainability challenges in edge cities. The study aims to enrich debates and decision-making processes over a future vision of more sustainable polycentric cities.

A case study of an 'edge city' within an emerging Australian multi-centred form examines the potential of a PRT system to change travel choice in a car-dominated urban form. The Macquarie Park case study not only extends the number of studies which identified the evolution of edge cities in a variety of national and continental settings, but demonstrates that edge cities have also evolved in Australia over the past two decades.

The thesis develops a design-based solution for increasing the accessibility of main transit nodes in Macquarie Park through a PRT network, and tests its service performance under different levels of demand, during peak and off-peak hours for an average weekday. Simulation results show a positive system performance, at high capacity demand during busy commuting hours and at low capacity demand for all-purpose trips during non-busy hours. The high theoretical performance and the positive return rate of investment draw the conclusion that PRT may be worth considering in future strategies.

This study presents a preliminary analysis of selected environmental, urban and health impacts compared to a business as usual projection of current transportation trends by 2031 and current planned transport improvements. The analysis confirms the findings from other studies regarding the low environmental and urban impacts of the PRT system. Potentially, the urban space released by retrofitting edge cities with a PRT system could be redesigned to encourage greater physical activity and social interaction. The original contribution of this research to the body of knowledge is the analysis of health impacts that a PRT system might have. Nevertheless, it points to further research which should be undertaken to fully understand the health implications of implementing such a novel transport system.

The thesis concludes that an non-traditional transit mode such as Personal Rapid Transit could bridge the gap between the car-dependent urban forms we have inherited and the transit-focused urban future that is essential in order to meet sustainability goals.

Chapter 1. Introduction

1.1. Introduction

This chapter provides a broad overview of the research problem, before narrowing the research focus to more specific questions that address the effectiveness of a Personal Rapid Transit system in edge cities and its contribution to more sustainable transport options for the emerging multi-centred cities of the future. The concept of Personal Rapid Transit is briefly presented, and some of its applications are highlighted. The critical issue of car dependency is discussed, along with different approaches to diminish the reliance on private cars in existing cities. The 'edge city' is identified as one of the newly emerging city forms displaying highly car-dependent travel patterns. However, sustainable transport options for retrofitting the existing edge cities have not been well analysed, and investigating different strategies for addressing the sustainable transport needs of edge cities is the aim of this thesis.

The nature, scope and key motivating question for this study are presented in Sections 1.3-1.4. The framework used to address each specific research question is also presented. The fifth section provides an overview of the research design and methods employed in this investigation. The sixth section explains the contribution of this research to the body of knowledge. The last section includes an outline and illustrative representation of the structure of this thesis.

1.2. Statement of the research problem

> Sustainable transport will require ways of accommodating car ownership but not car dependence.
> Peter Newman and Jeff Kenworthy, Sustainable Urban Form: Transport Infrastructure and Transport Policies (2007, p. 293)

Increasing use of petrol and diesel-fuelled motor vehicles is identified as one of the major threats to sustainability, with multiple costs for the environment, economy and society (UNEP 2011). Transport by private cars is convincingly associated with resource use, energy consumption, greenhouse gas emissions, air pollution and noise pollution. The external costs associated with congestion and the impact on employment levels, productivity and Gross Domestic Product (GDP) reflect the negative economic impact of transport by car (Geurs and Van Wee 2003; Glazebrook 2009; Trubka, Newman and Bilsborough 2010; UNEP 2011). The social costs are a result of the road transport systems influence on human health, safety and isolation (Appleyard 1981; Steg and Gillford 2005; UNEP 2011).

> The massive use of motor vehicles is a telling example of a large-scale commons (or common-resource) dilemma, reflecting a persistent conflict between many individual interests on the one hand, and a limited number of collective interests on the other hand (Vlek 2007, p. 434).

Finding a sustainable equilibrium between individual interests (travelling fast and comfortably) and collective interests (enhancing public health, and preserving the environment, natural resources and biodiversity) is a challenge in designing sustainable transport policies. Many factors account for the attachment of people to cars: freedom, autonomy, pleasure of driving, resistance to changing a habit, convenience, and time (Garling and Steg 2007). Moreover, many cities over the world, especially in the US, Canada and Australia display land use patterns that induce car dependency, as many people do not have any other choice of travel, except “by the inconvenient, irregular bus services or by long bike or walk trips” (Newman and Kenworthy 2007, p. 296). Furthermore, the construction of high-speed roads over the last decades has increased the difficulty of developing more sustainable transport and land use patterns.

Planning policies for sustainable development are inherently complex not only for the low-density residential suburbs but also for the emerging polycentric urban forms which require complex regulatory instruments. Changing the land use is difficult in any settled urban form (Lachapelle and Franks 2009) and even more difficult in ‘edge cities’ - urban sub-centres emerging at major traffic nodes, around airports, shopping malls or business parks, which include higher concentrations of employment than housing and are often poorly integrated into the larger regional context, and thus highly car-dependent. Redeveloping existing buildings to accommodate higher densities and mixed land use, and especially to provide an alternative to car dependence is difficult. Retrofitting existing edge cities is a challenge for the planners of the 21st century. This thesis is concerned with identifying a less unsustainable transport option for ‘edge cities’ to bridge the gap between the existing car-oriented urban form and the transit-oriented urban future that is essential for sustainable development.

A mass transit form, which borrows the attributes of personal cars and has a low environmental impact, is the Personal or Group Rapid Transit (PRT/GRT) system. Some researchers argue that it could contribute to a shift from car to public transport (Lowson and Lowson 2010; May and Muir 2009; Muller 2011). The system is based on small vehicles (usually up to eight seats for PRT and up to twenty seats for GRT), individually controlled and electrically driven, which run along dedicated narrow guideways. The first GRT system was built in Morgantown, Virginia for the University of West Virginia in 1972. Since then, many papers have been written about the PRT concept, most of them advocating its merits. The critics of PRT systems argue that the elevated guideways will be too expensive, aesthetically unacceptable and the system will not be able to handle large volumes of passengers (Mims 2011; Setty 2009; Vuchic 1999; Vuchic 2007).

> … the main objective of the PRT concept – to match the positive features of the private auto such as privacy and direct station-to-station travel - cannot be achieved without experiencing the major drawbacks of the auto/highway system in urban areas, such as high costs, large space requirements, low capacity, and poor reliability (Vuchic 2007, p. 474).

Many prototypes and pilot projects have been developed all over the world and in 2010 two fully operational PRT systems have been built - one in Masdar City, Abu Dhabi and another at Heathrow Airport, London. The third operational project is scheduled to open in 2013, in the Suncheon Bay coastal wetlands in South Korea. The Indian city, Amritsar, which is home of the Golden Temple along with many other religious and heritage sites, recently announced approval of a contract for building a PRT system by 2014 (The Times of India 2012).

The PRT concept has drawn the attention of many policy-makers, planners and transport authorities. Its potentially low environmental impacts and high levels of comfort, safety and convenience for individual passengers, have been investigated by scholars, planners, and local governments. In the US, the most recent PRT studies have taken place in San Jose, Portland, New Jersey, and Tyson Corner (ULTra Global PRT 2011). In Europe, several national agencies and local authorities commissioned extensive PRT studies between 2000 and 2010. Cardiff, Corby and Bath in the UK, Eindhoven in the Netherlands, Ciampino in Italy, and Huddince, Uppsala, Vasby and Sodertalje in Sweden are a few examples (Carnegie et al 2007; Karlsson 2011; Konradsson 2011; Nelstrand 2011; ULTra PRT 2009). A Sydney-based company developed a novel concept – Austrans - in the late 1990’s, based on its own patented concepts of ultra-light rail technology and high performance parameters (Austrans 2005). However, there is limited knowledge about PRT in Australia, compared to Europe and the US. This research will contribute to the continuously growing interest, both public and academic around PRT. Furthermore, the investigation of the potential health impacts of the PRT system developed in this thesis is a novel one. I am not aware of any existing research on the effects of the PRT system on public health.

Supporters of the PRT system envisage it serving airports precincts, large campuses or even an entirely car-free city, for instance Masdar City. A 'circulator' system which may include a PRT network in the future is proposed for Tyson Corner, the archetype of the American 'edge city', but PRT's applicability to edge cities has not been investigated to date. Moreover, sustainable transport options for retrofitting existing edge cities have not thoroughly analysed. This represents a serious gap in the knowledge required to evaluate efficient land-use and transport options for the multi-centred metropolitan region.

1.3. Aim and Scope of the Thesis

The aim of this thesis is to investigate how effective a Personal Rapid Transit (PRT) system could be in addressing the sustainable transport needs of edge cities, and hence in contributing to more sustainable transport options for the emerging multi-centred cities of the future.

The central question addressed by this thesis is:

To what extent could PRT address sustainability challenges in edge cities?

This thesis investigates whether PRT could be a feasible, cost-effective and sustainable alternative transport solution to retrofitting a key 'edge city' in an Australian context.

Selected environmental, urban and health impacts of different land use and transport scenarios are evaluated. The extent to which this non-conventional mass transit system could contribute to changing travel patterns by offering high transport service performance for *individuals*, while improving the accessibility of public transport services for large *volumes* of passengers is discussed in the final chapter.

Kenworthy (2006) developed a simple conceptual model for transforming the existing cities and new developments into 'eco-cities', a definition of more ecologically sound and liveable cities. Kenworthy argues that a different system approach is needed to transform existing cities into eco-cities. Rather than extrapolating existing trends ('predict and provide'), he argues that an appropriate systems approach should be based on "vision-oriented, reformist thinking ('debate and decide') (2006, p.85). However, debate will be more effective if it is based on an understanding of the potential offered by specific alternatives. There may be a role for 'predict' before decisions are made about what to 'provide'. This study aims to open up the debate about sustainable transport alternatives for edge cities, by evaluating the feasibility and impacts of an alternative dismissed by some as unrealistic.

This approach draws on Mees's argument that the network planning strategy should initially consider a "regional transport and land use plan that sets serious targets for modes shift to more sustainable forms of transport, and back these targets with appropriate institutions and resources"(2009, p.166). He advocates restructuring public transport as a priority, and investing in a multi-modal transport network which should offer the "anywhere to anywhere" services, similar to that provided by cars (Mees 2009, p.166).

This study examines a non-traditional option for improving public transport accessibility and enhancing active travel at the local level, in order to increase public transport attractiveness and thus reduce car dependency at the regional level. PRT's potential effectiveness in 'edge cities' is analysed with specific application to an Australian case study. It is recognised that 'edge cities' are not the only type of form found in multi-centred cities. However, they have become increasingly common reflecting decentralisation processes, economic factors and car-based transport systems. They pose special problems for providing more sustainable options.

Given the very small number of PRT type systems in actual operation, this analysis utilises desk research based on data collected from operational prototype systems and from simulations. The methods employed are presented in more details in Section 1.5.

In this thesis, I develop a possible PRT network for an edge city (Macquarie Park) that forms the basis for simulations that allow me to test out the level of service provided, to compare the potential PRT system's outcomes with those of two alternative scenarios. The scenarios are based on government projections of a continuation in current demand and of a future scenario with greater use of conventional public transit (buses and trains).

The following section explains the structure of the thesis, showing how the major research questions are addressed. An illustrative representation of the thesis structure is included in the last section of this chapter.

1.4. Thesis questions and framework for analysis

To address the broad question outlined above *(To what extent could PRT address sustainability challenges in edge cities?)*

I investigate three more specific questions:

Question 1:

What are the sustainability challenges of edge cities?

The literature review in Chapters 2 and 3 addresses this question, narrowing the discussion, from examining the sustainability challenges for urban transport in postmodern multi-centred cities, to more specific challenges of an 'edge city' built environment.

Chapter 2 examines the evolution of the concept of sustainability from a global to a local agenda, and explores different definitions of sustainable urban transport. It reviews the evidence for the impacts of the current transport trends on the environment, economy and society, with a focus on transport related emissions and public health impacts. Chapter 2 also evaluates the claims made for the Personal Rapid Transit system – that it is a more sustainable transport form – using case studies of operating PRT systems.

Chapter 3 explores the sustainability challenges of polycentric cities across the world, examining how development strategies and planning policies have responded to these challenges. It analyses trends in Australian cities towards multi-centred urban forms. I examine the concept of the 'edge city' in a variety of national and continental settings, and identify a similar development pattern in the newly specialised centres within the "City of Cities" multi-centred form of Sydney. Next, the chapter discusses the characteristics of the built environment in edge cities and the sustainability challenges of retrofitting their existing urban form. The final section reviews recent research on the impact that the built environment has on public health, bringing the discourse back to the metropolitan context.

The second specific question, addressed in Chapters 4-7, is:

Question 2:

How effective is the Personal Rapid Transit system in retrofitting edge cities?

In order to answer this question, Chapter 4 sets the context for the analysis through a detailed description of Macquarie Park, the selected case study of an Australian 'edge city'. Aside from the description of structure, history and built form, the chapter reviews current and projected employment and land use policies, and discusses transportation patterns in the study area. Based on this, Chapter 5 focuses on modelling different scenarios designed to allow reasonable estimates of the patronage and revenue a PRT system could attract, based on those estimated by the existing transport plans for the area. A concept design for a PRT network as a feeder for the existing major transit nodes in Macquarie Park is developed in Chapter 6. Simulations are used to estimate passenger waiting time, travel time, and vehicle kilometres travelled, for high capacity demand during peak hours, and low capacity demand during off-peak hours. Finally, the capital and operating costs of the PRT system are estimated in Chapter 7 in order to evaluate if a PRT system in Macquarie Park is a worthwhile investment.

The aim of this exercise is to determine whether a PRT system could deliver adequate passenger service performance at different levels of demand, and to evaluate what sort of stock investment would be needed to offer the proposed level of service.

The final question, addressed in Chapter 7, is:

> Question 3:
> ***What are the likely environmental, urban, and health impacts of different land use and transport strategies in edge cities?***

Environmental and public health impacts, and infrastructure investments, are all metropolitan-scale issues. Understanding the city-wide impacts of different scenarios requires a metropolitan-scale investigation, which is beyond the scope of the present study. I develop and compare alternative strategies to enable more sustainable travel patterns in the selected study area, Macquarie Park. The outcomes from the PRT simulations are used to compare the likely environmental, economic and health impacts of a scenario based on increasing local access by PRT to those of other two scenarios: a projection of current transport trends by 2031 and the current strategy for the area.

The environmental and urban impacts of each scenario are analysed based on energy use, emissions, noise and land area required for car parks in each scenario. Other environmental impacts, for instance loss of biodiversity or resource use are not discussed within this study.

The analysis of the social impact of each strategy is restricted to the impact on public health and transport-related safety; other social issues, such as equity or community severance are not analysed in this thesis. The health impact is assessed based on air pollution, road accidents and level of physical activity. Estimating the impact of the PRT system on public health is based on a review of other research studies, and is not a detailed epidemiological study. The avoided public costs associated with emissions, accidents and healthcare costs due to lack of physical activity are the unit of comparison between selected scenarios. Another social aspect which is not often considered in transport strategies is the passenger performance (waiting time, travel time, safety and comfort). These aspects are discussed in Chapter 7.

A preliminary cost-benefit analysis of implementing a PRT network in Macquarie Park over a 30-year period of assessment is also presented in Chapter 7. This is a hypothetical evaluation and thus is not based on detailed engineering solutions. A more detailed analysis of all the financing costs, including taxation, depreciation, fare elasticity and sensitivity tests would assess the feasibility of the PRT system more rigorously.

The next section outlines the methodological approach; more detail is provided in later chapters.

1.5. Research design and methods employed

The previous section outlined the specific research questions and the framework used to answer each of them. This section describes the methods used to investigate the research problem. The key motivating question of this research is: *To what extent could Personal Rapid Transit address the sustainability challenges in edge cities?*

Firstly, the literature was reviewed to identify the sustainability challenges of edge cities, in diverse political, cultural and economic systems. Understanding the specific urban form and land use characteristics of the edge cities, and how these constraint on travel patterns, helped to develop different strategies to address the challenges of retrofitting edge cities. The Personal Rapid Transit (PRT) system was investigated as a potential sustainable local transport system, which may increase public transport attractiveness and thus, reduce car dependency at the regional level.

1.5.1. Selecting a case study

I used a case study to test different land use and transport scenarios, in a specific place. Macquarie Park was chosen for this study because it represents an ‘edge city’ within an emerging Australian multi-centred city form. A detailed description of the study area is presented in Chapter 4. The chapter analyses urban form, land use and existing transportation system. Employment forecasts and predicted growth in floor space over the next 20 years are also discussed. These forecasts form the basis for estimating future trip demands.

1.5.2. Estimating demand

Data was collected from several different sources to estimate future trip demands:

- The NSW Department of Transport Bureau of Transport Statistics (BTS) provided extensive data of the Summary of 24-hour tours to Macquarie Park for 2011, 2016, 2026, 2031 and 2036 on request (NSW Department of Transport BTS 2011, Xu B., request 11270, 11 August). The estimated number of daily tours for commuting, work related business and education purposes for the current year 2011, and 2031 from the Strategic Travel Model are low compared to existing and future employment levels and student enrolments forecasts. To avoid underestimating the future demand (which is essential for analysing the PRT performance), the predicted increase of employment and Macquarie University student numbers from 2011 to 2031 was applied to the modelled demand for work trips and, education trips respectively, to develop a revised forecast for the future.
- Current and future estimates of student enrolments and travel patterns were extracted from the Macquarie University Transport Study (Maquarie University TMAP 2009)
- Trip demand for the residents of Macquarie Park was estimated based on data provided on request by the NSW Department of Transport Bureau of Transport Statistics, to replicate the household travel behaviour for this specific study area (NSW Department of Transport BTS 2011, Karantonis E., request 11270, 30 September).

A more detailed explanation of estimating future trip demand to, from and within Macquarie Park is presented in Section 4.7. Full modelling data provided by the NSW Department of Transport is available on request from the author.

The forecast of future trip demand forms the basis for developing alternative land use and transport scenarios.

1.5.3. Developing land use and transport scenarios

Two different scenarios – increasing Local Access by Personal Rapid Transit (LAPRT) and Personal Rapid and Transit Oriented Development (PRTOD) were developed, with a focus on reducing car dependence and increasing active travel within Macquarie Park. These two scenarios are compared to a 2031 projection of the current transportation trends (business-as-usual scenario) and a traffic study commissioned by City of Ryde, based on planned targets for accommodating the projected growth of the Macquarie Park Corridor by 2031 (”planned” scenario).

Trip demand, land use, and transport network assumptions for each scenario are discussed in Chapter 5. The LAPRT scenario is focused on increasing the accessibility of the study area by introducing a Personal Rapid Transit network as a feeder for the existing transit nodes. In order to estimate the total trips generated under this scenario, reasonable and defensible assumptions were made about mode share, by purpose of travel: work trips, tertiary education trips (for Macquarie University students), shopping, business and other purpose trips (see Section 5.4.1). The mode share assumptions for trips on the PRT system are not a function of a strategic transport model which I did not have access to within the time and budget constraints of this study. Instead, the mode share assumptions were based on the existing land use and transport strategies reflected in the "Planned" scenario and current planned transportation improvements, at the local and metropolitan level. Although these assumptions can be questioned and further research is necessary for more accurate estimates, they provide a realistic basis to test the PRT's capacity to handle large volumes of passengers.

The second scenario – Personal Rapid and Transit Oriented Development (PRTOD) - is based on changing the urban form to a transit oriented development and increasing local accessibility either by walking or by a PRT network. Land use and mode share assumptions are presented in detail in Section 5.5. This scenario is proposed as an alternative strategy to be investigated in the future as it is difficult to predict the distribution of trips without more accurate information about the location and density of future residential development, and future plans for mixed land use. However, the results from modelling the LAPRT scenario could be extrapolated to the PRTOD scenario.

1.5.4. Modelling the LAPRT scenario

A PRT network is proposed to provide high frequency access from the rail stations to the University, retail, office, and residential areas and to other destinations within Macquarie Park, as well as to peripheral car parks. The design decisions were based on the local street network and the existing layout of the Macquarie Park corridor. The PRT network was designed using the expert version of the ATS City Mobil software provided for this study by its developers (Lowson and Lees-Miller 2011, pers. comm., 14 August). A graphic representation of the loops, stations and vehicle depots is presented in Chapter 6. The network design and simulation process are also detailed in Chapter 6. The original design using the ATS City Mobil software, the simulation program and a tutorial for using the software are included in the CD attached to this thesis (Appendix 1).

At the end of the simulation, the software generates statistics for passenger waiting time (at each station and overall); percentages of passenger groups waiting less than one minute at each station; the number of passengers carried and the fleet required to service these passengers. The passenger trip distances and travel times are also generated. The simulation does not optimise the fleet size, allocating as many vehicles as are required to provide the level of demand with a minimum response time to passenger calls. In practice, fewer vehicles might be provided leading to a longer waiting time.

1.5.5. Evaluating and comparing environmental, health and economic impacts

The evaluation of the PRT option comprises an analysis of environmental and urban impacts, passenger performance, capital and operating costs, and health impacts (see Chapter 7).

Based on the statistics generated by the simulation, the overall energy use, reduction in emissions (CO2, NO, CO, VOC, Particulates) and noise can be estimated. These are translated into health indicators.

The simulations provide a broad range of information on the likely performance of PRT under different circumstances. Surveys from the existing operational PRT systems were used to qualitatively assess the passenger service performance in order to investigate how likely it is that commuters would prefer PRT to the car.

Based on the assumptions of mode shares and the simulation results, we will be able to see the impacts on traffic, major public transport modes and physical activity levels, which can be translated in health indicators. It will also allow for an estimate of car-parking requirements, which can be used to estimate the urban impact.

The likely environmental, health and economic impacts of the scenario including PRT as a feeder for the existing transit nodes (LAPRT) are compared to those of the other two scenarios, "Business-as usual" and "Planned". Impacts are estimated based on the vehicle kilometres travelled (VKT) for the car trips generated under each scenario.

The analysis in Chapter 7 answers four specific questions:

- How likely is it that the LAPRT scenario would be the preferred policy option compared to the BAU and Planned scenarios?
- How would the environmental and urban impacts of the LAPRT scenario differ from the likely future impacts of the other two scenarios?
- How would the health impacts of the LAPRT scenario differ from the likely future impacts of the other two scenarios?
- What are the likely capital and operating costs of building a PRT system?

By answering these questions we will be able to address the key motivating question of this thesis. The contribution of this research to the body of knowledge is presented in the next section.

1.6. CONTRIBUTION OF THIS THESIS TO THE BODY OF KNOWLEDGE

This thesis investigates the potential of an alternative more sustainable transit mode to change travel choices in a typical edge city. The study contributes to debates about policy options to improve the sustainability of multi-centred cities.

The Macquarie Park case study not only extends the number of studies which identified the evolution of edge cities as a function of the emerging polycentric metropolitan forms in various national and continental settings, but also demonstrates that edge cities have also evolved in Australia over the past two decades.

The thesis develops a design-based solution for increasing the accessibility of the main transit nodes, and offers a preliminary comparison of its impacts. This analysis supports the findings from other studies around the low environmental and urban impacts of the Personal Rapid Transit system. The main contribution of this study to the body of knowledge is the analysis of the health impact that a Personal Rapid Transit system might have, with the prospect of future research in the future.

This thesis aims to enrich debates and decision-making processes, by testing out an under-examined alternative that could bridge the gap between conventional public transit service and car-dominated urban forms. Although the study uses elements of the "predict and provide" approach some scholars have criticised, it does not assume that the status quo of travel choices is maintained. Instead, it investigates a viable but non-traditional transit alternative that could contribute to changing the debate over a future vision of more sustainable multi-centred cities.

1.7. STRUCTURE OF THE THESIS

In section 1.4, I explained the structure of this thesis, showing how the specific thesis questions are addressed. This section includes an illustrative representation of the thesis structure Figure 1.1.

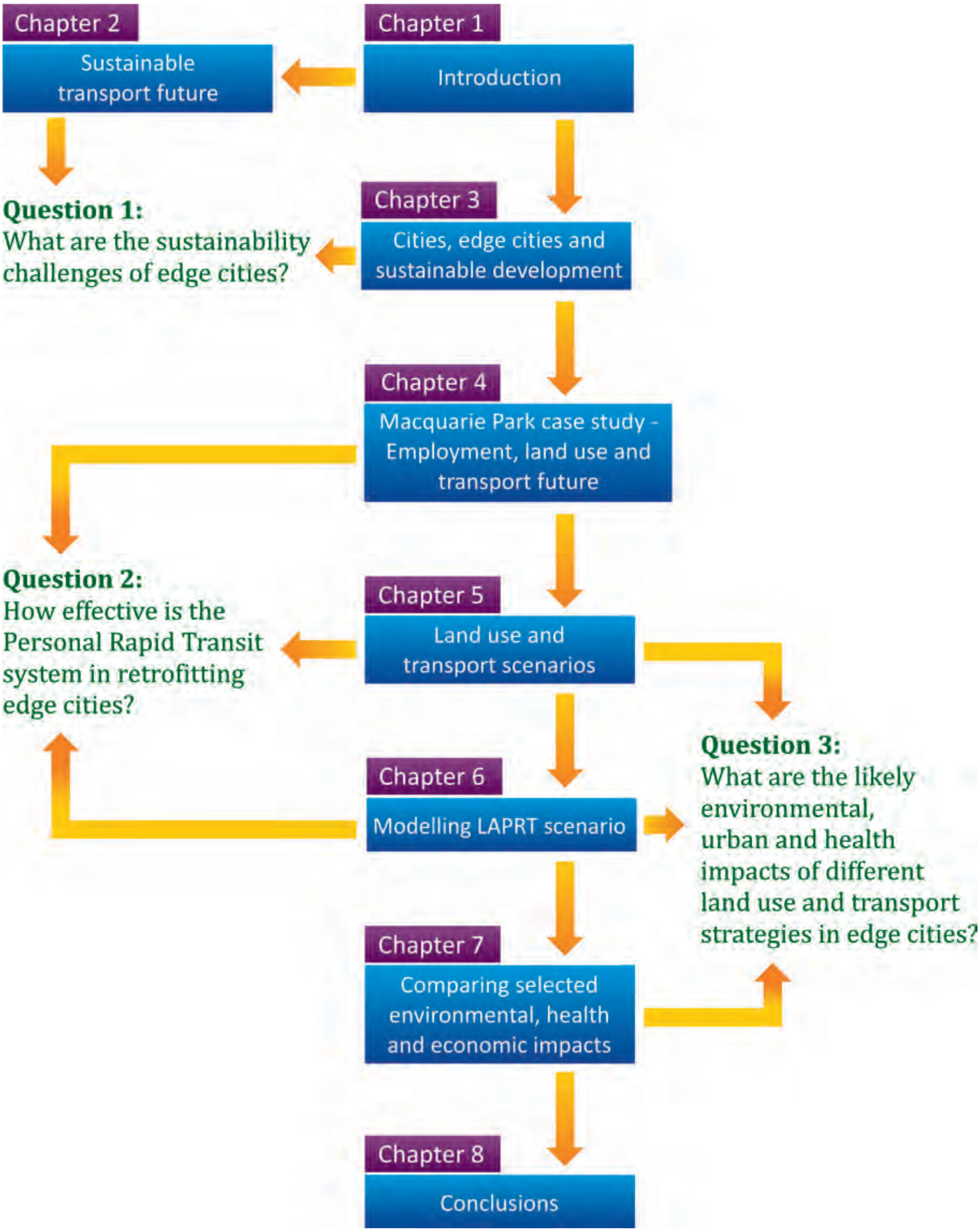


Figure 1.1 - Thesis structure

Chapter 2. Sustainable transport future

This chapter begins by reviewing the international and national context in which sustainable initiatives have evolved, and the significance of the transport sector for sustainability goals. The claims made for Personal Rapid Transit, and experience with current systems are reviewed.

2.1. Sustainability: from a global to a local issue

> Sustainability is a vision and a process, not an end product.
>
> Peter Newman and Jeffrey Kenworthy - Sustainability and cities – Overcoming Automobile Dependence (1999)

The concept of sustainability has evolved over the past forty years from a political process to an economic process, and from a global agenda to a local sustainability agenda. The 1972 UN Conference on the Human Environment in Stockholm was the first time that environmental issues were brought up on a global agenda (Newman and Kenworthy 1999), although these issues had already begun to emerge in the 1960s (Unyu 2004). However, environmental globalism was perceived as being in conflict with economic development, especially by the developing countries (Gleeson and Low 2003; Newman and Kenworthy 1999; Unyu 2004). In order to address these conflicts, the UN established the World Commission on Environment and Development (WCED) in 1983. The WCED published *Our Common Future* in 1987, also known as the Brundtland Report. The Brundtland Commission launched the concept of "sustainable development" which is still a key concept today.

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.
>
> World Commission on Environment and Development, 1987

One after another, countries started to respond to the Brundtland Report; Australia announced its Ecologically Sustainable Development (ESD) process in 1990 (Newman and Kenworthy 1999). The Commonwealth Government developed a National Strategy for Ecologically Sustainable Development involving government officials, industries, unions, community organisations and individuals through nine sectoral ESD Working Groups "covering agriculture, forest use, fisheries, manufacturing, mining, energy use, energy production, tourism and transport". Acknowledging its critical role in Australia's future sustainable development, the Council of Australian Governments endorsed the National Strategy in December 1992.

> ESD will mean changes to our patterns of resource use, including improvements in the quality of our air, land and water, and in the development of new, environmentally friendly products and processes.
>
> (Australian Government, Ecologically Sustainable Development Steering Committee 1992)

2.1.1. International context

A significant number of international environmental initiatives have been negotiated based on the Brundtland Report. Twenty years after the Stockholm Conference, the Earth Summit held in 1992 in Rio de Janeiro was considered "as global as is ever likely to be possible" (Newman and Kenworthy 1999, p. 5) with 179 nations signing its final resolution. The Earth Summit produced the Rio Declaration and the Forest Principles, the United Nations Framework Conventions on Climate Change (UNFCCC), an action plan for sustainability (Agenda 21), and the Convention on Biological Diversity (United Nations 2009). It was time for sustainability to move from a global political process to the global economic agenda.

UNFCCC demanded that each signatory country set emission and absorption targets for Greenhouse gas emissions, and formulate and implement specific policies to reduce emission levels to 1990 levels by 2000 (Unyu 2004). The UNFCCC's effectiveness was discussed in a long and intense series of Conferences of Parties (COP). Greenhouse gas emissions became the main focus of the conferences. In 1997, the Kyoto Protocol was adopted in order to encourage and commit the industrialised countries to achieving the reduction targets. The Protocol came into effect in February 2005, with three market-based mechanisms created to achieve the Greenhouse gas reduction targets in a cost-effective way appropriate for each country. The "Kyoto mechanisms" are:

- Emission trading, also known as the "carbon market"
- Clean Development mechanism (CDM)
- Joint implementation (JI)" (UNFCCC 2005).

The Kyoto protocol was ratified by 123 nations, except for the United States, one of the largest polluters. The U.S. government justified their opposition by arguing that the same control policies should apply to developing countries, especially India and China. At the most recent UN climate conference held in Cancun in November 2010, the U.S finally agreed to the pollution commitments, along with China and other major polluting countries (The Climate Institute 2010). However, other countries, including Japan and Russia, which had ratified the Kyoto protocol (in 2002 and 2004 respectively) turned against it at Cancun and argued for its end (Greenpeace International 2010). International political consensus remains elusive. However, some countries have taken the initiative in advancing the sustainability agenda.

2.1.2. Australian context

Australia ratified the Kyoto Protocol in 2007 and agreed to stabilise its Greenhouse Gas emissions at 591.5 Mt CO_2-e per year over the period of 2008 to 2012, at approximately 108% of the base year emissions; the base year is 1990 for energy, industrial processes, agriculture and waste; for CO_2-e emissions for land use, land use change and forestry (LULUCF) the base year is 2008 (Department of Climate Change and Energy Efficiency 2010).

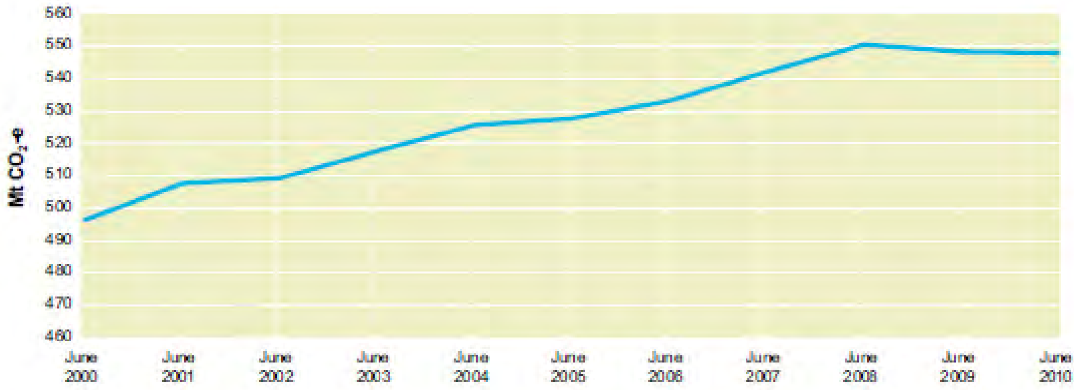
In 2009, Denmark hosted the fifteenth Conference of Parties (COP15) attracting a record number of participants, with 120 governments represented at the highest political level. Discussions on climate change were raised to a new level and every signatory of the Copenhagen Accord agreed to submit information on quantified economy-wide emission targets for 2020 for developed countries and on nationally appropriate mitigation actions for developing countries. In total, 141 nations expressed their intention to be listed as agreeing to the Accord.

At COP 15, Australia agreed to a very ambitious target over the next 20 years: to unconditionally reduce Greenhouse Gas emissions by 5% below the levels estimated in 2000 at 552.7 Mt CO_2-e including the LULUCF specific activities emissions (Department of Climate Change and Energy Efficiency 2010).

> Australia will reduce its greenhouse gas emissions by 25% on 2000 levels by 2020 if the world agrees to an ambitious global deal capable of stabilising levels of greenhouse gases in the atmosphere at 450 ppm CO_2-eq or lower. Australia will unconditionally reduce our emissions by 5% below 2000 levels by 2020, and by up to 15% by 2020 if there is a global agreement which falls short of securing atmospheric stabilisation at 450 ppm CO_2-eq and under which major developing economies commit to substantially restrain emissions and advanced economies take on commitments comparable to Australia's. (Penny Wong 2010)

The commitment has stimulated a series of political battles, primarily focused on the carbon tax concept. In reality, emissions increased from 496 Mt CO_2-e in June 2000 to

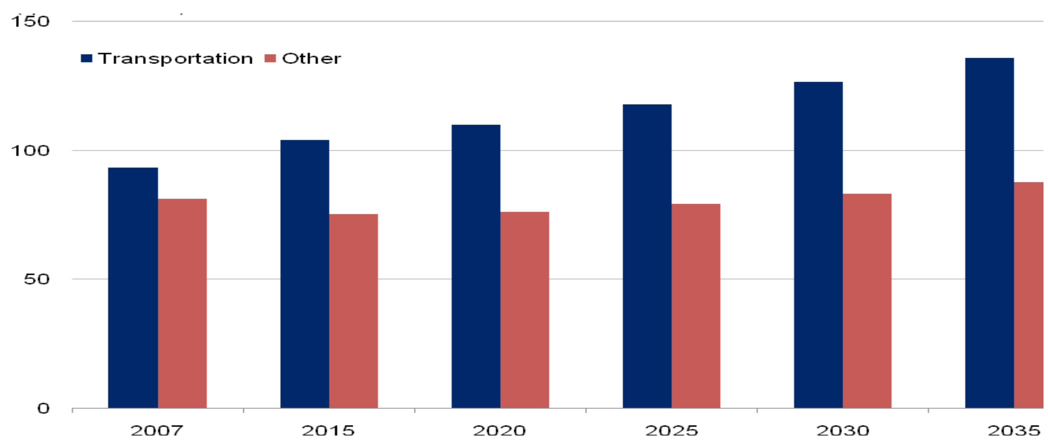
548 $MtCO_2$-e in June 2010 highlighting the difficulty of delivering on this ambitious commitment without fundamental reforms to the energy, transport, industrial processes, waste and agriculture sectors.



Source: Department of Climate Change and Energy Efficiency, Australian National Greenhouse Account, Quarterly Update of Australia's National Greenhouse Inventory June 2010, Figure 4: National Inventory, annual emissions-four quarter 2000 to 2010

Figure 2.1 - Annual emissions of CO_2 - four quarters to June quarter 2000 to 2010

According to the U.S Energy Information Administration (US EIA 2010), the transportation sector accounted for almost 20% of the global energy consumption and for more than 50% of liquid petroleum use in 2007. Its share is expected to increase to 61% by 2035.



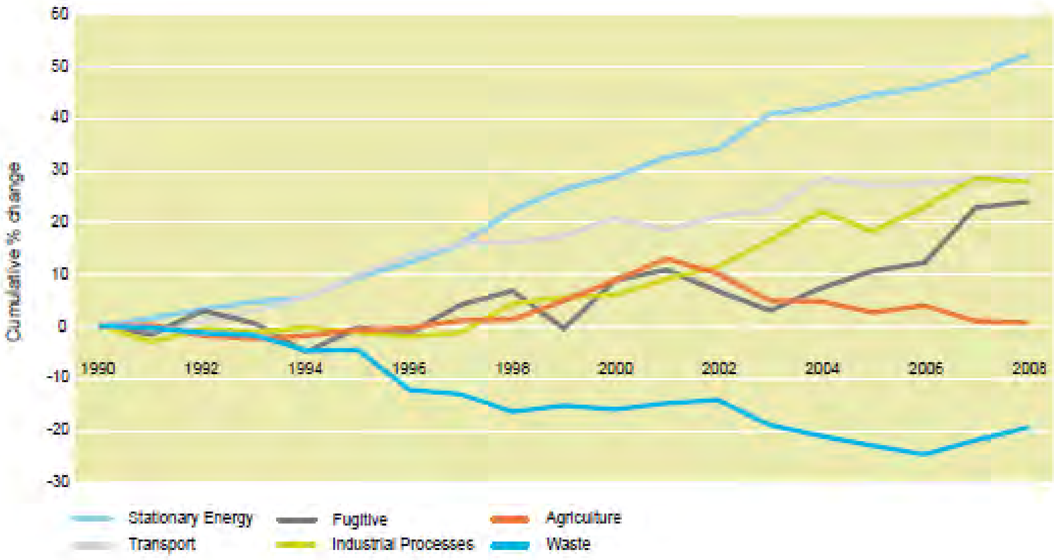
Source: US Energy Information Administration, International Energy Outlook (2010), Figure 91: World liquids consumption by end-use sector, 2007-2035

Figure 2.2 - World liquid petroleum consumption, 2007-2035

The transport sector is also responsible for 23% of world energy-related carbon dioxide emissions and these are projected to increase to 50 % by 2030 (US EIA 2010).

In Australia, the second largest increase in emissions over the 1990 to 2008 period occurred in the transport sector. Transport emissions increased by 29.2 % over this time. In 2008, emissions from transport amounted to 80 Mt CO_2-e, representing 14.6% of the national

Greenhouse Gas emission inventory. Emissions continued to increase to 83 Mt CO_2-e in 2009 and 84 Mt CO_2-e in 2010 (Department of Climate Change and Energy Efficiency 2010).



Source: Department of Climate Change and Energy Efficiency, Australian National Greenhouse Account, Quarterly Update of Australia's National Greenhouse Inventory June 2010, Figure 5: Trends in CO_2 emissions by sector-change since 1990

Figure 2.3 - Changes in CO_2 emissions by sector 1990-2008

Reforming energy use and emissions in the transport sector is clearly essential if Australia is to achieve any meaningful reduction in Greenhouse Gas emissions. Effective policies and long-term structural changes encouraging sustainable transport are needed.

More than forty years since environmental issues and sustainable development challenges were first placed on the global agenda, most governments of developed and developing countries have agreed to cooperate to achieve a global goal: mitigation of climate change. Most countries have made some commitments to promote sustainable development strategies and reduce Greenhouse Gas emissions. Mitigation on climate change will have different economic impacts, and different strategies will be feasible and appropriate in different countries.

The United Nations Intergovernmental Panel on Climate Change (IPCC) has called for immediate implementation of climate change measures, but has also admitted that these measures will have varying impacts on each sector. The panel identified the most vulnerable economic sectors, for both developed and developing countries, as follows: fossil fuels, renewable energy, energy intensive industry, transport, and the household and services sector (IPCC 2000).

The transport sector and sustainability challenges for urban transport are investigated in the next section.

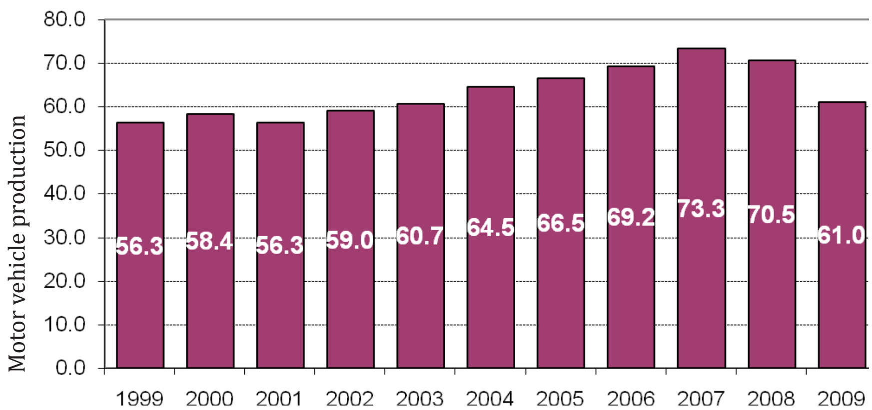
2.2. Sustainable Urban Transport: Meanings and Challenges

> 'Unsustainability'… means that there are some trends which cannot be extrapolated indefinitely into the future, because the arithmetic does not add up, or is catastrophic.
>
> Phil Goodwin, Simple Arithmetic (1996)

A standard definition of "sustainable" is *"capable of being maintained at a steady level without exhausting natural resources or causing severe ecological damage" (*Collins Discovery Encyclopedia 2011). But the "natural resources" consumed by transport include a wide range of assets: "energy, human and ecological habitats, atmospheric carbon loading capacity, and individuals' available time" (Goldman 2006).

Although no common definition of sustainable transport is generally accepted, there is widespread agreement that the current urban transport system displays unsustainable trends (Goldman 2006; Gleeson and Low 2003; Lowson 2004; Mees 2009; Newman and Kenworthy 1999; UNEP 2011).

With a very large consensus, the un-sustainable trends are associated with a continuing increase of the number of personal cars for passenger transport and number of trucks for freight. Since 1908 when the first model T Ford went on sale, the world car production reached its peak in 2007 with 73.3 million cars produced. The International Energy Agency predicts an increase of three or four-fold in the global vehicle fleet by 2050, with the biggest growth occurring in developing countries (UNEP 2011). IEA predicts a stock of 2.7 billion light-duty vehicles by 2050 and The Millennium Institute predicts 2.2 billion by 2050.



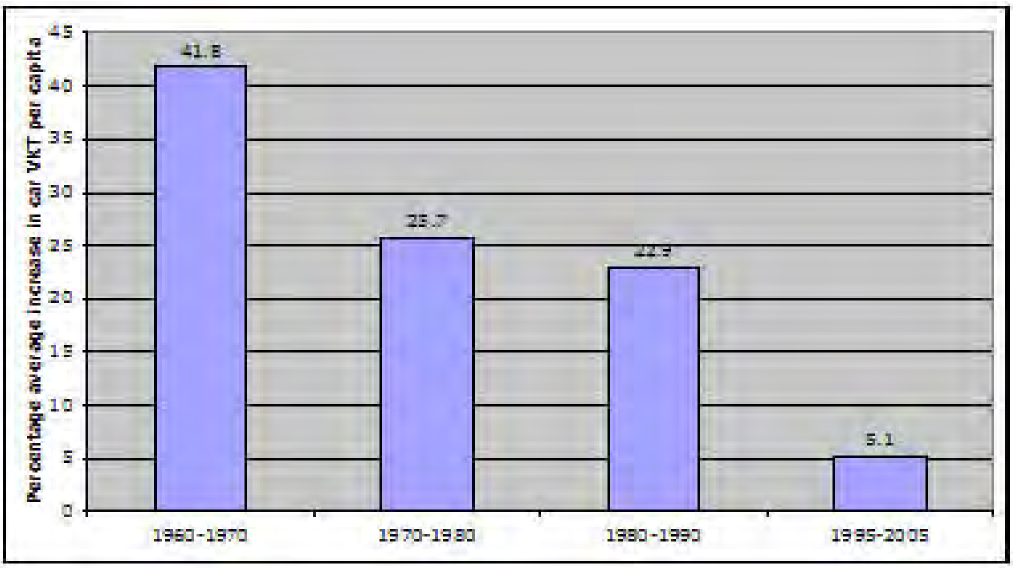
Source: Glazebrook 2011, World Car Trends

Figure 2.4 - Global Automotive Production

Following the "simple arithmetic" of Phil Goodwin, if the transport sector consumes 50% of the available liquid petroleum, 20% of global energy and accounts for 23% of world energy-related greenhouse gases emissions (US EIA 2010; IEA 2010), and multiplying by a three to four fold increase, the result is indeed catastrophic. Under a business as usual scenario modeled by the Millennium Institute and confirmed by projections made by IEA in 2010, energy use and carbon emissions from the transport sector will increase to more than 50% by 2030 (UNEP 2011).

Despite environmental issues being placed on a global agenda in 1972, the number of passenger kilometers by private car per capita increased by 90% in Western Europe and by 13% in the US between 1970 and 1990 (Steg and Gifford 2005).

The World Business Council for Sustainable Development (WBCSD) predicts an average growth of 1.7% per annum in private car transport by 2050, with the biggest increase in China (3%), Latin America (2.9%) and India (2.3%) (Vlek 2007). However, in some of the developed countries, the resistance to change has lowered, and a new phenomenom - 'the peak car use' has occured (Figure 2.5). The current travel patterns indicate a gradual increase in the public transport mode share and active travel (Glazebrook 2011; Muyers 2011; Newman and Kenworthy 2011).



Source: Newman and Kenworthy 2011, Figure 3. Car use growth trends in developed cities from 1960 to 2005 using Global Cities Database, p 33

Notes: The 25 cities from Global Cities Database are: Boston, Chicago, Denver, Houston, Los Angeles, New York, Phoenix, Portland, San Francisco, Calgary, Winnipeg, Adelaide, Brisbane, Melbourne, Perth, Sydney, Amsterdam, Brussels, Copenhagen, Frankfurt, Hamburg, London, Munich, Paris, and Stockholm

Figure 2.5 - Car use growth trend in 25 developed cities

In a paper summarising recent data related to 'peak car use' (Newman and Kenworthy 2011), the authors identified six possible causes of this new phenomenon:

1. Cities hitting the 'Marchetti Wall'– the "Marchetti Wall" is the limit to the expansion of a city beyond which travel time is unacceptable to residents (a 'one hour wide' city)

2. Increase in public transport mode share – by increasing public transport passenger-kilometres per capita, the amount of car kilometres travelled per capita is predicted to go down exponentially
3. Increase in density rather than urban sprawling - density multiplies the use of transit trips, and walking and cycling, as well as reducing the travel distance
4. The ageing population - older people tend to drive less
5. The cultural change associated with urbanism – the young and elderly move back into cities from the suburbs
6. The fuel price - the rise in fuel price contributes to reducing car use growth

Transport related environmental impacts from air pollutants and resource use might decrease in the developed countries – as a result of technological improvements - but these will be offset by the negative impacts in the urban areas of developing countries, where a rapid expansion of car usage is expected (UNEP 2011; Vlek 2007). Greenhouse gas emissions, congestion and traffic noise are anticipated to increase everywhere (WBCSD 2006, cited in Vlek 2007, p. 431). In the climate change context, extreme heat events can affect the air quality, and thus, worsen the impact on public health from transport related air pollution in the urban areas worldwide (Spickett, Brown and Rumchev 2011).

The WBCSD's multi-annual project – Sustainable Mobility Project (SMP) - produced the "Mobility 2030: meeting the challenges to sustainability" report, which is focused on increasing and improving 'mobility' while ignoring other components of transport systems, for example accessibility, health or safety (Goldman and Gorham 2006; Vlek 2007).

> A clear message of 'Mobility 2030' is that if we are to achieve sustainable mobility it will require contributions from every part of society throughout the world (The foreword to the WBCSD 2004, cited in Vlek 2007, p. 446).

The predicted traffic growth will require additional road infrastructure to be built at the expense of open landscapes, biodiversity and human health (UNEP 2011; Vlek 2007). Despite all the sustainable policies and plans for the future, car traffic is regarded as unavoidable and construction of new, wide, high-speed roads is still seen as a top priority, even by organisations such as the International Energy Agency (IEA), World Bank or WBCSD (Newman and Kenworthy 2007; Vlek 2007). The outcomes of the SMP's report are somehow predictable, as the experts consulted in this report represent mainly the automotive and energy industries. To some degree, The Council of Transport Ministers of the European Union encouraged "more systemic thinking about sustainable transport" but without identifying a mechanism to translate this into current policies (Goldman and Gorham 2006, p. 265).

In 1990 in Australia, car use per capita - and thus, energy consumption and CO_2 emissions from transport, was lower than in Unites State but higher compared to Europe or Asia (Glazebrook and Rickwood 2007).

Country/Region	US [1]	Australia [2]	Europe [3]	Wealthy Asian [4]	Developing Asian [5]
Car-km per person	166%	100%	69%	23%	28%
Private Transport energy Cons/capita	167%	100%	53%	21%	20%
Transport CO_2/capita	163%	100%	68%	42%	30%

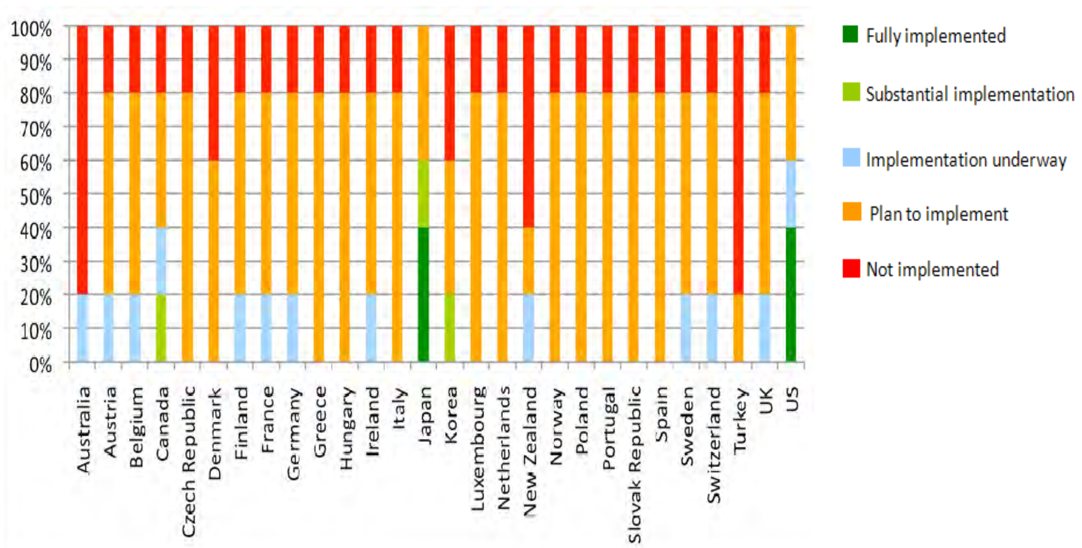
Notes:

1. Houston, Phoenix, Detroit, Denver, Los Angeles, San Francisco, Boston, Washington, Chicago, New York
2. Perth, Brisbane, Melbourne, Adelaide, Sydney
3. Hamburg, Frankfurt, Zurich, Stockholm, Brussels, Paris, London, Munich, Copenhagen, Vienna, Amsterdam
4. Tokyo, Singapore, Hong Kong
5. Bangkok, Jakarta, Kuala Lumpur, Manila, Surabaya, Seoul, Beijing

Source: Newman and Kenworthy 1999 (cited in Glazebrook and Rickwood 2007), Table 2: Relative Energy, Fuel and CO_2 Emissions For Various Cities (1990)

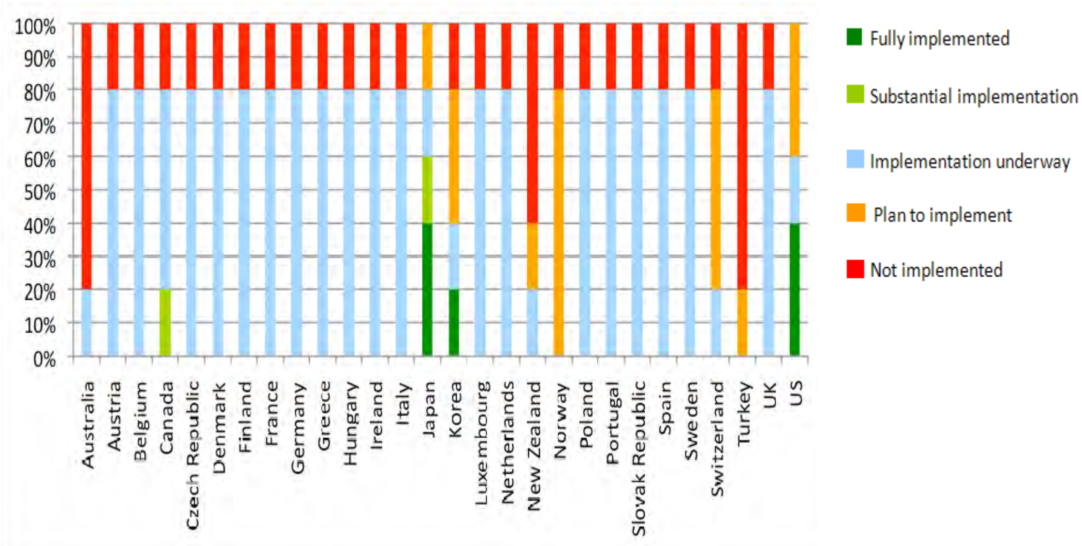
Table 2.1 - Transport related energy consumption and CO_2 emissions (1990)

According to a recent report by the International Energy Agency (IEA 2010), Australia made little progress between 2009 and 2010 in implementing the policies for increasing transport energy efficiency as per IEA recommendations (see Figure 2.6 and Figure 2.7).



Source: IEA 2010, TRANSPORT ENERGY EFFICIENCY, Figure 18: Comparison of country progress with implementing applicable transport recommendations

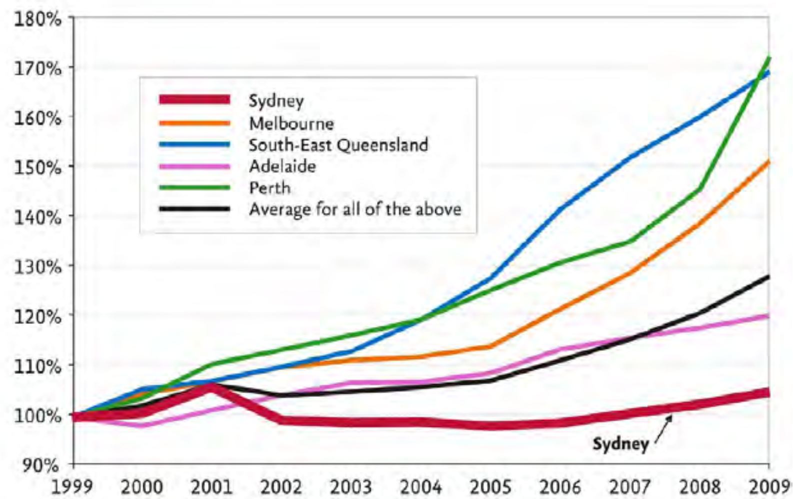
Figure 2.6 - Implementation of IEA transport recommendations as of 2009



Source: IEA 2010, TRANSPORT ENERGY EFFICIENCY, Figure 18: Comparison of country progress with implementing applicable transport recommendations

Figure 2.7 - Implementation of IEA transport recommendations as of 2010

However, since 1999, the public transport share has increased in all Australian cities, with Perth having the highest increase rate and Sydney the lowest one (see Figure 2.8).



Source: Glazebrook (2010), Increase in public transport patronage since 1999

Figure 2.8 - Increase in public transport share in Australian cities

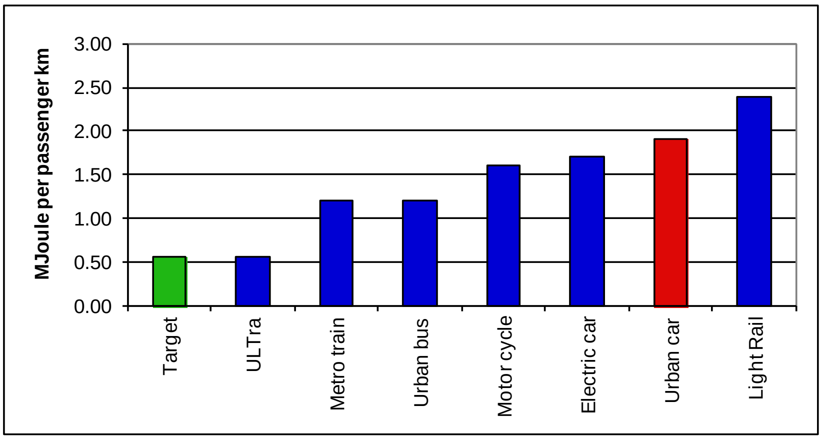
Walking and cycling are claimed by some to be the only genuinely sustainable transport modes, and their advocates argue that the shift towards extensive walking and cycling should get the highest priority in any future planning and transport policy. Increasing active travel is very important and should be considered in every strategy, local or regional. Recent research emphasises the benefits from active travel on public health (Frank, Andresen and Schmid 2004; Hankey et al 2012; Trubka, Newman and Bilsborough 2010). However, walking and cycling can only contribute a relatively small component of the overall travel task in large cities. They are highly dependent on weather, urban geography and form, trail connectivity and trip lengths (Handy et al 2002; Owen et al 2007; Wendel-Vos 2007; Winters et al 2010). Moreover, there are some population categories, for instance the elderly, young children or even parents with children, which might not be advantaged by walking and cycling as a transport mode for their daily routine (Black 1977; Gifford and Steg 2007).

Climate change should also be considered in any future urban intervention (Bambrick et al 2011; Black and Black 2009; Proust et al 2012; Spickett, Brown and Rumchev 2011). Extreme heat events and changes in local weather may affect air quality as well as travel behaviour, as outdoor activities – such as walking and cycling – will be the most exposed to risk. Increases in solar radiations could potentially increase the risk of skin cancer. Increases in temperature and number of sunny days are expected to have effects on quantity of pollen produced, as well as on the season's length. Consequently, an increase in the incidence of allergic reactions due to exposure to environmental allergens is likely to occur (Black and Black 2009). Children, elderly persons and individuals with pre-existing illness will be the most disadvantaged categories but cyclists and walkers would also be faced with a greater risk.

The argument made by this thesis is that the emphasis should be put on increasing the accessibility, attractiveness and efficiency of public transport coupled with measures to encourage cycling and walking as modes of travel, but also as modes of exercising.

Although most researchers argue that transport by personal cars is unsustainable, when we talk about public transport, there is no general consensus. As Mees (2000) noted, today's planners have to look for a less un-sustainable but achievable transport solution, rather than a completely ecologically sustainable solution that is practically impossible.

Public transport can only reduce environmental damage by producing fewer emissions, less noise, fewer accidents and injuries; this is possible only if public transport is very well patronized. Coffey and Lowson (1996) cited in Lowson and Lowson (2010) report that energy use for light rail (MJ per passenger km) is higher than energy use for urban cars (conventional or electric), considering the average load for each mode (e.g. 1.6 passengers for car and 20 percent load for bus)(see Figure 2.9). The Personal Rapid Transit system was found to be the most energy efficient transport mode, followed by buses and metro trains (Lowson and Lowson 2010).



Source: Lowson and Lowson (2010), Figure 10: Comparative energy for various transport options

Figure 2.9 - Energy efficiency for modes of transport

Similar results have been reported by Anderson (1998) cited in Carnegie et al (2007, p.61), who analysed the energy use for each element of different systems (light rail, heavy rail, trolley bus, motor bus, dial-a-bus, van pool, automobile and Personal Rapid Transit). However, these values might be biased against light rail.

Newman (2000) reported a value of 0.79 MJ per passenger kilometre for light rail/tram based on an average occupancy rate of 29.73. Other studies reported different values for bus and rail in Australia compared to USA. Kenworthy and Laube (2001) reported much higher energy efficiency for rail in Australian cities – 0.5 MJ per passenger-kilometre compared to American cities – 1.2 MJ per passenger-kilometre. However the last figure is very similar to the results reported by Lowson and Lowson (2010). Although the energy efficiency of Australian buses is better than American ones -1.7 MJ per passenger kilometre in Australia compared to 2.9 MJ per passenger kilometre in the US (Kenworthy and Laube 2001)- both values are much higher than the 1.2 MJ per passenger kilometre reported by Lowson and Lowson. However, the reported value of 0.55 MJ per passenger kilometre for PRT is lower than the energy use for buses or light rail, regardless of the different values for buses, rail or light rail reported by diverse studies.

On the other hand, energy use is influenced by passenger loading factor, the efficiency of the propulsion system, and auxiliary power used, as well as vehicle size, weight and speed. Different studies reported a value in the range of 3.8 - 4.78 MJ per vehicle kilometre travelled of energy use for road vehicles in Australia, which is higher than the value reported by Coffey and Lowson (Australian Greenhouse Office 2007; Kenworthy and Laube 2001; State Government of Victoria 2009).

Lowson and Lowson (2010) argue that an advanced technology such as a Personal Rapid Transit (PRT) system, well integrated into a conventional large mass transit system, will increase the attractiveness of public transport. PRT could attract trips that would otherwise be made by car (May and Muir 2009; Muller 2011). Thus, PRT could provide a more sustainable transport solution that meets the needs of an individual without compromising the future of the environment.

Currently un-sustainable transport trends have multiple impacts on the environment, economy and society. From the environmental point of view, urban transport can cause severe ecological damage due to resource use, energy consumption, greenhouse gases emissions, excessive land use and loss of biodiversity. Transport could also impose economic costs through congestion and effects on urban productivity (UNEP 2011), or may influence economic welfare, affecting Gross Domestic Product (GDP) and employment levels (Geurs and Van Wee 2003; Glazebrook 2009). Lastly, the transport system has a major influence on both society and individual quality of life, by affecting human health, safety and accessibility, and dividing communities (Steg and Gifford 2005; UNEP 2011).

The argument for strategies and interventions for diminishing the reliance on cars in the existing cities and preventing the new developments from car domination is still ongoing.

> Professional advice on how to advance sustainability will need constant political intervention as the modernist assumptions of automobile dependence, supplemented by slow buses, is not able to adequately answer the demands of an increasingly sophisticated public with more disposable income looking for better and more sustainable options.
>
> Newman and Kenworthy 2007, Sustainable Urban Form: Transport Infrastructure and Transport Policies,p. 308

2.3. Personal Rapid Transit (PRT)

> We cannot solve our problems with the same thinking we used when we created them.
>
> Albert Einstein

Its advocates consider Personal Rapid Transit (PRT) a sustainable transport solution with benefits for the environment, society and economy, as a technology that incorporates the advantages of private cars into a mass transit system (Anderson 1996; Andreasson 2011; Bly and Teychenne 2005; Lowson 2004; Muller 2011). Its opponents argue that the system combines the disadvantages of low-capacity small vehicles and the high cost of guideways, representing an unfeasible transit system with disproportionate costs (Vuchic 2007; Setty 2009).

Personal or Group Rapid Transit (PRT/GRT) is a passenger-transit, on-demand system, based on automated small and light electric vehicles (also known as “pods”) which run along dedicated guideways. The track lines can be built underground, at street level or elevated, with various design solutions. Different materials from simple concrete bases to steel or fibreglass grid floors can be used to construct the guideway. The tracks are low weight, and are designed to support light vehicles. Usually, the networks are designed as interconnected loops running on single or double tracks.

The stations are built off-line, making non-stop travel possible between any pair of stations. Low-demand loops may have on-line stations. Stations can be easily integrated within new buildings or customised to fit into a specific area.

Passengers arriving at a station can call a vehicle, which is usually waiting at the station. If not, the nearest available vehicle will be automatically directed from its current location. A software programme finds the optimum path for each passenger and enforces a minimum distance between the vehicles in order to avoid collisions. All PRT vehicles offer high safety and security standards for the passengers through track and vehicle location systems that permanently monitor each vehicle.

The vehicles are computer-controlled and do not require human drivers. They are equipped with comfortable seats, air-conditioning, and an on-board information system with audio and video communication channels. Pods are designed to accommodate passengers with wheelchairs, bicycles or prams. They can carry one or more passengers but a larger number will change the nature of the 'personal' transit system. Most of the vehicle prototypes are designed for two or four passengers (Ultra, 2getthere, Taxi2000), but there are also solutions for up to nine passengers (Austrans), known as Group Rapid Transit (GRT). Some researchers consider that increased ridership of the PRT vehicles or GRT systems with nine to twenty-seat vehicles, such as Austrans or the Morgantown system could more efficiently handle high capacity demand (Glazebrook and Associates 2002, Muller et al 2011).

The inventors and developers of the most recent PRT/GRT systems claim that they are designed to address all three sustainability bottom lines: environmental, social and economical.

Because the vehicles are electrically powered, the local air pollution in the city is zero, and the level of noise is very low. In addition, the light weight of the vehicles and their efficient usage mean overall low energy consumption per passenger-kilometre (although this is based on the occupancy rate) and thus, reduced Greenhouse Gas emissions. Because PRT has many of the features of travel by car, such as non-stop travel from point-to-point, speed, safety and convenience, it may attract a considerable number of car passengers, and thus, it will contribute to fewer emissions into the atmosphere and less resource use.

The critics of PRT systems argue that the system cannot prove its theoretical capacity and human-safety levels unless the technology is tested on large scales (Mims 2011, Setty 2009). They argue the elevated guideways will be too expensive, aesthetically unacceptable and may have negative impacts on the land uses beneath them (Derrible cited in Mims 2011, Setty 2009, Vuchic 2007).

2.3.1. History of Personal Rapid Transit

The idea of PRT seems to have originated in the last century but practical applications for the concept date from 1953 when Donn Fichter, a transport planner from Chicago, developed a new transit system called the Veyar (Anderson, 1996). A few years later, in 1960, William Alden, a graduate of the Harvard Business School, invented a system of small electric vehicles with a dual-mode system of driving named StaRRcar and it is believed that *"this was quite possibly the earliest dual-mode-system proposal"* (Anderson 1996, p. 3). As the dual-mode system was considered too complex to develop at that time, Alden concentrated his work on the development of six-seat vehicles running on an automated guideway and built a test track in Bedford, Massachusetts. The pilot project was successful and in 1970 it was selected as the most suitable transit system for the University of West Virginia in Morgantown.

The Morgantown system was a high-profile project advocated by Nixon in the 1972 election. It was implemented at the price of design compromises that increased the cost by four times compared to the initial projection (Anderson 1996). With the NASA Jet Propulsion Laboratory as the system manager, Boeing as the vehicle manufacturer, the control system supplied by Bendix Company, Michigan and the guideway, stations and other facilities designed and built by F.R. Harris Engineering Company, Connecticut, the Morgantown system is still operating today but the huge investment cost undermined confidence in the economic feasibility of wider applications of the PRT system in the USA and celsewhere. However, a recent study prepared for West Virginia University reported the total Net Present Value of the PRT improvements and operating costs were US$144.5 million over a 20-year period (2010 to 2030) (West Virginia University 2010). If the PRT system were to be replaced with a bus system, the total present value of the economic cost of increased congestion was estimated at US$148.9 million. The total net present value of the savings generated by the PRT system versus those of the bus system was estimated at US$115.6 million.

Between 1966 and 1999, a number of different PRT systems have been examined and full-size test tracks and vehicle prototypes have been built with governmental funds (Table

2.2) but none of them successful (Carnegie et al 2007; Lowson and Lowson 2010). Lowson and Lowson (2010) consider that the main reasons for failure were "an over emphasis on high capacity systems", most of them evolving into Group Rapid Transit (GRT) systems, and "inflexible (...) and unavailable technology for the demand of the system" at that time (p. 5). Carnegie et al (2007) argue that besides the technical issues that limited the capacity of the systems and increased the costs, the lack of political support contributed to the cancelations of the systems.

System	Cabtrack	Aramis	Cabinen Taxi	CVS	Aerial Transit System	Raytheon PRT 2000
Country	UK	France	Germany	Japan	US	US
Dates	1966-1972	1967-1988	1969-1974	1970-1979	1970-1974	1990-1999
Track	0.2 km	1 km	2 km	4.8 km	0.54 km	~ 1 km
Vehicles	1	3	5	19	?	3
Passengers	4	4++	3	4	6	3
Payload	400 kg	350 kg	400 kg	330 kg	410 kg	400 kg
Top speed	40 km h-1	50 km h-1	36 km h-1	80 km h-1	56 km h-1	40 km h-1
Headway	1 s	60 s	1 s	1 s	10 s	2.5 s
Type	Rubber on concrete	Rubber on concrete	Overhead support	Rubber on concrete	Monorail	Rubber on Steel

Source: Lowson and Lowson 2010, Personal Rapid Transit Systems, Table 1. Prototype Personal Rapid Transit systems

Table 2.2 - Prototypes of PRT systems

In the last decade, several PRT applications have been tested or investigated all over the world. Table 2.3 presents some of the most recent and extensive studies about PRT, the majority of which concluded that PRT systems would have positive outcomes (at least hypothetically) (Carnegie et al 2007; Glazebrook and Associates 2002; Karlsson 2011; Konradsson 2011; Nelstrand 2011).

Except for the Cincinnati Downtown Circulator which was rejected because of lower performance and higher costs compared to an improved shuttle system (Carnegie et al 2007), all the other studies concluded that, compared to buses, the PRT systems could bring considerable benefits in the selected locations and would be technologically feasible.

Program	Commissioner	Project duration and budget	Study location	Application	Methodology
EDICT	European Union – "City of Tomorrow" framework	2001- 2004 Budget $3.5M	Cardiff, Wales UK	Docklands redevelopment	Test track Passenger trials Economic modelling
			Ciampino, Italy	Connects the airport to the town centre	Feasibility study
			Eindhoven, Netherlands	To serve the Technical University of Eindhoven	Feasibility study
			Huddinge, Sweden	To service a large shopping centre	Simulation Cost-benefit analysis
Seattle Seatac Airport Circulator	City of SeaTac, WA	1992-1996	SeaTac	SeaTac airport	Comparison of two PRT systems to a shuttle system
Cincinnati Downtown Circulator	Ohio-Kentucky-Indiana Regional Council of Governments	2000-2001	Cincinnati	Covington-Newport-Cincinnati downtown circulator	Transit mode study comparing bus, light rail and PRT
Uppsala PRT network	Uppsala City	2006-2007	Uppsala, Sweden	Connects 30,000 work-places, a hospital, an university, stadium and the Science Park	Test track built by Vectus Ltd First solar powered transit system
Upplands Väsby PRT network	Upplands Väsby Planning and Environmnetal Comittee	2011	Upplands Väsby, Sweden	A new Stockholm suburb-wide PRT network	Pilot study
Södertälje PRT network	Municipality of Södertälje	2007-2008	Södertälje, Sweden	To connect housing, jobs and railway transportation	Pilot line and planning undertaken
AUSTRANS	Bishop Austrans	1998-2002 AU$14.3M -federal grant and Bishop's private investment	Sydney, Australia	City-wide Group Rapid Transit system	Test track built by Austrans Feasibility studies

Source: data compiled from Carnegie et al 2007, Karlsson 2011, Nelstrand 2011, Konradsson 2011

Table 2.3 - PRT studies

The line capacity of different passenger transit systems is usually calculated using the following formula:

Line capacity = N_{seats} x Frequency , where:

N_{seats} = number of seats on the transport system
Frequency = number of vehicle trips per hour.

Based on this simple formula, Table 2.4 compares the transit capacity for different transport systems. The theoretical capacity of a single-way track for the PRT system is higher than a bus or light rail system loaded at full capacity (seating and standing passengers) running at very high frequencies (2 minutes for buses and 5 minutes for light rail).

Type	No of seats	Headway/Frequency	Vehicles per hour	Base capacity Passengers per hour
PRT	4	6 s	600	2400
	4	3 s	1200	4800
	4	2 s	1800	7200
Bus	50	10 min	6 (each way)	600
	50	5 min	12 (each way)	1200
	50	2 min	30 (each way)	3000
	65 (seats + 30% standing people)	2 min	30 (each way)	3900
Light rail	200	15 min	4 (each way)	1600
	200	10 min	6 (each way)	2400
	200	5 min	12 (each way)	4800
	260 (seats+30% standing people)	5 min	12 (each way)	6240

Source: based on data from Lowson and Lowson (2010), Table 2, Base capacities of passenger transport systems, p 11

Table 2.4 - Transit line capacities for different passenger transport systems

The total investment cost for a PRT system, including guideway, stations and vehicles was found to be lower than light rail and higher than guided bus way (Kerr and Craig 2005; Lowson and Lowson 2010; Tegner 2003). Bly and Teychenne (2005) reported a higher investment cost for 30.3 kilometres of a PRT track in Corby, UK compared to 14.2 kilometres of a proposed light rail; the total Net Present Value of benefits over a 30-year assessment period is £188 million for the PRT system compared to a negative -£17.6 million for the light rail. All these feasibility studies reported lower operating cost for a PRT system compared to buses or light rail.

The most recent Swedish studies in Uppsala, Södertälje and Upplands Väsby concluded that the PRT system would solve major issues such as congestion, noise, emissions and would result in a more compact urban footprint by requiring smaller areas for parking. However, the Swedish municipalities that commissioned these studies decided to wait for more detailed architectural and financing analyses to be conducted (Karlsson 2011; Konradsson 2011; Nelstrand 2011). The main questions raised from these studies were: how to finance a PRT system, how to manage a PRT system and how to secure the land (Nelstrand, 2011). The very high "risk factor" for investing in the first PRT project with limited experience and planning expertise is one of the barriers to PRT implementation in a complex urban system (Carnegie et al 2007; Jonkind 2003).

2.3.2. Current applications of PRT

When this study begun, in March 2010, no Personal Rapid Transit system was fully operational except for Morgantown (which is technically a Group Rapid Transit system). As this study is reaching completion, two systems are fully operational for public use (ULTra PRT at Heathrow, London and Masdar PRT in Masdar, Abu Dhabi), with another one due to commence construction in 2012 (Suncheon Wetland in Suncheon, South Korea).

2.3.2.1. ULTra PRT – Heathrow, London

Construction of the first modern PRT system (named "ULTra PRT"), was completed in 2010 at London's Heathrow Airport, to link Terminal 5 to its business car park. The first public trial started on April, 2011 and the full service was introduced on May, 2011 replacing the existing car park bus system.

The system currently runs seven days per week, 22 hours during weekdays, 20 hours on Saturdays and 21 hours on Sundays with more than 70,000 passenger trips completed between May and September 2011. It is replacing more than 50,000 bus trips per year (Brown 2011).

Source: ULTra PRT 2011 Source: author

Figure 2.10 - Heathrow PRT – Construction phase and fully operational system

Its developers claim the £30M capital cost of the PRT system, including 3.8 kilometre of track, three stations and 21 vehicles is less than half of the capital cost for other competing systems. The system saves 40% on operating costs compared to the shuttle buses. In addition, the system has a lower environmental impact compared to buses by saving 365 tonnes of CO_2 per year, producing no pollution at the point of use and low levels of noise (Lowson 2011).

ULTra vehicles are battery-powered, using four lead-acid batteries which allow for rapid charging at station berths or at waiting points. The batteries are easily recyclable and the vehicles are designed to be adaptable to future power sources (such as hydrogen fuel cells, lithium ion battery systems). A central control computer communicates with the control computer from each station in order to distribute the vehicles, but they can also navigate autonomously using a laser sensor system which guides the vehicles if the communication with the central computer is disrupted.

The ULTra vehicles are controlled by a “synchronous” control system which does not allow a vehicle to start its journey until a clear path is available to the destination. Furthermore, there is an Automatic Vehicle Protection (AVP) system which ensures a safe distance between vehicles on the guideway – in case of a problem arising and one vehicle stopping, the next vehicle will stop at two “slots” distance avoiding collision (Advanced Transport Systems 2009; personal discussion with ULTra operators 2011). Similarly, if one vehicle decelerates, all vehicles will reduce speed at the same time.

In case of main power failure, each vehicle is individually battery powered and the control room, which also has a battery powered back up, will control the vehicles to complete their journeys. No new journeys would be allowed and the technical staff will organise an alternative transport system for passengers. One of the advantages of the ULTra system implemented at Heathrow is that it can count on the airport recovery service for intervention in case of a severe risk.

Source: author

Figure 2.11 - Computer screen showing network control

The safety of the ULTra system has been assessed under the Rail and Other Guided Systems legislation (ROGS) introduced in UK legislation in 2006. The Ultra PRT is compatible with the US federal and state PRT safety standards as well as with the US national fire escape code (NFPA 130) as per Code of Federal Regulations 659 (CFR 659) for the fixed guideway (a code applicable to PRT, APM, monorail, LRT, heavy rail, cable car, and heritage trolley) (ULTra PRT 2011). The ULTra system is designed to operate at aircraft standards of reliability and guideway blockages are "*prevented from occurring wherever possible*". However, in the case of an extreme event blocking the system, a service-vehicle is available to remove the blockage. Safety rails are attached to the non-electrified passive guideways, ensuring the safety of the maintenance personnel and safe evacuation of the passengers (ULTra PRT 2011).

Source: author

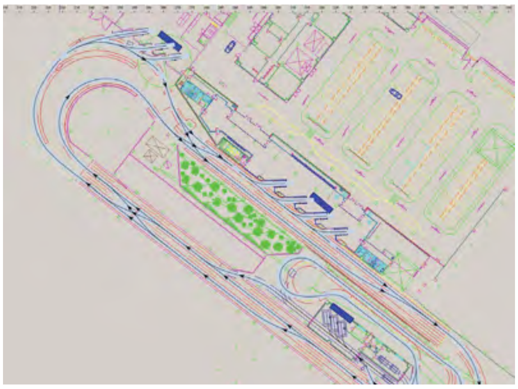
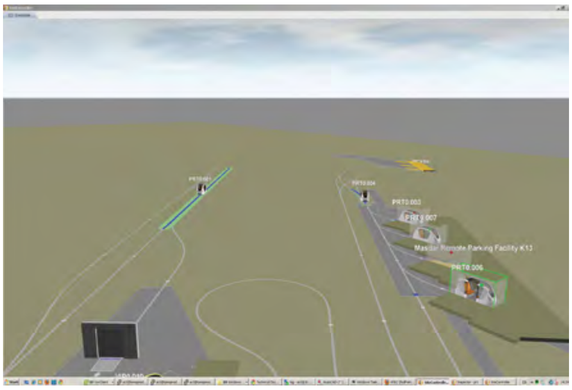
Figure 2.12 - Heathrow PRT - stations

After the first five months of operating, ULTra reported high reliability for the system - over 99%, with the 1% failure due to small delays of 1-2 minutes; the biggest delay was 11 minutes caused by recovery from a failure (Brown 2011). The system seems to demonstrate its theoretical benefits: predictability, safety, convenience, no waiting time (the average waiting time was 34 seconds), and reduced levels of noise, air pollution, and Greenhouse Gas emissions.

One of its critics argued that the lightweight aluminium chassis of an ULTra vehicle is inappropriate for multiple boarding and unboarding operations which are expected under high capacity demand (Setty 2009). In response to this, the ULTra system lead designer argued that the "fatigue life" of the vehicle exceeds the eight-year life of projected service considering maximum level of use, but he did not mention the estimated level of use over this timeframe (Publictransit.us 2009). The future will demonstrate whether the system can offer the projected level of capacity and whether or not it can sustain a heavy-duty transit service.

2.3.2.2. Masdar PRT – Masdar, Abu Dhabi

Part of the world's most ambitious sustainable development, the PRT system was introduced in November 2010 in Masdar City – the first carbon neutral, car-free city powered by alternative energy sources in the world. The Dutch company 2getthere supplied the fleet of ten passenger vehicles – of which two are VIP vehicles with a luxurious interior - and three freight vehicles for goods deliveries to stores, hotels and residents. In the first phase of the project, 1.7 kilometres of guideway were built, connecting the North Car Park and the Masdar Institute of Science and Technology.

Source: 2getthere: Lohmann 2011, The 5th Podcar City Conference Proceedings, Masdar Operations, pg 5,8

Figure 2.13 - Masdar PRT network

The architectural preference of building the PRT tracks in an "undercroft" – an artificial basement with open sides for better air ventilation, created by raising the pedestrian level to ensure the streets are totally pedestrian-accessible – was an expensive option and the high costs of construction, considered acceptable before the Global Financial Crisis, are considered "restrictive of expansion" in the current new economic context (Lohmann 2011).


Source: 2getthere: Lohmann 2011, The 5th Podcar City Conference Proceedings, Masdar according to Design Trade-off, pg 10; Masdar Operations pg 21.

Figure 2.14 - Masdar PRT - Construction phase and fully operational system

Although the company did not make the investment cost publicly available - considering it confidential commercial information – Robbert Lohmann, the Commercial Director of 2getthere, stated that "the currently realised systems are in the range of $12 to $16 million per mile approximately" following an article in the Txchnologist in which the science journalist Christopher Mims estimated the capital cost at $25 to $40 million per mile of guideway (Burke 2008 cited in Txchnologist 2011).

The four-seat vehicles are lithium-ion battery-powered. The batteries provide a range of approximately 60 kilometres and recharging can be done at the station berths or in a dedicated charging room. The theoretical speed of 40 kilometres per hour is reduced to a maximum 25 kilometres per hour to conserve energy. Similar to the ULTra system, the vehicles are controlled by a "synchronous" control system which distributes them at stations according to demand. Each vehicle is equipped with an advanced obstacle detection system, allowing the vehicle to slow and stop for obstacles thus avoiding collision. The position of the vehicle is verified by magnets embedded in the road surface (ATRA 2011).


Source: 2getthere: Lohmann 2011, The 5th Podcar City Conference Proceedings, Masdar Operations, pg 11, 18

Figure 2.15 - Charging room and intervention through a tow-vehicle

Similar to the ULTra PRT, the reliability of the Masdar PRT system has been between 98.6% and 99.9% in the first year of operation, operating seven days per week, 18 hours per day and servicing more than 230,000 passengers (Lohmann 2011). The intervention in the case of a problematic event can be manually or using a dedicated tow-vehicle which removes pods from the guideway quickly, without a severe guideway blockage.

The Masdar PRT project received operational certification based on a safety review by the Independent Safety Assessor Lloyd's Register, health review by the Independent Health Assessor Bureau Veritas and safety certification by Abu Dhabi Department of Transportation (Lohmann 2011).

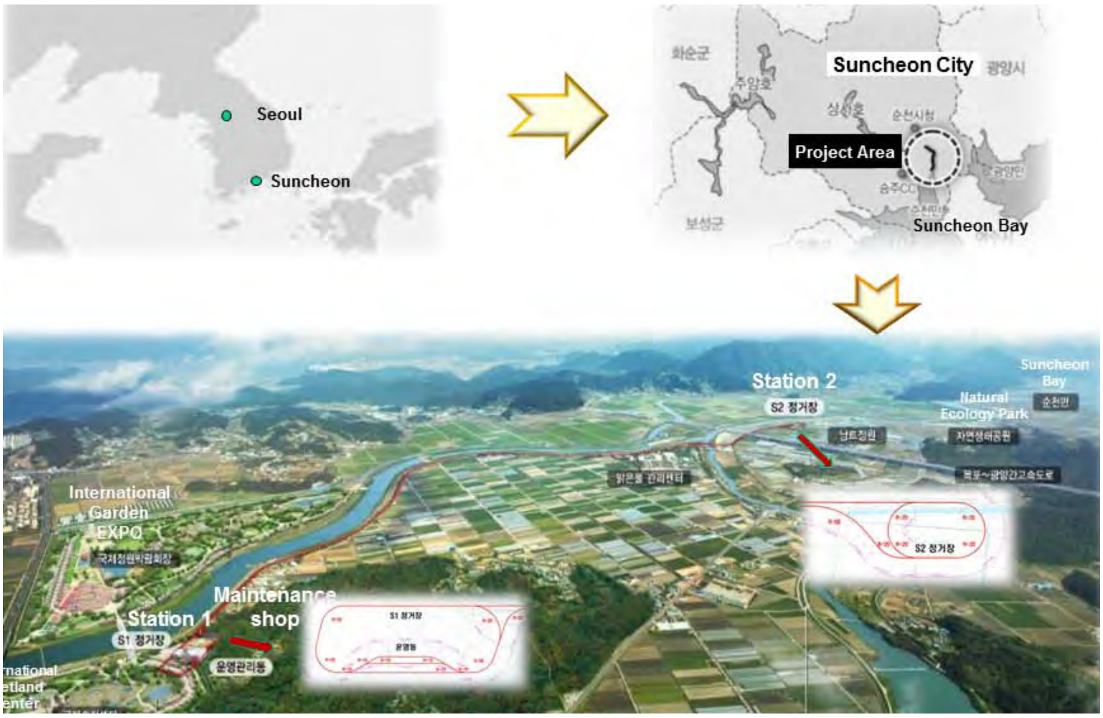
The same company, 2getthere, which is the supplier of the Masdar PRT project, has been operating a Group Rapid Transit system at Rivium in the Netherlands since 2005. The network connects the Rivium Business Park and the residential area Fascinatio, both located in a suburb of Rotterdam, as well as another business park - Brainpark III - located in the city of

Rotterdam. The GRT system links to metro and bus station Kralingse Zoom, Rotterdam (ATRA 2011, 2getthere 2011). It comprises 1.8 kilometres of dual-lane dedicated infrastructure at grade level, eight stations, and a fleet of six vehicles with a capacity of 20 people each. The GRT is considered a success and the operational contract is settled until 2016 (ATRA 2011).

2.3.2.3. Vectus PRT – Suncheon, South Korea

Another major event in the PRT field is the recently launched Suncheon project based on more than ten years of research and development and a successful pilot project built in Uppsala, Sweden in 2006; the pilot project was approved from the Swedish Rail Agency in 2008 (Vectus Intelligent Transit 2011).

The PRT system was chosen as appropriate to the unique eco-system in the Suncheon Bay coastal wetlands in South Korea (see Figure 2.16) based on its characteristics: low impact on environment, no local emissions and lower costs compared to other competitive systems (Pemberton 2011). The PRT system is scheduled for opening in 2013, replacing an existing bus system.

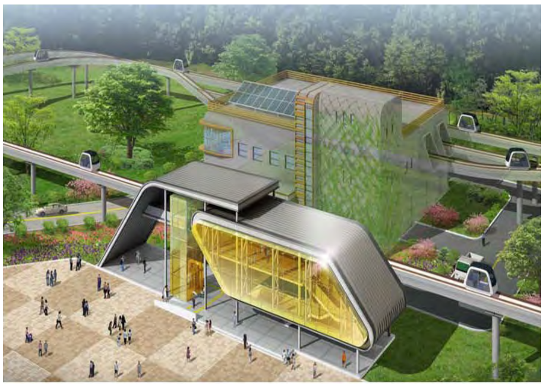


Source: Vectus Intelligent Transport: Pemberton M., 2011 The 5th Podcar City Conference Proceedings, Location

Figure 2.16 - Suncheon Bay PRT project area

The key components of this project are 4.6 kilometres of bi-directional guideways, two stations, and 40 vehicles. The guideway will be mostly elevated, built along existing roads and underground in the residential area. The two stations are very spacious, architect - designed with a four-berth loading platform and observatory (see Figure 2.17).

The maintenance depot includes the traffic control centre, administration offices, workshops, vehicle garaging with lift and a test circuit.



Source: Vectus Intelligent Transport: Pemberton M., 2011 The 5th Podcar City Conference Proceedings, Station1 and Station2

Figure 2.17 - Station 1 and maintenance depot and Station 2

The VECTUS control system consists of distributed and asynchronous controls with a dynamic moving block enabling various speeds along the track without impacting on the overall capacity of the system.

The vehicle design has been customised for the Suncheon project to increase safety, capacity and comfort of the passengers. The four seats have been replaced with benches accommodating eight people in the same space, increasing capacity; larger doors, electrically powered, have been provided allowing a wider access point in order to minimise the boarding time. The height of the vehicle has been increased to accommodate standing passengers. The vehicle cabin is very lightweight with a carbon fibre body shell but is also reinforced against shunt and collision and integrally insulated for high heating efficiency of the ventilating and air-conditioning system (Figure 2.18).

Source: Vectus Intelligent Transport: Pemberton M., 2011 The 5th Podcar City Conference Proceedings, Technical Advances

Figure 2.18 - Vehicle modular assembly

The VECTUS PRT system has been assessed under the European Union railway systems standard, EN 50126/IEC62278 "Railway applications – specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)" (Vectus Intelligent Transit, 2011).

For a sample system that was modelled and assessed through a Quantitative Risk Assessment including 78 sensitivity calculations, the passenger risk was quantified to 0.165 fatalities per billion person kilometres, which means the standard of VECTUS PRT system will be comparable to or higher than the current standards of West European railway systems (Vectus Intelligent Transit, 2011). The Suncheon project received construction approval in April 2011 from the Ministry of Land, Transport and Maritime Affairs and it is scheduled to be fully operational within two years.

2.3.2.4. The urban impact of the PRT systems

The urban benefit of PRT/GRT systems can be measured by the low space required to build the network and by the release of land which would be otherwise used for car parks. A PRT track requires only two metres width to be built compared with over ten metres width of a typical street (Figure 2.19). The capacity of a typical street is approximately 2000 vehicles per hour in each direction, if it is grade separated. The theoretical capacity of a PRT guideway is 1800 vehicles per hour (at two second headway); at full capacity (4 people per vehicle) it could compete with road capacity, but it is unlikely that a full loading rate would be achieved, especially during off-peak hours.

Source: ULTra PRT 2009, Figure 3.3.a. ULTra Guideway Dimensions; City of Ryde, DCP 2010, Chapter 5 Public Domain, Figure 4.5.55. Type 2 Street Section

Figure 2.19 - PRT track and Type 2 Street section

An off-line station can be 15-25 metres long, depending on how many berths are required. An online station can be only six metres long. The infrastructure characteristics of the three operational systems are presented in Table 2.5.

Infrastructure	ULTra	2getthere	Vectus
Track width (at grade/elevated)	1750 / 2100 mm	1750 / 1850 mm	1400 / 1400 mm
The system square clearance envelope (W*H)	2100 * 2000 mm	1850 / 2300 mm	2100 * 2500
Typical column spacing	18 m	NA	30 m
Maximum track gradient %	10	10	10
Minimum Turning Radius	5	5.5	5
Berth concept	Angled independent or straight in-line	Angled independent or straight in-line	In-line
Minimum multi berth station length per independent berth	3.2 m	4.3 m at 30 degrees	4.5 m
Minimum multi berth station width per independent berth (including vehicle and passenger area)	4 m	NA	NA
Maximum vehicle trips per 1 berth per hour	120	120	160-200

Source: ATRA 2011, PRT Application Characteristics, Comparison

Table 2.5 - Infrastructure characteristics of PRT systems

A station with a single berth requiring the same space as a bay in an underground car park can service 120 vehicle trips per hour, which means 480 passengers per hour at full capacity and allowing 30 seconds for boarding and unboarding operations. If these trips were made by car, a minimum of 120 parking spaces would be needed for short-term parking. Over a typical eight working hours in an average weekday, the same simple station with one berth could service more than 3840 passengers using the same space as a one-car parking bay. This is an important urban benefit which is worthwhile investigating.

2.3.3. PRT research in Australia

A Sydney-based company, Bishop Austrans, developed the Austrans system in the late 1990's. The system was based on its own patented concepts of ultra-light rail technology: a self-steering bogie, the grip wheels, a Z-rail section and a high-speed switch (Austrans 2005). A loop line and three vehicles were built in Sydney and a citywide system was designed. Its inventor, Arthur Bishop, privately funded Austrans; in February 1999, the system was awarded an AU$14.3 million grant by the Industry Research and Development Board.

The nine-seat vehicles are electrically powered and the speed can be as high as 120 kilometres per hour. The Austrans system allows an 8-metre radius curve and the vehicles can climb gradient up to 20 percent, which makes installation very flexible (Glazebrook and Associates 2002).

Source:PRT Consulting 2009 http://www.prtcons.com/gallery2.html#show

Figure 2.20 - Austrans vehicle

The Austrans system is compared with the existing operational systems in Table 2.6.

Vehicle parameters	ULTra	2getthere	Vectus	Austrans
Seats	4	4	8-seat benches	9
Weight empty (kg)	850	1400	1500	2700
Length (m)	3.7 m	3.92 m	3.6 m	5.4 m
Width (m)	1.47 m	1.46 m	2.08 m	1.9 m
Height (m)	1.8 m	2.01 m	2.42 m	2.2 m
Power	Battery stored electric	Battery stored electric	Electrical	Induction or battery powered
Drive principle	Electric motor	Electric motor	Linear motor	
Guidance method	Kerb referenced electronic controll	Dead reckoning with reference magnetic markers	Captive to steel track	Patented high-speed switches incorporated into track
Vehicle support	Pneumatic tyres on level road surface	Semi-solid tyres on level road surface	Proprietary low friction solid polymer wheels on steel track	Patented self-steering bogie with grip wheels on special rail track
Maximum speed (kph)	40	40	70	120
Maximum speed in curve with radius 20/50/100 m (kph)	18/28/40	16/26/36	16/26/36	NA
Headway current/ projected (sec)	6/2	5/2	3-4/NA	3 / NA
Maximum line capacity per direction current/ projected (passengers per hour)	2400/7200	2880/7200	5400-7200/NA	10,800

Source: based on data from ATRA 2011, PRT Application Characteristics, Comparison; Australian Technology Showcase, Bishop Austrans; Glazebrook 2005 Austrans-Potential Further Development

Table 2.6 - Vehicle parameters for PRT /GRT systems

Two Austrans systems, one for Canberra and one for Singapore, have been simulated using the RTSIM transit simulator developed by CSIRO in 2000. The Canberra system included 22 kilometres of track with two-way loops and 15 stations simulating a potential urban-wide system for a medium volume demand. The Singapore system was a short-length bi-directional route of 4.9 kilometres and 11 stations, a system designed as a feeder for the major railway nodes. Further tests of the operational performance of the Austrans system were recommended (Glazebrook and Associates 2002).

Source: Glazebrook and Associates 2002, Design of a City-Wide Austrans System, Figure 1.4 Austrans system attached to existing Roseville Bridge in Sydney

Figure 2.21 - Austrans rendering

Other studies of PRT feasibility in Melbourne and Canberra concluded that the system is worth considering (Wyatt 2006; Jones 2009). The most expensive PRT network to be implemented (in the Casey Local Government Area of Melbourne) would be cheaper than the EastLink freeway (at an estimative $905 million compared to $ 1 billion). The capital cost for another PRT sub-system proposed in the Monash LGA was estimated at $773 million, comparable to the cost of a roof for the Southern Cross railway station (Wyatt 2006). The author reported that by implementing a PRT system in Melbourne, pollution in peak hours would decrease by 16%, the amount of petrol used by car users previously commuting to the PRT serviced area would decrease by 23% and the system would significantly reduce traffic congestion during peak hours (Wyatt 2006). Jones (2009) concluded that a PRT system could have a greater level of penetration for the layout of Canberra and would be more cost-effective compared to the existing bus system.

There is limited knowledge about PRT in Australia compared to Europe and the USA. This thesis contributes to the body of knowledge by analysing the potential for a PRT system in a specific Australian location.

2.3.4. Conclusions

This chapter reviewed the literature on sustainable urban transport and its specific challenges.

Sustainability and Personal Rapid Transit were both visionary concepts which emerged in the 1960s. Sustainability was globally embraced since then and country after country recognised the value of the Ecologically Sustainable Development, with 141 signatory nations of the Copenhagen accord in 2009. European countries made substantial progress in 2010 in implementing the transport improvement recommendations of the International Energy Agency, as did Japan and the US (IEA 2010). Australia and New Zealand have made little progress yet, with 80% of policies to increase transport energy efficiency not implemented by 2010 (IEA 2010).

Personal Rapid Transit is an emerging technology with limited political support but is widely advocated by specialists with knowledge in advanced transit technologies. It is claimed to be a sustainable transport form with low environmental impacts and significant urban benefits, offering high levels of comfort, safety, convenience, and accessibility for passengers. It is criticised for offering low capacity at high capital and operating costs. However, comparative studies found out that the theoretical capacity of PRT (transit line capacity) could be equal to or higher than a bus system or a light rail (Anderson 1996; Carnegie et al 2007; Glazebrook and Associates 2002; Lowson and Lowson 2010).

The total investment cost for a PRT system is competitive with light rail and bus systems (Kerr and Craig 2005; Lowson and Lowson 2010; Tegner 2003). All these feasibility studies reported lower operating cost for a PRT system compared to buses or light rail.

After fifty years of research, doubts, debates, political indecision, financial uncertainties and funding debates, three PRT systems are ready for public operation. With very few professional critics (Vuchic being the most notable) and a considerable number of professionals, researchers or consultants from academia, public agencies or private companies advocating the merits of the PRT and GRT systems, is the literature biased? The continuous progress and technology improvements over the last fifty years addressed most of the questions about its technological viability. The recently built system addressed one of the most common questions: if the PRT system is as good as it is claimed by its advocates, why has the concept not been widely implemented yet?

No public transport system is able to handle low and high capacity demands for 24 hours and at the same time be cost-effective in every complex urban system around the world.

However, some systems may be more feasibile and appropriate in some locations. The three operational systems responded to specific challenges and planning priorities.

This study investigates whether a Personal Rapid Transit system could be a feasible, cost effective and sustainable transport option in a specific urban form, an edge city within an Australian multi-centre form. The next chapter will investigate what are sustainability challenges in edge cities.

Chapter 3. Cities, edge cities and sustainable development

> If our planet and our cities are to remain habitable, the time has come to move beyond the automobile age.
> Paul Mees, Transport for suburbia: beyond the automobile age (2009)

This chapter explores the transport and planning strategies of multi-centred cities in a variety of national and continental settings. It focuses on the concept of 'edge cities' comparing their role in multi-centred urban form across diverse political, cultural and economic systems. The chapter discusses the urban form and land use characteristics of edge cities, and the constraints these place on travel patterns. The final section summarises research on the impact that the built environment has on public health, and identifies challenges of retrofitting edge cities.

3.1. Automobile cities

Rapid urbanisation is a worldwide phenomenon. Throughout the last century, the population living in urban areas increased from 13% to 50% and it is expected to grow to 69% by 2050 (UNEP 2011). Urban areas generate approximately 80% of global economy outputs, but they are also responsible for more than three quarters of global energy use and carbon emissions (UNEP 2011). Modern cities have been shaped by transport technology driven by trams, trains, and cars (Newman, Kenworthy and Vintila 1992; Cervero 1998).

Urban structure evolved into a car-dependent form after the Second World War characterised by low-density urban sprawl and suburban isolation, especially in North America and Australia (Newman and Kenworthy 1999). Solving the problems created by "automobile cities" has become a central concern for urban planners. Transport planners can be divided into two camps: one of the planners embracing an "incremental approach" and the other advocating an "urban system approach" (Pritchard 2007).

Newman and Kenworthy (1999) consider that more fundamental urban system changes are required. Incremental changes are inadequate because they may solve the technological problem in short-term, but aggravate the problem in the long-term.

Prominent research in the late 1990s by Newman and Kenworthy stimulated heated debates on the role of the integrated transport and land-use strategies in overcoming the car dependence. They provided extensive data, constantly updated and expanded, on land use and transport patterns in more than 100 cities across the world (Newman and Kenworthy 1999; Newman and Kenworthy 2007). Bachels and Newman (2001) consider that automobile dependence in modern cities can be reduced through three planning approaches: integrating transport and land use, improving public transport, walking and cycling, and reducing travel demand. The authors explain that these strategies require policies to increase densities, prevent further urban sprawl, invest in transit infrastructure, improve all alternatives to car use, restrict parking, implement traffic calming measures, and introduce higher vehicle taxes.

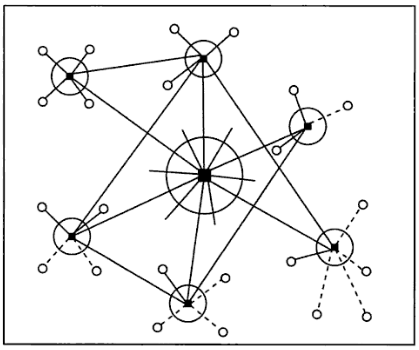
While some researchers emphasise the importance of increasing densities around public transport nodes and investing in transit infrastructure along corridors (Bachels and Newman 2001; Kenworthy 2006; Newman and Kenworthy 1999), other researchers claim that even in dispersed and low-density urban areas, a multi-modal network planning may address the car dependency problem (Mees 2009). However, Mees does not oppose the efficiency of dense city centres, but rather argues that increasing density is not the only solution to prevent car dominance. He advocates a multi-modal regional transport system sustained by a "transfer-based network", with high-quality interchange facilities and "transfer-friendly fares" (Mees 2009, pp 166-175). Rickwood and Glazebrook (2009) take the view that significant development will occur on the urban fringe regardless of policy; increasing local density without improving transport infrastructure will not increase transit use.

3.2. Multi-centred cities and sustainable transport strategies

> Stockholm's sustainability lies in the strong rail orientation of its new towns, rather than in any kind of balanced growth or self-containment .
> Robert Cervero, Cities, Sustainable new towns (1995)

Late 20th century urban form has evolved from the traditional central business district towards a more diffused set of employment and commercial nodes. Suburbanisation became the dominant urban form in America after World War II, although cities in Europe and Asia have also begun to evolve from a monocentric urban form to a multi-centred or polycentric development, displaying different patterns of suburban growth (Cervero 1995; Hall 1999; UN-Habitat 2004; Bontje and Burdack 2005). The phenomenon is not specific to developed countries only. Alpkokin et al (2007) identified similar trends of the evolution of urbanisation from mono to polycentrism in large metropolises in the developing word (e.g. Istanbul, Turkey). In Australia, suburbanisation was also identified as a feature of the post-war cities, emerging to a multi-centred urban form in late 1960s (Logan 1968 cited in Freestone 1997, p.248). Bertaud and Mallpezi (2003, p. 19) argue that cities can only have "degrees of monocentrism or polycentrism", rather than being wholly one or another.

White (1999, cited in Alpkokin et al 2007, p. 1446) has suggested that the main cause of polycentrism is that the traditional central business district has reached its limit. Multiple centres emerged to accommodate increasing employment and transport needs (for humans and goods). External economies of scale fostered the development of polycentrism. Cervero (1998) argues that polycentric cities represents the association of "hybrids cities" which are "partly transit-oriented and their transit services are partly adapted to the lay of the land" (pp. 6-13).



Source: Cervero (1998), Figure 1.3. Transit and polycentric city

Figure 3.1 - Polycentric urban form

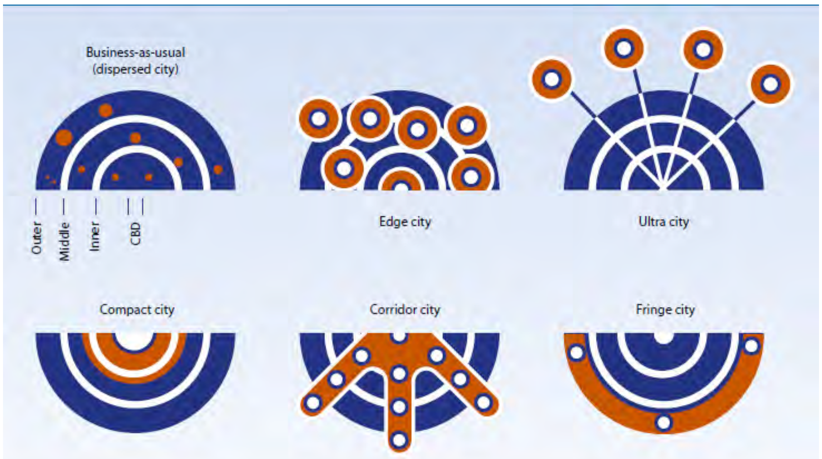
Polycentrism is also related to restructuring automobile cities around a series of local centres linked by transit services through the town centre (Newman and Kenworthy 2006). Applying the 'Marchetti Constant' (a one hour travel time budget) to the technology of building cities, Newman and Kenworthy (2006) identified the following limits to which a city could expand before becoming dysfunctional:

- 5-8 kilometres for walking cities (based on the average walking speed of 5-8 kilometres per hour)
- 20-30 kilometres for transit cities (based on an average train speed of 30 kilometres per hour)

– 50-60 kilometres for automobile cities (based on the average car speed of 50 kilometres per hour)

Therefore, emerging multi-centred urban forms are likely to result in sub-centres of 20-30 kilometres in diameter to maintain the one hour travel budget.

Multi-centred urban form can have different growth patterns, based on the distribution of employment and retail centres. The major typologies are: compact cities, corridor cities, edge cities, and fringe cities, as shown in Figure 3.2 (UNEP 2011).



Source: UNEP 2011, Towards a green economy, Transport, Figure 11: Growth patterns for cities around the world based on Vanderschuren (2003), after Pressman (1995), Minnery (1992), and Newton (1997), p.397

Figure 3.2 - Growth patterns for cities

The "compact city" and the "corridor city" are considered by many planners the most sustainable spatial forms of postmodern cities (Cervero 1995; Falconer, Newman and Giles-Corti 2010; Newman and Kenworthy 1999;).

In his book *The Transit Metropolis* (1998), Cervero presented twelve successful stories of integrating spread-out suburbs into regional transit corridors sort into four categories: adaptive cities (Stockholm, Tokyo, Singapore and Copenhagen), adaptive transit (Karlsruhe, Adelaide and Mexico City), strong core cities (Zurich and Melbourne) and hybrids (Munich, Ottawa and Curitiba).

In an extensive comparative study of 64 global cities presented at the General Meeting of the Pacific Economic Cooperation Council (PECC) in 2010, the "adaptive cities" (Stockholm, Tokyo, Singapore, Zurich and Copenhagen) are highly ranked based on environmental and sustainability criteria (Table 3.1). Fifteen indicators were analysed and classified in three categories: pollution, depletion of natural resources, and environmental initiatives indicators (Giap et al, 2010).

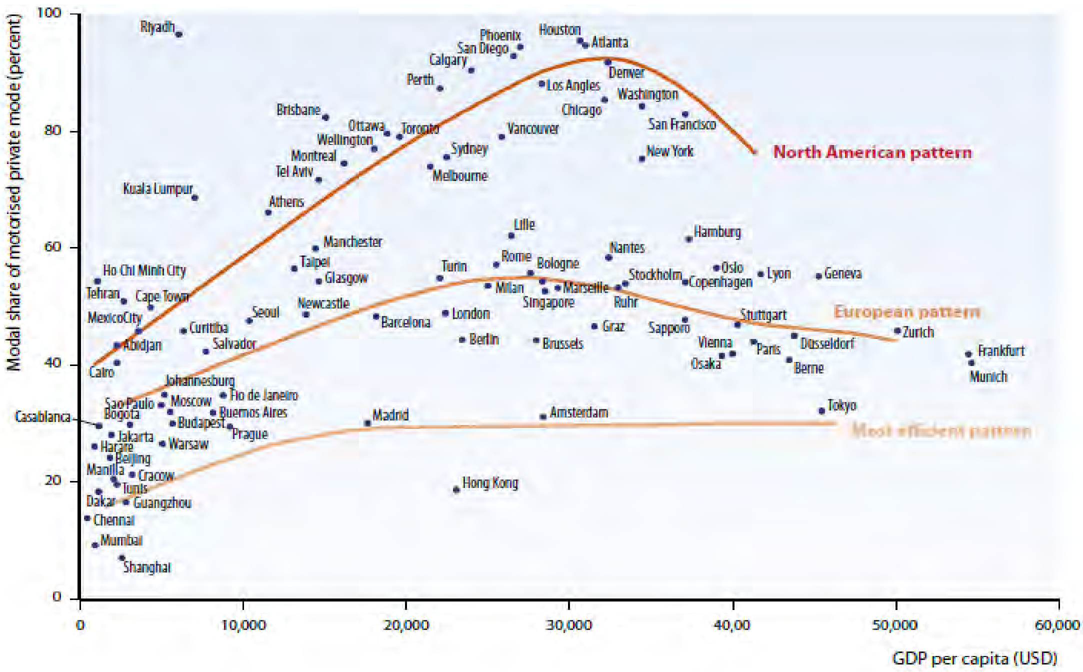
Name of Cities	Region	Environmental friendliness & sustainability	
		Score	Rank
Stockholm	Europe	8.47	1
Geneva	Europe	11.73	2
Zurich	Europe	11.73	2
Luxembourg	Europe	13.47	4
Berlin	Europe	14.60	5
Auckland	Oceania	16.93	6
Paris	Europe	17.00	7
Helsinki	Europe	18.27	8
London	Europe	19.67	9
Barcelona	Europe	20.60	10
Madrid	Europe	20.93	11
Sao Paulo	South America	21.47	12
Tokyo	Asia	22.47	13
Singapore	Asean	22.53	14
Copenhagen	Europe	23.00	15
Osaka-Kobe	Asia	23.73	16
Melbourne	Oceania	24.07	17
Sydney	Oceania	24.27	18
Prague	Europe	25.40	19
New York	North America	25.93	20
LA	North America	26.20	21
Vancouver	North America	26.33	22
Chicago	North America	26.40	23
Amsterdam	Europe	26.87	24
Rome	Europe	27.00	25
Yokohama	Asia	27.47	26
Kuala Lumpur	Asean	27.60	27
Amman	Middle East	29.13	28
Seoul	Asia	29.67	29
Taipei	Asia	29.73	30
Jerusalem	Asia	29.93	31
Philadelphia	North America	30.93	32
Boston	North America	30.93	32
Washington DC	North America	30.93	32
Bangkok	Asean	31.93	32

Name of Cities	Region	Environmental friendliness & sustainability	
		Score	Rank
Hong Kong	Asia	31.93	36
Incheon	Asia	31.93	36
Buenos Aires	South America	32.67	38
Mexico City	North America	32.93	39
Hanoi	Asean	33.93	40
Ho Chi Minh City	Asean	33.93	40
Karachi	Middle East	34.40	42
Mumbai	Asia	34.47	43
Manila	Asean	34.93	44
Ryadh	Middle East	35.60	45
Abu Dhabi	Middle East	35.73	46
Ahmedabad	Asia	36.20	47
Bangalore	Asia	36.20	47
Shanghai	Asia	36.27	49
Nanjing	Asia	36.87	50
Shenzhen	Asia	36.87	50
Delhi	Asia	36.93	52
Phnom Penh	Asean	37.00	53
Moskow	Europe	37.00	53
Chennai	Asia	37.27	55
Istambul	Middle East	37.73	56
Cairo	Middle East	38.40	57
Pune	Asia	38.40	57
Damascus	Middle East	42.27	59
Guang Zhou	Asia	43.07	60
Beijing	Asia	43.27	61
Tianjin	Asia	43.80	62
Chongqing	Asia	44.20	63
Jakarta	Asean	44.93	64

Source: Giap et al (2010), Table: Environmental friendliness & sustainability ranking for 64 global cities, p.

Table 3.1 - Sustainability ranking for 64 global cities

The same cities (Stockholm, Tokyo, Singapore and Copenhagen) demonstrated a significantly lower private car mode share (see Figure 3.3), achieved through better city planning policies and investments in public transport (UNEP 2011)



Source: UNEP 2011, Fig 5: Moving towards a green trajectory based on: UITP, 2006 (Courtesy of SYSTRA), p. 387

Figure 3.3 - Mode share of travel by car

What is interesting when comparing the above graphs is that some cities with very low private car mode share are quite low in the sustainability ranking (e.g. Hong Kong, Shanghai, Beijing or Mexico City). These cities are very dense metropolises, supporting the argument that "density is not destiny" (Mees 2009, p.7) and by implication neither is transit.

There is no single solution to the dilemma of balancing sustainability with urban growth. Nevertheless, there are strong arguments that land-use and transport policies should be integrated if political initiatives are to be effective in meeting the unique needs of each metropolis and its people. The following section examines three representative multi-centred cities in more detail, comparing the integration between transport investment and land development.

3.2.1. Stockholm - from monocentric to polycentric urban form

Stockholm, Sweden is a successfully planned multi-centred city demonstrating the potential of a visionary urban system approach. However, implementing the vision was a very slow process, with lengthy debates around key decisions. Table 3.2 summarises the most important planning and transport policies, and political decisions.

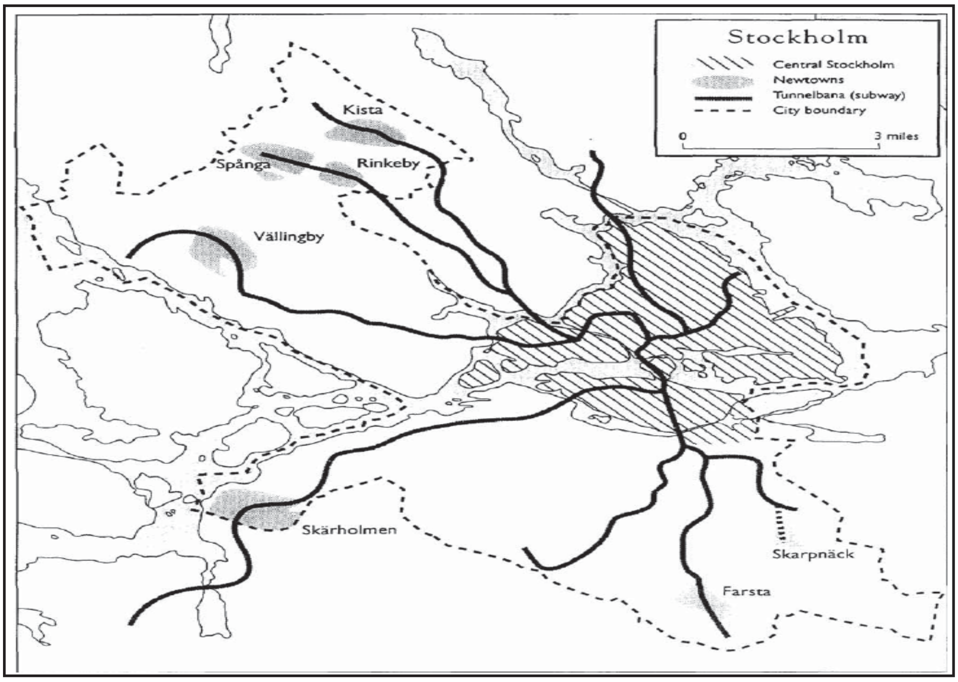
YEAR	TRANSPORT STRATEGIES		LAND USE POLICIES	
1904-1906	Automobile Ordinance	First Swedish regulation on driving: age for driving 18 years, limited speed to 20 kph in denser areas and 30 kph in rural areas	Planning for future expansion	Stockholm City Council started to buy land within and beyond its boundaries
1930	Mass Motorisation	Social Democrats governed Sweden for more than 30 years. Politicians and economists perceived the cars as the motor of economic prosperity and democracy	Improving Housing Policy	Government committed to improving housing to accommodate a new wave of immigrants and workers
1950	Tunnelbana	The 103 km of underground rail system began to run, well ahead of demands at the time	Sven Markelius General Plan	A visionary plan to accommodate what Markelius saw as the unavoidable suburbanisation. A plan for building new satellite towns connected by rail to Stockholm
1950-1980	Mass motorisation continue	"The car is a human right" (declaration of Prime Minister Mr. Ingvar Carlsson)	Planning policies for "half-contained" new towns	Public control of land started in 1906 (by 1980, 70 percent of the land owned by the council was within the city's boundaries and the remaining of 230 square miles beyond its limits) allowed planning for a jobs-to-housing balance in the new satellite towns. Plans for mix of housing types and land uses – commercial, industrial, retail
1992	Earth Summit in Rio de Janeiro	The newly-elected Conservative Party government brought road toll on political agenda for the first time	The newest towns evolved as more specialised communities	Kista, situated at 16 km northwest of Stockholm, considered the Sweden 'Sillicon Valley", can also be described as an "edge city"
1995-1997	Congestion tax project cancelled New Tunnelbana station opened near one of the new towns	Social democrats withdrew the project because of political difficulties	New human-scale approach on planning the newest satellite towns	Because of the "institutional feel" of the first new towns, a new design concept is applied: two to three storey structures, grid network, ground-level retail and sidewalk cafes and a mix of housing
2002-2006	Congestion fee project back in discussion	After 15 years of discussions, a trial of congestion tax started in City of Stockholm 2006		

YEAR	TRANSPORT STRATEGIES		LAND USE POLICIES
2007	Congestion tax has been imposed in the city centre	Trial results: • automobile traffic reduction by 22% • light lorries traffic reduction by 21% • CO2, NO and particulates emissions reduction between 8% to 14% • financial benefit of 1050 mil USD/year profit	
2009	By-pass motorway link approved	According to Swedish Road Administration, the by-pass motorway link will cost approximately 4 billion US Dollars	

Source: author based on data from Cervero (1995) and Tynell et al (2010)

Table 3.2 - Review of transport and land use policies in Stockholm

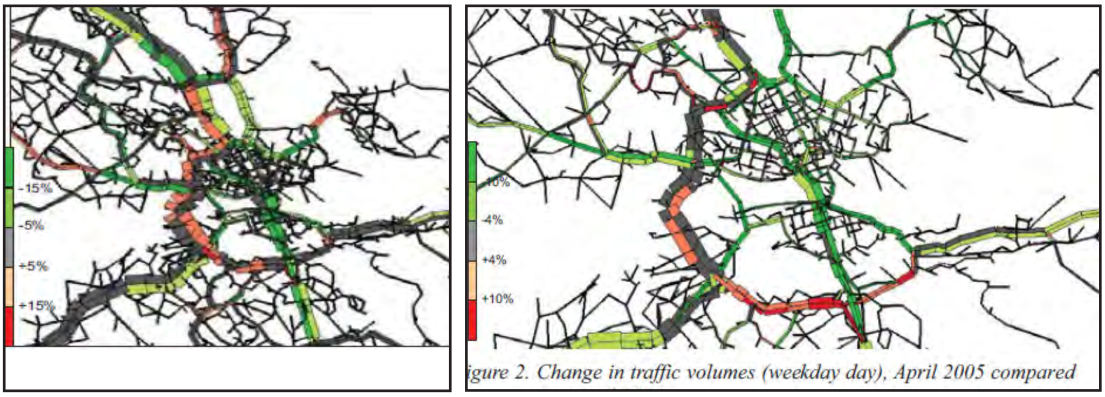
In contrast with most American cities, Stockholm's new towns were planned to promote rail commuting into the central business district. Good pedestrian access and bus connection to the central rail service within the new towns, together with fiscal policies such as low fares for the Tunnelbana, high vehicle registration fees, expensive parking rates in central Stockholm and a very high GST for motor vehicles guaranteed a high level of transit commuters (Cervero 1995). Planning strategies were effectively coordinated with investments in the transport system.



Source: Cervero (1995), Figure 1: Stockholm's new towns

Figure 3.4 - Satellite towns and railway in Stockholm

However, results from the trial confirmed what some planners argue: congestion charges will move traffic from congested to uncongested roads, rather than moving people from cars to other modes (Mees 2009; Downs 1962).



Traffic volumes (weekday day) Travel time (morning peak hour)

Source: City of Stockholm (2006), Facts and Results from the Stockholm Trial – Final version – December 2006, Figure 2: Change in traffic volumes (weekday day), April 2005 compared to April 2006 and Figure 3: Change in travel times (morning rush hour), April 2005 compared to April 2006

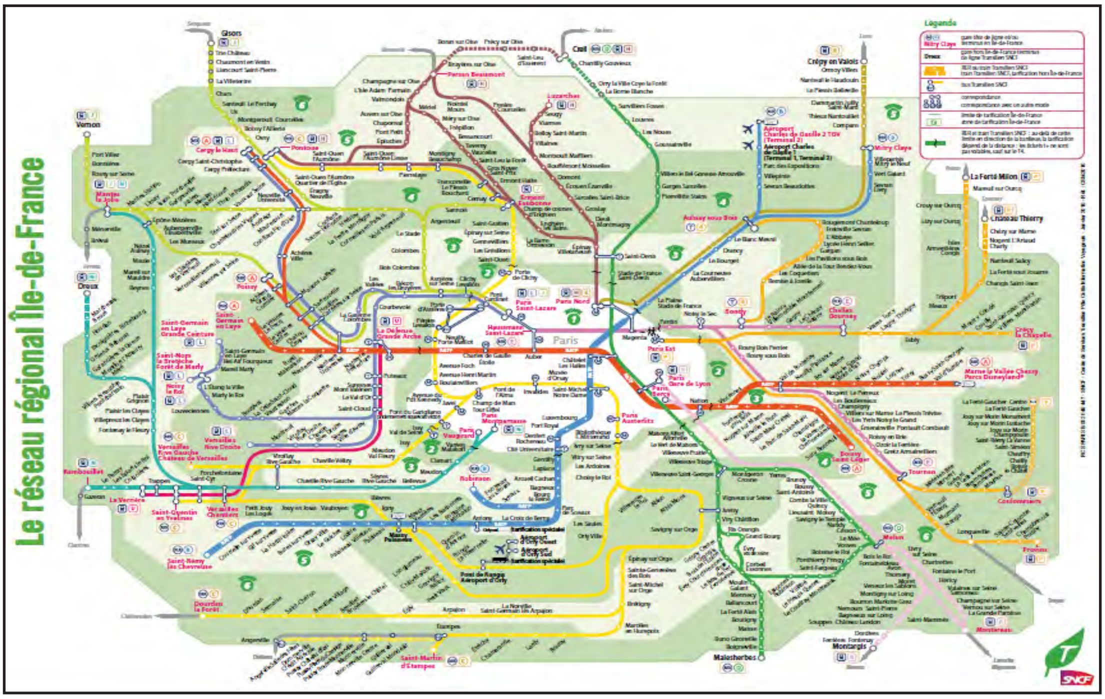
Figure 3.5 - Changes in traffic volumes (weekday) and travel times (morning peak hour), April 2005 compared to April 2006

Congestion charges have also been applied in London and Singapore and the results are still being analysed and interpretations vary, although reducing car trips is widely recognised. However, a congestion charge is only one of the possible measures that could build sustainable transport systems, and raise funds for improvements to the public transport system. Benefits to public transport are not guaranteed. In 2009, Swedish government decided to use funds from the congestion tax to cover a new by-pass motorway (Swedish Road Administration cited in Thynell et al 2010, p. 425).

3.2.2. Paris – metropolis of "ville nouvelles"

Another example of successfully coordinated transport and planning policies is Paris. Between 1964 and 1994, a consistent regional planning policy shaped the suburbanisation of employment in the Paris region (Ile de France) (Cervero 1995; Shearmur and Alvergne 2003; Aguilera 2005). The new towns, also known as 'ville nouvelles', emerged in the Paris metropolitan region as a strategy to restructure the city at a metropolitan scale. They complement the central city rather than compete with it, in contrast to the new towns that have emerged in the American polycentric city. The planning framework is composed of regional plans, urban "free zones", location permits, and taxes. There is strong correlation between regional and central policies to control urban sprawl, and create planned economic sub-centres at the periphery (Shearmur and Alvergne 2003).

Paris probably has the most comprehensive multi-modal transport network, comprising the Metro, express regional trains (RER), buses, trams, suburban trains, and funiculars (cable car). It also has an integrated ticketing system.



Source: Transilien SNCF, Ile de France Network Map

Figure 3.6 - Île-de-France transport network

In 2007, Paris launched VELIB, its bike-sharing program. With over 20,000 bikes and about 1,450 bike racks, a fleet of trucks which move bikes around the city during peak hours, and even a barge that serves as a bike-repair shop, VELIB is run as a real public transport system by 400 full-time workers (Dell 2008). In the first year of operation, it achieved a 5% reduction in car traffic. Initial capital costs were estimated at US$96 million in private investment, with the system generating revenues of US$3.96 million per year for the city and US$72 million per year for the private operator (UNEP 2011, p. 465). The reported profits came from advertising (Bernard Parisot, president of JC Decaux NA cited in Dell 2008).

Similar to Stockholm, Paris integrated urban system approach enabled successful controls on suburbanisation and reduction of urban sprawl.

3.2.3. Sydney - City of Cities

Australian cities have also developed multi-centred urban forms, but the transition has been driven mainly by market forces rather than planning policies in contrast to Stockholm and Paris. The majority of urban transport investments over the last three decades has targeted motorways and toll-roads, and in turn this has increased car dependency and long-distance commuting. Decision-making in Australian cities often reflects inconsistencies in local, state and national policies. In a review of the Australian transport policies, Bray, Taylor and Scrafton (2010) report that forty-three transport policies were published between 1965 and 2010 with no evident emphasis on land use and transport integration until the late 1980s. Transport policies have been very similar across Australian capital cities – Adelaide, Perth, Brisbane, Melbourne and Sydney - with an emphasis on shifting choice from private cars to public transport (Bray, Taylor and Scrafton 2010). The first plan with a focus on increasing public transport mode share - *The Sydney Area Transportation Study* – was published after the price of oil quadrupled within four months in 1974. The early studies were focused on testing different land use and transport scenarios. The first strategy which took into account the effect of transport on land use was *Cities for the 21st Century* published in 1995 (Table 3.3). However, few compelling measures to change travel behaviour were enforced, apart from levies on car parking. In contrast to the other capital cities, Sydney's urban transport policies did not establish targets for public transport mode shares until late 2000 (Bray, Taylor and Scrafton 2010).

Year	Strategy	Outcomes
1974	Sydney Area Transportation Study	Investigated the inducement needed to change the choice to public transport, rather than private transport
1988	Sydney Into its Third Century	Testing alternative land use or transport scenarios
1994	A Balanced Transport Future for Sydney	-
1994	State Rail Strategic Plan	-
1994	State Road Network Strategy	-
1995	Cities for the 21st Century	Integrated land use and transport study
1995	Integrated Transport Strategy	Identified strategies to provide transport infrastructure in support of "preferred land use and urban planning outcomes"
1998	Shaping our Cities	Integrated land use and transport study
1998	Action for Transport	Set targets for containing growth in the vehicle-kilometres travelled
2005	City of Cities	Integrated land use and transport study
2005	Transport Strategy for Sydney	Integrated land use and transport study
2010	Metropolitan Transport Plan: Connecting City of Cities	Integrated land use and transport study

Source: Bray, Taylor and Scrafton, 2010, data compiled from Table 2 – Transport strategies for the capital cities of mainland Australian states

Table 3.3 - Land use and transport strategies for Sydney

In recent years, metropolitan strategies for Sydney have encouraged the growth of major sub-centres in addition to the traditional central business district. The integrated land use and transport policies encouraged development around nodes and corridors following Sydney's rail system. In 2005, The NSW Government Metropolitan Strategy introduced the term "City of Cities" which clearly articulated the government's vision for Sydney's future. The 'City of Cities' concept is based on defining five cities (Sydney CBD, North Sydney, Parramatta, Liverpool and Penrith) critical for an efficient city, with each one operating on the 'Marchetti Constant' concept of one hour travel time budget. The five cities are sustained by other specialised and major centres within an economic and transport network. Strategic centres were differentiated by their future contribution to the growth of Sydney's economy: global, regional, specialised, and major centres (Figure 3.7).

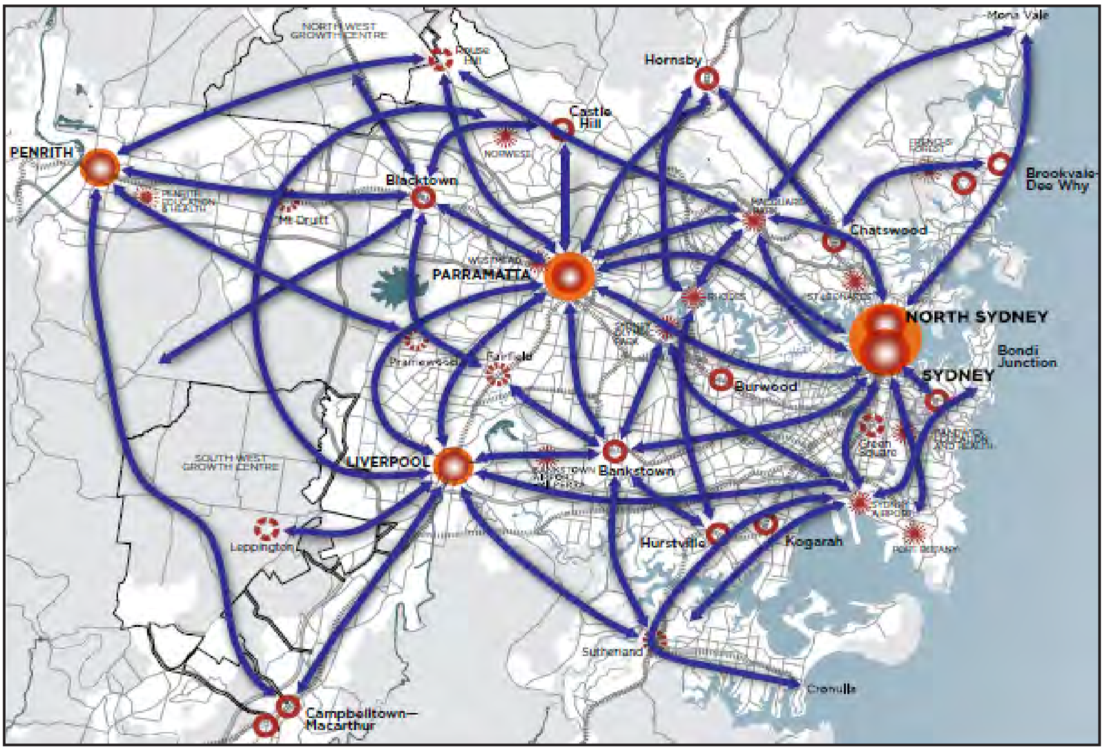
STRATEGIC CENTRES	GLOBAL SYDNEY	2 km	The main focus for national and international business, professional services, specialised health and education precincts, specialised shops and tourism, it is also a recreation and entertainment destination for the Sydney region and has national and international significance.
	REGIONAL CITY	2 km	Providing a full range of business, government, retail, cultural, entertainment and recreational activities, they are a focal point where large, growing regions can access good jobs, shopping, health, education, recreation and other services and not have to travel more than one hour per day.
	SPECIALISED CENTRE	approx 1 km	Areas containing major airports, ports, hospitals, universities, research and business activities. These perform a vital economic and employment role which generate metropolitan-wide benefits.
	MAJOR CENTRE	1 km	Major shopping and business centre serving immediate subregional residential population usually with a full scale shopping mall, council offices, taller office and residential buildings, central community facilities and a minimum of 8,000 jobs.
LOCAL CENTRES	TOWN CENTRE	800 m	Town Centres have one or two supermarkets, community facilities, medical centre, schools, etc. Contain between 4,500 and 9,500 dwellings. Usually a residential origin than employment destination.
	STAND ALONE SHOPPING CENTRE	N/A	Internalised, privately owned centres located away from other commercial areas, containing many of the attributes of a Town Centre but without housing or public open space—may have potential to become a traditional town centre in the long–term.
	VILLAGE	600 m	A strip of shops and surrounding residential area within a 5 to 10 minute walk contains a small supermarket, hairdresser, take–away food shops. Contain between 2,100 and 5,500 dwelllings.
	SMALL VILLAGE	400 m	A small strip of shops and adjacent residential area within a 5 to 10 minute walk. Contain between 800 and 2,700 dwellings.
	NEIGHBOURHOOD CENTRE	150 m	One or a small cluster of shops and services. Contain between 150 and 900 dwellings.
	RURAL TOWN, VILLAGE OR NEIGHBOURHOOD CENTRE	as above	Located in rural zones outside metropolitan urban areas with similar roles to towns, villages and neighbourhoods but rural in character with a wider driving catchment.

Source: NSW Government Metropolitan Strategy 2005, Table 7: Centre types and metro elements

Figure 3.7 - Strategic and local centres in Sydney

Specialised centres are clusters of high employment concentrations around technology and business parks, education and research activities, and large commercial and retail precincts.

The recently released *Metropolitan Strategy Review: Sydney towards 2036* restated the importance of strategic centres for the economic development of Sydney and recognised the importance of an integrated land use and transport approach. The key transport corridors linking all the centres are shown in Figure 3.8.



Source: Metropolitan Plan for Sydney 2036, Figure C2: 46 Key Transport Corridors

Figure 3.8 - Key transport corridors

The strategy is focused on urban renewal and transit-oriented development, emphasising a shift to public transport. Several major public transport projects are planned to be delivered over a medium timeframe (10 years):

- The Western Express Program, improving train services for the regional centres Parramatta, Penrith, Richmond and Blacktown
- The South West Rail Link
- Start construction of the North West Rail Link
- Over 1,000 more buses and implementation of bus priority measures
- CBD light rail service
- Extension of the existing cycleway network

For the first time since 2000, the latest metropolitan strategy includes targets for public transport mode share for work journeys to the regional centres:

- 80% to the CBD during the peak

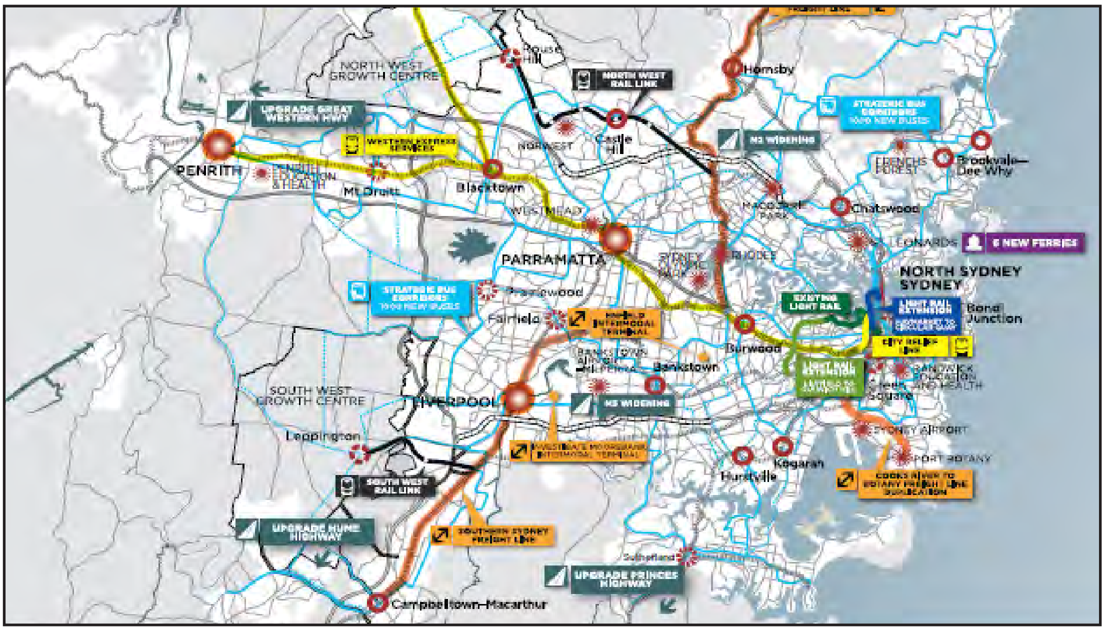
– 28% across the metropolitan area

– 50% to Parramatta during the peak

– 25% to Penrith during the peak

– 20% to Liverpool during the peak

A target for active transport mode share is also included in the strategy, with the aim of 5% bicycle mode share in the greater Sydney region.



Source: Metropolitan Plan for Sydney 2036, Metropolitan Transport Plan

Figure 3.9 - Metropolitan Transport Plan 2036

The 21st century is seeing the transition from the historical urban sprawl associated with *"scattered, unplanned fringe growth that is neither town nor country"* (Mees 2000) to the New Urbanism approach, that seeks to counteract urban sprawl and car dependence. New Urbanism advocates new suburban developments that are better integrated into a regional transit system, plans for increased and mixed densities, and better street connectivity at the local level (Falconer, Newman and Gilles-Corti 2010). Employment dynamics are re-shaping the urban form from a monocentric to a polycentric pattern. The shift from a mono to a multi-centred city has occurred in most major metropolitan regions, although it has taken different forms. Three major global cities have been discussed: Stockholm, Paris and Sydney. These cities were selected because they rank highly on environmental and sustainability indices, and have developed a multi-centred urban form in the past decades, but differ in the the evolution of policy and of the new centres.

Stockholm started to plan early for the new satellite towns to accommodate the growth of immigrants and workers, and to promote rail commuting into the central business district. The ‘villes nouvelles’ of Paris were born because of economies of scale. The strategic centres in Sydney aim to concentrate activities around public transport nodes, in order to reduce urban sprawl and car dependence. All three cities formulated integrated transport and land use strategies in order to achieve sustainable outcomes, although it is questionable whether Sydney really “adopts” them.

The centres within polycentric cities have different spatial forms and functions. One common typology evident in Stockholm, Paris and Sydney, is that of the ‘edge city’, which will be discussed in the next section.

3.3. Edge cities around the world

> BEAUTY CONTEST: An attempt to inject Quality of Life into an Edge City.
> Joel Garreau, Life on the new frontier, The Words – Glossary of a New Frontier (1991)

Technoburbs, urban villages, suburban downtowns, superburbia and forty other terminologies are all used to capture the new post-suburban form, but the term most recognised by the public (and academia) is ‘edge cities’ (Phelps 2009; Garreau 1991). Joel Garreau introduced the term in 1991 to describe new emerging urban centres in the United States characterised by a concentration of employment, rather than residential function. Garreau identified three stages in the evolution of postmodern American built form: suburbanisation (after World War II), malling (between 1960 and 1970), and building the Information Age society. Edge cities emerged from the third phase. Garreau identified five characteristics which would classify an urban centre as an edge city:

– More than 465.000 square meters (5 million square feet) of office space
– More than 56.000 square meters (600,00 square feet) of retail space
– More jobs than bedrooms
– A regional end destination perceived as “has it all” place
– Has grown and changed completely in the past thirty years

Phelps (2009, p. 377) described the ‘edge city’ as “the low-density, car-dependent commercial and residential development apparent at major intersections on the freeway system”, the outcome of the US federal and state planning policies responsible for urban sprawl. Phelps considers that urban sprawl is “the physical manifestation of the Fordist industrial complex” and that edge cities are a result of post-Fordist economy.

Some authors argue that edge cities fulfill similar functions in different social, cultural and spatial forms, as part of wider urban systems (Phelps 2009; Bontje and Burdack 2005). Others argue that an "edge city" is a centre, not a city, and is only as a phase in the decentralisation process (Bruegmann 2005: page 71 cited in Phelps 2009: pages 377-378).

> Like it or loathe it, the term edge city is one that continues to excite opinions both popular and academic. The phenomenon of edge cities can usefully be situated in a broader historical and geographical context in order that its value and limitations can be appreciated. (…)Yet edge cities, as incarnations of longer-term processes of suburbanization which have been as much nodal as seamless additions to contiguous urban areas, focus our attention on some of the most active and advanced patterns of urban development.
> (Phelps,2009, p. 380)

3.3.1. The Archetype of The American Edge City - Tysons Corner

The classic example of an "edge city" is Tysons Corner, Virginia - part of the Washington DC metropolitan area. Tysons Corner is located alongside one of the major highways surrounding Washington DC (Route 495 or "Capital Beltway") (Garreau 1991). In 1965, the area was still rural and it seems its progress was decided by its proximity to the Pentagon and to Dulles airport (Ceruzzi, 2000). Many military contractors (such as BDM, Planning Research Corporation, Bersoff Technology Group SRA International) moved their headquarters to be physically close to the Pentagon. These were followed by high tech manufacturers on which they relied (SAIC, Honeywell, BAE Systems, Compuware) and later on, by the corporate headquarters of USA Today, Hilton Worldwide, Spacenet and others (Ceruzzi 2000; Fairfax County Virginia 2011).

Today, the place houses around 17,000 residents. It contains high concentrations of employment, especially in the internet industry, high-technology and corporate headquarters. It has one of the largest shopping centres in America plus a number of other large stores (Ceruzzi 2000; PB Placemaking Group 2009). It is the 12th largest employment centre in the state with 110,000 jobs (TysonsCorner.com). The current floor space of the development is 46 million square feet and a major re-development proposal is now being considered (PB Placemaking Group 2009).

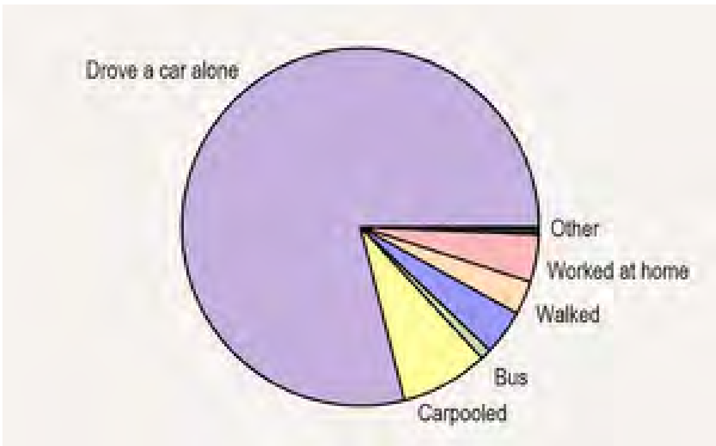
Tysons Corner developed along a highway, is planned around roads and cars. It does not have a nearby rail or Metro station, and the bus services are unreliable so the only option for travel is driving a car (Ceruzzi 2000; PB Placemaking Group 2009). There are 167,000 parking spaces on 40 million square feet of parking lots for workers and shoppers (TysonsCorner.com; PB Placemaking Group, 2009). The place is characterised by large building footprints, few open spaces or sidewalks, and lack of 'vibrant community feel' (Ceruzzi 2000; Fishman 1995).

Source: Tysons Corner, VA, http://www.city-data.com/picfilesv/picv29854.php

Figure 3.10 - Tysons Corner, aerial view

> To many architects and advocates of the New Urbanism, Tysons Corner represents everything that is wrong with America today. Many of them refuse even to go there. Although its commercial density ranks among the highest of all edge Cities, it is not, and never will be, dense enough to make the light-rail transit economically practical. Even if a rail system were built and running tomorrow, it would not reduce automobile congestion by more than a tiny fraction.
> (Ceruzzi, 2000: page 98)

The preferred mode of travel to work is driving a car, representing 79% of all journey-to-work trips, while only 1% travel by bus and 3% walk (City-data.com)



Source: http://www.city-data.com/city/Tysons-Corner-Virginia.html

Figure 3.11 - Journey to work in Tysons Corner, 2009

Planners are trying to transform Tysons Corner into a more sustainable place through a mix of planning and transport strategies. In 2005, the Tysons Land Use Task Force was established to promote mixed land use and transit oriented development (TOD) strategies, increase residential density, and provide for quality public spaces, parks, public art and other amenities (Fairfax County Virginia 2009).

Land uses are expected to remain similar, but with a greater emphasis on increasing residential density around metro stations and redeveloping the large surface parking and car dealerships "into more efficient, higher intensity land uses" (Fairfax County Virginia 2009, p. 26).

Recent regional plans include a Metrorail line to Tysons Corner. A 'circulator' system has been proposed as a feeder for the four Metrorail stations. The goals of the 'circulator' plan are to transform Tysons Corner into a walkable transit oriented urban environment, to provide high quality transit, and to support a multimodal regional transportation network (Fairfax County Virginia 2009). However, the mode of travel offered by the circulator has not been established yet. The plan is to start with buses operating in mixed traffic, then to exclusive bus rights-of-way, followed by a fixed guideway system (Personal or Group Rapid Transit concept).

> Creating a comprehensive PRT system in Tysons will create an example that could be imitated in scores of other places in the region and the nation, creating a true transformation of our urban spaces and our transportation paradigms.
> Steve Offutt, The Washington Post, December 31, 2009, Tyson's Corner Circulator Buses – Take a Book Along

3.3.2. The European Edge Cities

Although the concept of 'edge city' is usually seen as a typical North American phenomenon and Garreau identified over 200 existing edge cities in the United States, the concept has also been investigated in European context.

Bontje and Burdack (2005) identified four examples of "European Edge Cities" from the Paris metropolitan region (Massy-Saclay and Val d'Europe) and Randstad, Netherlands (Schipol and South Axis). Both Paris and Randstad are emerging polycentric metropolitan forms. The European examples are all characterised by a high degree of specialisation, housing a significant high skilled employment concentration developed in the last few decades.

Massy-Saclay is located 20 kilometres south-west of Paris. In 1950, the place was a peaceful suburb but its transformation started with the building of the Centre of Nuclear Studies (Centre d'Etudes Nucleaire CEN), followed by other research and higher education institutions, such as the Department of Natural Sciences of Sorbonne, Ecole Polytchnique, Suplec (Bontje and Burdack, 2005). Later, the goverment decided to create the largest technopole in France – Courtaboeuf on an area of 450 hectares. The place became more attractive in 1990 with the opening of the high-speed train (TGV) line. Bontje and Burdack (2005) reported a population of 205,000 people and 107,000 jobs, but more work places than local working population (generating a surplus of 14,800 commuting trips). Although this is not exactly one of the typical characteristics of an ’edge city’, the authors argue that the high degree of skilled jobs and the development over the past few decades to a research and science centre qualify Massay-Saclay as an ‘edge city’.

An excellent example of the role of the policy in planning urban growth is the Markelius General Plan for Stockholm discussed in the previous section of this chapter. Kista, one of the new satellite towns, situated at 16 km northwest of Stockholm and considered the Sweden ‘Sillicon Valley” with more than 200 companies and over 20,000 employees in 1995 (Cervero 1995) can also be described as an ‘edge city’. The main attraction for many multinational companies is its proximity to Arlanda International airport and “the university town of Uppsala”. Kista has mixed land uses, including a range of housing types (from high-rise apartments to single-family dwellings), multinational corporations, international electronic companies and an impressive indoor shopping and business centre (Cervero 1995).

Kista, the “region’s technopolis”, accommodates approximately 14% of the workers only, while the balance of 86% travel from Stockholm City or from the rest of county to their working places in Kista (Cervero 1995,p 1156).

Stockholm’s new towns were planned to be “natural centres for rail commuting” and the statistics confirm their policies success (Cervero 1995, p. 49). The concentration of housing and workplaces near the Tunnelbana rail stations and a vast grade-separated pedestrian pathway system has led to a great share of the public transport for commuting trips: almost 60% mode share is by public transport compared to approximately a 26% share for people driving to work. However, the residents of Kista are more car-dependent than inner-city Stockholm residents or Stockholm County as a whole (Cervero 1995). The preferred modes of transport for local trips are walking and cycling, as a result of the pathway system.

North American edge cities differ from European examples, which have much higher public sector involvement. North American edge cities reflect private development priorities and are driven by market forces rather than state policy. Therefore, they are less well integrated into the larger regional context. European edge cities, on the other hand, are seen to be complementary urban forms, planned to support the dynamic growth of the polycentric urban form. They are a result of a more comprehensive planning policy in which all levels of government (national, regional and local), play an active role.

3.3.3. Emerging Edge Cities in the Australian Context - Macquarie Park

In Australia, the concept of 'edge city' is not thoroughly investigated. Garreau identified North Sydney as an example of an Australian edge city (Garreau 1991). Freestone (1997) argues that North Sydney is not a good example, being more an extension of the central business district. He chose North Ryde as a case study of an Australian edge city and concluded that "the essential pre-conditions" for the evolution of edge cities in Australia are missing (p. 256). He argues that the major Australian cities are less freeway-dependent than the North American metropolis and "the Australian CBD remains the single most important employment and activity node in every major city" (Freestone 1997, p. 255). However, in recent years, metropolitan planning strategies for Sydney have encouraged the growth of major sub-centres in addition to the traditional central business district (CBD). The traditional CBD is now replaced by "The Global Sydney" comprising the CBD's of Sydney and North Sydney; regional cities, specialised centres, and major shopping and business centres in the close vicinity of residential suburbs are all part of the city's new polycentric structure (NSW Government 2010, p.28). Specialised centres are clusters of high employment concentrations around major airports, universities, large commercial precincts and business parks – similar to edge cities's development pattern. The investigation contained in this thesis suggests that this urban form can be recognised in Sydney too, identifying Macquarie Park as a typical 'edge city'.

Macquarie Park (described in more detail in Chapter 4) has changed rapidly over the last thirty years from bushland, market gardens and paddocks to a major centre housing a well-known university, multinational corporations, and an innovative research based high-technology sector. The original starting point of the site is the 1964 government decision to establish a public university surrounded by residential and industrial development. Since then, international and national companies have moved into the area; Johnson & Johnson, Raytheon, Canon, Fujitsu, Oracle Corporation, Compuware, AstraZeneca, Nestle Purina, Hitachi, Hyundai and Optus are only a few examples.

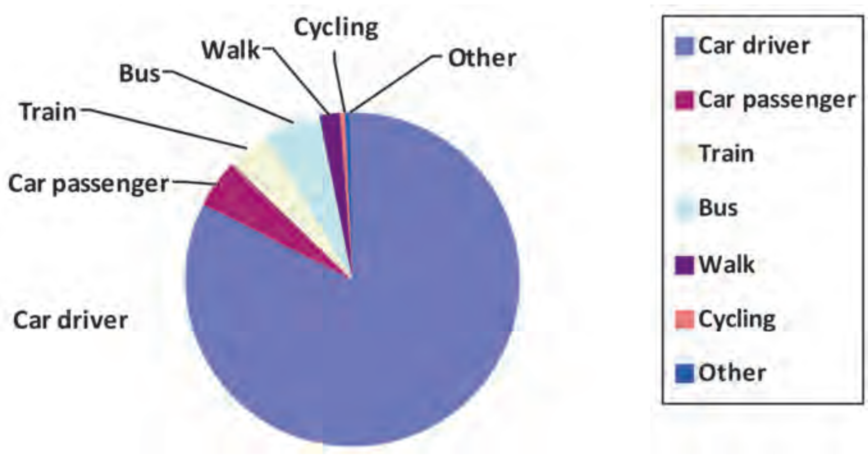
In 2006, the total employment number in Macquarie Park was approximately 32,000 compared to only 5,599 residents (Australian Bureau of Statistics 2006). It is a major high skilled employment centre, combining commercial, business, research and educational activities. Thus, Macquarie Park has all the characteristics of a typical 'edge city'.

Similar to Tysons Corner, the place is characterised by an ineffective local public transport service, large building footprints, and lack of pedestrian and cycleway access. Currenttly, it includes 800,000 square metres of commercial floor space and 73,000 square metres of retail space. The city forecasts an additional 1,299,000 square metres of development by 2031 (City of Ryde, LEP 2011). There are over 31,500 off-street parking spaces in the commercial zones. If the existing travel patterns do not change, twice as many car parking spaces will need to be provided by 2031 for the predicted 78,000 employees.

Macquarie Park, http://www.airviewonline.com.au/aerial/3681/Macquarie-Park.html

Figure 3.12 - Macquarie Park, aerial view

Until 2009, there was no rail service so car dependency was very high (87% journey to work in 2006). Preliminary data collected in the first month after the rail line opening indicated that only 25% of the rail passengers were not previous regular users of rail mode so car dependency may not be substantially reduced after the rail service began.



Source: author, based on data from Transport Data Centre 2008, Journey to Work by centre, 2001 and 2006, Maquarie Park Mode Share 2006

Figure 3.13 - Journey to work, Macquarie Park

The physical scale of Macquarie Park implies that many existing and potential destinations are not within walking distance of the rail stations. Thus, even though higher density land uses are to be clustered around the stations as the area redevelops, there is a need to increase accessibility to the peripheral parts of the area.

The medium and long term strategies of the local council include improving pedestrian access and cycling facilities within the area, integrating alternative modes of transport and reviewing car parking provision rates (City of Ryde 2009). However, the short term plans are focused on increasing the traffic capacity of the existing road network, without any provision for a local access transport system. A more detailed description of Macquarie Park will be presented in Chapter 4.

3.3.4. Urban form, land use and travel patterns in edge cities

Edge cities are considered a function of the economic growth (Garreau 1991; Scheer and Petkov 1998) and similar evolution paths have been identified in diverse political, cultural and economic systems. Romanos et al (1989) cited in Scheer and Petkov (1998, p. 3) distinguish three ways in which edge cities evolved:

- out of the growth of older business districts
- as new centres of uncontrolled economic growth surrounding a mall, university or other growth pole
- as new planned communities as a result of a planning policy

While the European edge cities analysed in the previous section (Massay Saclay and Kista) are a result of explicit planning policies, the North American and Australian edge cities are more a function of the economic growth which generated new centres. As a consequence, land parcels are sized for modern developments on large sites, the sizes and shapes are irregular and the street network is not fine-grained but rather isolates the buildings from each other.

The components of an edge city are over-scaled: the building footprints, the size of blocks, and the distance between major roads are much larger then those in traditional city centres (Scheer and Petkov 1998). These trends are recognised in the two edge cities discussed earlier, Tysons Corner and Macquarie Park.

Although most planners are dissatisfied with the urban form (Scheer and Petkov, 1998), the edge cities are a result of the market forces and thus, tend to be economically successful. The land owned by several stakeholders is zoned for commercial, education and retail activities, with relatively small areas of environmental and recreational zones, and low density residential areas. Changing the land use is difficult in any established urban form (Lachapelle and Franks 2009) and even more difficult in an edge city where the existing buildings have to be extensively redeveloped to accommodate a higher density and mixed land uses. Moreover, edge cities display a car-dependent travel pattern, which will be difficult to change without a strong and coherent strategy.

As Garreau pointed out, edge cities develop to the point where density is so high that it generates traffic congestion, but not high enough to "support the rail alternative to automobile traffic" (p. 470). The main constraints to transforming edge cities into more dense and pedestrian-oriented urban environments are physical: size and infrastructure (Scheer and Petkov 1998). Scheer and Petkov argue that increasing density and providing a fine grained network of streets is not possible without restricting the size of development parcels and controlling street layout. These policies would disrupt the traditional planning practice and market-based development processes (Scheer and Petkov 1998).

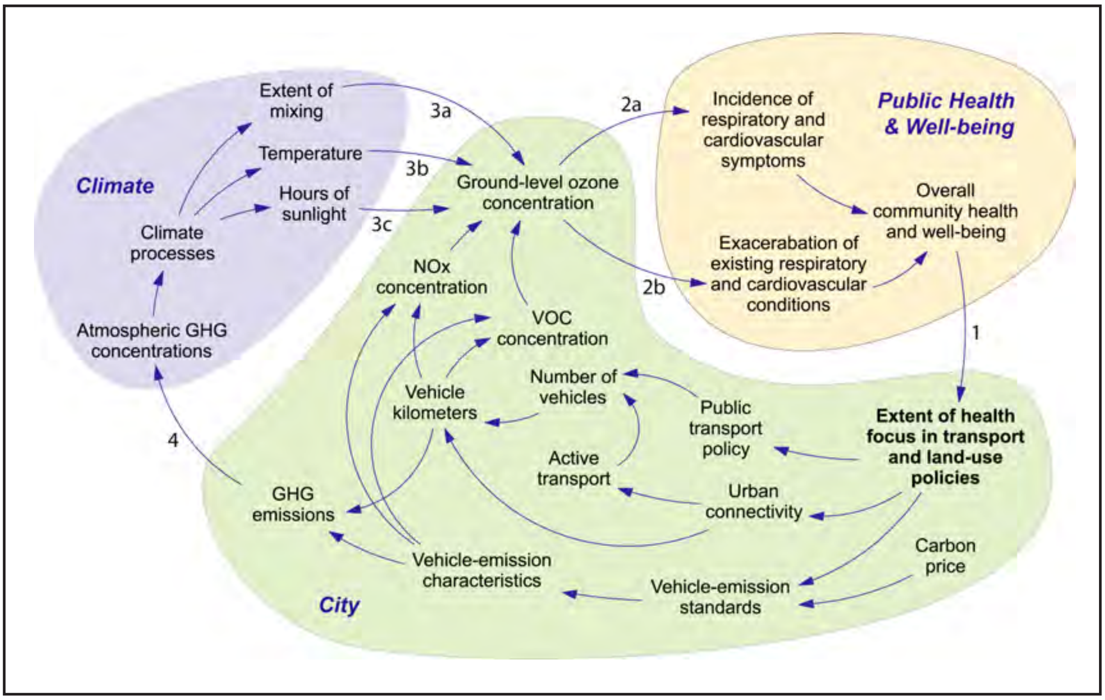
As many planners have done, Scheer and Petkov fail to consider infrastructure and transport options to support increased urban density, other than those to accommodate cars. However, they conclude that traffic capacity can not be expanded indefinitely and that congestion will inhibit city growth. They recommend more research on the maximum capacity of the edge cities, with a focus on transport systems as the key issue.

The following section addresses a related but separate issue, the association between urban form and public health. While no studies address the link between edge cities and public health directly, the growing literature on association between built environment and public health provides the base for the assessment developed in later chapters.

3.4. Built Environment and Public Health

> If we can improve both the quality of life and sustainability we may develop the opportunity to continue on the path to increased prosperity while simultaneously reducing our environmental impact.
> Peter J.Muller, Sustainable City Enabled by Personal Rapid Transit (2011)

Cities are dynamic human-environment systems, and their sub-systems are influenced by complex feedback effects (Proust et al 2012). Transport and land-use policies which affect patterns of urban development have impacted travel patterns and consequently public health (Black and Black 2009; Frank and Engelke 2005). Black and Black (2009) point out that the impacts on public health of transport, urbanisation and climate change are the new challenges for sustainable development. Using a system dynamics approach and formulating a hypothetical transport-public health-climate change feedback loop, Proust et al (2011) identified the "Extent of health focus in transport and land-use policies" as an important leverage point for the system change (Figure 3.14).



Source: Proust et al, 2011: An initial hypothesis concerning the relationship between transport and land-use policies and health

Figure 3.14 - Urban transport, climate change and public health

Reducing the ground-level ozone concentration will positively impact public health by reducing the incidence of cardio-vascular and respiratory disease. The main pollutants in large cities are ozone, particulates, nitrogen oxides, carbon monoxide and sulphur dioxide. The main source of air pollutants are emissions from road vehicles. Recent research indicates that 2.3% of mortality in Australia is caused by air pollution (NSW Ministry of Health 2012). The main air pollutants in Sydney are ozone and particulate matter. Health costs associated with air pollution are around AU$4.7 billion per year in New South Wales (NSW Ministry of Health 2012). A study investigating future air quality trends in Melbourne found out that the population's exposure to ozone will increase by 20% over the next twenty years if no policies to control emissions are introduced (Cope et al 2011).

Strategies combining active travel and reducing emissions from motor vehicles would give the largest health benefits (Marshal ,Brauer and Frank 2009; Woodcock et al 2009).

The built environment may influence the physical inactivity and air pollution levels, which are important risk factors for health. Two studies investigating the interaction between neighbourhood walkability and exposure to air pollution - one in southern California and the other one in Vancouver, Canada, outlined that the benefits of increased physical activity in high-walkability neighbourhoods may be offset by the high exposure to nitrogen oxide pollution (Hankey, Marshall and Brauer 2012; Marshall, Brauer and Frank 2009). A "high-walkability neighbourhood" refers to a built environment that encourages walking through high levels of residential density, intersection density, retail activity concentration and land use mix. The nitrogen oxides (NOx) concentration is an indicator of traffic exhaust fumes for both gasoline and diesel vehicles. A high concentration of activities within a highly walkable neighbourhood may result in exposure to high concentrations of pollutants, especially NOx although the vehicle use per capita is reduced. The health impacts of neighbourhoods depend on the spatial pattern of air pollution and on the pollutant. Both studies reported that the estimated mortality rate due to increased NOx were greater in high-walkability neighbourhoods compared to the low-walkability environments where NOx concentration is lower because the activities and emissions are dispersed. Ground-level ozone and particulates can worsen asthma and chronic obstructive pulmonary diseases and may even result in premature deaths (NSW Ministry of Health 2012). Sensitive groups may experience pains and aggravation of their health conditions, especially while exercising.

Many researchers from multi-disciplinary fields have investigated the relationship between the built environment and physical activity. However, the evidence of environmental determinants of physical activity is inconsistent to date (Wendel-Vos et al 2007; Giles-Cortie et al 2009). Some researchers argue that the environmental attributes may be defined inconsistently in different studies (Wendel-Vos et al 2007), while others point out that many studies failed to measure the behaviour-specific correlates, especially the age of participants in all these studies (Giles-Cortie et al 2009).

More recent reviews show stronger links between walkability and physical activity (Frank, Andresen and Schmid 2004). High-walkability (pedestrian-oriented) neighbourhoods, which are urban environments characterised by high residential density, mixed land uses, human scale streets and a highly connected street network, have more physically active individuals than low-walkability neighbourhoods, but these represent a small share of the total population (Hankey et al 2012). The ischemic heart disease mortality rates associated with physical inactivity were reported to be comparable in high and low-walkability neighbourhoods (Hankey et al 2012).

Obesity is also associated with the built environment seen as a result of diet, physical activity and urban form (Papas et al 2007). In an extensive review of the existing empirical research conducted between 1966 and 2007, Papas el al (2007) found that over 80% of the reviewed studies reported a significant positive association between different aspects of the built environment and obesity. Residents of low-walkability neighbourhoods were more likely to be classified as overweight, with a higher body mass index (BMI) than residents of high-walkability neighbourhoods (Doyle et al 2006 cited in Papas et al 2007). However, other research reported that there is no association between sprawl at the metropolitan-level and increased body mass index (Ewing et al 2006 cited in Papas et al 2007). Giles-Corti et al (2003) reported that obesity is also associated with poor access to recreational facilities.

Frank et al (2006) argue that walkability is more strongly associated with active transportation than with obesity. Men cycling or walking to work were found to be less likely to be overweight and obese compared to those driving to work (Wen and Rissel 2007). Although the same correlation could not be found for women, Cerin et al (2007) reported that regular walking to work resulted in women achieving the recommended physical activity level.

Evidence from the literature review showed that thirty minutes of physical activity per day is associated with health benefits, reducing the risk of major diseases such as cardiovascular diseases, diabetes, dementia, depression and obesity (Cerin et al 2007; Lachapelle and Frank 2009; Woodcock et al 2009; Trubka, Newman and Bilsborough 2010; Matan et al 2011). A study based on the US National Household Travel Survey found that 29% of transit users achieved more than 30 minutes of physical activity per day (Besser and Dannenberg 2005 cited in Lachapelle and Frank 2009). The minimum physical activity level recommended by the National Physical Guidelines for Australians is thirty minutes per day for at least five days per week (Trubka, Newman and Bilsborough 2010).

A systematic review of the existing literature in USA and Australia, published between 1980 and 2004 revealed that the most important environmental determinants of different types of physical activity in adults are socio-cultural environment (homes, schools, workplaces) and having a companion (Wendel-Vos et al 2007). The connectivity of streets and trails were convincingly associated with active travel (Wendel-Vos et al 2007; Owen et al 2007). The most important contributor to walking to work, especially among women, was found to be workplace proximity (Cerin et al 2007). A study conducted in Vancouver, Canada identified that environmental attributes such as topography, intersection density, signage, and mixed land uses are strongly associated with cycling (Winters et al 2010). The most influential factors were found to be "being away from traffic and noise pollution, having beautiful scenery, having separate bicycle paths for the entire distance, and having a flat topography" (Winters et al, 2010, page 970).

Walking and cycling were found to be more successful as modes of recreation than as modes of travel (Handy et al 2002). The neighbourhood's attributes are more influential on walking trips than the region's attributes, while car trips are influenced by the region's structure to a greater extent than the neighbourhood's characteristics (Handy et al 2002). Winters et al (2010) argue that all three spatial zones - origin, destination and routes - should be considered in future planning and policy decisions. They reported that the characteristics of cycling routes were more influential than origin or destination attributes, after examining the association between the decision to bicycle and the built environment.

Active or inactive, all individuals are exposed to outdoor air pollution (Hankey et al, 2012) and some categories, such as elderly people or children, and people affected by pre-existing health conditions, are more vulnerable to these risk factors (Black and Black 2009; Proust et al 2012). Changes in technologies to reduce emissions from vehicles would reduce the health burden due to ozone exposure (Woodcock et al 2009). Increasing walkability will increase active travel, which in turn will reduce the body mass index of travellers. Considering only origin or destination zones, planners and policy makers may ignore significant influential factors that could increase active travel.

3.5. Conclusions

This chapter explored the transport and planning strategies of various cities in different national and continental settings. Three major global cities were presented: Stockholm, Paris and Sydney, all of them displaying a polycentric urban form. The evolution of the multi-centred form and the policy approach were completely different in each city, but a common typology of "edge city" was recognised in each of them, despite their different political, cultural and economic systems.

The concept of an 'edge city' is usually associated with a typical North American phenomenon; however it has also been identified in European and Australian contexts. Tysons Corner, the archetype of an American 'edge city' is the result of private development and was driven by market forces more than by the state policy. Macquarie Park also displays all the characteristics of a typical "edge city", within the emerging

Australian multi-centred city form. Its urban form, land use and travel patterns are very similar to Tysons Corner. European edge cities, such as Massy-Saclay or Val d'Europe (around Paris) and Kista (Stockholm) are all a result of a more comprehensive planning policy at all levels of government. Tysons Corner and Macquarie Park, on the other hand, are a function of unregulated economic growth.

Although this study has been limited to analysing a small number of edge cities, some common characteristics have been identified.

Edge cities are defined as places that have a high degree of specialisation, did not exist in their current form a few decades ago, and house a significant skilled employment concentration. Although new towns such as Kista were carefully planned to concentrate mixed land uses around rail stations and to promote public transport, their residents are more cardependent than innercity residents. Moreover, Kista and the other European cities discussed in this chapter have an excess of working places over local working population, which is seen by some authors as an attribute of 'edge cities' although they may fail Garreau's strict definition of "more jobs than bedrooms". As Bontje and Burdack (2005, p 317) have argued "the European Edge Cities are not mere copies of their American counterparts but rather a typically European variation of the original Edge City model".

In France and Sweden, planning strategies were effectively coordinated with investments in the transport system, which translated into more sustainable urban forms compared to NorthAmerican and Australian caroriented urban developments. While the question for European edge cities is whether the conflict between economic growth and the traditional residential environment will limit urban growth, for the archetypal edge cities such as Tysons Corner, the traffic increase and the large scale urban form are the main issues. The question posed is how to retrofit them to allow for future sustainable growth.

Edge cities accommodate a large concentration of workplaces, and hence, commuting trips by car will expose local residents to more air pollution than residents of typical suburbs. Furthermore, increased commuting traffic may threaten public health by increasing exposure to air pollution and accidents, and discouraging walking which may increase the risk of obesity."

The 'edge city' is a destination point for large numbers of workers. Active travel is significantly influenced by the characteristics of routes, such as connectivity of trails and separation from traffic, noise and pollution. Consequently, policies to increase active travel should be related to the entire region rather than to the edge city only. However, walking and cycling can be promoted as healthy modes of exercise if the urban space will be more aesthetically pleasing and more pedestrian friendly.

The health focus in transport and land-use policies is important if urban systems are to change. Increasing numbers of transit users will have positive impacts on physical activity levels and consequently on public health by reducing the risk of cardiovascular diseases, diabetes, depression and obesity. Future policies to discourage travel by private cars, such as limiting parking, increasing the accessibility of the transit nodes, and transit oriented developments are very important strategies in transform edge cities into more sustainable places, and thus contributing to more sustainable cities.

In this study I investigate whether Personal Rapid Transit system (presented in Chapter 2) could bridge the car-oriented urban form that most edge cities have inherited with the transit-focused urban future that is essential to meet the sustainability goals. The next three chapters will analyse the effectiveness of PRT in contributing to more sustainable transport options in edge cities, with a focus on the Australian context.

Chapter 4.
Macquarie Park Case Study - employment, land use and transport future

This chapter sets the context for the analysis by describing the study area. Macquarie Park was chosen because it represents an 'edge city', within Sydney's multi-centred urban structure. The first part of the chapter presents an overview of Macquarie Park's role within the metropolitan context. The balance of the chapter reviews current and projected employment, land use and transportation patterns in the study area. This forms the basis for the alternative land use and transport scenarios discussed in Chapter 5.

4.1. Background

In Chapter 3, I argued that Macquarie Park has all the characteristics of a typical "edge city" defined in 1991 by the father of the concept, Joel Garreau (see Table 4.1).

Garreau's five functions of edge cities	Macquarie Park	Checklist Y/N
More than 5 million square feet (465.000 square meters) of office space	800,000 square meters commercial/ office space	Y
More than 600,000 square feet (56.000 square meters) of retail space	73,000 square meters (Macquarie Shopping Centre only)	Y
More jobs than bedroom	• 32,000 jobs + 30,000 students (2006) • 5599 residents (2006)	Y
Has grown and changed completely in the past thirty years	Has changed rapidly over the last 30 years from a bushland, market gardens and paddocks area to a major centre housing a well-known university, multinational corporations, and a continuously growing research and innovative hi-technology sector	Y
Is a regional end destination being perceived as an "has it all" place	• Macquarie University • Macquarie Shopping Centre • The Riverside Corporate Park • Macquarie Business Park	Y

Table 4.1 - 'Edge city' characteristics of Macquarie Park

The Macquarie Park Corridor is located within the Local Government Area of Ryde, in the northwest of Sydney, approximately 12 kilometres from the Sydney CBD, two kilometres from Epping and 20 kilometres from Sydney Airport.

The corridor is situated on the Chatswood-Epping rail route which connects Macquarie Park to Epping in the northwest, Olympic Park and Rhodes in the southwest, Sydney CBD and North Sydney in the southeast and Sydney Airport in the south. The corridor is bounded by two major roads, the M2 Motorway to the north, and the Epping Road to the south and east. It is bisected by Lane Cove Road from north to south. Although these major roads are designed to increase accessibility into the corridor, they actually isolate the corridor and limit its integration within the neighbourhood urban fabric.

The Lane Cove National Park borders the corridor in the north and east, but the M2 expressway limits direct access to the park. In the east, the corridor is linked to the Northern Suburbs Cemetery and Crematorium; however, the M2 expressway interferes between the corridor and cemetery. A highway and arterial street - dominated urban structure results in a car-dependent community, as the discussion of transport patterns (in the next section) demonstrates.

The area houses some heritage items of Aboriginal and European archaeological significance (as listed in City of Ryde Heritage LEP105).

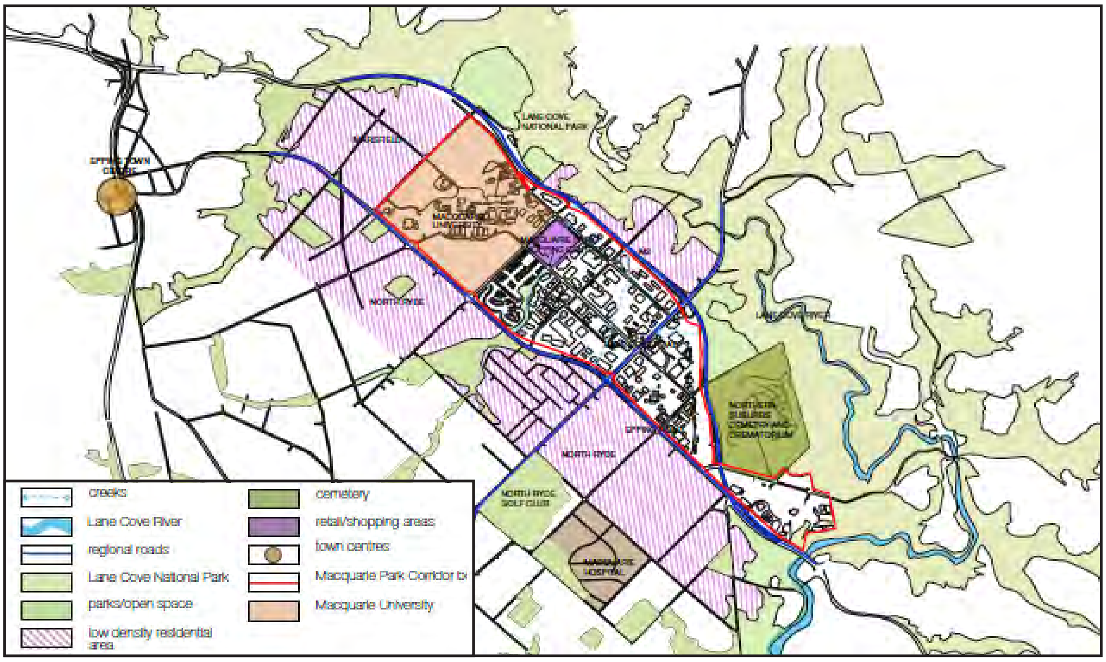
Macquarie Park has changed rapidly over the last thirty years from a bushland, market gardens and paddocks area to a major centre housing a well-known university, multinational corporations, and a continuously growing research and innovative hi-tech sector.

Macquarie Park includes a large diversity of land uses, from residential to educational, commercial, and retail. The major sites within the corridor are presented in Figure 4.1.

Macquarie University – this was the original purpose for which the area was rezoned in 1964, beginning the transformation from green belt to edge city. A public university was envisioned, surrounded by residential and industrial development. The concept was based on the Stanford University, California case where companies are involved in sponsoring courses and research activities, leading economic development in what become famous as “Silicon Valley”.

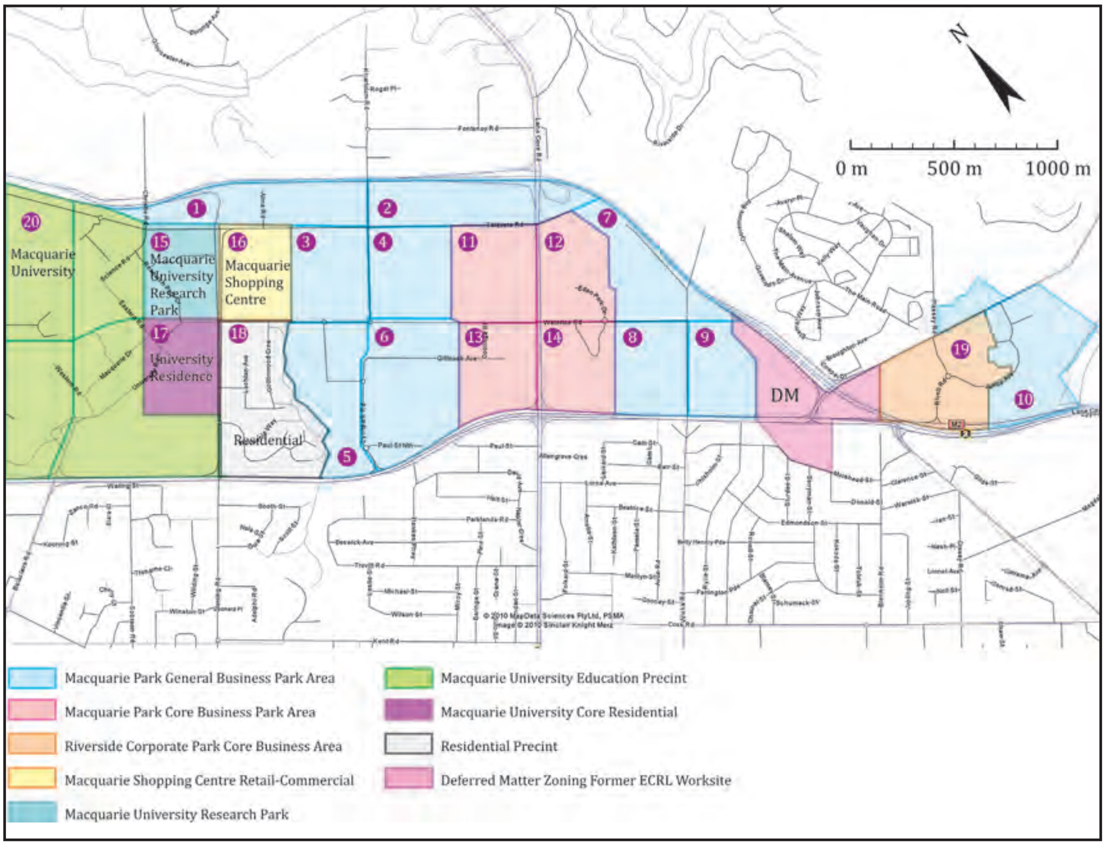
Macquarie University is situated on a 135 hectare site on the northern part of Macquarie Park Corridor. According to the GTA Sustainable Transport Plan 2008, there were 28,635 students enrolled and 9,772 staff at Macquarie University in 2007 (GTA Consultants

2008). Ryde Council estimates an increase over the next forty years to a total of 50,000 students and staff and an additional 390,000 square metres of commercial floor area.



Source: Development Control Plan 2010, Figure S1.03 Local Context

Figure 4.1 - Macquarie Park Corridor



Source: 2010 MapData Sciences PtyLtd, PSMA Image Sinclair Knight Merz

Figure 4.2 - Macquarie Park Corridor Major Sites

The Riverside Corporate Park – this is situated at the south-eastern end of the corridor and represents the largest concentration of CSIRO divisions in New South Wales, comprising CSIRO headquarters, Food Science Australia, the Division of Molecular Science, geosciences, building and engineering, as well as coal and energy technology. In addition, pharmaceutical companies and multinational corporations are located in the park. CSIRO itself has more than 6500 employees spread over 158,000 square metres of spaces partially constructed. Future development areas remain within the Park.

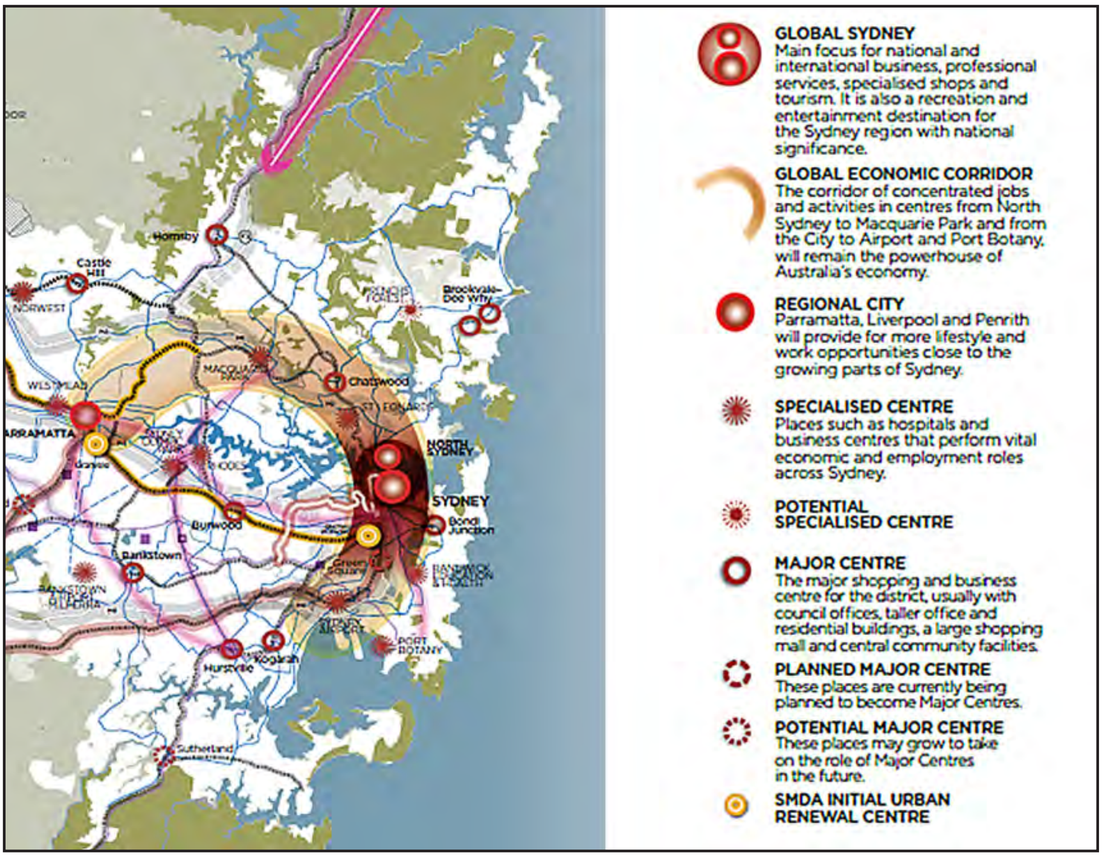
Macquarie Shopping Centre – located opposite to the Macquarie University, with a gross leasable floor area of 73,000 square metres in 2007, which is expected to grow to more than double by 2031. The centre serves local and regional shopping needs.

Macquarie Business Park – this is the core business area of the corridor with the highest projection for growth over the next thirty years. It is estimated that 21,000 new jobs and more than 750,000 additional square metres gross leasable floor area will be added to the business park by 2040.

4.2. Strategic context

Macquarie Park plays a significant regional role. The NSW Government's 2005 Sydney Metropolitan Strategy identified Macquarie Park as a Specialised Centre, occupying a prime location within the "Global Economic Corridor", which links Sydney Airport, Sydney CBD and Macquarie University. The key strategic goals were to strengthen the Global Economic Corridor from Macquarie Park to Sydney Airport and to promote Macquarie Park as 'Australia's leading Technology Park". In December 2010, the NSW Government's Metropolitan Plan for Sydney 2036 restated the importance to plan for growing the Specialised Centres and to extend The Global Economic Corridor from Macquarie Park to Parramatta as a key strategy stimulating Sydney's economy.

Macquarie Park is a major employment centre, combining commercial, business, research and educational activities and it had one of the highest growth rates of the Sydney Region between 2001 and 2006, with approximately 5000 additional jobs created (City of Ryde 2009). In 2006, the total employment of Macquarie Park Centre was approximately 32,000 including Macquarie University, Business Park and Macquarie Shopping Centre. In 2006, of the total 31,980 people working in the Macquarie Park Corridor, 18% of jobs were in Professional, Scientific and Technical Services, 15% were jobs in Education/Training combined with Health Care/ Social Assistance, and 7% were in the Information and Communication Technology sector (Figure 4.4).



Source: Metropolitan Plan for Sydney 2036

Figure 4.3 - Global Economic Corridor

The 2005 Metropolitan Strategy forecasts an employment level of 55,300 jobs by 2031 in Macquarie Park as a constant share of jobs in the Inner North Region. In consultation with the NSW Department of Planning, the Ryde Council forecasts an even higher employment level of 78,000 jobs by 2031, based on projected build-out of available floor space (City of Ryde 2009).

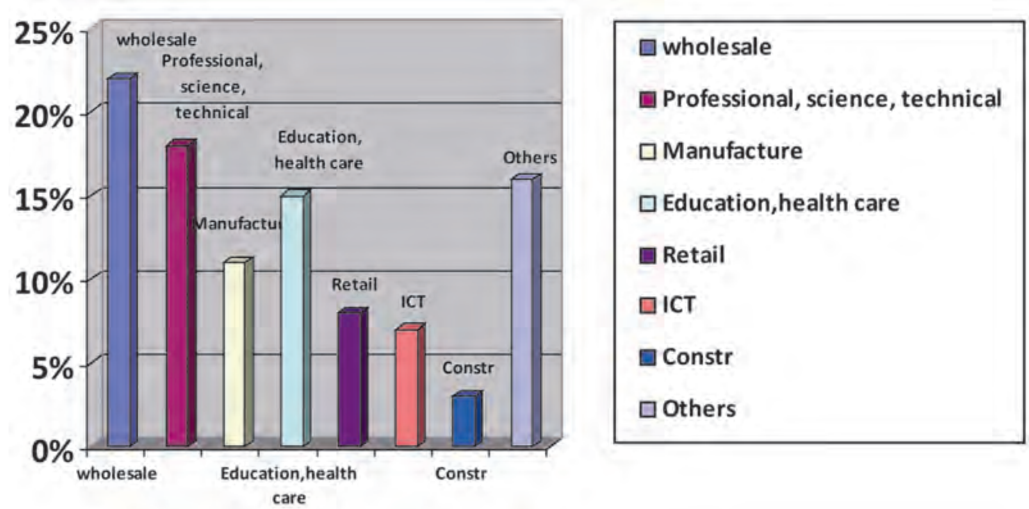
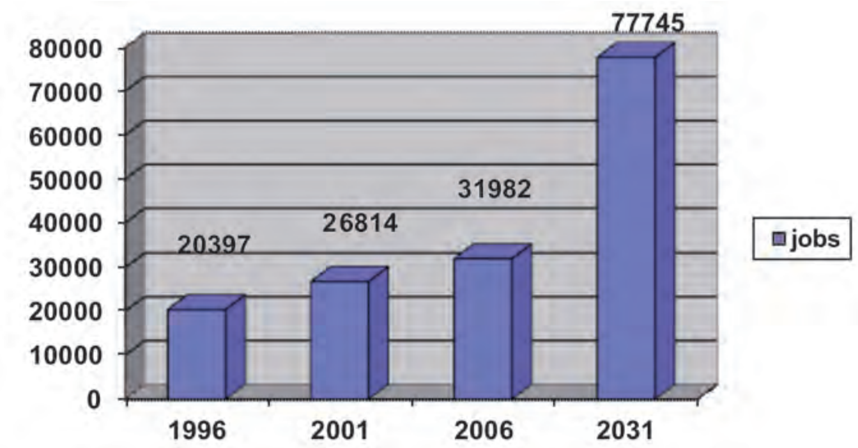


Figure 4.4 - Employment by industry in Macquarie Park (2006)

Macquarie Park Centre is a key location of three of the four clusters identified by the Metropolitan Plan 2036 as emerging high value industries over the next ten years:

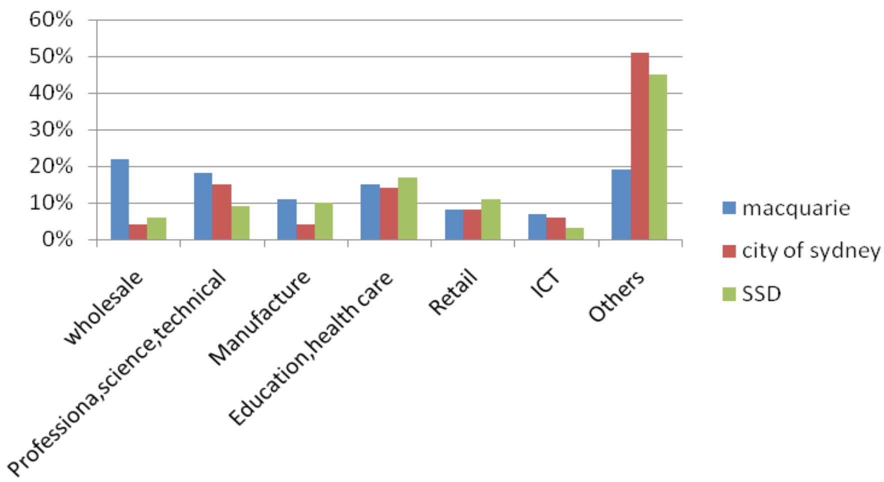
- **Professional, Scientific and Technical Services** – from existing science and research facilities in CSIRO and Macquarie University, and the growth of the new centre as Macquarie Park Technology Hub
- **Education and Health Care** – Macquarie University educational precinct, Macquarie Hospital
- **Information and Communication Technology (ICT)** – existing infrastructure and opportunities to consolidate growth of ICT sector



Source: calculations based on data from Transport Data Centres (2009) and City of Ryde estimates of employment

Figure 4.5 - Macquarie Park employment 1996-2031

In 2006, Macquarie Park was accommodating a higher share of jobs in these three major industries than City of Sydney or within the entire Sydney Statistical Division (Figure 4.6).



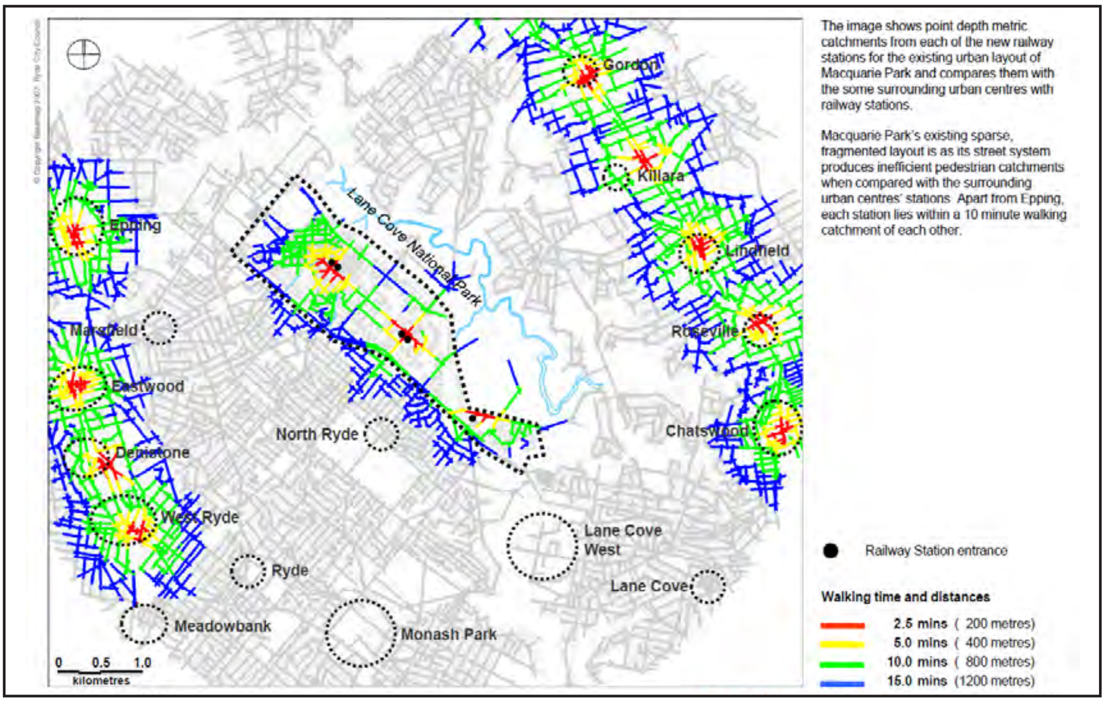
Source: ABS 2006

Figure 4.6 - Employment by industry, Sydney Statistical Division

The future trends depend on many uncertain assumptions; the economy is restructuring now and many job losses are in “the information industries” represented here. Assuming the previous trends continue in the future, the future employment growth forecasted by the City of Ryde Council is likely to occur.

In addition to the predicted employment growth to 78,000 jobs by 2031, the City of Ryde estimated an increase in the residential population of 5098 and an additional 28,000 university enrolments by 2031, making the Macquarie Park Centre a potential generator of 200,000 daily trips to and from the centre within two decades.

Historically, Macquarie Park Centre has attracted businesses by offering larger sites at lower prices compared with other regional centres, and very high levels of parking. A Macquarie Park Parking Study commissioned by City of Ryde Council identified over 31,500 off-street parking spaces available in commercial zones. According to 2006 Census Data there were 32,000 employees in the area. This generous car parking provision rate is strongly related to the high level of car use – 87% journey to work mode share was as vehicle driver and car passenger in 2006 (Transport Data Centre 2009). Since the opening of the Epping-Chatswood rail link in February 2009, with three new rail stations within the area (Macquarie University, Macquarie Park and Delhi Road), an increase of rail mode share is expected, but no data is yet available to establish how many of the existing rail users were previously car, bus or rail users.



Source: Macquarie Park Pedestrian Movement Study 2009, Figure 5.1.Public Transport analysis, Existing pedestrian metric catchment for all railway stations

Figure 4.7 - Existing pedestrian metric catchment for Macquarie Park rail stations

However, the physical scale of Macquarie Park (7 square kilometres) implies that many of the existing and potential destinations are not in walking distance of the rail stations. Thus, even though higher density land uses are to be clustered around the stations, there is a need to increase accessibility to peripheral parts of the area, including parts of the University campus.

The site has a sloping topography which makes walking and cycling difficult. Furthermore, only 14% of the workforce travels locally within the local government area of Ryde, which may be considered within ten kilometres distance. The remaining 86% of the employees travel more than ten kilometres which makes even cycling unlikely to increase substantially if the travel profile will remain similar in the future.

The Macquarie Park Case Study will therefore examine the options for enhancing public and active transport accessibility, both locally and regionally, in order to reduce car dependence.

4.3. Macquarie Park workforce travel profile

A study conducted by Arup based on 2006 Census journey to work travel data for the Macquarie Park Corridor concluded that the distribution of the workforce to and from Macquarie Park is well balanced from east and west, with approximately 38% travelling to and from Macquarie Park to the east of Ryde and 48% travelling to and from Macquarie Park area to the west of Ryde; the remaining 14% travel locally within the studied area.

Approximately 27% of the workforce travel to and from the six surrounding local government areas:

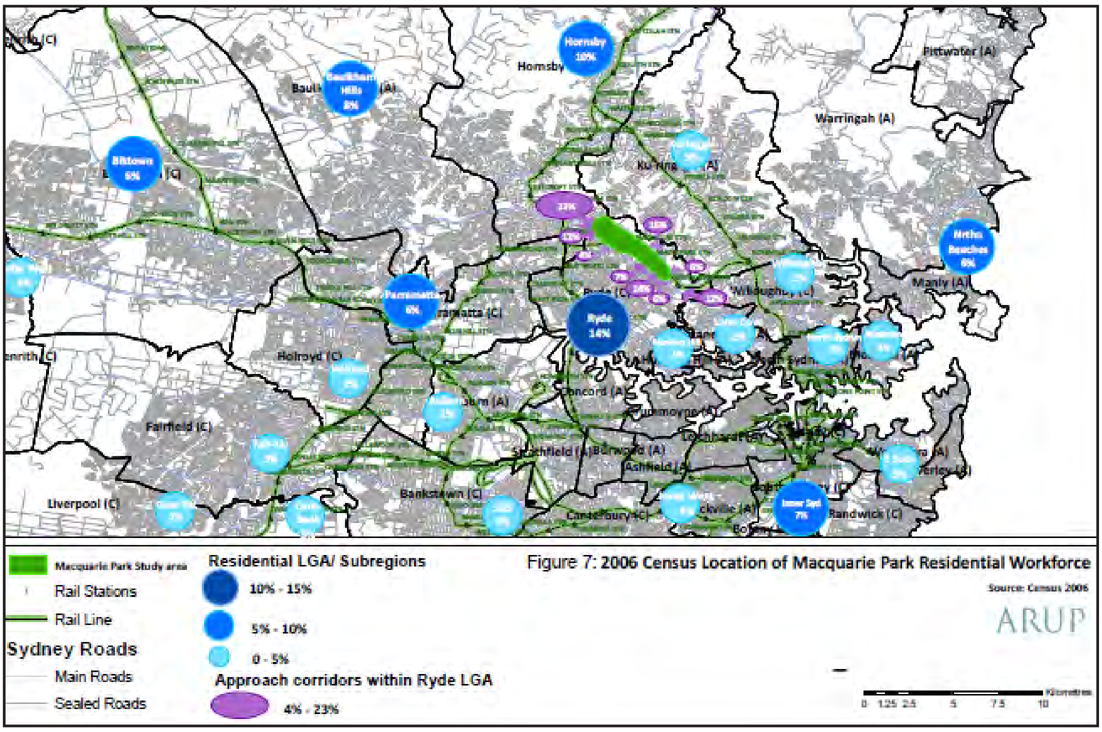
- 10% to and from Hornsby
- 6% to and from Parramatta
- 5% to and from Ku-ring-gai
- 3% to and from Willoughby
- 2% to and from Lane Cove
- 1% to and from Hunters Hill

Of the total workforce, 59% of commuters typically travel more than 15 kilometres from their homes to the Macquarie Park Corridor. The top five residential local government areas outside the radius of 15 km for Macquarie Park workers are:

- Baulkham Hills – 8%
- Inner Sydney – 7%
- Northern Beaches – 6%

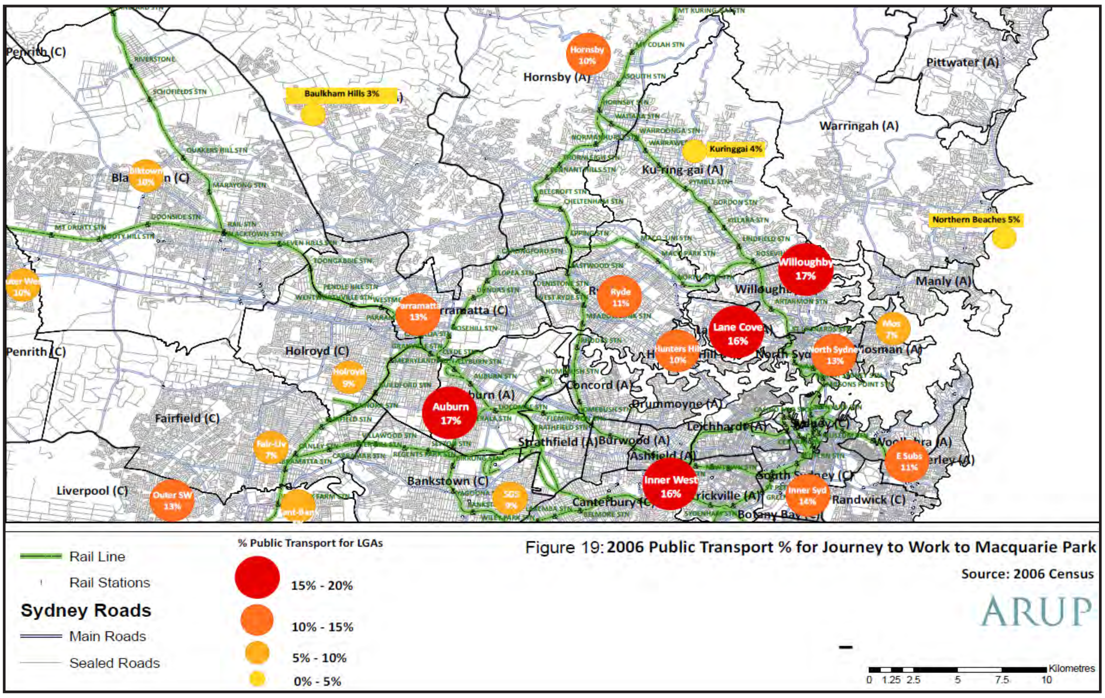
– Blacktown – 6%

– Inner West – 4%



Source: Macquarie Park Corridor Parking Study, Draft Study Report TOC,
2009 figure 7: 2006 Census Location of Macquarie Park Residential Workforce

Figure 4.8 - Residential distribution of Macquarie Park workforce



Source: City Of Ryde, Macquarie Park Corridor Parking Study, Draft Study Report TOC, chapter 7, fig 19: 2006 Public Transport % for Journey to Work to Macquarie Park

Figure 4.9 - Residential distribution of public transport work mode share for journey to work

Prior to the opening of the Epping – Chatswood rail line in February 2009, the majority of the workers and students would have used a private car as the preferred mode of travel. In 2006, 87% of the journey to work was either as vehicle driver or car passenger, 4 % by train, 5.7% by bus and only 2.5% walking and cycling (Transport Data Centre 2009). The lowest public transport mode share for journey to work to and from Macquarie Park was for employees residing in Baulkham Hills – 3%, followed by Ku-ring-gai with 4% and Northern Beaches with 5%. Even among residents of Hornsby or Hunters Hill, locations close to Macquarie Park and well served by public transport network, only 10% used public transport (City of Ryde 2009).

Macquarie Park displays one of the highest car dependency rates for work trips compared to other similar centres (see Table 4.2). A parking study commissioned by City of Ryde in 2009 identified that the lower public transport accessibility in Macquarie Park compared to the other centres is the main reason for the high car dependency.

Centre	Train	Bus	Vehicle driver	Car passenger	Cycle	Walk only	Other
Macquarie Park	4.0	5.7	82.1	5.1	0.5	2.0	0.5
Sydney CBD	47.7	22.3	16	3.5	0.8	5.8	4.0
North Sydney	43.3	10.2	33.9	4.0	0.6	6.5	1.5
St Leonards	22.5	6.0	59.8	4.1	0.5	6.5	0.6
Norwest Business park	1.6	1.5	89.5	6.3	0.2	0.7	0.1
Chatswood	29.3	7.2	50.5	4.7	0.4	7.6	0.3
Parramatta	25.8	6.4	55.3	7.2	0.4	4.7	0.3

Source: TDC 2009, TransFigures december 2008 re-released with corrections July 2009, table 3, pag 10

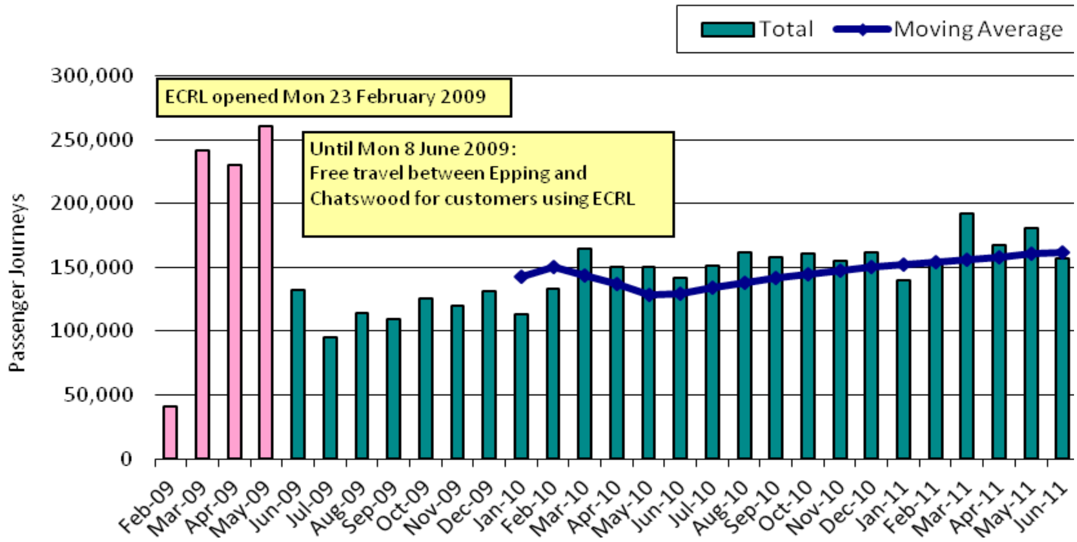
Table 4.2 - Journey-to-work mode share for comparable business centres (2006)

The target for the travel mode split for Macquarie Park Corridor established by the City of Ryde Council is an ambitious 40% for the journey-to-work trips by public transport, 50% as vehicle driver, 5% as car passenger and 5% walking and cycling by 2031 (Bitzios Traffic Study 2008).

The Macquarie University mode share targets are even more ambitious and these will be developed through the University Travel Plan: 45% public transport mode share, 40% car (driver and passenger) and 15% walking and cycling.

Preliminary data collected in the first month after the rail line opening indicated that

5000 persons (workers plus students) per day arrived during the morning peak period from 6.00 to 9.30 am, but only 25% of the rail passengers were not previous regular users of the rail mode. Through a simple arithmetic calculation, considering 32,000 jobs and 28,000 students this means about 8% rail mode share. Thus, the new rail line resulted in a 4% increase in commuting trips by train compared to 2006. Over the next three months following the rail link opening, the same trend continued (see Figure 4.10) as long as travel was free of charge. Since October 2009, when the fares were introduced, the rail patronage dropped off with more than 100,000 passenger trips each month (NSW Department of Transport BTS 2011, Lin C., request 20111808).



Source: Department of Transport 2011, ECRL patronage trend and hourly barrier data, request 20110818

Figure 4.10 - Epping to Chatswood Rail Link - Monthly Patronage

However, the opening of the Epping-Chatswood rail link will benefit those employees who live in areas already well served by the rail network, such as Gosford, Wyong or North Sydney, Inner Sydney and the Eastern Suburbs. For the regions with the lowest usage of public transport such as Baulkham Hill or Northern Beaches, and where there are no rail services or other options to increase accessibility of rail stations, the new rail link between Epping and Chatswood is unlikely to alter the traditional car-based travel pattern. However, the recently announced North-West Rail Link has the potential to significantly increase the rail patronage.

4.4. Macquarie Park land use

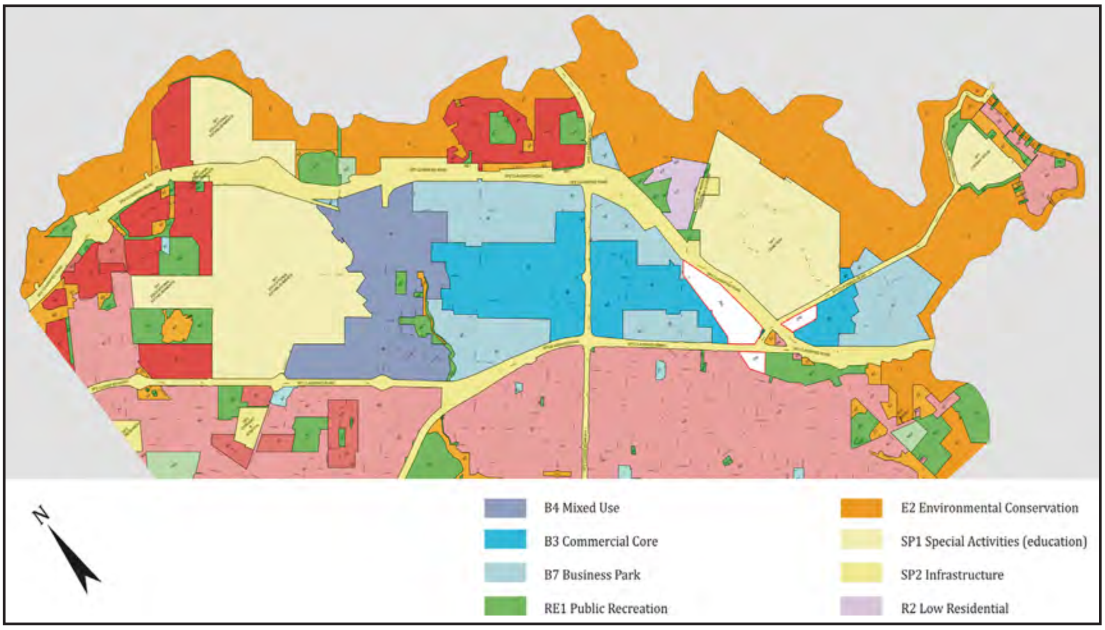
Under the City of Ryde LEP2010, Macquarie Park is mainly zoned Commercial Core (B3), Business Park (B7) and Mixed Use (B4) with very small areas of environmental and recreational zones and low density residential. The Draft City of Ryde LEP 2011 retains the same zoning of land for the Macquarie Park Corridor with very few exceptions, for example rezoning 130 Talavera Road from B4 Mixed Use to B7 Business Park and rezoning 14-22 Delhi Road from B7 Business Park to B3 Commercial Core. Another change proposed by the Draft LEP 2011 is that the area of land 160-162 Wicks Road zoned as RE1 Public Recreation to be rezoned to IN2 Light Industrial with a maximum height of 10m.

The purpose of B3 Commercial Core is to provide a wide range of land uses including retail, office, business and entertainment to serve the local and neighbouring communities.

The objective of the zone B4 Mixed Use is to provide a mixture of residential with compatible business, retail, office and other development in order to create an active and safe community within a strong employment centre. Another objective for the mixed use zone is to create a pleasant, safe and friendly pedestrian environment.

The B7 Business Park zone is designed to offer a wide range of office and light industrial uses, with an emphasis on the research and development industries. Besides reflecting its natural setting by high quality urban design, this zone should have strong links with Macquarie University and research institutions.

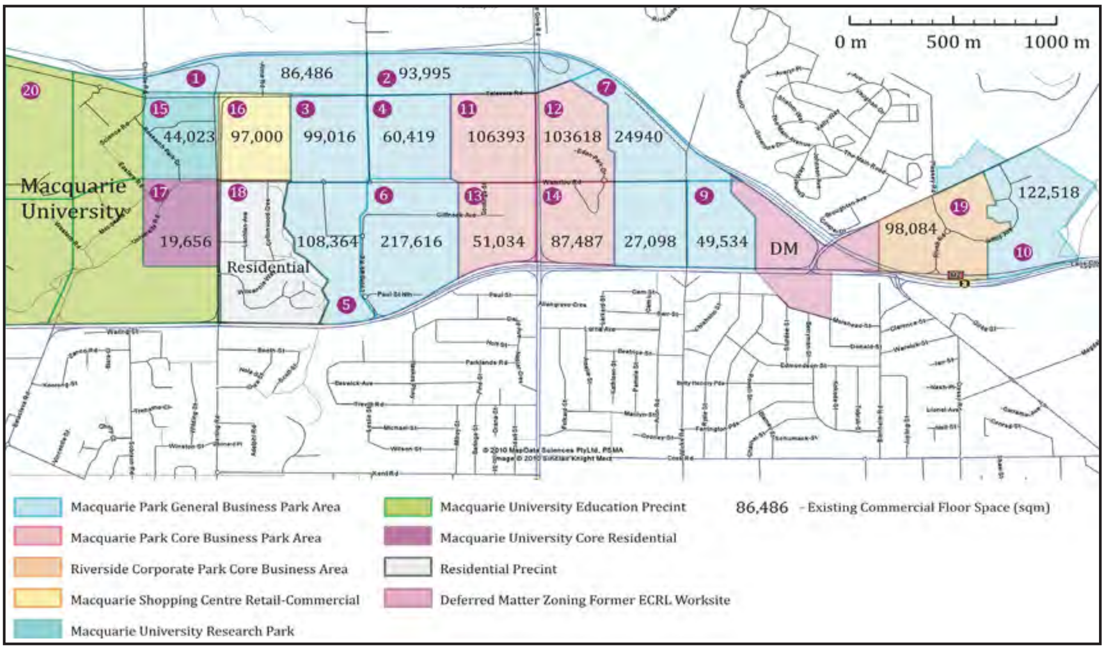
The maximum FSR allowable in Macquarie Park is 3:1 and only for developments around the two rail stations: Macquarie University and Macquarie Park. The maximum accepted heights of the buildings are 33.5 m around Macquarie University rail station and 37 m around Macquarie Park and Delhi Rd rail stations LEP2011).



Source: City of Ryde 2011, Local Environmental Plan 2011

Figure 4.11 - Macquarie Park land use

The existing commercial floor space is shown in Figure 4.12.

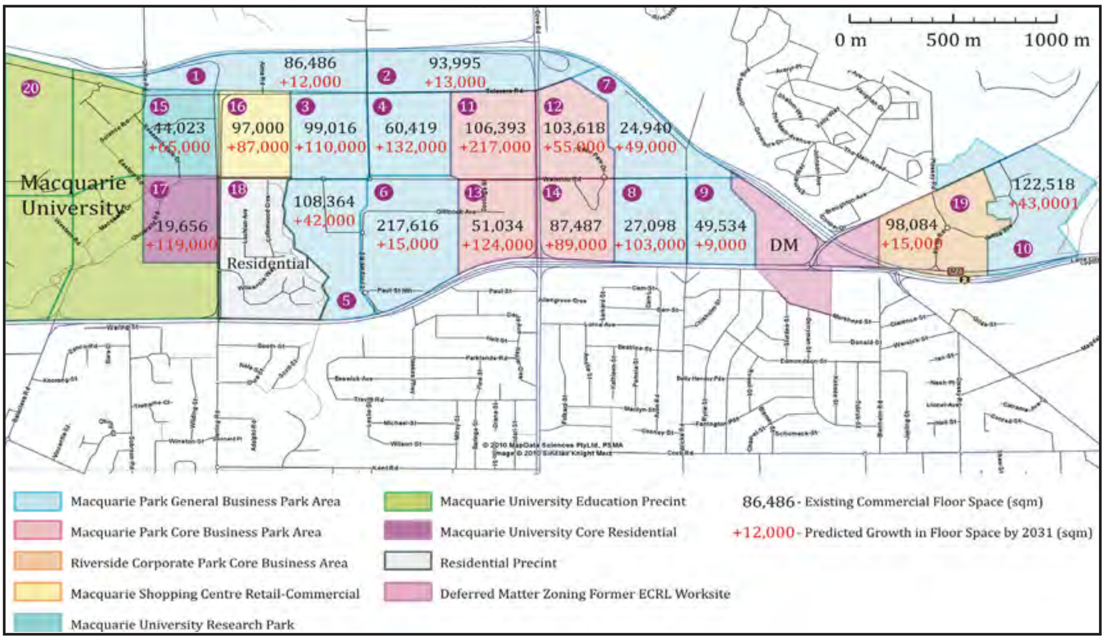


Source: Data adapted from Local Environmental Plan 2011, City of Ryde

Figure 4.12 - The existing commercial floor space in Macquarie Park

As part of the recent LEP and DCP planning process, the City of Ryde Council developed the future land use scenario to the year 2031, proposing an additional 1,029,000 square metres growth of the commercial floor area at Macquarie Park and approximately 400,000 square metres of additional commercial floor area within the Macquarie University.

The predicted growth in floor space over the next 20 years is shown in Figure 4.13.

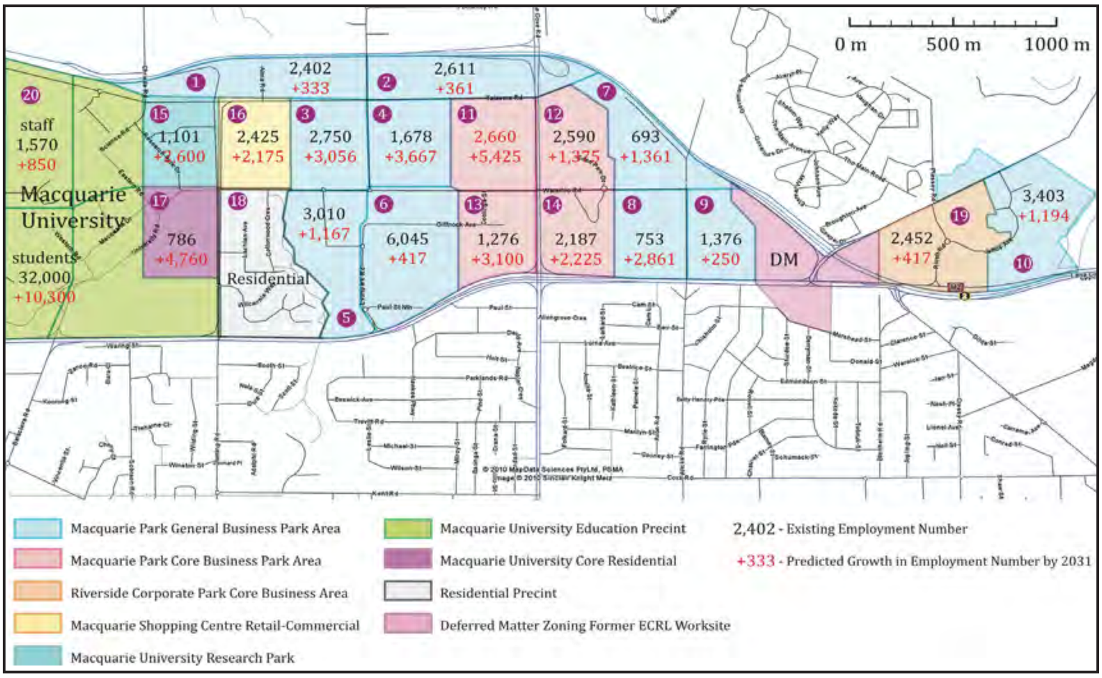


Source: Data adapted from Local Environmental Plan 2011, City of Ryde

Figure 4.13 - The predicted growth in floor space over the next 20 years in Macquarie Park

4.5. Employment forecast by 2031

The most important objectives of the Ryde council for all the zones are: encouraging employment opportunities in accessible locations, maximising public transport patronage and increasing walking and cycling. The future employment distribution within the corridor is presented in Figure 4.14.



Source: Data adapted from Local Environmental Plan 2011, City of Ryde

Figure 4.14 - Existing and future employment distribution within Macquarie Park

Based on the full development of the site and considering the same employment density as today, the potential number of jobs available by 2031 is estimated at 79,362 (Table 4.3).

Zone	2011 floor space (sqm)	Land use zone LEP2011	Employment density	Employment numbers LEP2011	Future floor space (sqm)	Future Addititional Employment numbers	TOTAL future floor space (sqm)	TOTAL future employment numbers
1	86486	B7-Bussiness Park	1:36	2402	12000	333	98486	2736
2	93995	B7		2611	13000	361	106995	2972
3	99016	B7		2750	110000	3056	209016	5806
4	60419	B7		1678	132000	3667	192419	5345
5	108364	B7		3010	42000	1167	150364	4177
6	217616	B7		6045	15000	417	232616	6462

Zone	2011 floor space (sqm)	Land use zone LEP2011	Employment density	Employment numbers LEP2011	Future floor space (sqm)	Future Addititional Employment numbers	TOTAL future floor space (sqm)	TOTAL future employment numbers
7	24940	B7		693	49000	1361	73940	2054
8	27098	B7		753	103000	2861	130098	3614
9	49534	B7		1376	9000	250	58534	1626
10	122518	B7		3403	43000	1194	165518	4598
11	106393	B3-Commercial Core	1:40	2660	217000	5425	323393	8085
12	103618	B3		2590	55000	1375	158618	3965
13	51034	B3		1276	124000	3100	175034	4376
14	87487	B3		2187	89000	2225	176487	4412
15	44023	B4-Mixed Use (M Uni Research Park)	1:25	1101	65000	2600	109023	3701
16	97000	B4-Mixed Use (Macquarie Shopping Centre)	1:40	2425	87000	2175	184000	4600
17	19656	B4-Mixed Use (M Uni Station South Precinct)	1:25	786	119000	4760	138656	5546
18		B4 – RE1 (low residential)					0	0
19	98084	B3-Commercial Core (Riverside Corporate Park)	1:40	2452	15000	417	113084	2869
20		Macquarie University		1570		850	0	2420
		Total		41769	1299000	37593	2796281	79362
		Total students		32000		10300		42300

Table 4.3 - TOTAL future employment numbers by 2031

The growth potential of the Macquarie Park Corridor is greater than the target established by the 2005 Metropolitan Strategy (Table 4.4). The total employment number of approximately 78,000 is the potential number of jobs as a result of the full development of the area under the existing local planning policies. The Metropolitan Plan for Sydney 2036 has established a target of 58,000 jobs by 2036 which is consistent with the 2005 Metropolitan Strategy target of 55,300 jobs by 2031.

	LEP2008	LEP2011	2005 Metropolitan Strategy
2031 Total employment	77,745	79,362	55300
2031 University enrolments (FTE)	28,214	25,200	-
2031 Total population (5599-Census 2006 + add 5098)	10,697	10,697	-
2031 Total GLFA, commercial (sqm)	2,125,369	2,612,281	1,700,000
2031 Total GLFA, retail (sqm)	170,910	184,000	-

Table 4.4 - Future growth targets

Based on discussions with City of Ryde Council representatives, the projected number of future jobs in Macquarie Park should take into consideration the influence of major public transport infrastructure capacity, governance and competition with other centres as North Sydney, Chatswood, and Norwest Business Park.

4.6. Trip forecast to, from and within Macquarie Park

The NSW Department of Transport, Bureau of Transport Statistics (BTS) Strategic Travel Model (model version STM 2.3) has been used to extract data for the base year 2011 and future years 2016, 2026, 2031 and 2036 for trips to Macquarie Park as a destination centre (Table 4.5).

The estimated total number of 91,403 daily tours is too low compared to the predicted numbers of workers (78,000) and students (42,000) by 2031.

The Strategic Travel Model input assumptions for future employment are based on the Transport Data Centre employment forecasts (TDC 2009) which are compatible to population and employment projections of the Department of Planning (2008) rather than the City of Ryde projections. The employment forecasts for the entire Statistical Local Area of Ryde are presented in Table 4.6.

Purpose of travel (tours)	2011	2016	2021	2026	2031	2036
Commuting	26,780	28,270	29,009	30,406	32,019	33,449
Work related business	5,433	6,005	6,518	6,927	7,336	7,707
Education	5,344	5,404	6,031	6,021	6,146	6,444
Shopping	11,643	12,817	13,894	14,653	15,671	16,365
Other (social/recreation, serve passenger, personal business, other)	20,642	22,758	25,273	27,529	30,231	31,591
Total tours	69,842	75,254	80,725	85,536	91,403	95,556

Source: NSW Department of Transport BTS 2011, Xu B., STM Summary of 24- hour tours to Macquarie Park, request 11270

Notes: The STM is based on 2006 SLAs and centres. A tour is defined as a round trip journey which starts and finishes at home. A tour is composed of two legs: the outward leg and the return leg. The outward leg is the trip from home to the first arrival at the primary destination. The return leg is the trip from last departure from the primary destination to home. Mode choice is modelled as it was symmetrical (92% of tours use the same main mode outbound and return). The purpose of the tour is the purpose at the primary destination (BTS 2011).

Table 4.5 - Summary of 24-hour tours to Macquarie Park

	2006	2011	2016	2021	2026	2031	2036
Ryde LGA employment forecast	70,769	77,059	80,336	85,252	87,784	90,140	93,305
Employment growth from 2006 base year (%)		9%	14%	20%	24%	27%	21%

Source: TDC Employment Forecasts, October 2009 Release: Technical Documentation, extras from Table 6.Employment forecast at The Statistical Local Area Level

Table 4.6 - Employment Forecast for entire Ryde Local Government Area (LGA)

The 2031 employment growth is estimated at 90,140 jobs, with 19,371 more jobs than in 2006, representing a 27% increase for the entire Statistical Local Area of Ryde. These forecasts contradict those of City of Ryde's own estimates of 78,000 jobs in Macquarie Park Corridor only, and also the 2005 Metropolitan Strategy target of 55,300 jobs. Macquarie Park Corridor itself has the potential to accommodate an additional 45,000 jobs which means an increase of 144% compared to 2006 (or 124% growth compared to 2011). For this reason, in future calculations of trip demand, the predicted increase from 2011 to 2031 will be applied to the STM modelled demand to and from Macquarie Park, and it will be considered as the revised forecast for the future.

The following assumptions were used for the estimation of the future trip demand in an average working day to and from Macquarie Park:

- The Strategic Travel Model (STM) generated 26,870 commuting tours in 2011; applying the 124% increase by 2031, results in approximately 60,000 daily commuting tours to Macquarie Park. The same increase was applied to the work related business tours (5,433 tours as per STM outputs for 2011), resulting 12,200 business tours by 2031.
- The above figures are also consistent with a different methodology of calculating trips demand: from 78,000 employees, the majority will be from professional, scientific,

healthcare, business or ICT industry, and represent office jobs mainly. Assuming five days per week and 17% leave days per year (annual leave, sick days and public holidays), this results in approximately 62,000 tours per working day. These numbers may be slightly lower depending on how many part-time or home-based jobs are available in 2031. For this reason we will use the forecast of 60,000 commuting tours and 12,200 work related business tours (Table 4.7), based on applying the STM modelled demand, as explained above.

– For estimating the Macquarie University student trips, we assumed 42,000 students enrolments by 2031, of which 90% are on campus (Macquarie University 2009). There are 34 teaching and exams weeks per year and assuming 3.5 days per week the average presence on campus, the result is 18,200 daily tours to Macquarie University. During teaching weeks, these numbers maybe much higher. The Macquarie University transport study (Maquarie University TMAP 2009) estimates 26,461 daily academic student trips in 2031 based on the current patterns. However, because the number of students who travel first to work and then to university is unknown, but presumably high, the average daily tours used in this study is 18,200.

Purpose of travel	Tours
Commuting	60,000
Work related business	12,200
Tertiary Education (students only)	18,200
Shopping	15,700
Other (social/recreation, serve passenger, personal business, other)	30,200
Total tours to Macquarie Park as destination	136,300
TOTAL trips to and from Macquarie Park	272,600

Source: TDC Employment Forecasts, October 2009 Release: Technical Documentation, extras from Table 6. Employment forecast at The Statistical Local Area Level

Table 4.7 - 2031 Tours Demand to Macquarie Park as destination

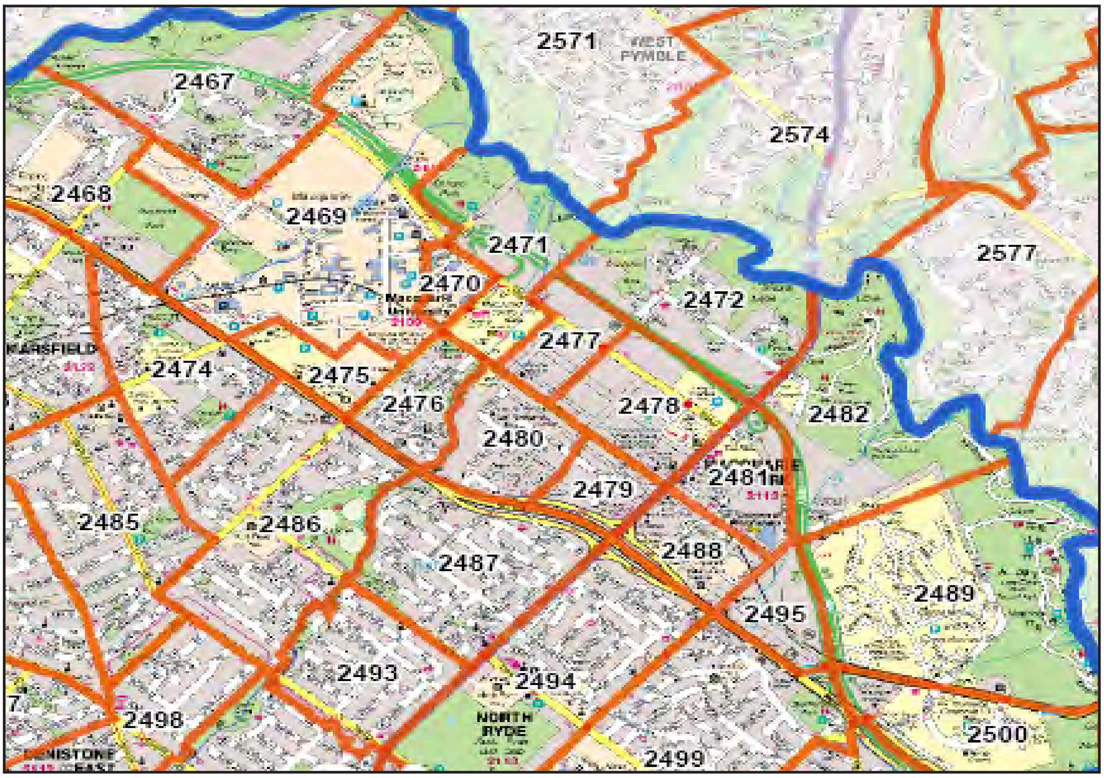
All the other trips are based on the Strategic Travel Model – the 2031 modelling outputs. Full modelling data from running the Strategic Travel Model are available on request from the author.

In order to estimate trip demand originating in Macquarie Park, data were extracted from the key transport indicators for Macquarie Park provided on request by the Bureau of Transport Statistics (NSW Department of Transport BTS 2011, Karantonis E., request 11270) who replicate the household travel behaviour for this specific geographic area. Because the residential component of Macquarie Park Corridor is relatively small (6835 population in 2009), another three adjacent residential zones were included in the Macquarie Park 2009/2010 Key Transport Indicators:

– 5237 residents from Trafalgar Square (zone 2467)

– 1715 residents from Epping Boys High (zone 2468)

– 1831 residents from North Ryde Station (zone 2489)



Source: BTS online, Standard SLA Maps M to R, Ryde Map

Figure 4.15 - Ryde Map

The same transport indicators were applied to the future population number of 10,697 by 2031 (Table 4.8). Full modelling data are available on request from the author.

Purpose of trips	Linked Trips	Percentage
Commute	10,438	30%
Work related business	3,427	10%
Education/child care	2,628	8%
Shopping	4,412	13%
Personal business	1,568	4%
Social/recreation	8,251	24%
Serve passenger	3,039	9%
Other	1,279	4%
Total	35,043	100%

Notes: Data were pooled from 9 waves of Household Travel Survey (2001/2002 – 2009/2010) and weighted to June 2009 population. Estimates of population are based on estimates of people in occupied private dwelling. Estimates of trips purpose are based on linked trips, except walk trips. Trips to return home are reallocated to previous priority trip purpose. Estimates of trip mode are based on unliked trips for an average weekday (NSW Department of Transport BTS 2011, Karantonis E., request 11270).

Table 4.8 - 2031 Trip Demand of Macquarie Park Residents

From these 35,043 linked trips, or 17,500 tours, it is very difficult to estimate how many are internal to internal (which have been included in STM summary of 24-hour tours to Macquarie Park) or internal to external. However, the commuting and work related business trips outside the Macquarie Park Corridor were estimated, based on assumptions that from 10,438 journey to work linked trips which represent 5,219 tours, 40% will be outside Macquarie Park, while 60% of the local labour force will live within Macquarie Park (similar to the City of Sydney workforce distribution). This is likely to be a conservative estimate of external trips. Further research for a more detailed analysis of the local labour force is recommended. These estimations will add an additional 2,000 commuting tours and 700 work related business tours to the total trip demand. The following table (Table 4.9) presents the base demand for all trips to/from and within Macquarie Park.

Purpose of travel	Tours	Trips	%
Work	62,000	124,000	45%
Business	12,900	25,800	9%
Tertiary Education (M Uni students only)	18,200	36,400	13%
Shopping	15,700	31,400	11%
Other purposes	30,200	60,400	22%
Total tours to/from and within Macquarie Park	139,000	278,000	100%

Notes: Data were pooled from 9 waves of Household Travel Survey (2001/2002 – 2009/2010) and weighted to June 2009 population. Estimates of population are based on Household Travel Survey estimates of people in occupied private dwelling. Estimates of trips purpose are based on linked trips, except walk trips. Trips to return home are reallocated to previous priority trip purpose. Estimates of trip mode are based on unliked trips for an average weekday (NSW Department of Transport BTS 2011, Karantonis E., request 11270).

Table 4.9 - 2031 Trip Demand to/from and within Macquarie Park

In conclusion, the full development of the Macquarie Park Corridor with over 2,600,000 square metres in commercial floor space and over 180,000 square metres in retail floor space as expected has the potential to generate 78,000 jobs by 2031 and accommodate 10,697 residents plus a predicted 42,000 students at Macquarie University. The sustainability challenges of 278,000 daily trips are substantial.

The following chapter develops several scenarios of how future travel patterns may evolve, based on the estimates of trip origins and destinations presented here.

Chapter 5. Land use and transport scenarios

> The street has always been the scene of this conflict, between living and access, between resident and traveller, between street life and the threat of death. This is the conflict we shall deal with in these pages.
> Donald Appleyard, Livable Streets (1981)

5.1. Introduction

In this chapter, I investigate alternative land use and transport strategies to enable more sustainable travel patterns in Macquarie Park. Two land use and transport scenarios, increasing Local Access by Personal Rapid Transport (LAPRT) and Personal Rapid and Transit Oriented Development (PRTOD) are developed, with a focus on reducing transport emissions and increasing public health by reducing car dependence and increasing active travel. These two scenarios are compared to a projection of the current transport trends by 2031 (business-as-usual BAU scenario) and a traffic study based on planned targets for accommodating the projected growth of the Macquarie Park Corridor over the next 20 years ("Planned" scenario).

Trip demand, land-use, and transport network assumptions for 2031 are discussed for each scenario. The Bureau of Transport Statistics (NSW Department of Transport BTS 2011, Xu B., request 11270) provided a summary of 24 hour tours to Macquarie Park as a destination centre for the current year 2011 and future years 2016, 2026, 2031 and 2036. The Strategic Travel Model input assumptions are based on the employment forecasts for 2006 - 2036 released by Transport Data Centre in 2009, which are much lower than the metropolitan strategy and local council forecasts. Thus, the modelled increase from 2006 to 2031 was applied to the existing demand and to develop a revised forecast for the future.

Future mode share assumptions for trips to, from and within Macquarie Park are presented. The mode share assumptions for the business-as-usual scenario are based on the Strategic Travel Model data for the current year (2011) applied to the future demand.

However, the Strategic Travel Model underestimates the rail patronage, therefore patronage trends and barrier count data provided by the Department of Transport at request (NSW Department of Transport BTS 2011, Lin C., request 20111808) were used to adjust the overall rail mode shares. For the "Planned" scenario, the local government targets for journey-to-work mode share were used; for the other trips mode share assumptions were based on the Strategic Travel Model outputs for 2031.

For the two scenarios (LAPRT and PRTOD) that include a Personal Rapid Transit system as a local access system, the mode share assumptions are not a function of a transport system. Firstly I did not have access to a whole metro scale model within the time and budget constraints of this study. Secondly, a strategic transport model is unlikely to give reliable results for a new system like a Personal Rapid Transit (PRT) system. The main reasons for this are that:

– the strategic model underestimates rail patronage, which is the main feeder to the PRT system, - it does not provide accurate information about "park and ride" passengers, which would again underestimate the rail patronage and even the PRT patronage

– it does not include a future potential increase in fuel prices or more restrictive future parking policies, which might change travel behaviour.

However, the mode share assumptions are based on the existing transport targets, reflected in the "Planned" scenario, and reasonable assumptions were made for trips on a local access system designed to increase the accessibility of the main transit nodes. The aim of this exercise is to determine whether a PRT system could deliver the transport performance necessary to handle a major mode shift and to evaluate whether it is a truly sustainable transport option. Future policies to discourage travel by private cars, for instance limiting parking, increasing attractiveness of public transport modes by increasing the accessibility of the transit nodes, and transit oriented developments are very important strategies to significantly change travel behaviour and to produce a major mode shift.

Strategies for improving the accessibility of public transport nodes and for increasing active travel are discussed in the next sections, after identifying the challenges of the existing plans.

After developing these scenarios, the study examines different indicators such as vehicle kilometres travelled (VKT), travel time, noise level and transport emissions, which are translated into health indicators in Chapter 7.

5.2. BUSINESS-AS-USUAL 2031 PROJECTION (BAU 2031)

This scenario represents a projection of the present trends over the next 20 years, based on the City of Ryde's 78,000 employment forecast and 10,697 population forecast. The Bureau of Transport Statistics (BTS) Strategic Travel Model (model version STM 2.3) was used to extract data for the current year 2011. Full modelling results are available on request from the author.

Transport Mode	Work	Education (Macquarie Univ. students only)	Shopping	Business	Other
Car Only (Driver)	79%	38%	62%	87%	50%
Car Only (Pass)	5%	6.5%	21%	6%	37%
Walk Only	2.5%	12%	11%	1%	7%
Cycle Only	1.5%	2.0%	1%	1%	1%
Train + Walk	6%	12.5%	1%	3%	3%
Bus + Walk	6%	29%	4%	2%	2%
TOTAL	100%	100%	100%	100%	100%
Total Car	84%	45%	83%	93%	87%

Source: NSW Department of Transport BTS 2011, Xu B., STM 2011 – 24 hours tours to Macquarie Park, request 11270

Table 5.1 - Mode shares (2031) – Business-as-usual (BAU) Scenario

The Strategic Travel Model input assumptions for the 2011 modelling are based on the following infrastructure network and policy assumptions (which are already in effect at the date of finishing this project):

- Lane Cove Tunnel completed
- Epping to Chatswood rail link completed
- Integrated bus networks
- MyZone fare system
- Fuel and toll cost rise with the Consumer Price Index (CPI)
- Public transport fares rise with CPI
- Assumed 1% growth in the annual income
- Behavioural models were estimated using Household Travel Survey (HTS) data up to and including 2008 and journey to work (JTW) data up to and including 2006 Census (Bureau of Transport Statistics 2011)

Applying the above mode share to the future demand to and from Macquarie Park, the estimated number of daily car tours by 2031 will be approximately 111,500 (Table 5.2), totalling 223,000 car trips per day compared to less than 36,000 trips by public transport or 20,000 trips by walking and cycling.

Transport Mode	Tours	Trips
Car Only (Driver)	91,953	183,906
Car Only (Pass)	19,528	39,056
Walk Only	7,704	15,408
Cycle Only	1,882	3,764
Train + Walk	7,445	14,890
Bus + Walk	10,488	20,976
TOTAL	139,000	278,000
Total car (trips)	111,481	222,962
Total car (mode share %)	80%	80%
Total active travel (walking + cycling)	9,586	19,172
Active travel (mode share %)	7%	7%

Table 5.2 - Total trips to/from Macquarie Park by mode of transport – BAU Scenario

In a traffic study initiated by City of Ryde council in 2008, the future 2031 traffic demand has been tested on the existing road network. The study used a traffic micro-simulation modelling package PARAMICS. This model assesses the movement of each vehicle by considering different parameters: acceleration, deceleration, headway and so on. After a few minutes of running the simulation, the network capacity was insufficient to accept the traffic demands. In the morning peak hour, traffic was not able to enter and similarly, traffic was not able to exit Macquarie Park at the afternoon peak due to capacity constraints (City of Ryde 2008, p. viii).

This "do-nothing" scenario reveals that the projected growth for Macquarie Park Corridor is not possible without an integrated land-use and transport strategy focused on reducing the use of private cars.

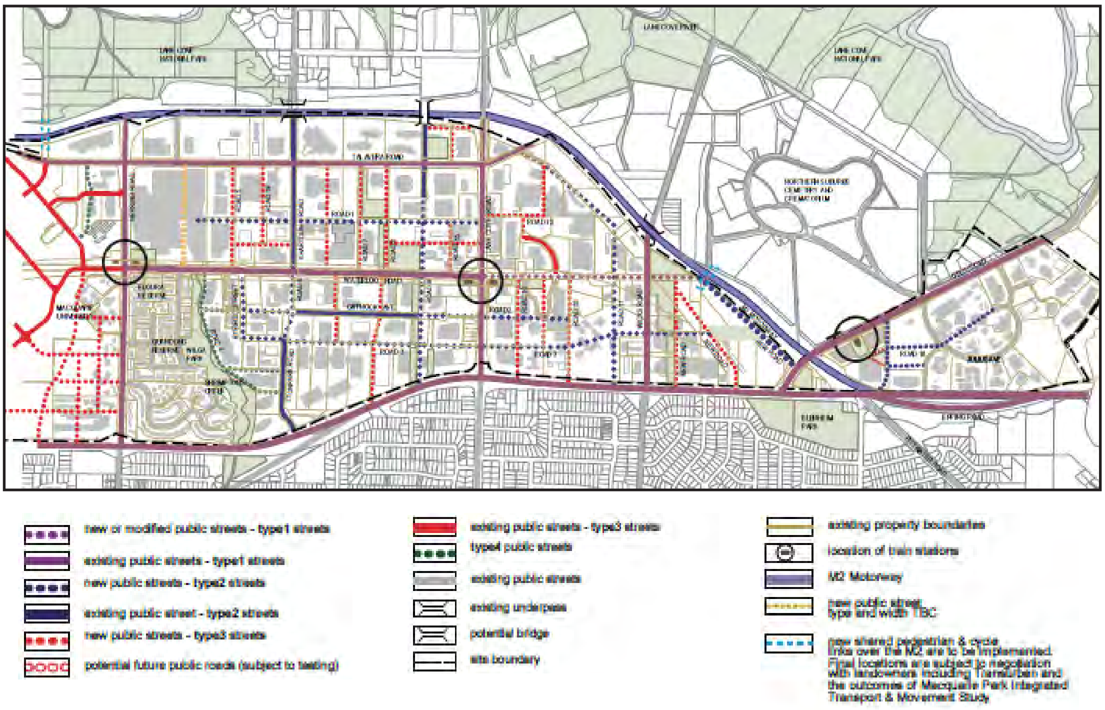
5.3. Transportation improvements currently planned for Macquarie Park - the "Planned" targets scenario

The City of Ryde council initiated the Macquarie Park Traffic Study in 2008 to determine what the impact of the LEP2008 growth potential will be by 2031. In order to assess the traffic impact, the council developed a case for a 40% target of public transport split for commuting trips.

The Macquarie Park Traffic Study (City of Ryde 2008) conducted by Traffix and Bitzios Consulting, was directed by a steering committee in which every important stakeholder was represented:

- City Of Ryde
- RailCorp
- Macquarie University
- TransUrban
- AMP (the owners of Macquarie Park Shopping Centre)
- Goodman International (a major property owner)

The Road Transport Authority (RTA) and Transport Planning and Data Centre (TPDC, now the Bureau of Transport Statistics within NSW Department of Transport) provided strategic model outputs for the Sydney Metropolitan area (City of Ryde 2008). This study aimed to determine road infrastructure improvements needed to cater for the expected significant increase in 2031 traffic levels based on the predicted 78,000 jobs and 28,214 full-time equivalent university enrolments, plus an additional residential population of 5098 (the same figures used in estimating the trip demand in the previous chapter, see Table 4.7). The study identified necessary changes to local internal roads and intersections, as well as major road network improvements which should be completed in order to accommodate the estimated traffic levels by 2031 (Figure 5.1).



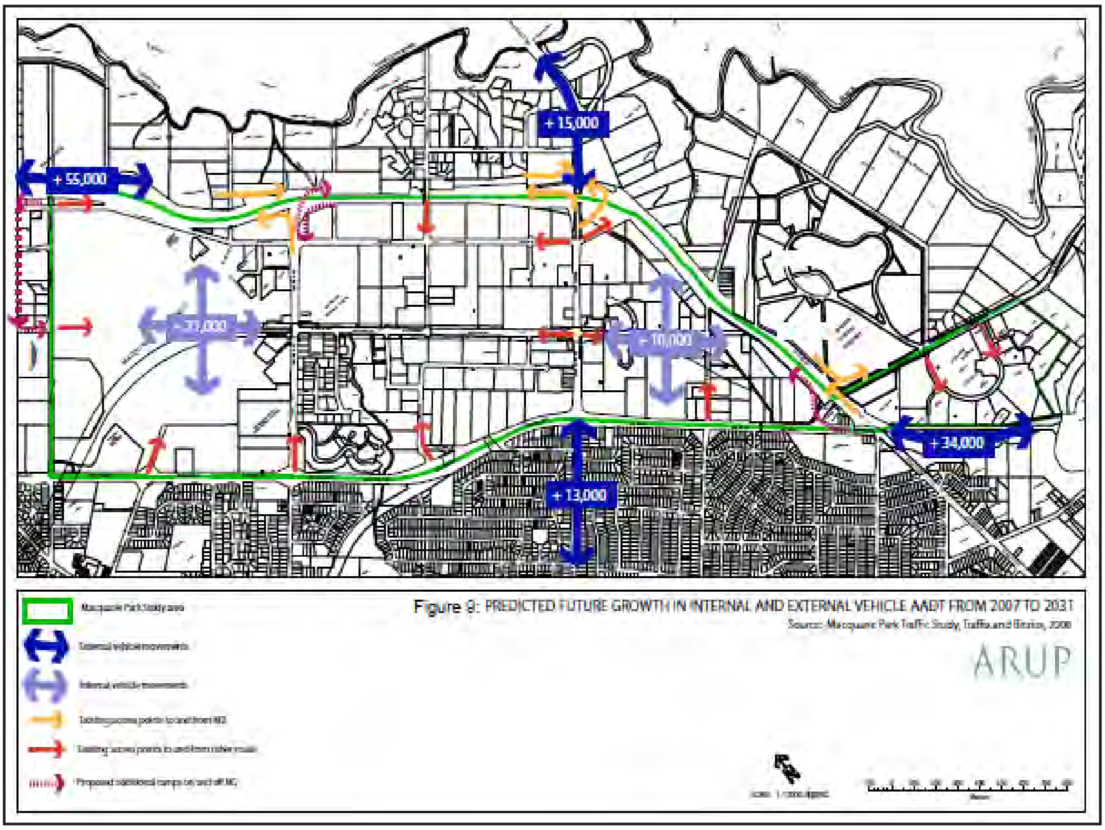
Source: Source: City of Ryde 2010, DCP10 Structure Plan, Figure 4.4.05 Street Network Structure Plan

Figure 5.1 - Macquarie Park street network plan

The target of 40% public transport mode split for Macquarie Park has been based on the following transport network assumptions (City of Ryde 2008, p. 25):

- the opening of the Epping to Chatswood Rail Line (ECRL) – completed in 2009
- the completion of the North West Rail Link from Epping to Rouse Hill
- the completion of the CBD Rail Link from Chatswood to Redfern
- the commitment of bus lanes on Lane Cove Road and additional bus services in the Macquarie Park Corridor
- limitations on car parking supply and increase of parking fees
- the requirement of workplace travel plans for all businesses

The study used the traffic micro-simulation modelling package PARAMICS. The simulation model includes a 'pattern' matrix to provide an accurate representation of traffic patterns in addition to the traffic counts. For the purpose of the traffic study, the 'pattern' matrix was developed based on the morning and afternoon peak hours (7:45 to 8:45 am, and 4:45 to 5.45 pm) for the base year 2007. This pattern matrix was the input for the 2031 morning and afternoon peak period models for the study area (City of Ryde 2008, pp. 2-13).



Source: City of Ryde 2009, Macquarie Park Corridor Parking Study, Figure 9: Predicted Future Growth in Internal and External Vehicles from 2007 to 2031, p. 32

Figure 5.2 - Traffic Increase from 2007 to 2031

Matrix estimation was based on all vehicles. The vehicle classification split assumption was: 90% cars, 8% rigid vehicles and 2% articulated vehicles (p. 13). The turning counts were from the traffic surveys and balanced so that flows match between upstream and downstream intersections (p. 17). The matrix estimation was run using a one hour pattern matrix and one hour turning counts at the GEH statistic of 5.0 or under.

The study concluded that an overall 20% increase in the morning peak traffic is expected compared to 2007, assuming a 40% split in non-car usage. Approximately 20,000 vehicle trips to and from the study area are expected and additionally 18,000 vehicle trips through the area are expected during one hour in the morning peak.

The largest increases in traffic generation are around Macquarie University (for locally-generated trips) and Lane Cove Road (for external trips) with all the other traffic growth within the Macquarie Park being expected to be taken up by public transport (p. 27).

However, the predicted 2031 traffic increase is approximately 148,000 vehicle trips per day compared to 2007 (Table 5.3).

Location	Daily Traffic Increase
M2 West of the study area	55,000
M2 and Epping Road east of the study area	34,000
Macquarie University	21,000
Lane Cove Rd south of the study area	15,000
Lane Cove Rd north of the study area	13,000
Macquarie Park east of Lane Cove Rd and west of M2	10,000
TOTAL	148,000

Source: City of Ryde 2008, Macquarie Park Traffic Study-Final report, Table 5.2 Major Traffic Movement Increases 2007 to 2031, p 27

Table 5.3 - Traffic Increase from 2007 to 2031

Although the Macquarie Park Traffic Study does not provide information about distribution of trips by mode or purpose, the majority of trips during morning peak hours are work trips, followed by education trips. Assuming 40% public transport mode share for journey–to-work trips and a more ambitious 45% for educational trips to Macquarie University as planned targets, and considering the Strategic Travel Model mode shares for all the other trips (e.g. shopping trips, business trips, social/recreational trips), the future 2031 mode split is presented in the following table.

Transport Mode	Work	Education (Macquarie Univ. students only)	Shopping	Business	Other
Car Only (Driver)	50%	30%	62%	85%	51%
Car Only (Pass)	5%	8%	21%	5%	35%
Walk Only	2.5%	13%	11%	1%	7%
Cycle Only	2.5%	4%	1%	0%	1%
Train	25%	17%	1%	7%	4%
Bus	15%	28%	4%	2%	2%
TOTAL	100%	100%	100%	100%	100%
Total Car	55%	38%	83%	90%	86%

Table 5.4 - Mode Shares (2031) – "Planned" Targets Scenario

Based on these mode share assumptions and the trip demand discussed in the previous section, the predicted number of daily car inbound trips is 72,561 by 2031 (Table 5.5) which means approximately 20,500 vehicle trips during the morning peak period (considering the 0.283 trip allocation coefficient at morning peak period). This result is consistent with the strategic PARAMICS model output of approximately 20,000 vehicle trips in the morning peak hours to/from and within the Macquarie Park corridor (City of Ryde 2008, p. 27).

Transport Mode	Tours	Trips
Car Only (Driver)	72,561	145,122
Car Only (Pass)	19,068	38,136
Walk Only	7,886	15,772
Cycle Only	2,737	5,474
Train	20,862	41,724
Bus	15,886	31,772
TOTAL	139,000	278,000
Total car trips	91,629	183,258
Total car mode share (%)	66%	66%
Total active travel (walking and cycling) trips	10,623	21,246
Active travel mode share (%)	8%	8%

Table 5.5 - Total trips to/from and within Macquarie Park, by mode of transport – "Planned" scenario

The overall mode share for all trips is 34% for non-car trips to/from and within Macquarie Park, of which 26% trips are by public transport (31,772 trips by bus and 41,724 trips by train), 6% walking, and 2% cycling.

The Traffic Study concluded with some recommendations for improvements on major roads and local intersection upgrades which were roughly estimated to cost more than AU$400 million, excluding the cost for upgrading the local street network within Macquarie Park. A more recent estimation indicated a cost of more than AU$500 million for enlarging the M2 motorway only (City of Ryde 2009). The study aim was to identify the necessary road infrastructure improvements to accommodate the expected traffic increase by car and it did not provide any options for a local access system. The existing shuttle bus is designed to service the Macquarie Park Shopping Centre, running during off-peak hours only (from 11.00 am to 3.00 pm) at every 20 minutes (City of Ryde 2007). It is not designed to increase the railway stations or bus node accessibility, or to serve the large numbers of commuters during peak hours.

However, the estimated level of traffic by 2031, even though achieving 40% public transport split, is expected to be about 20% higher than 2007 and hence the internal road network will face even more congested traffic than the existing level. Furthermore, the additional bus services required to accommodate the estimates of 32,000 passenger trips per day will put more pressure on traffic, worsening the existing traffic congestion and peak hour bus delays.

Moreover, the local network improvements will not address the main issue of low accessibility level of many parts of the Macquarie Park area to the rail stations which makes the predicted 40% mode share by buses and trains unlikely to happen.

5.4. Increasing local access by Personal Rapid Transit - the “LAPRT” scenario

This scenario is focused on increasing accessibility of the existing public transport transit nodes by introducing a Personal Rapid Transit network as a feeder for the three rail stations and a few peripheral bus stations.

Similar to other edge cities, Macquarie Park is characterised by a car-dominant environment. The existing three rail stations are not within easy access of walking (see discussion in Chapter 4, section 4.2.).

The quality of a public transport system is determined by the before (access) and after (egress) modes and, consequently the demand is influenced by the accessibility level of the public transport network (Krygsman 2004).

The low accessibility of the railway stations within Macquarie Park was seen as one reason for the lower public transport mode share compared to other urban centres (City of Ryde 2009) and consequently the high percentage of trips by private cars that dominate the area. The existing layout and sloping topography of the site make walking and cycling difficult, not only as access or egress modes, but for all trip purposes. Black (1977) explains that accessibility is a function of each transport mode and type of the urban activity (working, shopping, and going to school or recreational activities). He suggests that strategies for improving accessibility level should consider the relationship between transport mode and purpose of travel.

The PRT network has been designed to provide high frequency access from the rail stations to the University, retail, offices and other destinations in Macquarie Park. The network also provides convenient internal access for residents and easy access to the peripheral bus stations and car parks.

The major benefit of PRT is its high frequency of services and flexibility compared to buses or light rail at a smaller-scale physical footprint. The area is already very congested. Based on future employment growth, it is expected that traffic will increase two fold. The LAPRT scenario draws on the assumptions that by introducing a PRT system instead of building more roads and more car parking spaces, congestion will be maintained at the existing level, which is in itself a form of congestion control. Moreover, because the PRT system will be elevated, the space underneath the guideways could be used for creating footpaths and cycleways. Furthermore, the PRT network allows integration of the corridor with the neighbourhood urban fabric. At the moment, the major roads which bound and bisect the corridor actually isolate the area from the surrounding neighbourhoods, the only possible access being by cars.

Moreover, a simple loop in the PRT network could allow easy access to the Lane Cove Park and the Northern Suburbs Cemetery and Crematorium which are now accessible only by car because of the interference with M2 expressway. The features of the PRT system such as quiet operation, no emissions and much smaller footprint make it an appropriate solution for a national park (as the example under development in South Korea demonstrates).

5.4.1. Mode share assumptions for the LAPRT scenario

The same land-use and transport network assumptions were made for this scenario as the 2031 Strategic Travel Model input assumptions related to Macquarie Park; the most important transport network assumptions are:

– The North-West rail link from Epping to Rouse Hill to be completed by 2021

– The Parramatta-Epping rail link to be completed by 2031

– Increased frequency of the buses on the busiest routes by 2016

– Northern Beaches express bus ways completed by 2021

As the PRT system is proposed as a feeder for the rail and bus stations, the access and egress trips which are usually walking trips included in the public transport mode share (known also as "walked linked trips"), will be split for this project in walk and PRT linked trips. These trips will be linked to the main public transport mode.

In order to estimate the total trips generated under the LAPRT scenario, the following assumptions were made about mode share, by purpose of trip:

1. Mode share for journey- to- work trips:
    - Lower targets were assumed for work trips by rail (20%) and bus (12%) with walking as the main access/egress mode (train + walk, bus +walk) compared to the planned targets but additional trips were assumed for rail (5%) and bus (5%) with PRT as the access/egress mode; consequently, the total public transport mode share will increase since the main transit nodes will be more accessible
    - A small increase in cycling and walking was assumed compared to the planned targets but not very substantial (1% only) because the majority of workers travel from other suburbs with 59% travelling more than 10 kilometres from their residential suburbs
    - A 2% mode split for trips by car and PRT based on the rationale that PRT can attract workers from the surrounding neighbourhoods who might decide to drive and park the car in the public car parks at the outskirts of the corridor instead of facing peak hours congestion (approximately 27% of the workforce travel from the surrounding local governments)
    - That 2% of the local workforce (14% of the current workforce lives within the corridor) might walk to the nearest PRT station and travel to their workplace or to connect to a bus or train
    - The same percentage of the car passenger trips as in the Planned" scenarios was assumed (5%)

- The remaining trips (43%) were allocate to the car drivers only

2. Mode share for Macquarie University trips
   - The same targets for trips by train + walk (17%) and bus +walk (28%) as the planned targets were assumed, plus an additional 8% for train + PRT, and 4% for bus + PRT; it is expected that PRT will be very attractive for students (as in the case of Morgantown and Masdar)
   - No increase in walking for students trips, because currently 90% of the students walk through the campus; PRT might have an influence in decreasing the amount of walking, depending on the cost of fares
   - It was assumed that 2% of the local or surrounding neighbourhood students might walk and ride a PRT vehicle (pod) and 2% might decide to 'park and ride a pod'
3. Mode share for shopping trips
   - No shopping trips were assumed for rail +PRT or bus +PRT because the shopping centre is very well served by existing buses and trains and it is already easily accessible
   - No shopping trips by car + PRT because it is expected that people who drive will go direct to the shopping centre; this may change if the parking policy is changed (for example reducing the parking time to ½ hour free parking instead of 3 hours)
   - Same percentage for walking as the planned targets
   - 4% shopping trips were assumed for walk +PRT because the PRT system can attract old or young people who cannot drive
4. Mode share for business trips
   - The business trips are related to the work trips (representing about 40%), so the same overall distribution of trips by mode was assumed as for the work trips: 3% for trips by train + PRT, 2% by bus + PRT, 2% for 'park and ride a pod' and 2% who might walk to the nearest PRT station and travel on a pod
   - Higher targets for walking (2%) and cycling trips (2%) than the planned targets (1%, respectively 1%) based on the rationale that the area will become more pedestrian-friendly than it is at the present
5. Mode share for trips for other purposes (social/recreational, serve passenger, entertainment etc)
   - Higher target for walking (10%) and cycling (2%) trips than the planned targets (7%, respectively 1%) based on the rationale that the area will be safer, more attractive and people-oriented rather than car-oriented; for recreational and social trips, active travel is generally a preferred mode, especially if the public space is carefully planned for the community benefit

- 2% overall target for PRT as a connecting system to all public transport modes based on the rationale the PRT can attract local residents or from neighbourhoods, especially old or very young people who cannot drive

A significant increase in walking +PRT for recreational and entertainment trips could occur if a PRT loop to Lane Cove National Park is provided.

Transport Mode	Work	Education (Macquarie Univ. students only)	Shopping	Business	Other
Car Only (Driver)	43%	17%	54%	71%	42%
Car Only (Pass)	5%	6%	21%	5%	27%
Walk Only	3.0%	12%	11%	2%	10%
Cycle Only	3.0%	4%	2%	2%	2%
Train + Walk	20%	17%	2%	7%	6%
Bus + Walk	12%	28%	6%	4%	4%
Train + Local Access PRT	5%	8%	0%	3%	3%
Bus + Local Access PRT	5%	4%	0%	2%	2%
Car + Local Access PRT	2%	2%	0%	2%	2%
Walk +PRT	2%	2%	4%	2%	2%
TOTAL	100%	100%	100%	100%	100%
Total Car	50%	25%	75%	78%	71%

Table 5.6 - Mode Shares (2031) – LAPRT scenario

The mode shares proposed for PRT are very cautious, between 2% and 5% for different trip purposes, with a maximum of 8% assumed for students trips based on the performance of the system already demonstrated at two campuses, West Virginia University and Masdar Institute for Science and Technology. However, increased accessibility, safety and minimum waiting time are key motivators for choosing public transport, hence the PRT could be very attractive for local residents or for commuters who may decide not to drive and catch public transport instead if the PRT system can prove its reliability and performance.

5.4.2. Distribution of trips under the LAPRT scenario

The overall mode share for all trip purposes in this scenario is 43% for non-car trips to/from and within Macquarie Park, with approximately 26,000 fewer trips by car compared to the “Planned” scenario (Table 5.7).

Transport Mode	Tours	Trips
Car Only (Driver)	60,075	120,150
Car Only (Pass)	16,288	32,576
Walk Only	9,049	18,098
Cycle Only	3,764	7,528
Train + Walk	18,523	37,046
Bus + Walk	15,202	30,404
Train + Local Access PRT	5,849	11,698
Bus + Local Access PRT	4,690	9,380
Car + Local Access PRT	2,466	4,932
Walk + PRT	3,094	6,188
TOTAL	139,000	278,000
Total Car trips	78,829	157,658
Car trips mode share (%)	57%	57%
Total active travel (walking and cycling)	15,907	31,814
Active Travel mode share (%)	11%	11%

Table 5.7 - Total trips to/from and within Macquarie Park, by mode of transport – LAPRT scenario

The number of daily trips by train to and from Macquarie Park, estimated at approximately 49,000, will generate a potential 14,000 trips to Macquarie Park during the morning peak period, assuming 0.574 trip allocation coefficient for the morning peak period for rail for the inbound trips (based on the STM tour time period allocation) and consequently up to 8,000 trips in the busiest morning hour.

In order to carry up to 8,000 people in peak hour, there is a need for 12 trains per hour each way and approximately 350 passengers per train alighting or boarding at Macquarie Park (all three railway stations) which represents 30% of the entire train capacity (assuming eight carriage trains with seating capacity up to 900 passengers plus an additional 200-300 standing people).

This could be possible if the government is fully committed to building the North West Rail Link and the Epping-Parramatta line by 2031. The North-West rail link proposal has been recently submitted to Infrastructure Australia. The existing plans are to build the North - West rail link by 2020 with eight or ten trains in peak hours, possibly 12 trains per hour by 2031 (Transport for NSW 2011). In addition, it may continue with four trains per hour from the northern line, but this is uncertain and also there is no commitment for the Epping – Parramatta line which could secure the expected capacity.

Similarly for buses, there are now 24 routes and 896 buses serving Macquarie Park (City of Ryde 2007) with 218 bus services in peak hours. In order to carry 5000-6000 passengers in the busiest peak hour, more than 300 bus services per hour will be necessary, which could be possible if integrated bus networks are completed by 2031.

The share of public transport patronage is very important for the accuracy of the PRT demand forecast. Assuming the planned transport infrastructure projects will be finalised by 2031, the expected number of trips through a local access system within Macquarie Park is over 3,800 trips during a one hour morning peak, in an average weekday (Table 5.8). Conventional local transport systems have lower capacity than the expected demand: a minibus system usually has 300 passengers per hour capacity (considering 25 seats, full occupancy rate and minibuses running at five minutes frequency); running 152 minibuses per hour will involve additional costs for infrastructure (for example bus stations with multiple bays to allow two to three minibuses loading per minute, a big fleet of vehicles, drivers for each vehicles, three shifts per day). However, the congestion will be even higher during morning peak because cars, buses and minibuses will compete for space on the sparse layout and ineffective street network of the corridor. The light rail has a theoretical capacity of 3675 passengers per hour (if we consider a full occupancy rate of 200 seats and additional 30% standing people in a three-car LRT, running at eight minutes frequency). Further research is recommended to investigate whether these systems are worthwhile investments.

The aim of this study is to determine whether PRT could be a sustainable transport option for the future. The next chapters will investigate whether the PRT network has enough capacity to carry the expected passenger number of 3,800 in one peak hour, and the investment required to provide the expected level of service.

	Trips	AM peak factor	AM peak period (2 hours) trips	AM peak hour trips
Train + Local Access PRT	5,849	0.574	3,357	1,678
Bus + Local Access PRT	4,690	0.587	2,753	1,376
Car + Local Access PRT	2,466	0.283	698	349
Walk +PRT	3,094	0.258	798	399
Total Trips Using PRT	16,099		7,606	3,803

Table 5.8 - Trips using local access PRT

In conclusion, the LAPRT scenario assumes that by increasing local access to the existing rail stations and bus nodes through a Personal Rapid Transit system, the overall mode share for car trips will decrease from the expected 80% if the current transport trends continue over the next 20 years, to 57%.

This scenario is based on the same targets as the local government targets for commuting trips: 40% public transport mode share and 60% car trips. However, there is an expected 20% increase in traffic compared to the current level. The existing plans for the area are to build more roads to accommodate future growth, which in turn will induce more traffic if active measures to control congestion are not in place. The LAPRT scenario draws on the assumption that introducing a PRT system instead of building more roads and providing a limited number of parking spaces will keep congestion at the existing level. Moreover, the small footprint of the system could release the land for other purposes and encourage greater physical activity.

The total active travel (walking and cycling) within Macquarie Park is expected to increase from 19,000 trips per day (business-as-usual scenario) to over 31,000 trips per day in 2031. Nevertheless, by increasing public transport mode share from 13% in the business-as-usual scenario to 32% in the LAPRT scenario, more walk trips as access or egress mode or to change transport modes will occur; this possible increase is not included in the projected trips.

5.5. Towards Personal Rapid and Transit Oriented Development scenario - PRTOD

This scenario is based on a different land-use and transport approach to the previous scenarios. It is proposed as an alternative strategy to be investigated in the future. It is not investigated in detail in this study.

Transit Oriented Development (TOD) is defined as an urban form that can provide an active transport-served neighbourhood by providing local services and access to transit stops within walking distance for an increased urban population (Newman et al 2009, Calthorpe 1993). In a research study conducted in Sydney, McKibbin (2011) found that transit oriented development or higher densities do not necessarily result in a large decrease of car use, unless the population growth is focused on highly accessible areas.

The Personal Rapid and Transit Oriented Development (PRTOD) scenario draws on the assumptions of increasing residential population within Macquarie Park Corridor and increasing accessibility of the area by introducing a Personal Rapid Transit network. Similar to the LAPRT scenario, the PRT network will act as a feeder for the three rail stations and a few peripheral bus stations. However, the PRT will not only increase the destination accessibility for the commuters coming to the Macquarie Park but it will also increase other destinations' accessibility by public transport for the residents travelling from Macquarie Park.

The residential population could be increased by increasing floor space ratios, by up-zoning from the lowest residential density zone around the periphery of the corridor or by introducing mixed-use commercial and residential uses in future developments. Regarding the first two options, strong opposition from local residents is expected and as a consequence, there may be a lack of political will to adopt any of these strategies. The mixed uses in future developments could be more acceptable than up-zoning the existing lower density areas, so the PRTOD scenario will consider this option.

By rezoning some lots from B3 Commercial Core to B4 – Mixed Use, future commercial floor space could be transformed to residential space. The floor space area of the lots involved is: 217,000 + 55,000 + 124,000 + 89,000 = 485,000 sqm. The total land area is approximately 690,000 sqm (69 ha). Assuming that only half of the land - 345,000 square metres - is developed as residential and assuming a density of 100 dwellings per hectare and an average household size of 2.2 inhabitants, there is a potential for a 7,500 increase in the residential population. This equals 46 square metres per person and 101 square metres per dwelling.

Considering the entire floor space of 485,000 square metres floor space will be rezoned as residential, and considering 46 square metres per person, then 10,543 residents could be accommodated in the future. Transforming parking spaces into housing lots could be another solution. The CoR identified 4,720 at-grade parking spaces which could be redeveloped for different purposes (Macquarie Park Parking Study-Final report, pg 22).

The minimum floor space required for offstreet structured parking spaces, including manoeuvring lanes and blind aisles is 28.67 – 29.41 square metres (City of Ryde DCP 2010); for disabled parking, a bigger space is required. Considering an average of 30 square metres for offstreet parking spaces, it results in more than 141,600 square metres which could accommodate future housing for 3,115 people.

Based on the above calculations, an additional 11,905 14,858 residential population over the predicted 10,600 population by 2031 could be achieved by different land use policies.

Another option is building housing over the rail lines and around Macquarie University. Around North Ryde station, a mixed-use development on the Transport Infrastructure Development Corporation (TIDC) site is proposed with a potential of additional 1,200 dwellings (City of Ryde 2010).

These are only a few options to plan for a higher number of dwellings and consequently, a significant increase in population numbers. The purpose of this project is not to analyse in detail the locations of the potential housing construction which should be part of future land use policies. This study aims to identify the best strategies to address sustainability challenges for a very high activity generator such as Macquarie Park.

In conclusion, an additional residential population of 14,500 over the predicted 10,600 population by 2031 could be achieved by different land use policies and it is one of the input assumptions for the PRTOD scenario.

5.5.1. Mode share assumptions for the PRTOD scenario

Rezoning B3 – Commercial Core (1:40 employment density) to mixed-use commercial and residential uses, without increasing floor ratio may result in less potential jobs within Macquarie Park. However, the commercial space of 950,000 square metres with the potential of generating 23,750 jobs based on an employment density of 1:40, might be over-zoned, so the assumption of 78,000 total jobs might be unrealistic (see discussion from Chapter 4, section 4.3).

Mixed-use zoning and the 55,000 potential jobs the 2005 Metropolitan Strategy and the Metropolitan Plan 2036 forecast might be a more appropriate approach. The input assumptions for the PRTOD scenario are as follows:

- 55,000 jobs
- 25,000 residential population
- 42,000 Macquarie University students (28,000 FTE)

In order to estimate the trip demand under this scenario, the same methodology described in the previous section (5.4.) was used for trips to Macquarie Park generated by 55,000 commuters and 42,000 students, based on the Strategic Travel Model 24-hour tours to Macquarie Park as destination. The transport indicators for Macquarie Park (NSW Department of Transport BTS 2011, Karantonis E., request 11270) that replicate the household travel behaviour for this specific area have been applied to the additional 14,500 population (Table 5.9).

This new ratio between jobs and residents will not change the characteristics of an "edge city" for Macquarie Park but it may change the "regional end destination" and accordingly, the trip distribution by mode and purpose in each direction. Ogle (2011, pers. comm., 9 November) suggests that the 'edge' city could became a 'node' city, "each being on the edge of the others, and all on the edge of the original Sydney CBD".

Purpose of trips	Tours to MP destination	Tours from MP origin	Total Tours
JTW	42,300	7,074	49,374
Business trips	8,600	2,323	10,923
Tertiary	18,200	1,781	19,981
Shopping	15,600	2,990	18,590
Other	30,200	9,582	39,782
Total Tours	114,900	23,750	138,650
Total Trips	229,800	47,500	277,300

Table 5.9 - Total trips to/from and within Macquarie Park, by purpose of travel – PRTOD scenario

As expected, the total number of trips will not change significantly but the trip distribution by purpose and consequently by mode will considerably change.

The mode share for trips to Macquarie Park as the destination is similar to the LAPRT scenario. The mode share for trips originated in Macquarie Park for the additional residential population is based on assumptions that the housing construction will occur around rail stations which will make public transport very attractive, especially by train. Also, as a basic principle of Transit Oriented Development, local services, jobs and other attractions will be within walking distance. Moreover, the PRT network will further increase the accessibility of all local services and also the accessibility of railway and bus stations.

Transport Mode	Work		Education (Macquarie Univ. students only)		Shopping		Business		Other	
	to MP	from MP	to MP	from MP	to MP	from MP	to MP	from MP	to MP	from MP
Car Only (Driver)	43%	10%	17%	0%	54%	15%	71%	42%	42%	20%
Car Only (Pass)	5%	5%	6%	0%	21%	4%	5%	5%	27%	7%
Walk Only	3.0%	10%	12%	50%	11%	50%	2%	4%	10%	30%
Cycle Only	3.0%	5.0%	4%	25%	2%	2%	2%	4%	2%	10%
Train + Walk	20%	40%	17%	0%	2%	2%	7%	20%	6%	2%
Bus + Walk	12%	15%	28%	0%	6%	2%	4%	8%	4%	2%
Train + PRT	5%	5%	8%	0%	0%	0%	3%	5%	3%	2%
Bus + PRT	5%	5%	4%	0%	0%	0%	2%	5%	2%	2%
Car + PRT	2%	0%	2%	0%	0%	0%	2%	2%	2%	0%
Walk +PRT	2%	5%	2%	25%	4%	25%	2%	5%	2%	25%
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Total car	50%	15%	25%	0%	75%	19%	78%	49%	71%	27%

Table 5.10 - Mode Shares (2031) – PRTOD scenario

5.5.2. Distribution of trips under the PRTOD scenario

The overall mode share for all trips in this scenario is 49 % for non-car trips to/from and within Macquarie Park, with approximately 14,000 fewer trips by car compared to the LAPRT scenario and 38,000 fewer trips by car each way compared to the planned targets scenario (Table 5.11). Moreover, the car trips will be distributed both ways, internal to external and external to internal, which will balance the traffic pressure on a single direction in peak hours.

The most significant result of implementing a scenario such as PRTOD is the total active travel increases from 19,000 trips under a business-as-usual projection and 21,000 trips in the planned targets scenario to more than 38,000 trips per day by 2031.

Transport Mode	Tours To Mp	Tours from Mp	Total Tours	Total Trips
Car Only (Driver)	48,551	4,241	52,792	105,584
Car Only (Pass)	15,088	1,314	16,402	32,804
Walk Only	8,372	6,032	14,404	28,808
Cycle Only	3,087	1,593	4,680	9,360
Train + Walk	14,282	3,578	17,860	35,720
Bus + Walk	12,666	1,527	14,193	28,386
Train + PRT	4,735	662	5,397	10,794
Bus + PRT	3,619	662	4,281	8,562
Car + PRT	1,986	46	2,032	4,064
Walk + PRT	2,614	4,045	6,659	13,318
TOTAL	115,000	23,700	138,700	277,400
Total car trips	65,625	5,601	71,226	142,452
Car mode share (%)	57%	24%	51%	51%
Total active travel (walking and cycling)	14,073	11,670	25,743	38,168
Active travel mode share(%)	12%	49%	36%	14%

Table 5.11 - Total trips to/from and within Macquarie Park, by mode of transport – PRTOD scenario

The PRTOD scenario combines the increased accessibility of the main transit nodes by PRT as in the LAPRT scenario, with an increased residential population, applying Transit Oriented Development principles to Macquarie Park Corridor. Mixed-use zoning to accommodate future growth of employment and population in an area that is highly accessible by public transport, locally and regionally, will result in a decrease in car mode share from 80% in the business-as-usual scenario to 51% in PRTOD scenario. Consequently, the conventional public transport mode share will increase from 13% to

30% in the PRTOD scenario. In addition, the predicted 37,700 trips on the PRT system would be made by car in the absence of a local access system. The forecast capacity being distributed to and from Macquarie Park, will be accommodated by the future planned infrastructure.

5.6. Conclusions

Macquarie Park has been identified as a key "edge city" for Sydney, with all the characteristics of a typical "edge city". Its built form is characterised by large building footprints, lack of active street edges and very limited amounts of open spaces. The main rail stations are not easily accessible by walking or cycling. The sloping topography makes walking and cycling even more difficult. Macquarie Park has a much lower public transport mode share than the Sydney CBD or other comparable centres.

Two land use and transport scenarios – increasing Local Access through Personal Rapid Transit (LAPRT) and Personal Rapid and Transit Oriented Development (PRTOD) have been developed and compared to a business-as-usual projection by 2031 and a traffic study based on planned targets for Macquarie Park. The following table provides an overview of the total trips by mode of transport projected under each scenario.

Transport Mode	BAU	Planned	LAPRT	PRTOD
Car Only (Driver)	183,906	145,122	120,150	105,584
Car Only (Pass)	39,056	38,136	32,576	32,804
Walk Only	15,408	15,772	18,098	28,808
Cycle Only	3,764	5,474	7,528	9,360
Train + Walk	14,890	41,724	37,046	35,720
Bus + Walk	20,976	31,772	30,404	28,386
Train + Local Access PRT	0	0	11,698	10,794
Bus + Local Access PRT	0	0	9,380	8,562
Car + Local Access PRT	0	0	4,932	4,064
Walk + PRT	0	0	6,188	13,318
TOTAL	278,000	278,000	278,000	277,400
Total car trips	222,962	183,258	157,658	142,452
Total car mode share (%)	80%	66%	57%	51%
Total PRT trips	0	0	32,198	36,738
Total PRT mode share (%)	0	0	12%	13%
Total walking and cycling	19,172	21,246	31,814	51,486
Active travel mode share (%)	7%	8%	11%	19%

Table 5.12 - Total home-based trips to/from and within Macquarie, by mode of transport

The comparison between different land use and transport scenarios shows that:

1. A continuation of the existing travel patterns over the next 20 years will generate such a high traffic demand that the road network capacity is insufficient to accommodate the expected 223,000 car trips per day. The costs for the environment, economy, and society that are linked with resource use, energy consumption, GHG emissions, congestion, and human health and safety offer a strong rationale for rejecting this "do-nothing" scenario.

2. The "Planned" targets scenario, although very ambitious in establishing 40% mode share for public transport, is expected to generate more than 183,000 car trips per day, with 20% more than today and hence the improved road network will face even more congestion. Moreover, the additional bus services required to accommodate the estimated 32,000 passenger trips per day will put more pressure on traffic, worsening the existing traffic congestion and peak hour bus delays. The weakness of this scenario based on the existing targets and plans, is that local road improvements will not address the main issue of the low accessibility level of the rail and bus stations which makes the predicted 40% mode share by public transport unlikely to happen.

3. The LAPRT scenario is expected to generate 158,000 daily trips by car, based on the assumption that by increasing local access to the existing rail stations and bus nodes, which are not easily accessible by walking or cycling, the public transport system will become more attractive and the overall mode share for car trips will decrease to 57%. The PRT network will liberate the streets for pedestrians and cyclists and consequently active travel within Macquarie Park is expected to increase to approximately 32,000 daily trips by 2031. Aside from the environmental benefits of the PRT - no local emissions, low levels of noise, low energy use - the system also features an urban benefit through its small physical footprint and potential land use changes by requiring fewer car parks. This scenario draws on assumptions that the full development (2,000,000 square metres of future floor space and 78,000 future jobs) proposed by local planning policies will occur, which may be seen as unrealistic in the today's economic climate. Also, the transport infrastructure assumptions require a full commitment of the governments (present and future) to invest in major transport projects such as North-West rail link, Parramatta-Epping rail line, Northern Beaches express bus way, and integrated bus networks.

4. The PRTOD scenario is based on the assumptions of increasing residential population from the predicted 10,600 to a potential 25,000 by 2031 through introducing mixed-use buildings with the future developments in Macquarie Park and increasing accessibility of the area by introducing the PRT network. Under this scenario, an even larger decrease in car use than the LAPRT scenario is expected, from 57% to 51%. Furthermore, the conventional public transport (buses and trains)

capacity required to accommodate the predicted patronage can be supported by the existing infrastructure projects which are already on the political agenda. The most significant outcome of a scenario such as PRTOD is the total active travel of more than 51,000 trips per day (walking and cycling).

In conclusion, increasing local accessibility to the main transit nodes either by walking or by PRT network and changing the urban form to a transit oriented development will result in a significant decrease in car dependency and more important, a substantial increase in active travel.

Although the mode share assumptions can be questioned and further research is necessary for more accurate estimates, the assumptions presented here are in line with current official projections of jobs and trips. The two scenarios generated in this study offer alternatives that make it feasible to accommodate projected travel demand. Several social benefits are associated with walkable, transit oriented and highly accessible urban form. Reductions in transport emissions can be achieved by reducing the use of cars; innovative technologies should be considered not only for the environmental and urban benefit, but also to increase the attractiveness of public transport, resulting in a substantial mode shift.

At this stage it is difficult to predict the distribution of trips under the PRTOD scenario because of many unknowns: location of the future residential areas, mix of future land uses, and residential density. However, the results from modelling the LAPRT scenario could be extrapolated to the PRTOD with even greater benefits. Further research is recommended to investigate a strategy which combines Transit Oriented Development principles with an innovative local transport system such as PRT, a strategy having the merit that it could provide significant positive impacts on transport emissions reduction and increase physical activity.

In the following chapters, a PRT network design will be presented and simulations run under the LAPRT scenario assumptions. The outcomes from the PRT simulation will be used to compare the likely environmental, economic and health impacts of the LAPRT scenario to those of the two alternative scenarios, the business-as-usual projection by 2031 and the “Planned” scenario.

Chapter 6.
Modelling the LAPRT scenario

6.1. Introduction

In this chapter, I present a proposed design for a Personal Rapid Transit (PRT) network to serve as a feeder for the existing major transit nodes. I estimate the demand for the PRT system by developing origin-destination matrices, based on the Increasing Local Access through PRT (LAPRT) scenario outlined in the previous chapter.

The LAPRT scenario assumed an overall PRT mode share of 11% of total trips to and from Macquarie Park area, of which 4% are train passengers, 3% are bus passengers, 2% are car passengers and 2% will walk and ride a PRT pod for local trips. The rationale for these assumptions was presented in Chapter 5.

Demand is estimated for three time periods (morning and afternoon peak, and off-peak daytime travel), and the results are totalled for a 24-hour period. The discussion in this chapter focuses on the rationale for the assumptions adopted, and summarizes the estimated trip volumes. The accuracy of these estimates depends on the validity of the forecasts of travel, and of the assumptions adopted. This chapter aims to present well-grounded defensible estimates that can be used to compare the likely impacts and costs of a PRT system to those of the two alternative scenarios, a continuation of the current situation (business-as-usual, or BAU) and the transportation improvements currently planned for the area (“Planned”). These comparisons are developed in the following chapter. The specific questions I address in this chapter are:

> ***What is the likely PRT passenger service performance at different level of demand?***

To answer this question, we use the simulations to estimate passenger waiting time, travel time, and average distances travelled for high capacity demand during peak hours and low capacity demand during non-busy hours.

What sort of PRT stock investment would be needed to offer the proposed level of service?

We answer this question by developing estimates of PRT vehicle occupancy at various travel periods during a typical day.

6.2. Macquarie Park PRT network

The PRT network was designed as a feeder for the three rail stations (Macquarie University, Macquarie Park and North Ryde) using the ATS City Mobil software. A simplified version is available for download from the ULTRA website (www.UltraGlobalPRT.com). For this project, an expert version was provided by its developers (Lowson and Lees-Miller 2011, pers. comm., 14 August).

The network design and simulation tools are as follows:

- A PRT network can be built using a background map; for this study the Macquarie Park map was downloaded from www.nearmap.com (Street Map Data 2011, courtesy of open streetmap) and edited by the author
- The stations can be positioned at any point on the map and the network can be edited by adding or removing stations, and changing interconnections; the stations were placed near train stations, major bus stops, and a few peripheral car parks, with the purpose of servicing the Macquarie University campus, residential areas and different locations with future high concentrations of jobs (sections 6.2.1 and 6.2.2 present the design decisions and station locations in detail)
- The passenger demand levels can be specified in two ways: the simulator can distribute the demand using a gravity model or a demand matrix can be entered. For this study, I entered my own demand matrices; the origin-destination matrices were built for morning, afternoon and off-peak hours (see Chapter 6, Sections 6.3-6.5)
- The simulation can be run in real time or much faster; for this study I ran simulations in real time for one hour morning peak (based on the origin-destination matrix for morning peak), one hour afternoon peak (based on the origin-destination matrix for afternoon peak) and one hour inter-peak (based on the origin-destination matrix for inter-peak peak)

Waiting passengers are shown on the simulator display at each station. The arrival time of each passenger at each station is controlled by a random number generator within the software.

The simulator display shows how individual vehicles run on the guideways, wait at stations until they are loaded and then are directed to the requested destination to unload passengers. All stations are assumed to be built off-line. For each station, the software allocates a minimum of two berths and a maximum of five berths based on the level of demand required for each station. In practice, the stations can be built online or off-line, with one berth only or more than five berths for high demand levels.

On the simulator display, the vehicle berths are shown as small circles with different colours based on the status of the vehicle:

- Green – when passengers board a vehicle
- Blue – when passengers disembark the vehicle
- Red – when the vehicle has been unloaded and is empty
- Grey – when an occupied vehicle has to wait before leaving the station (before a time slot is cleared and a safe journey can start)

The moving vehicles are controlled by the synchronous control method – every journey is given a uniquely different timing so vehicles always arrive at merges with a minimum three second headway (see ATS CityMobil PRT tutorial). The number of vehicles in this simulation is limited to 300 vehicle trips travelling into and out of each station per hour. The empty vehicles are automatically moved around in order to balance the distribution of the available vehicles.

At the end of the simulation, the software generates statistics for passenger waiting time at each station and overall, percentages of passenger groups waiting less than one minute at each station; the number of passengers carried and the fleet required to service these passengers are provided. The passenger trip distances and travel times are also generated. The simulation does not optimise the fleet size, allocating as many vehicles as are required to provide the level of demand with a minimum response time to passenger calls. In practice, fewer vehicles might be provided leading to a longer waiting time.

The PRT network and simulation results are provided in a CD attached to this thesis (see Appendix 1). A schematic graphic of the network, stations and points of interest is presented in Figure 6.1.

The PRT network design decisions are based on the local street network and the existing layout of the corridor. The location of the PRT stations is based on the future land uses and employment distribution according to the Local Environmental Plan (LEP) 2011. Around the residential areas, the track follows two existing roads, thus even if the guideways are elevated, the impact on dwellings (privacy, safety, noise) is the minimum possible.

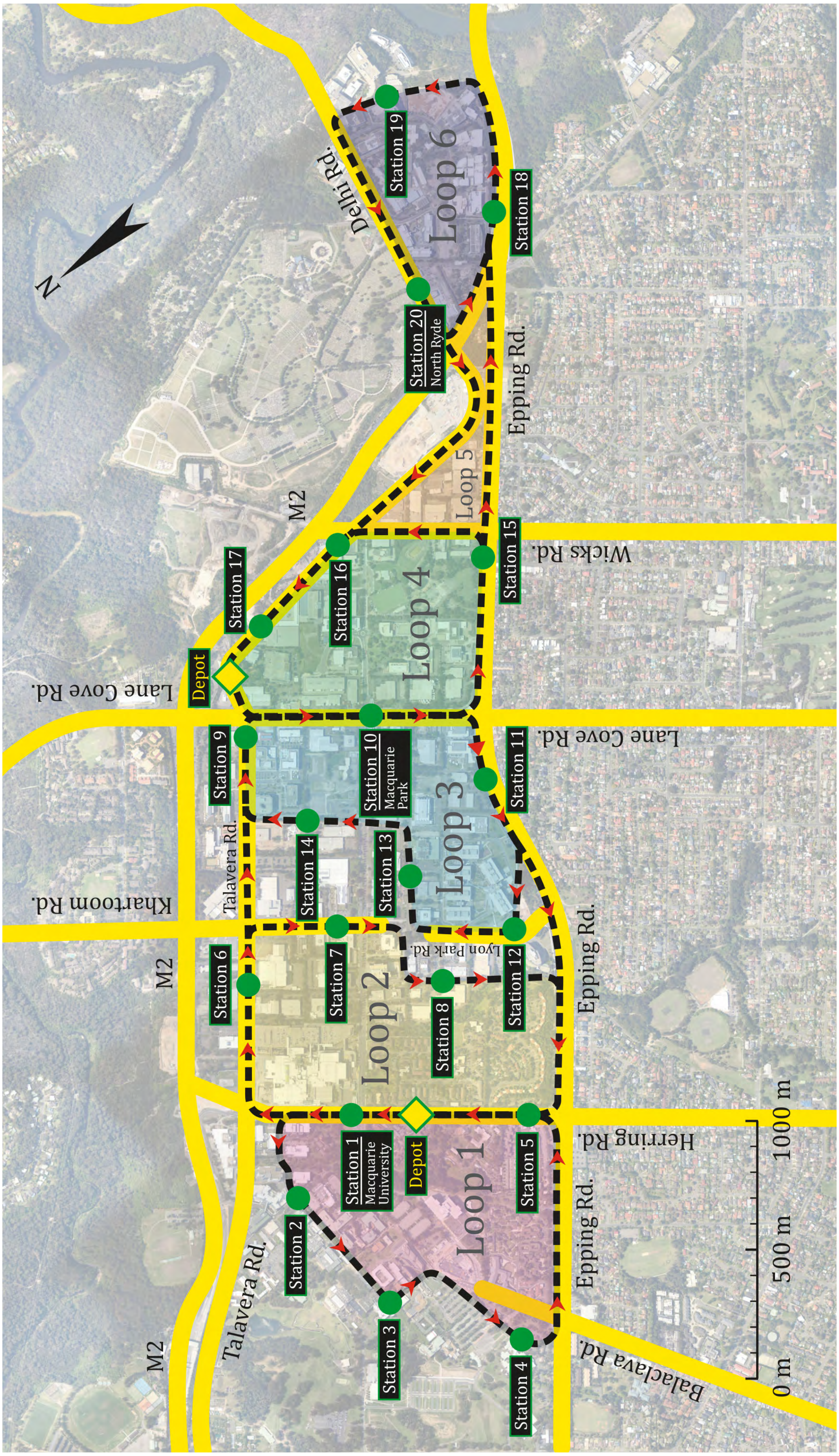


Figure 6.1 - Schematic graphic of the network, stations and points of interest

6.2.1. PRT Network

Around each rail station, two loops were created to cover an approximately one-kilometre radius catchment area. All six loops are connected together, so the passengers can travel from any station to any point of interest within Macquarie Park on the shortest route available.

The track line follows the major roads within Macquarie Park and will be predominantly elevated. It could be built at grade level with a few bridges over the intersections along Epping Road where the interaction with pedestrians is minimal. Another option could be to build the Northern track at-grade level along the M2 Hills Motorway, instead of the current proposal which is elevated over the Talavera Road. However, for this study, approximately 70%-75% of the tracks will be elevated to minimise traffic conflicts.

Source: ULTRA 2009, p. 11

Figure 6.2 - A visualisation of ULTra guideway design in an office park environment

The PRT stations are placed near to the train stations, major bus stops, and a few peripheral car parks, with the purpose of servicing the Macquarie University campus, the residential areas, and different locations with future high concentrations of jobs.

The depots are placed near the busiest stations - Station 1 'Macquarie University' and Station 10 'Macquarie Park' - in order to minimise the waiting time for passengers calling a pod. Based on the future demand, the placement of the depots could be changed or additional depots could be included.

6.2.2. Station locations

The trips on the conventional public transport system (train and buses) to Macquarie Park as destination will generate trips at 'origin' stations in the PRT system. For the return to home trips by train or bus, the PRT stations closest to rail stations or bus stops will be the 'destination' stations on the PRT system. For people driving to Macquarie Park and deciding to park the car in a peripheral public car park, the nearest PRT station will be the 'origin' station for their trip to a destination within Macquarie Park corridor and the 'destination' station for their return trip to the car park. For Macquarie Park residents, the PRT stations located near the residential areas will be the 'origin' for their outbound trips and 'destination' for the inbound trips back home.

Source: Nelstrand 2011, Municipality of Upplands Väsby, Sweden, "Vasby and Podcars", Podcar City conference presentation 2011

Figure 6.3 - A possible design of a PRT station within a commercial centre

Details of the proposed stations are provided below:

Station 1 - located near Macquarie University rail station and a major bus interchange node (bus routes connect to Sydney CBD, Strathfield, Epping, Blacktown and other locations); this station could be built inside the Macquarie Shopping centre (see Figure 6.3). Station 1 would serve as an origin station for passengers alighting at Macquarie University rail station and bus interchange node who will continue their trips to other points of interest within Macquarie Park, mostly around Macquarie University campus, residential areas and job locations within a radius of 0.8 - 1.5 kilometres from the rail station. The locations closer than 800 metres can be accessed by walking; the locations further than 1.5 kilometres can be accessed through other rail stations. It would be the destination station for passengers boarding at Macquarie University rail station and the bus interchange node or shoppers at Macquarie Shopping Centre.

Station 2 - located near the Macquarie Hospital, Health services, Faculty of Science, Macquarie Graduate School of Management, Administration offices, Chancellery Building, Art Gallery and Museums, cafe, restaurant, newsagency. There are many parking spaces in close proximity, and a public car park could be built in this location. This would be the destination station for students, staff, and hospital visitors. It might be an origin station for people driving to Macquarie Park and parking in the public car park. For their return trips it would be the destination station.

Station 3 - located near The Sports and Aquatic Centre, The Lighthouse Theatre, Campus Hub, Faculty of Human Science, Centre for Open Education, Childcare, bookshops, bank, and other university buildings. Station 3 would be the destination station for students, staff, and visitors coming to the above points of interest. It would be the origin station for their trips back to the Macquarie University rail station or to other points of interests within Macquarie Park campus or Business Park.

Station 4 - located on Balaclava Road and the corner of Epping Road, near a busy bus stop with services from Auburn, Parramatta, Eastwood. This would be the origin for students and staff (mostly Macquarie University staff, but not only) alighting from buses or car drivers from the West who would park there and continue their trips by PRT. It would be the destination station for their trips back home.

Station 5 - located near the residential area. This would serve as an origin station for all home-based trips for Macquarie Park residents. It would be the destination for returning trips for the residents. It would also service students and university staff, as it is closedto some of the university buildings and housing.

Station 6 - located on Talavera Road. Station 6 would serve as a destination station for office workers from the North-West part of Talavera Road (e.g. Astra Zeneca). It would be the origin station for their trips back to the Macquarie University rail station or to other points of interest

Station 7 - located on Khartoum Road. This would serve as a destination for trips to offices with address on the corner of Khartoum Road and Waterloo Road (e.g. Fuji Xerox, Janssen-Cilag, Brother International, Alliance Equipment

Finance and others). It would be the origin station for trips back to the Macquarie University rail station or to other points of interest.

Station 8 - located on Byfield Street. This would be the destination for trips to offices within a 500 metre radius (e.g. Laser Corporation Holdings, National Instruments Australia, Australian Radio Network, Interactive Telecoms Pty and others).

Station 9 - located on Talavera Road, near to a busy bus station with services from the City, Epping, Mona Vale and Gordon; a public car park would be a good option here for 'Park and Ride a Pod' because this is a major access point to Macquarie Park through Lane Cove Road, which is a major North-South artery in the corridor. Station 9 would serve as an origin station for bus passengers and Park and Ride patrons for trips to different points of interest within Macquarie Park. It would serve as a destination station for their trips back to the bus station or car park.

Station 10 - located in the vicinity of Macquarie Park rail station. This would serve as an origin station for passengers alighting at Macquarie Park rail station who will continue their trips to other points of interest within Macquarie Park, mostly around the rail station, within a radius of 0.8km - 1.5 km. The locations closer than 800 metres can be accessed by walking; locations further than 1.5 km can be accessed through other stations. Station 10 would be the destination station for passengers boarding at Macquarie Park rail station for their return trips.

Station 11 - located on Epping Road, near a bus stop with services from Epping and North Epping. This would be the origin for passengers alighting from buses coming mostly from South, who would continue their trips by PRT to different points of interest outside the walking catchment. It would be the destination station for their trips back home.

Station 12 - located on Lyon Park Road. This would serve as a destination for trips to offices within 500 metre radius. The main business located here is Optus Australia Headquarters.

Station 13 - located on Griffnock Avenue. Station 13 would be the destination for trips to offices within 500 metres radius (e.g. Alstom Australia, Douglass Hanly Moir Pathology, Bard Australia and others). It would be the origin station for trips back to the rail stations or to other points of interest within Macquarie Park.

Station 14 - located in the middle of a high-concentration job centre, between Lane Cove Road and Khartoum Road. There is no road access at present, but a new public street is planned to be built by 2030 (City of Ryde 2009). This would serve as a destination for work trips and business trips to the new employment locations. It would be the origin station for the return trips to home.

Station 15 - located on Epping Road corner to Wicks Road, near a busy bus stop servicing suburbs as Epping, Marsfield, Parramatta and Chatswood. This would be the origin for passengers alighting from buses coming mostly from South-East, who will continue their trips by PRT to different points of interest outside the walking catchment. It would be the destination station for their trips back to home.

Station 16 - located on Wicks Road corner to Waterloo Road. This would be the destination for trips to offices within 500 metres radius (e.g. Seekmedia Com, Print Media Group, Citizen Business Machines and others). It would be the origin station for trips back to the rail stations or to other points of interest within Macquarie Park.

Station 17 - located at Eden Park Centre. Station 17 would be the destination for trips to Eden Park centre, and the origin station for trips back to the rail stations or to other points of interest within Macquarie Park.

Station 18 - located on Epping Road, near a bus stop and car park; it is an entrance point to the corridor from Manly, Crows Nest, Sydney CBD, or Milsons Point. This would serve as an origin station for passengers coming to North Ryde by buses, alighting here and continuing their trips by PRT pods and for people driving to Macquarie Park and parking in the public car park. It would be the destination station for their trips back home, and would also serve residents living close by.

Station 19 - located on Julius Avenue. This would be the destination for trips to the North Ryde Business Park, and the origin station for trips back to the rail stations or to other points of interest within Macquarie Park.

Station 20 - located near the North Ryde rail station. Station 20 would serve as an origin station for passengers alighting at North Ryde rail station who continue their trips to other points of interest within Macquarie Park, mostly around rail station, within a radius of 0.8- 1.5 kilometres. The locations closer than 800 metres can be accessed by walking; locations further than 1.5 kilometres can be accessed through other stations. This would be the destination station for passengers boarding at North Ryde rail station for their return trips.

Overall, the proposed PRT network is 17.8 kilometres in length, with twenty stations and two depots. The track line is a one-way single loop, of which approximately 70% is elevated. The track route follows the existing street network and the station locations have been chosen to serve zones with future high concentrations of jobs. The concept design is only indicative at this stage, in order to test the PRT system performance at high capacity demand using simulations, and to estimate the total capital investment required.

6.3. Estimating demand in the morning peak hour

Demand during a one hour morning peak was calculated using the Strategic Travel Model tour time period allocation (Bureau of Transport Statistic 2011). The morning peak period covers all trips between 7.00 am and 9.00 am. The total trips per hour for people using PRT in the morning peak (based on projections for the scenario developed in Section 5.4.2 above) are presented in Table 6.1.

2031 LAPRT	train+PRT		bus +PRT		car+PRT		walk+PRT		TOTAL PRT
	to	from	To	from	to	from	to	from	
JTW trips	1046	35	1028	34	328	11	276	9	2767
Shopping trip	0	0	0	0	0	0	37	0	37
Business trips	67	4	35	2	37	2	30	2	179
Other trips	57	0	27	0	50	0	49	0	183
Total trips at PM peak	1170	39	1090	36	415	13	392	11	3166
Macquarie University students	387	0	195	0	80	0	70	0	732
M Uni staff (4% JTW) trips	42	1	41	1	13	0	11	0	111
TOTAL TRIPS	1557	39	1285	36	495	13	462	11	3898

Table 6.1 - PRT trips for one hour AM peak, average weekday

6.3.1. Distribution of trips by origin stations

In order to build the origin-destination (OD) matrix, the following assumptions were made about the distribution of trips by origin stations:

1. Distribution of trips by train stations:
    - The distribution of the passengers alighting in the morning at the three rail stations is based on the current distribution of the existing Epping-Chatswood Rail Link (ECRL) passengers: 50% at Macquarie University station (Station 1),

40% at Macquarie Park station (Station 10), and 10% at North Ryde station (Station 20);

- The distribution of passengers boarding in the morning: 90% at Macquarie University (Station 1), 10% at North Ryde (Station 20); these passengers are mainly residents who will board a pod at Station 5 and they will connect to train at Station 1 or Station 20

2. Distribution of trips by bus stops:

- The current distribution of the local workforce based on the place of residence is: 75% from the South and 25% from the North of the corridor (City of Ryde 2009). Most of the bus routes enter or exit the corridor through Epping Road, the southern border of Macquarie Park (24 bus services compared to 5 services along Talavera Road)
- It is assumed that 75% of bus passengers will arrive on a bus route via Epping Road, so they will use either the PRT stations 4 (30%), 11 (30%), 15 (20%) or 18 (20%). The remaining 25% will arrive from the North, boarding the PRT system at stations 1 and 9 in an equal proportion, as both of them are major bus nodes; the percentages are based on the job concentration around these stations

3. Distribution of Park and Ride PRT trips:

- Some of car drivers may prefer to park in a public car park on the outskirts of the Macquarie Park instead of facing congestion within the area during the morning peak.
- The Macquarie Park corridor is bordered by three major roads at its Northern edge: the M2 Motorway, Lane Cove Road and Delhi Road and only one major road at the South, Epping Road. Two car parks are proposed for the Northern edge, and another two on the Southern border.
- It was assumed that 75% of the car passengers who might ride the PRT would arrive via one of the three Northern roads and use either one the PRT station 2 or 9 near the public car park. The remaining 25% will drive along Epping Road, using car parks near stations 4 and 18.
- It was assumed that 50% of students who drive will park near station 2 and 50% near station 4; 25% of the remaining car passengers from the North will use the car park near station 2, and 75% will use the car park near to station 9, close to the highest concentration of jobs.

4. Distribution of local trips:

- Local residents are expected to walk to station 5 or station 19 (closest to the residential areas) and board a pod to their final destination within Macquarie

Park, or to connect to train or bus services which are beyond walking distance from the residential areas.

- The most concentrated residential area is around station 5, thus I assumed that 90% of residents will use station 5 and 10% station 19.

Stations 1, 4, 5, 9, 10, 11, 15, 18 and 20 were selected for trip origins during the morning peak, based on the above rationale.

6.3.2. Distribution of trips between pairs of origin and destination stations

The matrix of trips between origin and destination stations is shown in Table 6.2.

The following assumptions were made about the distribution of trips between pairs of stations:

From Station 1 (origin for rail and bus patrons) passengers could travel on Loop 1 (stations 1-2-3-4-5-1) to Macquarie University or Loop 2 (1–6-7–8-5–1) to workplaces to the east, within one kilometre radius. I assumed university students and staff would use Loop 1. Based on the campus map, the highest concentration of faculties are near stations 2 and 3, so I assumed 40% of trips would be from 1 to 2, 40% from 1 to 3, and 20% from 1 to 4. Workers using Station 1 were assumed to use Loop 2. Based on the concentration of jobs near each PRT station, I assumed 15% of trips for all purposes would be from 1 to 6, 50% from 1 to 7, and 35% from 1 to 8.

Although Station 2 will be primarily a destination station, some trips might be made by people (mainly university students and workers) coming to Macquarie Park by car and parking in the public car park, connecting to other points of interest. I assumed that 60% of the university students and staff trips would be from 2 to 4 and 40% from 2 to 5 based on the concentration of faculties and administrative buildings, with no trips from 2 to 3 because these stations are too close to justify a ride on a PRT pod. Trips for work, business and other purposes from Station 2 were assumed to be equally distributed between stations 7 and 8.

Similarily, from Station 3 where many parking spaces are available and Macquarie University staff and students could park and ride a pod, I assumed equal distribution of trips to stations 4 and 5.

From Station 4 (origin for bus and car passengers coming mainly from the West), I assumed that 60% of the students and Macquarie University staff will travel to station 2 and 40% to station 3. Passengers using Station 4 for all other purposes were assumed to be equally likely to travel to stations 6, 7 and 8 (approximately 33% to each station).

From Station 5 (origin for residents) students and staff who live in Macquarie Park could travel on Loop 1 to the university campus or Loop 2 to local workplaces. The residents of Macquarie Park who work outside the corridor could board a pod at this station to connect to train or bus stations beyond the walking distance. I assumed 45% of students and university staff trips would be from station 5 to station 2 and 45% from station 5 to station 3, with the remaining 10% to station 4 which can be easily accessed by walking or cycling. I assumed the local residents trips are distributed equally between station 6, 7 and 8. Residents using the train were assumed to travel to station 1 – Macquarie University rail station. Residents travelling by bus could travel on Loop2 to station 1 or to station 9; trips were equally distributed between these two stations. Some additional trips may occur from local residents who work in North Ryde and might prefer to ride a PRT pod from Station 5 to Station 19, rather than to drive due to traffic congestion in the morning peak.

From Station 9 (origin for bus and car passengers, coming from the North), I assumed trips would be equally distributed between stations 11, 12, 13 and 14 (25% each).

From Station 10 (origin for rail patrons arriving at Macquarie Park station) passengers could travel on Loop 3 (see Figure 6.1) to workplaces and to other points of interest to the west or on Loop 4 to the east. I assumed that 70% of trips originating at station 10 will be on Loop 3 and 30% on Loop 4, based on the future commercial floor space (see Chapter 4, Figure 4.13). Based on the job distribution, trips on Loop 3 were assumed to be distributed in the following proportion: 16% from station 10 to station 11, 12% from 10 to 12, 12% from 10 to 13 and 40% from 10 to 9. I assumed trips on Loop 4 would be 35% from station 10 to station 15, 35% from 10 to 16 and 30% from 10 to 17.

From Station 11 (origin for bus passengers coming from the South) passengers could travel on Loop 3 to stations 9, 13 and 14. I assumed trips would be equally distributed between these three stations. No trips were allocated to station 12 because it is too close to the bus station, or to Loop 4, because passengers could alight at station 15 for the destinations along Loop 4.

From Station 15 (origin for bus passengers coming from South-East), I assumed trips would be equally distributed among stations 10, 16 and 17 on Loop 4. No trips were allocated to Loop 3 because passengers could alight at station 11 for the destinations along Loop 3.

From Station 18 (origin for bus and car passengers in North Ryde) I assumed trips would be equally distributed between stations 19 and 20. No trips to other destinations were assumed because it is unlikely that bus passengers and car drivers will stop at North Ryde if their destination is on the other side of the Macquarie Park.

Although Station 19 is not defined as an origin station, some trips would occur from local residents (only 10% of residents live in North Ryde) travelling to Macquarie University campus (station 3) or to connect to the train (at station 20) or to bus (at station 18).

From Station 20 (origin for train passengers arriving at North Ryde station), I assumed trips would be equally distributed of trips between station 19 and 20. No trips to other destinations were assumed because train passengers would not alight at North Ryde if their destination is closer to Macquarie University or Macquarie Park rail stations.

Based on the above assumptions, the following origin-destination matrix was built for all trips during one hour of the morning peak (Table 6.2)

	Destination																				
	Stations	Macquarie University Loop1					Macquarie University Loop 2			Macquarie Park Station Loop 3						Macquarie Park Station Loop 4			North Ryde Loop 6		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Origin	1	0	172	172	86	0	65	361	252												
	2	0	0	0	32	21		32	32												
	3		0	0	20	20															
	4	0	143	95	0	0	85	85	85												
	5	51	37	37	8	0	127	127	127	16										10	
	6						0	0	0												
	7							0													
	8								0												
	9									0		92	92	92	92						
	10									131	0	52	39	39	66	49	49	42			
	11									82		0		82	82						
	12												0								
	13													0							
	14														0						
	15										54.5					0	55	55			
	16																0				
	17																	0			
	18																		0	108	108
	19			12															4	0	4
	20																		59	59	0

- Rail stations
- Major bus stops and public car parks
- Residential area

Table 6.2 - PRT trips per hour at AM peak

6.3.3. Simulation results for one morning peak hour

For this study, I assumed that two people would travel in each pod for all trips in the morning peak from all origin stations except from station 1. For the vehicles departing from station 1 ('Macquarie University'), I assume a full occupancy rate of the vehicles (4 people per pod). This translates into an average of 2.34 occupants per pod trip across the total network.

Based on this occupancy rate, the following origin-destination matrix was built for the pod trips during one hour of the morning peak (Table 6.3)

Origin	Station	Destination																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	1	0	43	43	22	0	16	90	60	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	16	11	0	16	16	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	10	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	71	47	0	0	42	42	42	0	0	0	0	0	0	0	0	0	0	0	0
	5	26	18	18	4	0	63	63	63	8	0	0	0	0	0	0	0	0	0	5	0
	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	46	46	46	46	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	66	0	26	20	20	33	25	25	21	0	0	0
	11	0	0	0	0	0	0	0	0	41	0	0	0	41	41	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	27	27	0	0	0
	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	54
	19	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29	29	0

Full occupancy rate of the vehicles

Table 6.3 - PRT Pod trips per hour at AM peak

The origin-destination matrix for morning peak was the input for the simulation program used by ATS City Mobil. At the end of one hour simulation period, the following results were provided:

- The overall waiting time was 16 seconds
- The maximum waiting time was 75 seconds at station 20
- The overall percentage of passenger groups waiting less than 60 seconds was 90%
- The number of passenger groups carried was 1635 per hour, which means 3826 passenger trips per hour (at 2.34 occupancy rate)

- The average passenger distance travelled was 1.94 km
- The average passenger trip time was approximately 3 minutes (194 seconds), with a maximum of 15 minutes from station 2 to station 20
- The number of vehicles used was 204

This simulation does not optimize the fleet size, using as many vehicles as are required to respond to the passenger calls. In practice, the fleet size might be optimized, in which case the mean waiting time would be longer.

The full results of the simulation and screen shots of the simulation results are presented in Appendix 2.

PRT pod trips per hour were estimated based on the following assumptions about vehicle occupancy. Because the majority of trips are journey-to-work trips and education trips during morning peak, it is likely that people will share a vehicle, especially if fare policies are in place (e.g. a fare per vehicle to encourage shared rides, Workplace Travel plans, or discounted student fares for shared rides).

The ULTRA PRT system at Heathrow currently displays the following message encouraging sharing:

Sharing a vehicle can be encouraged by a lower fare per trip if more passengers use the same pod. For example, the on-board computer could display the following set of Questions and Answers:

Question: How many passengers will share this pod?

- Answer 1 – Please pay $1.60
- Answer 2 – Please pay $1.50 x 2 = $3.00
- Answer 3 – Please pay $ 1.25 x 3 = $3.75
- Answer 4 – Please pay $1.00 x 4 = $ 4.00

Statistics from ULTRA and Masdar after ten months of operating show an average 2.14 occupancy factor. Martin Lowson (President, ULTRA Heathrow) and Robbert Lohmann

(Commercial Director, 2getthere, Masdar) reported passengers were willing to share vehicles (The 5th Podcar City conference, personal communication).

6.4. Estimating demand in the afternoon peak hour

Demand during one hour afternoon peak was calculated using the STM tour time period allocation (Bureau of Transport Statistics 2011) for the afternoon peak period. The afternoon peak period covers all trips between 4.00 pm and 6.00 pm. The total trips per hour for people using PRT in the afternoon peak are presented in Table 6.4.

2031 LAPRT	train+PRT		bus +PRT		car+PRT		walk+PRT		TOTAL PRT
	to	from	To	from	to	from	to	from	
JTW trips	782	26	717	24	328	11	286	10	2184
Shopping trip	0	0	0	0	0	0	70	0	70
Business trips	96	5	44	3	56	3	47	3	257
Other trips	188	0	98	0	82	0	85	0	453
Total trips at PM peak	1066	31	859	27	466	14	488	13	2964
Macquarie University students	375	0	159	0	80	0	92	0	706
M Uni staff (4% JTW) trips	31	1	29	1	13	0	11	0	87
TOTAL TRIPS	1441	31	1018	27	546	14	580	13	3670

Table 6.4 - PRT trips for one hour PM peak, average weekday

The origin stations in the morning peak are now destination stations for people returning home in the afternoon. Stations 2, 3, 6, 7, 8, 12, 13, 14, 16, 17 and 19 were selected as origin stations for trips in the afternoon peak hours.

6.4.1. Distribution of trips by destination stations

The distribution of trips was estimated using the same percentages of trips as in the morning peak, but in the reverse direction. For each destination station, which was an origin station in the morning, the same proportion of trips was distributed among the afternoon peak origin stations.

1. Distribution of return trips to the train stations:
    - The assumption was that more people will use Macquarie University rail station for their return trips due to the proximity to the shopping centre: 55% trips to Macquarie University station (Station 1), 35% to Macquarie Park station (Station

10), and 10% to North Ryde station (Station 20). The trip distribution is similar to the current barrier count in the afternoon peak hours (NSW Department of Transport BTS 2011, Lin C., request 20111808)

2. Distribution of return trips to the bus stops:
   - The assumption was that 75% of bus trips will return to the South of the corridor, so the passengers will board on a pod selecting one of the stations 4, 11, 15 and 18 as destination, assuming the same distribution of the return trips as in the morning (30% will go back to station 4, 30% to station 11, 20% to station 15 and 20% to station 18, based on the job concentration around these stations).
   - The passengers going to the North (25% of all bus patrons) will select either station 1 or 9 as their destination to connect to buses. I assumed an equal proportion of trips between stations 1 and 9, as in the morning peak.
3. Distribution of trips to the car parks:
   - People who parked their car in the morning and continued their trip by PRT will go back to the same car parks for their return trips in the afternoon
   - Based on the morning trips distribution, I assumed that 50% of student car passengers and drivers will go back to station 2, and 50% to station 4.
   - 75% of all car drivers will use one of the three Northern major roads, of which 25 % will go to station 2 and 75% to station 9.
   - 25% of all car drivers will use the Southern road (Epping Road), alighting at station 4 or 18 near to the car parks.
4. Distribution of local residents returning home
   - The most concentrated area of residential houses is around station 5, thus I assumed that 90% of residents will alight at station 5 and 10% at station 19

6.4.2. Distribution of trips between pairs of origin and destination stations in the afternoon peak

The distribution of trips between pairs of stations follows a similar rationale to the one used to distribute trips in the morning peak, but in the reverse direction.

For example, to Station 1 (destination for rail and bus patrons) passengers could travel on Loop 1 from the Macquarie University campus or on Loop 2 from the workplaces on the east side (see Figure 6.2) from section 6.2.1). I assumed university students and staff would use Loop 1. Based on the morning peak trips distribution, I assumed 40% of trips would be from 2 to 1, 40% from 3 to 1, and 20% from 4 to 1. Passengers coming from stations 6, 7 and 8 and having Station 1 as destination to connect to train or buses were assumed to use Loop 2. Based on the concentration of jobs near to each PRT station, similar to the morning distribution, I assumed 15% trips would be from 6 to 1, 50% trips from 7 to 1, and 35% trips from 8 to 1.

A detailed description of the assumptions made about the distribution of trips between pairs of origin and destination stations is presented in Appendix 3.

Based on these assumptions, the following origin-destination matrix was built for all trips during one hour of the afternoon peak (Table 6.5).

Origin / Destination: Stations	Macquarie University Loop1					Macquarie University Loop 2			Macquarie Park Station Loop 3						Macquarie Park Station Loop 4			North Ryde Loop 6		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0				40															
2	163	0	0	113	47															
3	163	0	0	75	47														13	
4	81	32	20	0	10															
5	0	21	20	0	0															
6	72			74	159	0	0	0												
7	345	30		74	159		0													
8	243	44		74	159			0												
9					12				0	104	64									
10										0					43					
11									92.38	42	0									
12									92.38	31		0								
13									92.38	31	64		0							
14									92.38	52	64			0						
15										39					0					
16										39					43	0				
17										34					43		0			
18																		0	3	53
19					0													94	0	53
20																		94	3	0

Rail stations (yellow): 1, 10, 20, 19 column...

Rail stations

Major bus stops and public car parks

Residential area

Table 6.5 - PRT pod trips per hour at PM peak

6.4.3. Simulation results for one afternoon peak hour

In order to calculate the PRT pod trips per hour, I assumed an occupancy rate of two people per pod for all trips in the afternoon peak from all origin stations to all destinations, except trips to station 1 and student trips to station 5. For vehicles arriving at station 1 ('Macquarie University'), I assumed that vehicles would be fully occupied (four people per pod). Similarily, a full occupancy rate of four people per pod was assumed for vehicles departing stations 2, 3 and 4 and arriving at station 5, because these trips are made by students returning to their residence place so it is very likely they would share a pod.

It is reasonable to expect that more pods would be fully occupied during the afternoon peak. The destination stations in the PRT network are connected to train or bus stops, so more passengers will have a common destination. Moreover, most passengers are workers leaving offices at same time who may know each other, so it is more likely they will share a pod. A higher occupancy rate will improve the performance of the system, especially its capacity to respond to higher demands.

However, the average occupancy rate of 2.40 during the afternoon peak was assumed for this project. The origin-destination matrix for pod trips per hour during the afternoon peak is presented in the Table 6.6.

	Stations	Destination																			
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Origin	**1**	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	41	0	0	57	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	41	0	0	38	12	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
	4	20	16	10	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	11	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	18	0	0	37	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	87	15	0	37	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	61	22	0	37	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	6	0	0	0	0	52	32	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0
	11	0	0	0	0	0	0	0	0	46	21	0	0	0	0	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	46	16	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	46	16	32	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	46	26	32	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0
	16	0	0	0	0	0	0	0	0	0	20	0	0	0	0	21	0	0	0	0	0
	17	0	0	0	0	0	0	0	0	0	17	0	0	0	0	21	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	27
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	27
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	2	0

Full occupancy rate of the vehicles

Table 6.6 - PRT Pod trips per hour, PM peak

The origin - destination matrix for the afternoon peak was the input for the simulation program ATS City Mobil. The simulation was run for one hour and the following results were provided:

- The overall waiting time was 72 seconds
- The maximum waiting time was 187 seconds at station 14
- The overall percentage of passenger groups waiting less than 60 seconds was 50%
- The number of passenger groups carried was 1524 per hour, which means 3658 passenger trips per hour (at 2.40 occupancy rate)
- The average passenger distance travelled was 1.84 km
- The average passenger trip time approximately three minutes (184 seconds) with a maximum of 16 minutes from station 2 to station 20
- The number of vehicles used was 197.

The full results of the simulation and screen shots of the simulation results are presented in Appendix 4.

6.5. ESTIMATING DEMAND IN THE INTER-PEAK HOURS

The trip demand for one off-peak hour was calculated using the STM tour time period allocation (BTS 2011) for the inter-peak period. The inter-peak period covers trips between 10.00 am and 4.00 pm (six hours). Both inbound and outbound legs of the home-based tour were considered. In contrast to the peak hours when one transit direction dominates, the off-peak trips are more uniformly distributed to and from the corridor. The total estimated trips for people using PRT in the one off-peak hour are presented in Table 6.7.

2031 LAPRT	**train+PRT**		**bus +PRT**		**car+PRT**		**walk+PRT**		**TOTAL PRT**
	from	to	from	to	from	to	from	to	
JTW trips	17	71	38	96	27	39	32	32	352
Shopping trip	0	0	0	0	0	0	56	57	113
Business trips	12	20	13	18	16	15	20	20	134
Other trips	51	94	51	73	32	36	34	37	408
Total trips at PM peak	80	185	102	187	75	90	142	146	1007
Macquarie University students	60	98	36	51	20	27	22	36	350
M Uni staff (4% JTW) trips	1	3	2	4	1	2	1	1	14
TOTAL TRIPS	140	283	138	238	95	117	164	182	1357

Table 6.7 - Total estimated trips for people using PRT in one off-peak hour

6.5.1. Distribution of trips between origin and destination stations during inter-peak hours

Two distinct origin-destination matrices were built, one for trips with Macquarie Park as destination and one for trips originated in Macquarie Park. For trips coming to Macquarie Park, the same origin stations (1, 4, 5, 9, 10, 11, 15, 18 and 20) and the same distribution of trips between each pair of stations as in the morning peak hour were assumed (see section 6.2). The origin-destination matrix for trips to Macquarie Park is presented in Table 6.8.

		Destination																			
	Stations	Macquarie University Loop1					Macquarie University Loop 2			Macquarie Park Station Loop 3						Macquarie Park Station Loop 4			North Ryde Loop 6		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Origin	1	0	40	40	20	0	17	55	41												
	2	0	0	0	9	6		8	8												
	3		0	0	7	7															
	4	0	33	22	0	0	17	17	17												
	5	0	17	17	4	0	48	48	48	0										0	
	6						0	0	0												
	7							0													
	8								0												
	9									0		19	19	19	19						
	10									21	0	8	6	6	10	8	8	7			
	11									14		0		14	14						
	12												0								
	13													0							
	14														0						
	15										9					0	9	9			
	16																0				
	17																	0			
	18																		0	20	20
	19			0															0	0	0
	20																		9	9	0

Rail stations
Major bus stops and public car parks
Residential area

Table 6.8 - PRT trips to MP during one hour Inter-peak

For returning trips from Macquarie Park, the same origin stations (2, 3, 5, 6, 7, 8, 12, 13, 14, 16, 17 and 19) and same distribution of trips as in the afternoon peak hour were assumed (see Section 6.3). The origin-destination matrix for trips originated in Macquarie Park is presented in Table 6.9.

Origin	Destination																			
Stations	Macquarie University Loop1					Macquarie University Loop 2			Macquarie Park Station Loop 3						Macquarie Park Station Loop 4			North Ryde Loop 6		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	24	24	12	0															
2	0	0	0	7	4															
3	0	0	0	5	5														0	
4	0	23	15	0	0															
5	0	11	10	2	0															
6	9			10	47	0	0	0												
7	28	6		10	47		0													
8	20	7		10	47			0												
9					0				0	8	8									
10										0					5					
11									14	3	0									
12									14	2		0								
13									14	2	8		0							
14									14	4	8			0						
15										3					0					
16										3					5	0				
17										3					5		0			
18																		0	0	4
19					0													12	0	4
20																		12	0	0

Rail stations
Major bus stops and public car parks
Residential area

Table 6.9 - PRT trips from MP during one hour Inter-peak

6.5.2. Simulation results for inter-peak hour

In order to calculate vehicle trips per hour, an average 1.45 vehicle occupancy was assumed, similar to the average car occupancy. Based on these assumptions, the following origin-destination matrix was built for all trips during one inter-peak hour (Table 6.10).

The OD matrix for the Inter peak was the input for a new simulation run with ATS City Mobil. The simulation was run for one hour and the following results were provided at the end of the simulation:

- The overall waiting time was 16 seconds
- The maximum waiting time was 62 seconds at station 15
- The overall percentage of passenger groups waiting less than 60 seconds was 91%

- The number of passenger groups carried was 903 per hour, which means 1309 passenger trips per hour (at 1.45 occupancy rate)
- The average passenger distance travelled was 1.81 km
- The average passenger trip time was three minutes with a maximum of 16 minutes from station 2 to station 20
- The number of vehicles used was 110

The full results of the simulation and screen shots of the simulation results are presented in Appendix 5.

	Stations	Destination																			
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Origin	**1**	0	45	45	22	0	12	38	28	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	11	7	0	5	5	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	8	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	4	0	38	25	0	0	11	11	11	0	0	0	0	0	0	0	0	0	0	0	0
	5	0	19	19	4	0	33	33	33	0	0	0	0	0	0	0	0	0	0	0	0
	6	6	0	0	7	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	7	19	4	0	7	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	8	14	5	0	7	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	5	18	13	13	13	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	14	0	6	4	4	7	9	5	5	0	0	0
	11	0	0	0	0	0	0	0	0	19	2	0	0	10	10	0	0	0	0	0	0
	12	0	0	0	0	0	0	0	0	9	2	0	0	0	0	0	0	0	0	0	0
	13	0	0	0	0	0	0	0	0	9	2	5	0	0	0	0	0	0	0	0	0
	14	0	0	0	0	0	0	0	0	9	3	5	0	0	0	0	0	0	0	0	0
	15	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	6	6	0	0	0
	16	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0
	17	0	0	0	0	0	0	0	0	0	2	0	0	0	0	4	0	0	0	0	0
	18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	16
	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	3
	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	6	0

Table 6.10 - PRT Pod trips at Inter peak hour

6.6. Discussion of simulation results

In this chapter, I estimated the demand for the PRT system by developing origin-destination matrices for morning, afternoon and inter peak daytime travel. I explained the rationale for the assumptions made about trip distribution for each mode and purpose of travel to and from Macquarie Park. For each time period, a one hour simulation was run using the ATS City Mobil software. The results are consolidated in Table 6.11.

The ATS City Mobil model is not peer reviewed but it is practicebased. The software has been provided by its developers – Prof. Martin Lowson and Dr. John LeesMiller from University of Bristoland it is a simplified version of the real system operating at Heathrow airport. The simulation results from this model are very similar to the real data reported after the first months of operation at Heathrow and Masdar (Lowson 2011; Lohmann 2011) which confirm its reliability.

Major criticism of PRT systems have focused on its inability to meet the capacity demands of a high activity generator centre such as a Central Business District and the cost of the construction process if the system is in a low demand suburb or centre (Vuchic 2007).

This chapter investigated the passenger performance of the PRT system at different capacity demands, and what sort of stock investment would be needed to assure the projected level of service.

Indicator	AM peak	Inter peak	PM peak
Mean waiting time (seconds)	16 s	16 s	72 s
Maximum waiting time (sec)	75 s	62 sec	187 s
Waiting time less than 60 sec (%)	90%	91%	50%
Passenger groups per hour	1635	903	1524
Average distance travelled (km)	1.94 km	1.81 km	1.84 km
Average trip time (sec)	194 s	181 s	184 s
Maximum trip time (sec)	937 s	937 sec	937 s
Fleet required	204	110	197
Average occupancy rate	2.34	1.45	2.40
Passenger trips per hour	3826	1038	3658

Table 6.11 - Simulation results for peak and off-peak hours

6.6.1. What is the passenger service performance of the PRT system?

The simulation results showed that the overall performance of PRT is very effective, even in the busiest hours of the morning and afternoon peak, when a high capacity is required.

A waiting time in the range of 1 to 75 seconds in the morning peak, when people are in a hurry and finding a parking space could be more difficult and time consuming than during other hours, might be a significant factor in influencing the decision about travel mode. In the morning peak, approximately 90% of passengers will be serviced by a pod within less than one minute. In the afternoon peak, 50% of passengers will wait less than a minute before a pod arrives on call. An average waiting time of 72 seconds during afternoon hours is also a good performance indicator.

During the non-busy hours, the performance of the PRT system is even better, with an average waiting time of 16 seconds and a maximum of 62 seconds. The simulation showed that 91% of total passengers waited less than one minute to be served by a pod. This waiting time is less than the time required for parking thus making the PRT system attractive for car drivers and hence, may contribute to a change in travel behaviour.

One of the weaknesses of any network with a one-way track similar to the one proposed in this study, is that it involves additional travel distance compared to bi-directional guideways and thus, a travel time penalty. The maximum travel time resulting from the simulation is 937 seconds for trips from Station 2 to Station 20. The distance travelled between these two stations is 9.37 kilometres on the PRT track, at 36 kilometres per hour speed. The distance by road between these two stations is approximately four kilometres. During off-peak hours, the estimated travel time by car is 540 seconds. However, during peak hours, the average speed of a car is 15 kilometres per hour (this route is one of the busiest routes in Macquarie Park) so the travel time will be 960 seconds, very close to the travel time of the PRT vehicle. However, car drivers would need additional time to park their car, so even in off-peak hours and with a one-way single loop, PRT may still be a competitive option.

In conclusion, the passenger performance of the PRT system measured by waiting time and travel time is very competitive, with an average waiting time of 16 seconds in the off-peak hours and 72 seconds in the peak hours, which will make transit easier and will increase the attractiveness of conventional public transport. The PRT travel time is comparable to travel time by car during busy hours and because it does not require additional time for parking, the PRT system may be preferred to travelling by car. Furthermore, the features of the system, such as non-stop travelling, modern design, and comfort, are positive indicators of the passenger performance.

6.6.2. What level of PRT stock investment would be needed to offer the projected level of service?

With ten hours of simulation using the ATS City Mobil software and the morning peak matrix input, the fleet required to carry 39,094 passengers consisted of 219 pods, at an average occupancy rate of 2.34 (simulation results in Appendix 6). Allowing an additional 10% of the total vehicles for maintenance and spares, a fleet of 240 pods is required to meet the projected level of demand (under the LAPRT scenario the total demand is 32,198 trips for an average weekday). The advantage of the PRT compared to cars is that 240 PRT vehicles could replace over 8,350 cars, using the same occupancy rate.

Based on the trip demand assumptions presented in the previous sections of this chapter, the simulation software allocated the following number of berths to each station:

- 5 berths – stations 1, 4, 5, and 9
- 4 berths – station 10
- 3 berths – stations 2, 7, 8, and 11
- 2 berths – all the remaining stations (3, 6, 12, 13, 14, 15, 16, 17, 18, 19 and 20)

Some of these stations may need only one berth and they could be built on-line if demand is very low. However, the software allocates a minimum of two berths per station in order to store empty vehicles. This way, the vehicle depots are simple storage stations which will not require much space or a complex infrastructure.

The proposed network is a 17.8 km long, one-way single loop with approximately 70% of the track elevated. A one-way track has lower capacity per hour than the bi-directional guideways. The simulation program generated 1635 passenger groups per hour during morning peak which translates into 3896 passenger trips per hour at the average occupancy rate of 2.34 and two seconds headway. This theoretical capacity could be even higher in theory (up to 7200 passenger trips at full occupancy of four people per pod and two seconds headway). In practice, though, the capacity might be lower based on the minimum headway accepted by the safety regulations in each country. The current emergency deceleration rate is 2.5 m/s^2 for ULTRA vehicles and 4.7 m/s^2 for Masdar vehicles (ATRA 2011). At a speed of 36 km/h, the minimum headway is four seconds for ULTRA and two seconds for Masdar.

However, both systems currently operate at six seconds headway with the two seconds planned in the near future. At an occupancy rate of 2.34 and six seconds headway, the maximum capacity of the PRT system would be 1404 passenger trips per hour which is much lower than the peak hour demand. This capacity could be enlarged by increasing occupancy rates, building bi-directional guideways or multiple loops.

Real data from operational systems is crucial to understanding how PRT might perform in a complex city-wide system, while the current applications are for airports only (ULTRA) or for very small scale systems (Masdar or Suncheon).

In conclusion, if the existing operational systems succeed in achieving their designed performance parameters, a simple loop track as proposed in this project for Macquarie Park, with twenty stations and a fleet of 240 pods, would be sufficient to offer the projected level of service by 2031. A capacity of 3826 passengers per hour is comparable to the capacity of a light rail service running at 8 minute headways in both directions. A local shuttle system would require about 152 minibuses loaded at full capacity (25 seats) running at 23 second headways or about 80 conventional buses (fully loaded) to run at 45 seconds in one peak hour, which would further increase the existing level of congestion within Macquarie Park during busy hours. Nevertheless, the buses or minibuses require drivers while the pods do not; this implies additional wage costs which should be considered in any further analysis of the financial viability of any system. Another option could include a bike-hire system – similar to Velib, Paris (see Chapter 3) but the difficult topography of the corridor and rainy weather could be an impediment in attracting enough passengers to generate a significant change in travel behaviour. Moreover, 59% of commuters travel more than 15 km from their homes to Macquarie Park so a bike system can't solve the problem of 87% car trips, as it only leads to improvement for a small proportion. However, the LAPRT scenario assumed 100% increase in cycling compared to the current situation.

If future demand is higher than 4000 passenger trips per hour, a more complex network structure will be required. Further research and a more accurate cost-benefit analysis would be required to determine if the bi-directional PRT system is a worthwhile investment. Other options should also be investigated, for instance a Group Rapid Transit system with up to ten seats per vehicle such as the Austrans system, or a complementary local system, for instance Personal Mobility Devices (PMD) which are now under review by the City of Ryde. It is not the purpose of this project to analyse all possible transport options, but to evaluate the effectiveness of the PRT as a potential local access system.

A detailed comparison of passenger performance, environmental, and health impacts among the three scenarios is presented in the next chapter.

Chapter 7. Comparing selected environmental, health and economic impacts

7.1. Introduction

In this chapter, I investigate how effective the Personal Rapid Transit (PRT) system is in contributing to more sustainable transport options for Macquarie Park by evaluating the likely environmental, health and economic impacts of the scenario including PRT as a feeder for the conventional public transport nodes ("LAPRT" scenario) compared to those of the two alternative scenarios - a projection of present transportation trends by 2031 (business-as-usual or "BAU") and transportation improvements currently planned for the area ("Planned").

Based on the 24 hour trip demand outlined in Chapter 5 and synthetised in Table 7.1, I estimated impacts by calculating the vehicle kilometres travelled (Car VKT) for the car trips generated under each scenario (Table 7.2).

Mode of transport	BAU	Planned	LAPRT	Average distance travelled (km)
Car (Driver)	183,906	145,122	120,120	9.7
Car + PRT	0	0	4,932	5.0
Car + Passenger	39,056	38,136	32,576	7.5
Walking	15,408	15,772	24,286	0.8
Cycling	3,764	5,474	7,528	5.0
Rail (total walk + PRT)	14,890	41,724	48,744	17.6
Bus (total walk + PRT)	20,976	31,772	39,784	6.5
PRT (local access only)	0	0	32,198	1.84

Table 7.1 - Macquarie Park passenger trips per day, by mode of transport

The average distance travelled by each mode is based o the 2009/2010 Household Travel Survey (BTS 2011) for conventional transport modes. For the PRT system, the average distance travelled is 1.84 kilometres based on the simulation result presented in the previous chapter.

Mode	BAU	Planned	LAPRT
Car Only (Driver)	1,783,888	1,407,683	1,190,115
Car Only (Pass)	292,920	286,020	244,320
Walk	12,326	12,618	19,429
Cycle	18,820	27,370	37,640
Train	262,064	734,342	857,894
Bus	136,344	206,518	258,596
Local Access only	0	0	59,244
Total Car VKT	1,783,888	1,407,683	1,190,115
Total PT [1] passenger km	398,408	940,860	1,116,490
Total PRT passenger trips			32,198
Total PRT pod trips [2]			22,206
Total PRT PodKT [3]			40,858

Notes:

1. PT=conventional public transport (bus and train)
2. Pod is the PRT vehicle; The projected demand for the PRT system is 32,198 pass trips over 24 hours; The value of 22,206 pod trips resulted assuming an average occupancy rate of 1.45, similar to the car occupancy rate; from the simulation outputs (see Chapter 6, Table 6.11), total passenger trips result is 25,442 at an average 1.878 occupancy rate, using the formula (AM peak hour trips*2)+(PM peak hour trips*2)+(OFF peak trips*8)
3. PodKT = vehicles kilometres travelled by pods; the average distance travelled is 1.84 km as per simulation results

Table 7.2 - Distance travelled by mode, average weekday

The specific questions I investigate in this chapter are:

> ***How likely is it that the LAPRT Scenario would be the prefered policy option compared to the BAU and Planned scenarios?***

To answer this question, I will investigate how likely it is that commuters would prefer PRT to the car and how this will change the likely modal split. The simulation findings provide reliable quantitative estimates of travel time and waiting time. Passenger service performance will be qualitatively assessed based on surveys from the operational systems.

> ***How would the environmental and urban impacts of the LAPRT Scenario differ from the likely future impacts of the other two scenarios?***

To answer this question, the environmental and urban impacts will be evaluated based on estimated differences in energy use, emissions, noise, and land area required for car parks. The estimates are based on findings from other related studies in comparable contexts.

How would the health impacts of the LAPRT Scenario (emissions, accidents and level of physical activity) differ from the likely future impacts of the other two scenarios?

The health impacts will be assessed based on emissions, accidents and level of physical activity. This assessment is not based on a detailed epidemiological study, but existing research provides a solid basis for identifying the major relative public health impacts of the LAPRT scenario compared to the other two scenarios. The avoided public costs associated with emissions, accidents and healthcare costs will be the unit of comparison.

What are the likely capital and operating costs of building a PRT system?

The capital and operating costs for the Macquarie Park PRT will be estimated based on available data from three fully operational systems (Heathrow Airport/London, Masdar City/Abu Dhabi and West Virginia University/Morgantown) and from information and estimates for prototype systems, accounting for inflation since the period of construction (Sydney/Austrans and Cardiff/ULTRA). For this case study, a conservative approach will be used for cost estimations.

The final section of this chapter develops a qualitative overall rating scale comparing the three scenarios on the dimensions investigated.

7.2. Passenger performance: travel time, waiting times, comfort, safety

The analysis conducted in the previous chapter, based on the simulation results, provided a broad range of information on the likely performance of PRT as a local access system.

A waiting time in the range of 1 to 75 seconds in the morning peak is less than the time required for parking, thus it might influence the decision about travel mode, especially if future policies restricting parking are in place. The travel time is comparable to the travel time by car and because it does not require additional time for parking, the PRT system may compete with travelling by car. Moreover, the speed is constant during any time of the day; therefore the passengers will not face congestion during peak hours as passengers of road vehicles do.

Furthermore, the features of the system, for instance non-stop travelling, modern design and comfort are positive indicators of the passenger service performance. The results of a survey conducted at ULTRA Heathrow and presented at the 5th Podcar City Conference held in 2011 in Stockholm showed a very positive passenger perception regarding the overall experience of the PRT system, rating customer satisfaction 4.6 out of 5 (Lowson 2011). The customer satisfaction rating was based on the following criteria: personal safety, overall experience and personal comfort, modern image, ease of boarding on pods, waiting time, passenger interface and information available. Lowson (2011) reported that 88% of the interviewed passengers considered the PRT system "better than bus". Appreciative comments were also posted by PRT users on social networks such as Twitter (MoMat 2011).

Generally, there might opposition from residents to elevated guideways which can be aesthetically intrusive and disturbing, especially around private dwellings. However, Macquarie Park - as any other "edge city" - is characterised by many more commercial buildings than residential houses and much less activity and travel after working hours and during night time. Consequently, the residents would not be disturbed during their sleeping hours. The network proposed in this project does not interfere with the residential area too much and it follows two existing roads on the outskirt of the residential zone. Furthermore, the low noise and no local emissions features of the system will minimise effects on residents. A more pedestrian-friendly environment can be created as a replacement for the existing congested, car-dedicated roads in addition to a customised design of the PRT infrastructure which would fit well into the specific character of Macquarie Park as technology hub.

The specific character of Macquarie Park as the future "Australia's leading Technology Park" makes it a suitable candidate for an innovative transport system which can be well integrated into new developments. Furthermore, the PRT network would be an appropriate extension of the recently announced elevated high-speed rail – Skytrain - as part of the projected North West rail line.

7.3. Environmental and urban impact

The LAPRT scenario draws on the same targets as the metropolitan and local government targets for mode share trips (the "planned" scenario) and it assumes that PRT might contribute to achieving these targets and even to attracting more passengers to public transport. The rationale for this assumption is that by increasing local access to the existing rail stations and bus nodes, which are not easily accessible by walking or cycling, the public transport will become more attractive and the overall mode share for car trips will decrease from the existing 80% to 57% by 2031. The consistent performance of the PRT system at any time of the day, during peak hours or off-peak hours, analysed in the previous section, might change the likely modal split by competing with travelling by car.

The "Planned" scenario, although very ambitious in establishing 40% mode share for journeys to work by public transport, is expected to generate up to 20% more car trips per day than existing traffic levels; hence the improved road network will face even more congestion. The weakness of the existing plans is that there is no provision for a local access system to address the main issue of the low accessibility level of the rail and bus stations which makes the predicted 40% mode share by public transport unlikely to happen.

The LAPRT scenario is expected to generate 32,198 trips in a local access system over 24 hours. In the absence of a local access system, local trips will continue to be made by car. The PRT system performance will be assessed under the LAPRT scenario assuming the same trips which are made by pods (PRT vehicles) will be made by car.

In order to estimate the fleet required to service the predicted demand of 32,198 passenger trips, a ten hour simulation (the maximum simulation time allowed by the ATS City Mobil software) was run with the origin destination matrix for one hour morning peak (the busiest hour) as the input. The simulation results (see Appendix 6) showed that 219 pods were required to carry 39,094 passengers, at an average occupancy rate of 2.34. If the average occupancy rate is 1.45 (similar to cars), a fleet of 353 pods is required to service more than 39,000 passengers within 10 hours. I assume that the same number of pods will be required to provide services for the lower projected demand of 32,198 passenger trips over 24 hours. An additional 10% of vehicles were allowed for maintenance.

Based on the simulation results for trips during morning, afternoon and non-peak hours, the average distance travelled using the PRT system is 1.84 km. Assuming the same trips will be made by car, the total vehicle kilometre travelled (VKT) in an average weekday is 40,858, considering local trips only. In reality, the distance travelled might be different because a car does not have the choice of selecting the shortest route that a computer controlled PRT vehicle does. However, for this study the same average distance has been considered for both local access options – PRT and cars. The results presented in Table 7.3 show that a fleet of 390 pods will offer the same level of service as 11,100 cars and the same quality of service as offered by car: on-call service, convenience, reliability, and comfort. The ratio of 1:28 resulting from this calculation is lower than the range of 1:30 to 1:40 reported by developers of PRT systems (ULTRA 2011), showing that the PRT fleet has been overestimated. However, the simulations used conservative estimates of the stock needed to minimise waiting time.

Local access system trips	CAR	PRT
Trips [1]	32,198	32,198
Vehicle trips [2]	22,206	22,206
Vehicle fleet [3]	11,103	390
Passenger kilometers (average 1.84km)	59,244	59,244
Local VKT/PodKT	40,858	40,858

Notes:

1. Trips are unlinked trips and they are converted from home based tours, explained in Chapter 5. In fact, a lot more local trips will occur during the day, especially from workers and students during lunch time. These trips are not considered in this analysis.
2. Vehicle trips by car are calculated considering 1.45 average occupancy rate (BTS 2011)
3. Car fleet is calculated as 50% of the vehicle trips assuming each home based tour is made of two legs ; the number of pods is converted from the 219 vehicles resulted from 10 hours of simulation at a load factor of 2.34 multiplied by a factor of 1.62 to allow for the same 1.45 load factor as a car; additional 10% vehicles were allowed for maintenance

Table 7.3 - Distance travelled by local access system, average weekday

7.3.1. Energy use and CO_2 emissions

The literature review revealed different estimates of primary energy use for vehicles (Table 7.4). The energy consumption is dependent on vehicle characteristics, for instance size and weight, occupancy rate, speed, number of starts and stops and propulsion system (Carnegie et al 2007) and hence, caution should be used when comparing energy use among different modes of transport. There is relative agreement between the two most recent estimates for Sydney; as they are more likely to offer appropriate assumptions, the energy use for private automobiles will be estimated at 3.8 MJ/VKT.

MJ/VKT	Source	Region and year
3.8	Australian Greenhouse Office 2007	Australia 2005
4.0	Kenworthy and Laube 2001	Sydney 1995
3.5	Lowson 2004	USA 2001

Note: The above values do not include any petrol extraction or energy distribution costs.

Table 7.4 - Primary energy use for road vehicles

For PRT vehicles, the Advanced Transit Association (ATRA) provides comparative values for three systems, two of which are already fully operational and providing empirical data (Masdar and Heathrow).

MJ/PodKT [1]	PRT application	Region and year
0.69	2Getthere	Masdar, Abu Dabi 2010
0.47	ULTRA [2]	Heathrow Airport, London 2011
0.87	VECTUS	Suncheon, South Korea - to be operational 2013

Notes:

1. Conversion used 1KWH=3.6 MJ; average speed 30 km/h;
2. The value of 0.47MJ/PodKT is provided by ATRA (2011); Ultra reports a value of 0.55 MJ/passenger-kilometres for their system considering an average speed of 36 km/h, the average passenger load 1.4 and continuous power usage of 2kW which means a lower value of energy per traveled kilometer (0.39 MJ/PodKT)

Table 7.5 - Primary energy use for PRT systems

Because the simulation outputs are based on the ULTRA system performance and its specific characteristics (vehicle size and weight, speed, propulsion system), the value of 0.47 MJ/PodKT - provided by ATRA for ULTRA systems - will be used for this study.

Levels of CO_2 emissions ranged from 175g CO_2/km to 237 g CO_2/km for the new passenger vehicles sold in Australia in 2010 with an average value of 205g CO_2/km (Department of Infrastructure and Transport 2011). In order to estimate emissions for passenger cars in 2031, two assumptions have been made. The first one is based on the same CO_2 emission level by 2031 compared to 2010 for all cars (this means that the entire vehicle fleet will be replaced by 2031). The second assumption is based on 25% CO_2 emissions reduction from the 2010 level in accordance with some of the official targets (City of Ryde 2007; Department of Infrastructure and Transport 2011; Penny Wong 2010).

For the PRT system, the emission level was estimated at 71 gCO_2/km, value converted from 0.545 kgCO_2/kWh and energy use 0.13 kWh/km (ATRA 2011). The emissions from producing energy have not been considered in this study. The targets for 2031 are based on the current CO_2 emission level, assuming no improvements in PRT technology. Assuming 300 operating days per year, the PRT system will produce only 870 tonnes CO_2 per year compared to 1,900 tonnes produced by the substitute car trips.

In a recent report prepared by the University of West Virginia, a value of 0.642 kg CO_2/kWh has been used as the “upstream CO_2” generated by PRT vehicles (West Virginia University 2010). The “upstream CO_2” is defined as emissions generated by “the power plants producing the energy that powers electric vehicles like the PRT” (p. 18). Their study found that a substitute bus system replacing the existing Morgantown PRT system would produce eight times more CO_2 emissions (2472 tonnes of CO_2 compared to 297 tonnes produced by PRT) (West Virginia University 2010).

	BAU	Planned	LAPRT	Local access by car	Local access by PRT	LAPRT vs. BAU	LAPRT vs. Planned
Vehicle kilometers traveled (km)							
Total VKT/day[1]	1,783,888	1,407,683	1,190,115	40,858	40,858	-178	-65
Energy use (MkWh)							
Energy use (MkWh)[2]	567	448	378	13	2	-187	-68
Energy use (10% reduction)[3]	511	403	341	12	2	-168	-61
CO_2 equivalent emissions (tonnes)							
CO_2-e (2010 level)[4] tonnes	109,709	86,573	73,192	2,513	870	-35,647	-12,510
CO_2-e (2031 target)[5] tonnes	82,951	65,457	55,340	1,900	870	-26,740	-9,247

Notes:

1. For this analysis, I considered 300 days per year which is commonly used in transport studies, given that some work-related travel occurs on many Saturdays
2. Energy used adjusted to kWh/km using the conversion rate 1kWh = 3.6 MJ; 1.06 kWh/km for cars and 0.13kWh/km for pods
2. Considering 10% reduction in energy used by cars based on different technologies and fuel switch by 2030; no reduction of the energy used by the pods
2. Carbon dioxide equivalent of GHG emissions 2010 level: 205 gCO_2/km for cars and 71g CO_2/km for pods
5. Target 155 gCO_2/km for cars and 71g CO_2/km for pods. CO_2 level (tonnes) is calculated with the following formula: VKT x CO_2 emissions (gCO_2/km) x 300 / 1,000,000

Table 7.6 - Annual Energy use and Carbon Dioxide emissions

In conclusion, a PRT system implemented in Macquarie Park could reduce the CO_2 emissions by more than 35,600 tonnes per year compared to the business as usual scenario, representing a decrease of 32% compared to the existing level. Moreover, PRT could contribute to reducing CO_2 emissions by 9,200 tonnes per year, representing a 14% decrease in emissions compared to the "Planned" scenario. These assumptions are relatively conservative from the PRT perspective since they accept the ambitious public transport mode share target of 40%, and the projected 25% Co2 emissions reduction for cars achieved by 2031, but no improvements in the current efficiency of the PRT system.

7.3.2. Noise

In a review of public health and productivity benefits from different urban transport modes (Matan et al 2011), several authors identified the following effects on public health from transport-related noise.

Effect on health	Authors and year
Hypertension	Jarup et al 2007 Bodin et al 2009 De Kluizenaar et al 2011
Increased stress	Bodin et al 2009
Disturbed sleep	Bodin et al 2009 World Health Organisation 2011
Increased risk of cardiovascular disese	Cappuccio et al 2007
Risk for adverse outcomes during pregnancy	Okun et al 2009

Source: data from Matan et al 2011

Table 7.7 - Health impact from transport-related noise levels

The World Health Organisation reported one million healthy life years lost (YLL) from transport related noise in Western Europe (Matan et al 2011) and Infras/IWW assumed a 20% increase in mortality associated with levels of noise higher than 65 dBA (Austroads 2003).

The Australian threshold level of noise is 50dBA-55dBA (Austroads 2003). The noise level for PRT is 45dBA measured at 10m from a vehicle driving at 36 km/h (ULTRA PRT 2009), which means no risk of mortality associated with the level of noise from PRT usage.

One approach to estimating the cost of noise is hedonic pricing, which estimates the reduction in property value from incremental increases in exposure to noise. In Australia the Noise Depreciation Index is 0.5% of property value per dBA over 50 dBA. Another approach is based on willingness to pay (WTP) for noise reduction and health effects (Austroads 2003).

Based on the WTP approach, a cost of AU$0.011 per vehicle kilometres travelled (VKT) in 2001 dollars was reported by Austroads in 2003. In his Thirty Year Public Transport Plan for Sydney, Glazebrook (2009) assumed an external cost of 0.02 A$/VKT for noise and water pollution combined, which is the value used for this project.

	BAU	Planned	LAPRT	Local access by car	Local access by PRT	LAPRT vs BAU	LAPRT vs Planned
Total VKT (‘000 000)	535.166	422.305	357.035	122.574	0	-178	-65
Noise, water pollution, other cost ($ million)[1]	12	10	8	0.28	0.00	-4	-1

Note:

1. Value used for this study is AU$0.02 per VKT (2006 prices); the total costs are estimated using the annual average inflation rate of 3% by 2011

Table 7.8 - External costs associated with transport-related noise

In conclusion, the PRT could contribute to reducing costs associated with transport related noise by AU$4 million per year compared to the business as usual scenario and AU$1 million per year compared to the planned scenario.

7.3.3. Land required for car parks

One of the most important benefits of the PRT is the small footprint of the system and consequently, the value of land released for other uses. A one-way PRT track requires only two metres width of space compared to a width of over ten metres for a major road. The urban impacts can be measured by comparing the physical footprints of the new infrastructure required for each scenario, including the amount of land needed for car parks. However, it is difficult to estimate the land needed for all aspects of the infrastructure under each scenario. The “Planned” and LAPRT scenarios draw on the land use assumptions under the Local Environmental Plan (LEP 2011) and Development Control Plan (DCP 2010) of the Ryde council presented in Chapter 5. The Traffic Study commissioned by City of Ryde in 2009 estimated the construction costs for major road improvements at around AU$300 million with an additional AU$60-AU$100 million cost of major intersection upgrades (City of Ryde 2009, p. 64). These indicative costs did not include the internal street upgrades or costs with parking. Major roads improvements will be necessary in any case in order to accommodate such a huge increase in traffic demand.

For this study, the indicator I use to compare impacts is based on the floor space required for the new car parks required for each scenario. A Parking Study commissioned by the City of Ryde in 2009 identified 31,500 off-street and 1,000 on-street car parking spaces for approximately 32,000 employees. Additionally, there are 5,200 car parking spaces for Macquarie University staff and students (City of Ryde 2009).

The amount of floor space required for future car parking spaces based on trip forecasts under each scenario is presented in Table 7.9.

	BAU	PLANNED	LAPRT	Local access by car	Local access by PRT[1]	LAPRT vs BAU	LAPRT vs Planned
Trips by car only (driver)	183,906	145,122	120,150	22,206	3,402		
2031 Parking Demand							
Total car parks	91,953	72,561	60,075	11,103	1,701	-30,177	-10,785
Existing car parks	37,700	37,700	37,700	0	0	0	0
Future car parks required	54,253	34,861	22,375	11,103	2,091[2]	-29,787	-10,395
Cost of multistorey/underground car parking							
Floor space required for new car parks (sqm) [3]	1,627,590	1,045,830	671,250	333,083	62,721	-893,619	-311,859
Costs ($ Million) [4]	2,170	1,394	895	444	84	-1,191	-416

Notes:

1. 1701 'park and ride a pod' spaces considered for trips by car + PRT;
2. Space required for PRT depots to store 390 pods was considered similar to the space required for car parking
3. The minimum floor space required for cars, including manoeuvring lanes, blind aisles and columns is between 28.67 and 29.41 square metres (City of Ryde DCP 2010); for disabled parking spaces a bigger space is required. For this study I considered an average of 30 square metres for offstreet parking spaces; a similar space was assumed to store the PRT pods
4. Cost for a basement car space ranges between $27,000 and $40,000 per bay (City of Ryde Parking Study 2009; Newman and Scheurer 2010); for the 2031 estimates, a minimum cost of $40,000 will be considered; if we apply the inflation index of 3% per year, the cost per bay would range between $48,765 and $72,244 by 2031 so the cost of $40,000 is at the very low end of price range; same cost per berth was considered

Table 7.9 - Floor space required for building new parking spaces by 2031

Under the business-as-usual scenario, about 54,000 additional car parking spaces will have to be provided by 2031, requiring over 1.6 million square metres of developable space and an estimated cost of over two billion dollars in building the new car spaces only, without considering the value of land. Under the LAPRT scenario, approximately 22,000 new car parking spaces will be needed, with a saving in building costs of the new parking bays of more than 1.2 billion dollars. These spaces could be provided in new public car parks built outside the busy centre and near the rail stations and main bus stops.

Once more, a cautious approach was used from the PRT perspective. The pod sizes are 3700 mm length and 1470 mm width (ULTRA Global 2011), smaller than a car; Holden II Cruze, advertised as "Australia's smallest car" has a length of 4518 mm and a width of 1797 mm. Although the space required to store a pod is less than the space required to park a car, I assumed that the same amount of floor space is necessary for both of them. The empty pods are stored either in stations (the PRT network has 20 stations and 58 berths, so 58 pods could be stored at stations) or in PRT depots which are simple storage spaces for the remaining 332 pods. However, I assumed that 390 storage spaces will be needed for pods at the same cost as the multistorey car parking construction of AU$40,000 per bay. Hence, the benefit compared to the "Planned" scenario is of AU$416 million savings from building parking spaces only. This benefit does not account for the parking spaces which would have to be provided if the estimated 22,206 local trips were made by car instead of PRT, requiring an additional 270,362 square metres of floor space for parking spaces (see Table 7.9, Columns 6-5: 333,083 sqm – 62,721 sqm = 270,362 sqm), which will add an extra AU$360 million to the total savings, raising the benefits to AU$776 million.

7.4. Health impacts: pollution, accidents, level of physical activity

7.4.1. Air pollution

The air pollution impacts of the three scenarios are compared based on the emission factors (Table 7.10) estimated by the National Pollutant Inventory (DEWHA 2008, pp49-51).

Substance	Petrol car	Diesel car	LPG car
Carbon Monoxide CO	0.0044	0.00095	0.0062
Oxides of Nitrogen NOx	0.0008	0.00064	0.0006
Particulate matter PM2.5	0.0000075	0.00019	0
Particulate matter PM10	0.000008	0.0002	0
Sulfur dioxide SO2	0.000012	0.0000016	0

Table 7.10 - Emission factors (kg/km) for passenger cars

The emission factors are estimated based on fuel consumption rates of 11.06 L/100 km for petrol cars, 9.5 L/100 km for diesel cars and 21.4 L/100 km for LPG passenger vehicles at a driving speed of 30 km/h (DEWHA 2008, pp49-51).

Of the total registered fleet in 2009, 84% were vehicles with petrol fuel, 12.8% vehicles with diesel fuel and 3.2% with LPG (Australian Bureau of Statistics 2009). Assuming a similar proportion within the passenger car fleet by 2031, the annual emissions from transport by car for each of the three scenarios are presented in Table 7.11.

Substance	BAU	Planned	LAPRT	Local access by car	Local access by PRT[1]	LAPRT vs BAU	LAPRT vs Planned
CO	2,144	1,692	1,430	49	0	-714	-261
NOx	414	326	276	9	0	-138	-50
PM2.5	17	13	11	0.38	0	-6	-2
PM10	17	14	12	0.40	0	-6	-2
SO_2	6	4	4	0.13	0	-2	-1

Note: 1. Pollutants from the power stations which generate the electricity to recharge batteries are not included

The following formula was used to calculate the pollutants under each scenario:

Annual pollution (tonnes/year) =(VKT x $Emission\_factor_{petrol\ car}$ x 0.84 + VKT x $Emission\_factor_{diesel\ car}$ x 0.13 + VKT x $emission\_factor_{LPG\ car}$ x 0.03) (kg/day) x 300 days/1000;

where VKT represents vehicle kilometres travelled under each scenario as per Table 7.2

Table 7.11 - Annual air pollution (tonnes/year)

The PRT system could save 49 tonnes of carbon monoxide and 9 tonnes of oxides of nitrogen annually, from local trips only. Furthermore, by reducing vehicle kilometres travelled compared to a business as usual scenario, the PRT system could contribute to reducing carbon monoxide emissions by 714 tonnes, oxides of nitrogen by 138 tonnes, particulate matter by 12 tonnes and sulphur dioxide by 2 tonnes per year.

The emissions are proportional to fuel consumption, driving speed and technology efficiency. It is expected that new vehicles will use more efficient technology and fuels over the next twenty years, and hence lower levels of air pollutants are expected from the new car fleet. However, the advantage of the zero emissions of the small electric powered vehicles of the PRT system will remain unchanged unless all private cars are electric or hybrid - an unlikely transition by 2031.

Overall, under the LAPRT scenario, the annual emissions of the main air pollutants are estimated to decrease by 33% compared to business-as-usual, and by 15% compared to planned targets.

The human health effect costs due to air pollution have been estimated by different studies at between 0.7 and 2.7 cents per vehicle kilometre travelled with a midpoint around 2 cents per VKT expressed in 2001 prices (Austroads 2003). These costs are based on estimates of transport volumes and emissions for 17 European countries between 1995 and 2010 using TRENDS (Transport and Environment Database System) data. The pollution unit values have been converted to Australian dollars in 2001 prices, adjusted for population weighted population-density, vehicle occupancy and an Australian Purchasing Power Parity of 1.3 (Austroads 2003, pg 10). Glazebrook (2009) estimated the external costs of air pollution at 3 cents per VKT expressed in 2006 prices, which confirms the value used by Austroads (2003) in their evaluation of the environmental and other externalities. For this report an average cost of $0.03 per VKT in 2006 prices was used, and the annual cost has been adjusted to 2011 prices assuming an annual inflation index of 3% (see Table 7.12).

	BAU	Planned	LAPRT	Local access by car	Local access by PRT	LAPRT vs BAU	LAPRT vs Planned
Total VKT ('000 000)	535.166	422.305	357.035	122.574	122.574	-178	-65
Air pollution cost ($ million)	21	16	14	0.48	0	-7	-3

Table 7.12 - Air pollution costs ($ million per year)

In conclusion, by implementing the PRT system within Macquarie Park, the avoided cost due to air pollution totals AU$7 million per year compared to a continuation of present trends. Furthermore, considering the projected targets and transport improvements under the "Planned" scenario being achieved by 2031, the PRT could still save another AU$3 million per year by reducing overall car trips.

7.4.2. Accidents

Road transport is considered one of the biggest threats to public safety. In the USA, the average monthly deaths from road transport (3,421) is higher than the number of people killed in the terrorist attack on 9/11 (Muller 2011). In Australia, although death rates remain high, the number of road deaths has decreased since 1980, from 22.3 to 6.1 deaths per 100,000 people in 2010 (Matan et al 2011). The number of fatalities per 100,000 people is lower in NSW (5.6) than the Australian average rate of 6.1 (RTA 2011). The Centre for Road Safety for NSW (RTA 2011) reported 42,299 road crashes with a rate of 0.61 fatalities per one million vehicle kilometers travelled in 2010 and a total cost of 5.1 billion dollars. The average cost of 0.076 $/VKT estimated based on these statistics is very close to the cost assumed by Glazebrook (2009) in his calculation of the external transport costs (0.09 $/VKT in 2006 prices). In this study, an average cost of 0.076 $/VKT will be assumed.

The PRT, as an automated fixed guideway transit system, claims to have a high level of safety. The 144 automated people movers (APM) systems operating over the world reported 4.6 million passengers per day and 100 times fewer accidents per passenger mile compared to private cars (ULTRA PRT 2009). The Morgantown PRT which has been operating in West Virginia, USA since 1975, reported 75 million passenger trips without any serious injury since its opening (ATRA 2011; West Virginia University 2010). The number of accidents for the PRT system has been calculated as one percent that of cars.

If we consider the above rates, under the LAPRT scenario, 109 road crashes could be avoided every year with a saving benefit of 14 million dollars per year compared to a business as usual scenario (Table 7.13).

	BAU	Planned	LAPRT	Local access by car	Local access by PRT	LAPRT vs BAU	LAPRT vs Planned
Total VKT ('000 000)	535.166	422.305	357.035	122.574	122.574	-178	-65
Road accidents	326	258	218	7	0.07	-109	-40
Accidents cost ($ million)	43	34	29	1	0.006	-14	-5

Table 7.13 - Annual road accidents and their costs

Some researchers argue that although a decrease in car traffic has the potential to reduce danger, the corresponding increase in cycling and walking might increase the exposure of pedestrians and cyclists to road danger (Woodcock et al 2009). They reported an increase by 418 Years of Healthy Life lost (YLL) and 101 Years of Healthy Life lost as a result of Disability (YLD) per million population from road traffic crashes in London under two scenarios based on increased active travel compared to a business as usual scenario (Woodcock et al 2009, pg 30). However, when they took into consideration measures to increase the safety of pedestrians and cyclists (such as reduced speed limits and improved infrastructure similar to Netherlands, a country with low injury rate because a lot of people walk and cycle), they reported the injury rate was reduced by 14% in London (Woodcock et al 2009, pg 30).

Other research supports the argument that fatality rates per kilometre travelled decrease when cycling and walking rates increase because the awareness of drivers increases (Jacobsen 2003; Pucher and Buehler 2010 cited in Matan et al 2011).

However, the likely public safety impact of PRT compared to car travel (shown in Table 7.13 above) suggests potential savings of one million dollars per year, as a result of substituting local trips by car with PRT. Because PRT, elevated or not, is completely grade separated from pedestrians and cyclists, the system will not increase risk even if walking and cycling levels increase significantly.

7.4.3. Level of physical activity

Evidence from the literature review showed that thirty minutes of physical activity per day is associated with health benefits, reducing the risk of major diseases such as: cardiovascular diseases, diabetes, dementia, depression and obesity (Lachapelle and Frank 2009; Matan et al 2011; Trubka, Newman and Bilsborough 2010; Woodcock et al 2009). Active travel -

walking and cycling - is an important part of daily physical activity. Transit users have also been identified as walking approximately 30 minutes per day from access/egress trips to and from bus and train stations. A study based on the US National Household Travel Survey found that 29% of transit users achieved more than 30 minutes of physical activity per day (Besser and Dannenberg 2005 cited in Lachapelle and Frank 2009). The minimum physical activity level recommended by the National Physical Guidelines for Australians is 30 minutes per day for at least 5 days per week (Trubka, Newman and Bilsborough 2010). The healthcare cost saving due to increased physical activity levels has been estimated at AU$3.02 per hour in 2010 prices (Trubka, Newman and Bilsborough 2010). Assuming that only 20% of transit users achieved more than the minimum level of physical activity and that the average trip duration of cycling is similar to that of walking trips (in fact, cycling could account for a higher level of physical activity than walking), the total hours of benefit from physical activity have been calculated under each scenario.

Active travel (passenger trips)					
	BAU	**Planned**	**LAPRT**	**LAPRT vs BAU**	**LAPRT vs Planned**
Total walking only	7,704	7,886	9,049	1,345	1,163
Total cycling only	1,882	2,737	3,764	1,882	1,027
Total PT (bus, rail and PRT) passenger trips	17,933	36,748	49,824	31,891	1,3076
Physical activity hours (30min. per day, 5 days per week, 52 weeks)					
Cumulative time spent walking by transit users (hours)	466,258	955,448	1,295,424	829,166	339,976
Cumulative time spent walking and cycling only (hours)	1,246,180	1,380,990	1,665,690	419,510	284,700
Estimated savings benefits due to increased physical activity levels [1]					
Total hours benefit due to increased physical activity	1,712,438	2,336,438	2,961,114	1,248,676	624,676
Savings benefit ($ million)				3.88	1.94

Note:

1. The value of 1 hour health benefit has been obtained by a "cost-to-illness approach" with the following formula: 1 hour health benefit = Total national savings potential/adult population of Australia/recommended hours of moderate-intensity activity a year (2007 prices) (Trubka, Newman and Bilsborough 2010). The resulting value of $3.02 has been indexed to 2011 prices at the average annual inflation rate of 3%, obtaining a value of $3.11 per hour

Table 7.14 - Total hours benefit due to increased physical activity

Assuming that $3.11 (in 2011 prices) is the avoided healthcare cost associated with each hour that a person engages in moderate physical activity, the total impact of the LAPRT scenario estimates savings of approximately four million dollars per year compared to the business-as-usual scenario, and two million dollars per year compared to the planned targets scenario.

7.5. Economic impact of Personal Rapid Transit System

7.5.1. Capital costs

The capital and operating costs for the Macquarie Park PRT have been estimated based on available data from fully operational systems (Heathrow Airport/London, Masdar City/Abu Dhabi and West Virginia University/Morgantown) and from prototype systems based on historical costs and inflation since the period of construction (Sydney/Austrans, Corby and Cardiff/ULTRA). The costs are subject to commercial confidentiality, so these estimates might be viewed as hypothetical. However, ULTra PRT has publicly provided the total investment costs. The fully operational PRT system the firm developed and built in London's Heathrow Airport entailed an investment of £30 million for 3.8 kilometres of track, three stations, and a fleet of 21 vehicles (ULTra Press release, September 2011). This gives an average cost per track kilometre of approximately AU$11.7 million. The same company, ULTra PRT estimated the capital costs for a new system, planned to start operating in the US in 2012, at US$7 million to US$15 million per mile of guideway, including tracks, stations and the control system (ULTra 2011). Converted to Australian dollars, the capital cost would vary between AU$ 4.2 million to AU$ 9 million per kilometre of guideway.

Estimated costs have also been supplied by the Commercial Director of the Masdar project, Robbert Lohman (2Getthere 2011, personal email) in the range of AU$ 9.8 to AU$14.8 million per kilometre of guideway (8 to 12 million euro) with the current PRT applications running at the high end of the range or even higher if many vehicles are required to provide high capacity.

The cost estimates from operational prototype systems vary within the same range: from AU$ 5.04 million per kilometre (converted from £4.81 M per kilometre in 2008 prices) in the case of the Corby pilot study to AU$ 7.37 million per kilometre of guideway (converted from £4.45 M per kilometre in 2006 prices) from the Cardiff case study (Bly and Teychenne 2005).

The capital cost for a city–wide network in Sydney has been estimated at AU$ 7.3 million in 2002 prices ($ 9.13 M in 2010 prices) per route-kilometre including guideways, nine-seat vehicles, stations, switches and control systems (Austrans 2002).

Some system configurations are more efficient than others. According to Martin Lowson, one of the PRT developers, an optimum cost system would have the following characteristics (ULTRA PRT 2011):

- More than 16 kilometres of track length

- High percentage of at-grade guideway
- Simple stations and fewer than 2-2.5 stations per kilometre of guideway
- Lower demand
- Favourable soil and terrain conditions
- Lower construction costs
- High use of standardised components

The proposed Macquarie Park network has a track length of 17.8 kilometre, twenty simple stations with two to five berths, most of them off-line, and favourable terrain conditions - all characteristics of a lower cost system. However, the cost will increase with the elevated guideways (approximately 70% of total tracks will be elevated), and the high capacity demand, especially during peak hours. Also, the system will probably require a high percentage of customised components in order to fit well within the new developments, to be non-intrusive and attractive for the public. A capital cost unit of AU$8 million - AU$10 million per kilometre - track (middle–high end of range) could be an appropriate value for estimations.

Application	Price ($M/km)	Track length (km)	Guideway	Vehicles	Stations	Demand (mil pass per year)
Heathrow	11.7	3.8	elevated	21	3	0.34
Masdar	9.8 - 14.8	1.2	undercroft	10	2	0.21
Morgantown	20	6	at grade	71	5	2
Austrans[1]	9.13	727 km double-track 2500 km single track	80% elevated, 10% tunnelled	24,000	3,571	450,000 pass in peak hour
Corby	5.04	30	44% elevated	365	31	13.87
Cardiff	7.37	7.7	80% elevated	136	12	5.67
Optimum capital cost system						
Characteristics	4.2-9.0	more than 16 km	high percentage at grade		less than 2-2.5 stations per km	lower demand
Macquarie Park		17.8	70% elevated	244	20	9.66
MP Checklist		yes	no		yes	no

Note:

1. Austrans, Corby and Cardiff data are based on feasibilities studies from operational prototype systems (Austrans 2002; Bly and Teychenne 2005)

Table 7.15 - PRT applications characteristics and capital cost

Taking a conservative approach, a value of AU$10 million per kilometre of guideway will be considered for the purpose of this study, thus the total investment for the Macquarie Park network would be approximately AU$178 million in 2011 prices.

However, detailed civil engineering calculations and specific site factors would need to be further investigated for a thorough financial evaluation.

7.5.2. Operating costs

The operating costs include: maintenance, staff, energy, station security, ticketing costs and others; consequently they are highly dependent on patronage, as well as on local area characteristics and planning requirements and regulations. Lohman (2011, pers. commun., 17 September) indicated 8%-10% of the investment cost as operating costs, excluding infrastructure costs. Assuming the infrastructure cost at 40%-50% of the total investment, the average operational cost per year would range between 5%-6% of the capital costs. The same range of 5%-6% of the investment cost has been estimated in the Corby and Cardiff case studies (Bly and Teychenne 2005). Assuming the operational cost is 6% of the capital cost for the Macquarie Park project, the annual cost will be AU$10.68 million in 2011 prices.

Trips Indicators, average weekday	
Total trips	32,198
Vehicle trips	22,206
Passenger trips	32,198
Passenger km	59,244
Fleet	390
Operating costs	
	2011 prices
Capital cost ($ millions)	178
Operating cost ($ millions per year)	10.68
Operating cost per passenger trip	1.10
Annual patronage and revenue	
Annual patronage[1] (million passengers)	10
Annual revenue ($ millions)	16

Note:

1. 32,198 passenger trips x 300 = 9,659, 400 per annum rounded at 10 million passenger per annum

Table 7.16 - Macquarie Park PRT – capital cost, operating cost and annual revenue

The operating cost might be viewed as too high for the predicted patronage as other studies indicate an average cost of US$0.40 per passenger-mile (Carnegie et al 2007) which means an average cost of AU$0.25 per passenger-kilometer and consequently an annual operating cost of AU$4.4 million compared to the AU$10.7 used for this analysis. However, the higher value was considered for the purpose of this study maintaining the same conservative approach for costing PRT.

The annual revenue has been calculated assuming the cost of one passenger trip at $1.60 (the existing cost of a prepaid bus ticket in Sydney is $1.68 for distances of less than 3 km). This excludes any student or pensioner discounts. The profit could be increased if more patrons will be attracted to the PRT system. At an occupancy rate of 2.34, the patronage could increase to 53,294 passengers per day. At a lower fare to encourage shared rides, for instance 1.00 per passenger trip (see Chapter 6), the system could generate an annual revenue of AU$23 million and an annual profit of AU$12.5 million, which might allow for a more complex fares policy, including student and pensioner discounts, integrated fares with trains or buses, and Workplace Travel plans. Moreover, the results of the simulation presented in Table 7.3 are based on the average weekday home-based tours. A substantial additional number of unlinked trips (not counted in this analysis) is expected to occur during the day, especially at lunch time, which would increase the annual revenue and the operating profit.

7.5.3. Cost-benefit analysis

To assess the financial and economic performance of the PRT network, a more detailed analysis of the financing costs, taxation, depreciation, and fares elasticity is required. This analysis is beyond the purpose of this thesis. However, a fairly simple cost-benefit analysis is presented in this section, with the purpose of establishing whether the PRT system is a worthwhile investment.

The LAPRT scenario draws on the same land use and transport network assumptions as the "Planned" targets scenario, presented in detail in Chapter 5:

- the completion of the North West Rail Link from Epping to Rouse Hill
- the completion of the CBD Rail Link from Chatswood to Redfern
- the commitment of bus lanes on Lane Cove Road and additional bus services in the Macquarie Park Corridor
- limitations on car parking supply and increase in parking fees
- the requirement for workplace travel plans for all businesses

The recent announcement of the NSW government commitment to building the North West rail link from Epping to Rouse Hill by 2020 (Transport for NSW 2011)) and possibly the Parramatta–Epping rail by 2030, implies a high increase in rail patronage and correspondingly a higher mode share, which justifies the assumed targets under the LAPRT scenario. The debate is still ongoing regarding whether the funds will be allocated first to the Epping – Rouse Hill link or the Epping – Parramatta rail link. However, the new integrated transport authority, Transport for NSW, intends to radically reform the RailCorp with the purpose of offering "efficient, reliable and customer-focused services" and attracting more patrons for trains.

After ten years of planning and controversy around the project, the North West rail link seems to be on track, with the construction to commence in 2014 and the completion date around 2020 (Transport for NSW 2011). This project includes a four kilometer elevated structure for the Skytrain with the purpose of releasing the land for community uses, for instance open spaces, cycle ways, parks – similar to the PRT network purpose.

Allowing eight years of PRT planning to be undertaken while more accurate data from existing and future operational PRT systems will be available and assuming the PRT system construction will commence in 2020 when the North-West rail link might be also completed, the Macquarie Park PRT system could be fully operational by 2021. I assumed that the patronage builds up at 40% from 2021 to 2025 when the rail link will be fully operational, and at 70%, 90% and 100% of 2031 estimates from 2026 to 2031. The total capital cost for the Macquarie Park PRT system was estimated at AU$178 million, with an annual operating cost in 2022 (first year of operation) of AU$4.28M, rising thereafter to AU$10.7M in 2031. The operating costs are dependent on patronage, thus I assumed a proportional distribution of costs as patronage increase from 2022 to 2031. The $416M savings from parking provided were equally spread over the ten years from 2021 to 2030. From 2031 to 2050, a constant demand was assumed.

A summary of total costs and benefits is estimated for year 2031, the point at which I assume the demand forecast is achieved and over the 30-year period of assessment, from 2020 to 2050, is presented in Table 7.17. The benefits are estimated based on the comparison results of the LAPRT scenario with the "Planned" scenario, to determine whether the PRT network, offers a cost-effective alternative.

	Year 2031 NPV over 10 years	Net Present Value over 30 years
Financial assessment (AU$ million)		
Total capital cost	178	178
Operating cost	78.11	281.41
Revenue	112	416
Operating profit (revenue-operating costs)	33.89	134.59
Urban impact assessment (AU$ million)		
Savings on Parking	416	416
Savings on Roads	Not counted	-
Social, environmental and health cost-benefit assessment (AU$ million)		
Noise costs saved	14.00	52.00
Air Pollution costs saved	21.00	78.00
Accidents costs saved	35.00	130.00
Health costs saved	14.00	52.00
CO_2 emissions costs saved (at $25/t CO_2)	1.68	6.24
Road Congestion costs saved	32.20	119.60
Passenger time costs saved	Not counted	-
Total avoided costs	117.88	437.84
TOTAL NPV at 7% real discount rate	199.96	301.60
BENEFIT/COST RATIO	1.12	1.69

Table 7.17 - Macquarie Park PRT network - Costs and benefits estimated for 2020-2050

The positive Net Present Value of AU$200 million and benefit/cost ratio of 1.12 in 2031 indicate that the PRT system may be a worthwhile investment even when demand is lower (between 2021 and 2030); the system covers its capital cost in full in the first ten years of operation at a 7% real discount rate, which is considered an appropriate rate for standard public investment (Bly and Teychenne 2005). The total Net Present Value over 30 years has a positive value of AU$301.60 million. The benefit/cost ratio of 1.69 indicates that the PRT system could provide a high rate of return.

The Sydney Light Rail Inner West Extension Study reported a Net Present Value of AU$25 M and a benefit/cost ratio of 1.6 at 7% discount rate for the light rail extension between Lilyfield and Lewisham (GHD 2010, p.3). The total investment cost for the 3.8 kilometers of track and five stations was estimated at AU$30M (including structure, electrical costs, project management and other costs), which means an approximate value of AU$8.85 per kilometer, lower than the value estimated for the PRT network (AU$10 million per kilometer). The investment costs of the light rail are low because the track is already built. For the second option of the light rail extension between Lilyfield and Dulwich Hill–5.6 km and seven stations, the Net Present Value reported was AU$1.5M only and a rate of return of 1.0 for the AU$48 million total investment cost, which is lower than the PRT project return rate.

The amount of land required to build a PRT network is one-fifth the amount of a major road network with the same capacity. The estimated construction costs for major road improvements and intersection upgrades to accommodate the estimated traffic growth by 2031 under the "Planned" targets scenario are around AU$400 million (City of Ryde 2009, p. 64). The savings from major roads and internal street upgrades if the PRT were to be built have not been counted in this project because at this stage, it is difficult to estimate the land required for all aspects of the infrastructure. The Development Control Plan (DCP) does not have any available corridor for building a PRT network and the only available land to Ryde Council consists of public roads (Ogle 2011, pers. commun., 24 October). Whether the PRT network will be built on private land holdings or on public roads has to be determined by further research. Furthermore, the impact of the elevated guideways on traffic signals, street lighting, and on all the public utilities, as well as the impact on street trees, should be further investigated.

The assumptions regarding costs and savings are considered to be conservative from the PRT perspective. The savings from building new parking spaces are based on the assumption that the space required to store a pod (either at depots or at stations) is similar to the space required to park a car and the same cost value per bay or berth was assumed. These estimated costs of AU$15.6 million for 390 pods were not deducted from the total capital cost of AU$178 million but they were included in the total cost of building new parking spaces. Moreover, the AU$360 million savings from building even more parking spaces under the hypothesis that the 22,206 trips forecasted in the PRT system would be made by car were not included in this cost-benefit analysis.

7.6. Summary of the comparisons results

The evaluation of the Macquarie Park PRT system comprised of an analysis of environmental and urban impacts, passenger performance, and health impacts under the Local Access through PRT ("LAPRT") scenario and a comparison of the results to two other scenarios: the 2031 business-as-usual projection of the current trends by 2031 ("BAU") and the scenario based on the planned transportation improvements ("Planned"). These two scenarios do not include any information about the local access mode, simply because no local access system is currently in place or in future planning plans. Consequently, the PRT performance has been assessed under the LAPRT scenario assuming the same trips would be made by cars instead of pods. The same average distance has been considered for both local access options – PRT and cars.

How likely is it that the LAPRT Scenario would be the preffered policy option to BAU and Planned scenarios?

In a highy car-dependent centre like Macquarie Park, a switch to public transport is absolutely essential in breaking with current unsustainable trends. If these trends continue, the implications for the environment, economy and society linked with resource use, energy consumption, greenhouse gas emissions and human health will be terrifying. More than 1.6 million square metres of floor space will be wasted for parking cars, which in return will pollute the air with more than 2,500 tonnes of the most dangerous pollutants for human health, will contribute to greenhouse gas emissions by more than 82,000 tonnes of CO_2- equivalent and will hurt more than 300 people in accidents every year.

The "Planned" scenario is based on the very ambitious target of 40% public transit mode share for journey-to- work trips formulated by the City of Ryde council as a response to growth forecasts. The existing plans do not include any provision for a local access system, although the estimated trips on a local system are substantial, with over 32,000 home-based trips during an average weekday. In the absence of a local access system, the local trips will continue to be dominated by cars which could undermine achievement of the planned targets for reducing the car trips from an existing 80% to an optimistic 60%.

The "LAPRT" scenario assumes that a strategy of increasing the accessibility of train and bus stations within Macquarie Park through a PRT network might contribute to achieving the metropolitan and local targets for increasing public transport mode share and attracting more passengers to public transport, based on the high performance of the system.

The PRT could contribute to increasing public transport mode share by offering a convenient option for the "last-mile" trip. Every year, the Household Travel Survey shows that the main reasons for commuting by car, besides the convenience of the car, are related to public transport services: they are indirect, too slow, do not go where required and they are constrained by the timetable (Bureau of Transport Statistics 2011). The PRT, well integrated with conventional transport services (train and bus) could have the merit of addressing all these issues for the "last-mile" trips: the services are direct, faster than a car during peak hours (36 km/h constant speed for pods compared to 15-20 km/h variable speed for cars in peak time and congested roads), from point-to-point with no stops. There is no timetable constraint because a waiting time from 16 seconds to a maximum 3 minutes in peak hours would not require any timetable.

The high performance of the PRT system, analysed in the previous sections and its potential effect on increasing the attractiveness of conventional public transport modes, makes the planned targets of mode share more likely to happen.

How would the environmental impacts of the LAPRT Scenario differ from the likely future impacts of the other two scenarios?

The environmental impact has been evaluated based on energy use and CO_2 emissions with an estimate of the potential emissions and cost savings under the LAPRT scenario compared to business-as-usual and "Planned" targets scenarios.

	LAPRT vs. BAU		LAPRT vs. Planned	
Energy saved (MkWh)	168	33%	61	15%
Savings on CO_2 emissions (tonnes)	26,740	33%	9,247	15%
Cost saving				
GHG Offset Cost 25$/t	0.67		0.23	
GHG Offset Cost 100$/t	2.67		0.92	
Total environmental costs ($ million)	0.67 – 2.67		0.23 – 0.92	

Notes: Different values of cost per tonne of CO_2 were assumed in various reports: $25 in Trubka, Newman and Bilsborough 2010, between US$ 38 – 117 in Glazebrook and Newman 2009, Austroads 2003 based on IEA 2008

Table 7.18 - Savings on CO_2 emissions

The business-as-usual scenario draws on the assumptions that the same travel trends will continue over the next twenty years but the overall CO_2 emissions from cars will decrease by 25% from the 2010 level, which is very optimistic assumption. The emissions from the PRT vehicles are based on the current level, so no reduction has been considered for PRT emissions. Nevertheless, the implementation of PRT as a local access system at Macquarie Park might reduce the CO_2 emissions by 33% per year compared to the business-as-usual scenario and by 15% compared to the "Planned" scenario. Rating the impact, reducing the CO_2 emissions by 26,740 tonnes per year from a targeted level of 155 g CO_2/km for cars (reduced by 25% from the existing levels) could be considered a highly positive contribution to the environment.

Compared to the "Planned" scenario, the positive impact might be seen as lower, but in fact LAPRT draws on similar mode share targets to the planned targets thus the reduction of 9,200 tonnes of CO_2 is supplementary to the existing targets of emission reductions. A fully–operational local access system is essential in Macquarie Park, in order to achieve the desired substantial shift from private automobiles to more sustainable transport modes. In the absence of this system, 1,900 additional tonnes of CO_2 equivalent will be discharged by cars annualy.

Assuming a carbon price of AU$25 per tonne CO_2 equivalent, the potential saving under the LAPRT scenario is about AU$670,000 per year compared to the business-as-usual scenario and AU$230,000 compared to the planned scenario. The climate change mitigation strategies to control CO_2 emissions could impact on carbon prices raising the offset costs from US$100 by 2012 to as high as US$500 per tonne CO_2 by 2020 in the attempt to reduce global warming in the worst-case scenario (Glazebook and Newman 2009). On the other hand, the environmental cost of producing energy has not been included in this study and this is a very important factor to be investigated in order to determine if an electric system is a worthwhile investment in a country where the current production of electricity is based on coal. Alternative sources of energy, for instance solar, wind or fuel-cell technologies should be further investigated.

How would the urban impacts of the LAPRT Scenario differ from the likely future impacts of the other two scenarios?

The scarcity of land is the main concern of every urban planner and yet, hundreds of hectares of valuable land are developed as car parks in every city. The urban impact analysis investigated the effect of the PRT network on the land used for parking spaces as an alternative to current travel patterns which will generate such a considerable number of car trips that 1,627,590 square metres of developable floor space will be occupied by parking spaces.

In order to reduce car dependency to a level comparable to other similar centres, the LAPRT scenario has been designed to address the following parking management and supporting strategies from the medium to long term action plan of the City of Ryde (Parking Study 2009, p. 10):

- Integrate alternative modes of transport to improve multi modal transport
- Promote unbundling of parking supply from land use
- Review commercial car parking provision rates
- Provide peripheral car parking and park and ride strategies

Under the LAPRT scenario the parking demand will decrease by 55% compared to the business-as-usual scenario and by 30% compared to the planned scenario, which is clearly a positive urban impact.

The huge benefit which might not be seemingly encountered by the policy makers is the amount of land saved: more than 311,800 square metres of floor space which might produce a better return in a development than car parks.

The fact that the cost of building car parks is usually supported by private operators and not through public funds should not be an impediment in considering these huge costs not only in money but also in land for future planning policies. The amount of land taken for car parks could be used for the benefit of the entire community otherwise the centre will become a huge car park for people driving to work from other suburbs and leaving an empty and soulless centre after working hours for its own residents. These benefits alone could be an incentive for policy makers to investigate the merits of the PRT system as a local access option in more detail.

Aside from the benefits of the PRT system associated with the space saved from building car parks, an urban benefit could be provided by placing PRT guideways and stations within new developments, and potentially increasing the property value of these developments. In a study of the railway's impact on housing prices in Macquarie Park (Ge et al 2012), the authors reported that the property value appreciated by 12% in 2010, after the completion of the rail link, outperforming the growth in the Ryde local government area (9.4%) or in the entire Sydney statistical division (11%). Moreover, the study found that the most substantial increase occurs for locations closer to the rail station as a result of the increased accessibility level to the transit nodes. The proposed PRT stations are close to the main attractions within Macquarie Park as well as servicing zones with future high concentrations of jobs. Therefore, the PRT network could have positive effects on future developments values by providing better accessibility.

Although I do not measure this impact, it might be considered in future decisions regarding the merits of implementing the PRT system in Macquarie Park.

> ***How would the health impacts of the LAPRT Scenario (emissions, accidents and level of physical activity) differ from the likely future impacts of the other two scenarios?***

The health impact has been evaluated based on emissions of the most dangerous pollutants for human health (carbon monoxide, oxides of nitrogen, particulate matters PM2.5 and PM10, and sulphur dioxide), accidents and physical activity level due to active travel for each scenario. A summary of the findings is presented in Table 7.19.

Health impact	LAPRT vs. BAU		LAPRT vs. Planned	
Air pollution impact				
Saving on Pollution[1] (tonnes pollutants)	778	33%	285	15%
Annual benefits ($ million)	7		3	
Impact on passengers safety				
Savings on Accidents	109	33%	40	15%
Annual benefits ($ million)	14		5	
Increased physical activity impact				
Increased Physical activity (active travel hours)	1,248,676	73%	624,676	27%
Annual benefits ($ million)	3.88		1.97	
Total savings on Health ($ million)	25		10	

Note:

1. I considered 10% reduction in vehicle's emissions due to technology efficiency by 2031 compared to the existing levels

Table 7.19 - Avoided costs due to air pollution, accidents and lack of physical activity

The avoided annual costs associated with air pollution, accidents and healthcare costs due to lack of physical activity total $25 million when weighed against a continuation of the existing transportation trends; the PRT could save another $10 million annualy from health related costs in addition to the savings from the planned transport improvements.

The greatest advantage of the LAPRT scenario is the amount of physical activity, with an impressive 73% increase in annual hours of physical activity due to active travel only. The impact of the number of hours of physical activity on public health has been calculated assuming that 20% of transit users achieved more than the minimum level of physical activity (30 minutes per day for at least five days per week). The estimated cost-benefit due to increased levels of physical activity is AU$4 million per year compared to the business-as-usual projection by 2031 and AU$2 million per year compared to the "Planned" targets scenario.

The contribution of the PRT system to increasing physical activity is reflected by its potential to boost the attractiveness of public transport and hence, to generate a major switch in the modal shift from car to public transport. Another factor contributing to the increased active travel is the potential of PRT to liberate the streets for pedestrians and cyclists and to provide a positive return on the investment which should stimulate policy makers to rethink the urban space as designed for people and not for cars. Similar arguments are made in support of the recent project announced by the NSW government – Skytrain, a four kilometer elevated rail link as part of the North-West Rail Link with the purpose of giving community access to land for use as parks, cycleways, open spaces and community grounds (Transport for NSW 2011).

What are the likely capital and operating costs of building a PRT system?

The total capital cost for the Macquarie Park PRT system was estimated at AU$178 million, with an annual operating cost in 2022 (first year of operation) of AU$4.28M, rising thereafter to AU$10.7M in 2031 as patronage increases.

At a 7% discount rate, the total Net Present Value has a positive value of AU$302 million over a 30-year period of assessment. The benefit/cost ratio of 1.69 is an indicator that the PRT system is a worthwhile investment providing a high rate of return, even though a conservative approach was used in estimating costs. The estimated capital cost of AU$178 million could be entirely offset by the $416 million savings from the construction costs of the parking spaces alone. Assuming the trips forecast on the PRT system were made by car, an additional cost of $444 million would be necessary to provide the estimated car park spaces.

However, this is a hypothetical study. Detailed civil engineering calculations and specific site factors should be further investigated when evaluating the potential for implementing a PRT system. Nevertheless, these preliminary findings suggest a more detailed analysing of all the financing costs, taxation, depreciation, fares elasticity and sensitivity tests for various parameters would be justified, in order to rigorously assess the feasibility of the PRT system.

In conclusion, the comparison between the three different scenarios presented in this chapter supports the argument that increasing the accessibility of the main transit nodes will have a positive impact on increasing public transport mode share and thus, a positive impact on the environment and public health. Personal Rapid Transit system in Macquarie Park would be a feasible and cost-effective alternative to current plans and business-as-usual scenario. This study only investigated the Personal Rapid Transit system as a local access option for Macquarie Park. A shuttle bus system would further increase the existing congestion on the local streets and a light rail system could not permeate this area very closely based on its layout and existing streets grid. Future research is recommended to investigate if these options are worthwhile investments.

The analysis of the Personal Rapid Transit system revealed that the investment should provide a high rate of return, as well as generating substantial environmental, urban and health benefits.

Regardless of the strong business case which can be made in support of PRT, the practicability of the system in an urban context is still unknown. However, the eight year period proposed before implementing this innovative system would allow enough time for the real systems to be tested in several locations (Heathrow, Abu Dhabi, Suncheon, Uppsala, and Amritsar) and to prove whether the system can offer the promised performance in a complex urban environment.

The following chapter summarises the findings from this study and formulates answers to the specific questions addressed by this thesis.

Chapter 8. Conclusions

This concluding chapter restates the specific questions formulated at the beginning of the thesis and summarises the key findings. Areas for future research are identified and the significance and potential contribution of the research is discussed.

8.1. Summary of key findings

The central question addressed by this research is:

To what extent could PRT address sustainability challenges in edge cities?

In order to answer this broad question, three specific key questions were posed at the beginning of this thesis:

Question 1:
What are the sustainability challenges of edge cities?

Question 2:
How effective is the Personal Rapid Transit system in retrofitting edge cities?

Question 3:
What are the likely environmental, urban and health impacts of different land use and transport strategies in edge cities?

I discuss each of these questions below.

8.1.1. What are the sustainability challenges of edge cities?

Edge cities are characterised by a large scale urban form, large building blocks, and irregular lot sizes and shapes. Their street network isolates the buildings from each other and creates a pedestrian-unfriendly environment. Edge cities display a highly car-dependent travel pattern, with very limited reliance on walking and cycling as modes of travel. If current travel trends continue, traffic congestion will worsen, and increased traffic may threaten public health by increasing exposure to air pollution and accidents. Measures to transform these cities into denser and more walkable neighborhoods may be offset by the high levels of air pollutants from road traffic generated by the high numbers of commuters. Edge cities accommodate more employees than residents, and hence local residents are more exposed to air pollution than residents of typical suburbs.

The analysis of edge cities, especially those in North-American and Australian context (see sections 3.1.4-3.1.6) supports Scheer and Petkov's theory that "it is more likely that existing edge cities, lacking inherent flexibility, will reach capacity, mature, and eventually become obsolete" (1998, p.11).

Although this research is based on a single case study (Macquarie Park), similar sustainability issues were identified in the other edge cities analysed in this thesis (e.g. Tysons Corner and to some extent):

– An urban form characterised by large building footprints, limited amounts of open spaces, and low accessibility levels to many destinations within the area, including the existing rail stations
– A wide range of land uses including retail, commercial, business and mixed use but very small areas of environmental and recreational zones and low density residential areas
– A highly car-dependent travel pattern defined by motorways and arterial streets that dominate the urban structure; many existing and potential destinations (university, research and business parks, peripheral points of interest) are not within walking distances of the rail stations and thus, not easily accessible.

Macquarie Park encounters similar sustainability issues as those faced by other edge cities (Ceruzzi 2000; Fishman 1995; Garreau 1991; Phelps 2009; Scheer and Petkov 1998). The Macquarie Park case study demonstrate that 'edge cities' have started to emerge in Australia, and their growth pattern can be recognized in the evolution of some of the specialised centres defined in the Sydney Metropolitan strategy (NSW Government 2010).

8.1.2. How effective is the Personal Rapid Transit system in retrofitting edge cities?

The simulation results provided in Chapter 6 led to a better understanding of the theoretical performance of the PRT as a local feeder system for the main transit nodes within an edge city, and more specifically in Macquarie Park.

Professor Vuchic, one of the most notable critics of the PRT system, argues that PRT systems are not appropriate as urban transport systems because of the "high costs, large space requirements, low capacity, and poor reliability (Vuchic 2007, p. 474).

The operational PRT systems recently built - ULTRA Heathrow, London and Masdar, Abu Dhabi, and Suncheon, South Korea (scheduled for opening in 2013) prove that the system can be appropriate and viable in some urban contexts. The three systems responded to new planning priorities: the need to move large numbers of airport users rapidly, the need to offer a zero carbon transport system that would compete with cars, and the need to build a transit system in an environmentally sensitive location. However, these three systems are small scale, usually simple loops connecting two or three destinations in places where travel demand can be easily predicted. The applicability and feasibility of a PRT system in a complex urban environment is still unknown.

The Macquarie Park case study suggests that PRT may have another urban application, as a feeder to the main transit nodes within an 'edge city'. The simulation results showed that the overall performance of the PRT is effective, even in the busiest hours of the morning and afternoon peak. In Macquarie Park, a 17.8 kilometre-long, one-way single loop network with twenty off-line stations and two simple depots can handle as many as 3,800 passengers per hour (see Section 6.6). The maximum capacity depends on minimum headway, the capacity of each station to handle large volumes of passengers, and the occupancy rate of the vehicles. Real data from operational systems is crucial in understanding how PRT might perform in a complex city-wide system.

Similar levels of passenger performance (as measured by waiting time, travel time, safety and comfort) are demonstrated by the preliminary data and surveys from two operational systems (Heathrow and Masdar). They support the simulation results from this study (see Sections 6.3.3, 6.4.3 and 6.5.2). PRT travel time is comparable to travel by car during busy commuting hours and because it does not require additional time for parking, it may be preferred to travelling by car. The non-stop trips, modern design and comfort levels are also positive indicators of passenger performance. A PRT system built to increase the accessibility of the existing mass transit systems and other destinations in an edge city might increase the attractiveness of the conventional public transport system and thus, contribute to a shift in travel pattern.

An important benefit of the PRT is the small footprint of the system and consequently, the value of land released for other uses. A PRT track requires only two metres width compared with over ten metres for a major road but can still handle large volumes of passengers. Also, the low level of noise makes buffers to adjacent land uses unnecessary. A PRT station with a single berth requires the same space as a bay in an underground car park. Over a typical eight-hour working day, while one single private car remains parked in the same space, the PRT station can service more than 3,800 passengers (see Section 2.3.2.4).

Scheer and Petkov (2007) pointed out that the major constraints on future growth of the edge cities are physical: size and road infrastructure. The findings of this study suggest that a PRT network may address these constraints. The PRT network may allow for future growth, while providing alternatives to the construction of new major roads.

Huge amounts of valuable land are developed as car parks in every edge city; 3.7 million square metres of parking lots were provided for workers and shoppers in Tyson Corner in 2009 (PB Placemaking Group 2009) and approximately 400,000 square metres in Macquarie Park in 2006 (City of Ryde 2009). If existing travel trends continue without coherent and strong parking management policies, the developable space occupied by parking lots in Macquarie Park could be as high as 1 million square metres. A strategy including PRT as a local access system for the main transit nodes in Macquarie Park could save more than 1.1 billion dollars of the costs of building new car parking spaces, without considering the value of land.

A parking study commissioned by City of Ryde recommends that parking provision rates should be maintained at the same level in the short term (0-2 years), start transitioning to overall lower levels in the medium term (2-5 years) and be considerably reduced only when coupled with alternative strategies to improve transport accessibility for the area (City of Ryde 2009). Integrating the PRT system into future transport plans for the area could be one of these alternative strategies.

The cost-benefit analysis in Section 7.5 suggests that a PRT system is a worthwhile investment in Macquarie Park, potentially providing a high rate of return over a 30-year period of assessment. In principle the estimated investment cost could be entirely offset by the savings from the construction costs of the parking spaces alone. Moreover, the PRT network could have positive effects on the value of future developments by providing a higher level of accessibility, which may be associated with an increase in neighbouring values (Ge et al 2012). Increasing accessibility could also attract future developments, which may occur somewhere else as a result of applying more restrictive parking policies. This is one of the main concerns of the local council (City of Ryde 2009).

However, detailed civil engineering calculations and a more detailed financial analysis are required in order to evaluate the feasibility of a PRT system in Macquarie Park, and to extend the analysis to edge cities. Nevertheless, the findings from this hypothetical study substantiate the findings of other feasibility studies of the PRT systems which conclude the PRT can be a cost-effective mass transit system (Bly and Teychenne 2005; Kerr and Craig 2005; Lowson and Lowson 2010; Tegner 2003).

8.1.3. What are the likely environmental, urban and health impacts of different land use and transport strategies in edge cities?

Future strategies to address the sustainability needs of edge cities should solve specific local problems but must also be integrated within regional strategies. Mees (2009) suggests that regional strategies should establish targets for mode shares with a focus on more sustainable transport modes. The latest Sydney metropolitan strategy sets targets for commuting trips to the regional centres, as well as for active transport in the greater Sydney region (NSW Government 2010). The Local Access by Personal Rapid Transit (LAPRT) scenario - developed in Chapter 5 – assumes that increasing the accessibility of train and bus stations through a PRT network might contribute to achieving the metropolitan and local targets for public transport mode share. The rationale for this assumption is that the PRT system offers a convenient option for the “last-mile” trip. Well integrated within conventional transport systems, the PRT could improve the public transport services at the local level and might increase the overall attractiveness of public transport by providing an acceptable transit link that meets passenger preferences. The comparison between the three scenarios in Chapter 7 supports the argument that increasing the accessibility of the main transit nodes will have a positive impact on increasing public transport mode share and thus, a positive impact on the environment and public health.

The analyses in Sections 7.3.1 and 7.3.2 suggest that a PRT system implemented in Macquarie Park could reduce greenhouse gas emissions by 32% compared to projections from current transportation patterns, or by 14% compared to the “Planned” scenario. The findings from this study suggest that the PRT could produce three times less CO2 emissions than the substitute car trips, assuming the same CO2 emission level by 2031 compared to 2010 for cars and the entire vehicle fleet replaced by 2031. Although the lack of carbon dioxide emissions from PRT vehicles is offset to some extent by the emissions at the power stations producing the electricity, other research on this topic has estimated that considerable savings of greenhouse gas emissions would still occur (Bly and Teychenne 2005; Lowson 2005; West Virginia University 2010).

The low level of noise is another positive feature of the PRT system. Traffic-related noise is convincingly associated with increased stress, disturbed sleep and increased risk of cardiovascular diseases (Austroads 2003; Black and Black 2009; Matan et al 2011). Introducing a PRT system as a local access system could reduce the level of noise not only at the local level, but also at the metropolitan level by increasing the overall public transport mode share, and hence contributing to a reduction in the risk of cardiovascular diseases.

Increasing public transport mode share and reducing car traffic would positively affect public health by reducing accidents and air pollution, and by increasing physical activity due to an increased number of transit users. The analysis in Section 7.4.2 shows that under the LAPRT scenario, 109 road accidents could be avoided every year compared to a business-a-usual projection by 2031.

The impact of transport pollutants at a local scale is difficult to estimate because of many unknown factors: the vulnerabilty of specific segments of population to pollutants, the chemical processes and the dispersion of air pollutants, among others. However, there is a strong evidence of the negative health effects due to transport-related air pollutants (Black and Black 2009; Cope et al 2011; NSW Ministry of Health 2012; Proust et al 2012). The PRT system has zero local emissions, which is why it has been considered an appropriate solution even for a unique eco-system in South Korea and for the zero-carbon city Masdar, Abu Dhabi. The analysis in Section 7.4.1 of the impacts of air pollution for the three scenarios estimated that under the LAPRT scenario, the annual emissions of the most dangerous pollutants for human health (carbon monoxide, oxides of nitrogen, particulate matters and sulphur dioxide) could decrease by 33% compared to a business-as-usual scenario, and by 15% when compared to the "Planned" scenario. The pollutants from the power stations which generate electricity were not included in the analysis. The findings from this research are comparable with other evaluations of PRT systems (Wyatt 2006).

Another health indicator covered by this study is the impact on physical activity. The analysis was restricted to the minimum level of physical activity from the access/egress trips of transit users (assuming that 20% of transit users achieved 30 minutes of physical activity per day, five days per week) and walking and cycling as active modes of travel. The findings in Section 7.4.3 show that the annual hours of physical activity could increase by 73% under the LAPRT scenario compared to a continuation of existing trends (business as usual). The LAPRT scenario could increase the level of physical activity by 27% even when compared to the ambitious targets of the "Planned" scenario. The contribution of the PRT system to increasing physical activity is supported by the predicted major shift from car to public transport. Its potential to release local streets from the pressure of car traffic and congestion, and consequently from noise, pollution, and danger could contribute to an increase in walking and cycling. However, some trade-offs might occur, particularly for short-distance trips. People might prefer to travel by PRT instead of walking, especially if the stations are integrated within new buildings. Further research, analysing the various trade-offs, is recommended before commencing the planning process. Current patterns of active travel in all edge cities analysed in this study indicate very low levels of walking and cycling. Potentialy, the urban space released by retrofitting edge cities with a PRT system could be redesigned and revised to ecourage greater physical activity and social interaction.

In analysing the health impacts of the three scenarios, I have demonstrated that it is possible to obtain significant health benefits from implementing a PRT system as a feeder to main transit nodes in Macquarie Park, and this may be achieveable in other edge cities too. This is a topic that has been neglected in other studies of PRT potential.

8.2. Future research

Some areas for future research have already been identified in the previous discussion. This section discusses some other directions for future research and policy implications.

In Chapter 5 (section 5.4), an alternative scenario was developed – Personal Rapid and Transit Oriented Development (PRTOD) based on increasing the residential population within the study area by developing mixed-use buildings around stations, and increasing the accessibility to all urban activities by introducing the PRT network. A strategy which combines the Transit Oriented Development principles with an innovative transport alternative could provide significant positive impacts on reducing emissions and boosting physical activity. Future research is recommended to a more thorough investigation of this strategy.

The PRT system, fully integrated within existing and future transit infrastructure, could generate more economic benefits if strategies to increase patronage are pursued. Lower fares for shared rides, integrated fares with trains or buses, and student and pensioner discounts could attract more passengers not only for PRT, but for all public transport modes. Workplace Travel plans to include multi-modal transport options (including PRT) could reduce the number of people driving to work. Integrated fares with peripheral public car parks could lessen the pressure of traffic and congestion. As substantial numbers of unlinked trips occur during the day for shopping, recreation, and other purposes, an “all-day” or “all-week” card could attract a wider range of passenger trips. A free service for students and transit users could be considered. There are many ways to increase revenues from other sources, for example from advertising, as is the case for VELIB in Paris. At Heathrow airport, the fares for PRT trips are included in the parking fees. In Masdar, Abu Dhabi, travelling by PRT is a free service for the local community.

Regardless of the strong business case which can be made in support of PRT, options to finance such a system should be further investigated. Furthermore, the impact of the elevated guideways of traffic signals, street lighting, local vegetation, urban landscape, and public utilities, as well as on residential areas should be further investigated. However, this kind of analysis is required for any transport system, not only for PRT.

Risk factors still exist, such as financing a new technology, untested performance under complex urban environments or negative network externalities which will surely postpone the decisions to adopt a non-traditional transit system. However, innovative solutions are needed in order to address the problem of increased car dependency.

8.3. Concluding remarks

If we are to re-invent cities, particularly multi-centred cities designed around cars, we need new visions of sustainable transport futures (Kenworthy 2006). However, new visions also need specificity. Debate and discussion will be enhanced through a clearer understanding of alternative solutions, based on defensible forecasts of how they might change travel behaviour, how they may alter the built environment, and the impact they may have on a variety of social goods – health, environmental quality, and public investment returns. This thesis aims to contribute to future debates about policy options by developing a design-based solution for a case study, and evaluating its likely impacts on these factors.

> It is reasonable to assume that by the late 21st century, planners will use PRT to finally bring back into the city unprecedented amounts of countryside flora, fauna, fresh air and open space.
> (Ray Wyatt 2006, p.12.30)

APPENDIX 2.

AM PEAK – 1 HOUR SIMULATION

Simulation results

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Passenger waiting times by station (with 1.00 hours of simulation data):

Station	Mean (s)	% <= 60s	N (groups)
Station 01	1	100	283
Station 02	10	100	47
Station 03	12	96	26
Station 04	21	87	231
Station 05	1	100	271
Station 06	0	0	0
Station 07	0	0	0
Station 08	0	0	0
Station 09	7	100	186
Station 10	11	100	235
Station 11	25	83	109
Station 12	0	0	0
Station 13	0	0	0
Station 14	0	0	0
Station 15	45	62	62
Station 16	0	0	0
Station 17	0	0	0
Station 18	64	46	113
Station 19	8	100	16
Station 20	75	53	56
Total	**16**	**90**	**1635**

Estimated fleet size: 204 vehicles.

Close

Network distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest-time station-to-station distances in kilometers.

↗	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.59	1.11	1.70	2.77	0.87	1.39	1.98	1.81	2.37	2.98
Station 02	2.85		0.52	1.11	2.18	3.72	4.24	4.83	4.66	5.22	5.83
Station 03	2.33	2.92		0.59	1.66	3.20	3.72	4.31	4.14	4.70	5.31
Station 04	1.74	2.33	2.85		1.07	2.61	3.13	3.72	3.55	4.11	4.72
Station 05	0.67	1.26	1.78	2.37		1.54	2.06	2.65	2.48	3.04	3.65
Station 06	2.81	3.40	3.92	4.51	2.14		0.52	1.11	0.94	1.50	2.11
Station 07	2.29	2.88	3.40	3.99	1.62	3.16		0.59	4.10	4.66	5.27
Station 08	1.70	2.29	2.81	3.40	1.03	2.57	3.09		3.51	4.07	4.68
Station 09	3.32	3.91	4.43	5.02	2.65	4.19	4.71	5.30		0.56	1.17
Station 10	2.76	3.35	3.87	4.46	2.09	3.63	4.15	4.74	2.93		0.61
Station 11	2.15	2.74	3.26	3.85	1.48	3.02	3.54	4.13	2.32	2.88	
Station 12	5.01	5.60	6.12	6.71	4.34	5.88	6.40	6.99	1.69	2.25	2.86
Station 13	4.39	4.98	5.50	6.09	3.72	5.26	5.78	6.37	1.07	1.63	2.24
Station 14	3.79	4.38	4.90	5.49	3.12	4.66	5.18	5.77	0.47	1.03	1.64
Station 15	4.70	5.29	5.81	6.40	4.03	5.57	6.09	6.68	4.87	1.94	2.55
Station 16	4.12	4.71	5.23	5.82	3.45	4.99	5.51	6.10	4.29	1.36	1.97
Station 17	3.65	4.24	4.76	5.35	2.98	4.52	5.04	5.63	3.82	0.89	1.50
Station 18	7.17	7.76	8.28	8.87	6.50	8.04	8.56	9.15	7.34	4.41	5.02
Station 19	6.32	6.91	7.43	8.02	5.65	7.19	7.71	8.30	6.49	3.56	4.17
Station 20	5.35	5.94	6.46	7.05	4.68	6.22	6.74	7.33	5.52	2.59	3.20

Total track length: 17.8km

Mean demand-weighted passenger trip distance: 1.94km

Close

Straight Line Distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Straight line station-to-station distances in kilometers.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.36	0.70	1.05	0.67	0.65	0.74	0.63	1.51	1.55	1.42
Station 02	0.36		0.52	0.98	0.92	0.85	1.05	0.99	1.77	1.87	1.78
Station 03	0.70	0.52		0.50	0.86	1.33	1.44	1.23	2.21	2.24	2.05
Station 04	1.05	0.98	0.50		0.85	1.71	1.72	1.40	2.52	2.46	2.18
Station 05	0.67	0.92	0.86	0.85		1.19	1.02	0.61	1.81	1.66	1.34
Station 06	0.65	0.85	1.33	1.71	1.19		0.42	0.74	0.93	1.13	1.21
Station 07	0.74	1.05	1.44	1.72	1.02	0.42		0.44	0.80	0.82	0.80
Station 08	0.63	0.99	1.23	1.40	0.61	0.74	0.44		1.20	1.06	0.82
Station 09	1.51	1.77	2.21	2.52	1.81	0.93	0.80	1.20		0.49	0.92
Station 10	1.55	1.87	2.24	2.46	1.66	1.13	0.82	1.06	0.49		0.48
Station 11	1.42	1.78	2.05	2.18	1.34	1.21	0.80	0.82	0.92	0.48	
Station 12	0.97	1.34	1.51	1.58	0.73	1.06	0.68	0.36	1.27	0.99	0.61
Station 13	0.97	1.32	1.64	1.84	1.05	0.75	0.34	0.44	0.81	0.62	0.47
Station 14	1.17	1.45	1.87	2.16	1.44	0.66	0.44	0.83	0.37	0.49	0.73
Station 15	2.26	2.60	2.91	3.05	2.21	1.90	1.56	1.69	1.17	0.78	0.87
Station 16	2.25	2.56	2.95	3.16	2.35	1.77	1.52	1.77	0.89	0.71	1.06
Station 17	1.95	2.23	2.65	2.92	2.16	1.40	1.22	1.55	0.47	0.55	1.02
Station 18	3.55	3.88	4.21	4.36	3.51	3.12	2.82	2.99	2.25	2.01	2.18
Station 19	3.99	4.30	4.67	4.85	4.02	3.50	3.25	3.47	2.59	2.43	2.68
Station 20	3.22	3.55	3.90	4.07	3.23	2.77	2.49	2.69	1.89	1.67	1.89

Close

Trip time

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest station-to-station times in seconds.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		59	111	170	277	87	139	198	181	237	298
Station 02	285		52	111	218	372	424	483	466	522	583
Station 03	233	292		59	166	320	372	431	414	470	531
Station 04	174	233	285		107	261	313	372	355	411	472
Station 05	67	126	178	237		154	206	265	248	304	365
Station 06	281	340	392	451	214		52	111	94	150	211
Station 07	229	288	340	399	162	316		59	410	466	527
Station 08	170	229	281	340	103	257	309		351	407	468
Station 09	332	391	443	502	265	419	471	530		56	117
Station 10	276	335	387	446	209	363	415	474	293		61
Station 11	215	274	326	385	148	302	354	413	232	288	
Station 12	501	560	612	671	434	588	640	699	169	225	286
Station 13	439	498	550	609	372	526	578	637	107	163	224
Station 14	379	438	490	549	312	466	518	577	47	103	164
Station 15	470	529	581	640	403	557	609	668	487	194	255
Station 16	412	471	523	582	345	499	551	610	429	136	197
Station 17	365	424	476	535	298	452	504	563	382	89	150
Station 18	717	776	828	887	650	804	856	915	734	441	502
Station 19	632	691	743	802	565	719	771	830	649	356	417
Station 20	535	594	646	705	468	622	674	733	552	259	320

Mean demand-weighted passenger trip time: 194s

Close

Appendix 3.

Distribution of trips between pairs of origin and destination stations in the afternoon peak

The following assumptions were made about the distribution of trips between pairs of origin and destination stations:

To Station 1 (destination for rail and bus patrons) passengers could travel on Loop 1 (stations 1-2-3-4-5-1) from the Macquarie University campus or on Loop 2 (1–6-7–8-5–1) from the workplaces on the east side. I assumed university students and staff would use Loop 1. Based on the morning peak trips distribution, I assumed 40% of trips would be from 2 to 1, 40% from 3 to 1, and 20% from 4 to 1. Passengers coming from stations 6, 7 and 8 and having Station 1 as destination to connect to train or buses were assumed to use Loop 2. Based on the concentration of jobs near to each PRT station, similar to the morning distribution, I assumed 15% trips would be from 6 to 1, 50% trips from 7 to 1, and 35% trips from 8 t 1.

Station 1 will also be an origin station for residents returning home in the afternoon, by train or bus. I assumed 90% of the residents returning home by train will ride a pod from station 1 to station 5, with the remaining 10% alighting from train at North Ryde and using the PRT system from station 20 to station 19.

To Station 2 (destination mainly for university students and workers who parked their car near station 2) it was assumed that 60% of the university students and staff trips would be from station 4 and 40% from 5 based on the same assumptions as in the morning peak. Workers trips from stations 7 and 8 to station 2 as destination for their home-return trip by car were assumed to be equally distributed: 50% from 7 to 2 and 50% from 8 to 2.

Station 2 will also be an origin station for Macquarie University students and staff passengers returning home in the afternoon by train (station 1), bus (station 4) or PRT (station 5). The trip distribution between these stations is presented in each paragraph explaining the assumptions at each destination.

To Station 4 (destination for bus and car passengers travelling to the West to Auburn, Parramatta or Eastwood suburb), I assumed that 60% of the students and Macquarie University staff will arrive from station 2 and 40% from station 3. For their return trip from work, business or other activities, passengers arriving at Station 4 were assumed to equally board at stations 6, 7 and 8 (approximately 33%).

To Station 5 (destination for residents) students and staff who live in Macquarie Park could travel on Loop 1 from the university campus. I assumed 45% of students and university staff trips would be from station 2, 45% from station 3, with the remaining 10% from station 4 to station 5. Residents returning home by train were assumed to board at station 1. Residents returning home by bus could connect to PRT at station 1 or station 9; equal distribution of trips from these two stations was assumed. For Macquarie Park residents returning home by bus on one of the routes on Epping Road, no trips were allocated on PRT because they can alight from buses at the nearest stop to their residence.

Local residents working within the area could walk to the nearest PRT station and travel to station 5. I assumed equal distribution of trips originated at stations 6, 7 and 8.

To Station 9 (destination for bus and car passengers, travelling to the North to Mona Vale, Chatswood, Gordon), I assumed equal distribution of trips (25% each) originated at stations 11, 12, 13 and 14

To Station 10 (destination for rail patrons boarding at Macquarie Park station) passengers could travel on Loop 3 (stations 10-11-12-13-14-9-10) from workplaces and other points of interest from the west (70% of total trips arriving at station 10 to connect to train) and on Loop 4 (stations 10-15-16-17-10) from the east (30% of total trips arriving at station 10). Based on the jobs distribution, trips on Loop 3 were assumed to be distributed in the following percentages: 16% from station 11, 12% from station 12, 12% from station 13 and 40% from station 9 to station 10. I assumed trips on Loop 4 would be 35% from station 15, 35% from station 16 and 30% from station 17.

To Station 11 (destination for bus passengers travelling to Epping for example) passengers could travel on Loop 3 from stations 9, 13 and 14; equal distribution of trips between these three stations was assumed. No trips were allocated from station 12 because it is too close to another bus stop, so the passengers could walk and catch the bus.

To Station 15 (destination for bus passengers travelling to Epping, Parramatta or Chatswood), I assumed equal distribution of trips from stations 10, 16 and 17 on Loop 4.

To Station 18 (destination for bus and car passengers from North Ryde) I assumed equal distribution of trips from stations 19 and 20.

To Station 19 (near to a small residential area; about 10% of residents live in North Ryde) some trips would occur from local residents travelling from the Macquarie University campus (station 3) or passengers alighting from train at North Ryde station (near the Station 20) or from bus , at station 18.

To Station 20 (destination for train passengers boarding at North Ryde station), I assumed equal distribution of trips from station 18 and 19.

APPENDIX 4.

PM PEAK – 1 HOUR SIMULATION

Simulation results

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Passenger waiting times by station (with 1.00 hours of simulation data):

Station	Mean (s)	% <= 60s	N (groups)
Station 01	4	100	14
Station 02	20	94	117
Station 03	23	86	106
Station 04	1	100	46
Station 05	1	100	28
Station 06	56	50	142
Station 07	88	19	220
Station 08	157	0	201
Station 09	8	100	76
Station 10	9	100	26
Station 11	31	79	63
Station 12	93	20	64
Station 13	121	13	72
Station 14	187	3	97
Station 15	3	100	22
Station 16	16	92	40
Station 17	19	89	29
Station 18	20	88	35
Station 19	87	43	81
Station 20	29	84	45
Total	**72**	**50**	**1524**

Estimated fleet size: 197 vehicles.

Close

Network distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest-time station-to-station distances in kilometers.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.59	1.11	1.70	2.77	0.87	1.39	1.98	1.81	2.37	2.98
Station 02	2.85		0.52	1.11	2.18	3.72	4.24	4.83	4.66	5.22	5.83
Station 03	2.33	2.92		0.59	1.66	3.20	3.72	4.31	4.14	4.70	5.31
Station 04	1.74	2.33	2.85		1.07	2.61	3.13	3.72	3.55	4.11	4.72
Station 05	0.67	1.26	1.78	2.37		1.54	2.06	2.65	2.48	3.04	3.65
Station 06	2.81	3.40	3.92	4.51	2.14		0.52	1.11	0.94	1.50	2.11
Station 07	2.29	2.88	3.40	3.99	1.62	3.16		0.59	4.10	4.66	5.27
Station 08	1.70	2.29	2.81	3.40	1.03	2.57	3.09		3.51	4.07	4.68
Station 09	3.32	3.91	4.43	5.02	2.65	4.19	4.71	5.30		0.56	1.17
Station 10	2.76	3.35	3.87	4.46	2.09	3.63	4.15	4.74	2.93		0.61
Station 11	2.15	2.74	3.26	3.85	1.48	3.02	3.54	4.13	2.32	2.88	
Station 12	5.01	5.60	6.12	6.71	4.34	5.88	6.40	6.99	1.69	2.25	2.86
Station 13	4.39	4.98	5.50	6.09	3.72	5.26	5.78	6.37	1.07	1.63	2.24
Station 14	3.79	4.38	4.90	5.49	3.12	4.66	5.18	5.77	0.47	1.03	1.64
Station 15	4.70	5.29	5.81	6.40	4.03	5.57	6.09	6.68	4.87	1.94	2.55
Station 16	4.12	4.71	5.23	5.82	3.45	4.99	5.51	6.10	4.29	1.36	1.97
Station 17	3.65	4.24	4.76	5.35	2.98	4.52	5.04	5.63	3.82	0.89	1.50
Station 18	7.17	7.76	8.28	8.87	6.50	8.04	8.56	9.15	7.34	4.41	5.02
Station 19	6.32	6.91	7.43	8.02	5.65	7.19	7.71	8.30	6.49	3.56	4.17
Station 20	5.35	5.94	6.46	7.05	4.68	6.22	6.74	7.33	5.52	2.59	3.20

Total track length: 17.8km

Mean demand-weighted passenger trip distance: 1.84km

Close

Straight Line Distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Straight line station-to-station distances in kilometers.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.36	0.70	1.05	0.67	0.65	0.74	0.63	1.51	1.55	1.42
Station 02	0.36		0.52	0.98	0.92	0.85	1.05	0.99	1.77	1.87	1.78
Station 03	0.70	0.52		0.50	0.86	1.33	1.44	1.23	2.21	2.24	2.05
Station 04	1.05	0.98	0.50		0.85	1.71	1.72	1.40	2.52	2.46	2.18
Station 05	0.67	0.92	0.86	0.85		1.19	1.02	0.61	1.81	1.66	1.34
Station 06	0.65	0.85	1.33	1.71	1.19		0.42	0.74	0.93	1.13	1.21
Station 07	0.74	1.05	1.44	1.72	1.02	0.42		0.44	0.80	0.82	0.80
Station 08	0.63	0.99	1.23	1.40	0.61	0.74	0.44		1.20	1.06	0.82
Station 09	1.51	1.77	2.21	2.52	1.81	0.93	0.80	1.20		0.49	0.92
Station 10	1.55	1.87	2.24	2.46	1.66	1.13	0.82	1.06	0.49		0.48
Station 11	1.42	1.78	2.05	2.18	1.34	1.21	0.80	0.82	0.92	0.48	
Station 12	0.97	1.34	1.51	1.58	0.73	1.06	0.68	0.36	1.27	0.99	0.61
Station 13	0.97	1.32	1.64	1.84	1.05	0.75	0.34	0.44	0.81	0.62	0.47
Station 14	1.17	1.45	1.87	2.16	1.44	0.66	0.44	0.83	0.37	0.49	0.73
Station 15	2.26	2.60	2.91	3.05	2.21	1.90	1.56	1.69	1.17	0.78	0.87
Station 16	2.25	2.56	2.95	3.16	2.35	1.77	1.52	1.77	0.89	0.71	1.06
Station 17	1.95	2.23	2.65	2.92	2.16	1.40	1.22	1.55	0.47	0.55	1.02
Station 18	3.55	3.88	4.21	4.36	3.51	3.12	2.82	2.99	2.25	2.01	2.18
Station 19	3.99	4.30	4.67	4.85	4.02	3.50	3.25	3.47	2.59	2.43	2.68
Station 20	3.22	3.55	3.90	4.07	3.23	2.77	2.49	2.69	1.89	1.67	1.89

Close

Trip time

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest station-to-station times in seconds.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		59	111	170	277	87	139	198	181	237	298
Station 02	285		52	111	218	372	424	483	466	522	583
Station 03	233	292		59	166	320	372	431	414	470	531
Station 04	174	233	285		107	261	313	372	355	411	472
Station 05	67	126	178	237		154	206	265	248	304	365
Station 06	281	340	392	451	214		52	111	94	150	211
Station 07	229	288	340	399	162	316		59	410	466	527
Station 08	170	229	281	340	103	257	309		351	407	468
Station 09	332	391	443	502	265	419	471	530		56	117
Station 10	276	335	387	446	209	363	415	474	293		61
Station 11	215	274	326	385	148	302	354	413	232	288	
Station 12	501	560	612	671	434	588	640	699	169	225	286
Station 13	439	498	550	609	372	526	578	637	107	163	224
Station 14	379	438	490	549	312	466	518	577	47	103	164
Station 15	470	529	581	640	403	557	609	668	487	194	255
Station 16	412	471	523	582	345	499	551	610	429	136	197
Station 17	365	424	476	535	298	452	504	563	382	89	150
Station 18	717	776	828	887	650	804	856	915	734	441	502
Station 19	632	691	743	802	565	719	771	830	649	356	417
Station 20	535	594	646	705	468	622	674	733	552	259	320

Mean demand-weighted passenger trip time: 184s

Close

APPENDIX 5.

1.1. INTER PEAK – 1 HOUR SIMULATION

Simulation results

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Passenger waiting times by station (with 1.00 hours of simulation data):

Station	Mean (s)	% <= 60s	N (groups)
Station 01	3	100	189
Station 02	3	100	23
Station 03	9	100	19
Station 04	9	100	88
Station 05	15	93	145
Station 06	22	88	51
Station 07	31	77	59
Station 08	22	85	63
Station 09	26	88	43
Station 10	18	96	56
Station 11	17	92	41
Station 12	39	80	5
Station 13	36	61	21
Station 14	26	80	20
Station 15	62	57	21
Station 16	1	100	4
Station 17	1	100	4
Station 18	12	96	25
Station 19	22	75	12
Station 20	1	100	14
Total	**16**	**91**	**903**

Estimated fleet size: 110 vehicles.

Close

Network distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest-time station-to-station distances in kilometers.

↗	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.59	1.11	1.70	2.77	0.87	1.39	1.98	1.81	2.37	2.98
Station 02	2.85		0.52	1.11	2.18	3.72	4.24	4.83	4.66	5.22	5.83
Station 03	2.33	2.92		0.59	1.66	3.20	3.72	4.31	4.14	4.70	5.31
Station 04	1.74	2.33	2.85		1.07	2.61	3.13	3.72	3.55	4.11	4.72
Station 05	0.67	1.26	1.78	2.37		1.54	2.06	2.65	2.48	3.04	3.65
Station 06	2.81	3.40	3.92	4.51	2.14		0.52	1.11	0.94	1.50	2.11
Station 07	2.29	2.88	3.40	3.99	1.62	3.16		0.59	4.10	4.66	5.27
Station 08	1.70	2.29	2.81	3.40	1.03	2.57	3.09		3.51	4.07	4.68
Station 09	3.32	3.91	4.43	5.02	2.65	4.19	4.71	5.30		0.56	1.17
Station 10	2.76	3.35	3.87	4.46	2.09	3.63	4.15	4.74	2.93		0.61
Station 11	2.15	2.74	3.26	3.85	1.48	3.02	3.54	4.13	2.32	2.88	
Station 12	5.01	5.60	6.12	6.71	4.34	5.88	6.40	6.99	1.69	2.25	2.86
Station 13	4.39	4.98	5.50	6.09	3.72	5.26	5.78	6.37	1.07	1.63	2.24
Station 14	3.79	4.38	4.90	5.49	3.12	4.66	5.18	5.77	0.47	1.03	1.64
Station 15	4.70	5.29	5.81	6.40	4.03	5.57	6.09	6.68	4.87	1.94	2.55
Station 16	4.12	4.71	5.23	5.82	3.45	4.99	5.51	6.10	4.29	1.36	1.97
Station 17	3.65	4.24	4.76	5.35	2.98	4.52	5.04	5.63	3.82	0.89	1.50
Station 18	7.17	7.76	8.28	8.87	6.50	8.04	8.56	9.15	7.34	4.41	5.02
Station 19	6.32	6.91	7.43	8.02	5.65	7.19	7.71	8.30	6.49	3.56	4.17
Station 20	5.35	5.94	6.46	7.05	4.68	6.22	6.74	7.33	5.52	2.59	3.20

Total track length: 17.8km

Mean demand-weighted passenger trip distance: 1.81km

Close

Straight Line Distance

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Straight line station-to-station distances in kilometers.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		0.36	0.70	1.05	0.67	0.65	0.74	0.63	1.51	1.55	1.42
Station 02	0.36		0.52	0.98	0.92	0.85	1.05	0.99	1.77	1.87	1.78
Station 03	0.70	0.52		0.50	0.86	1.33	1.44	1.23	2.21	2.24	2.05
Station 04	1.05	0.98	0.50		0.85	1.71	1.72	1.40	2.52	2.46	2.18
Station 05	0.67	0.92	0.86	0.85		1.19	1.02	0.61	1.81	1.66	1.34
Station 06	0.65	0.85	1.33	1.71	1.19		0.42	0.74	0.93	1.13	1.21
Station 07	0.74	1.05	1.44	1.72	1.02	0.42		0.44	0.80	0.82	0.80
Station 08	0.63	0.99	1.23	1.40	0.61	0.74	0.44		1.20	1.06	0.82
Station 09	1.51	1.77	2.21	2.52	1.81	0.93	0.80	1.20		0.49	0.92
Station 10	1.55	1.87	2.24	2.46	1.66	1.13	0.82	1.06	0.49		0.48
Station 11	1.42	1.78	2.05	2.18	1.34	1.21	0.80	0.82	0.92	0.48	
Station 12	0.97	1.34	1.51	1.58	0.73	1.06	0.68	0.36	1.27	0.99	0.61
Station 13	0.97	1.32	1.64	1.84	1.05	0.75	0.34	0.44	0.81	0.62	0.47
Station 14	1.17	1.45	1.87	2.16	1.44	0.66	0.44	0.83	0.37	0.49	0.73
Station 15	2.26	2.60	2.91	3.05	2.21	1.90	1.56	1.69	1.17	0.78	0.87
Station 16	2.25	2.56	2.95	3.16	2.35	1.77	1.52	1.77	0.89	0.71	1.06
Station 17	1.95	2.23	2.65	2.92	2.16	1.40	1.22	1.55	0.47	0.55	1.02
Station 18	3.55	3.88	4.21	4.36	3.51	3.12	2.82	2.99	2.25	2.01	2.18
Station 19	3.99	4.30	4.67	4.85	4.02	3.50	3.25	3.47	2.59	2.43	2.68
Station 20	3.22	3.55	3.90	4.07	3.23	2.77	2.49	2.69	1.89	1.67	1.89

Close

Trip time

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Shortest station-to-station times in seconds.

	Station 01	Station 02	Station 03	Station 04	Station 05	Station 06	Station 07	Station 08	Station 09	Station 10	Station 11
Station 01		59	111	170	277	87	139	198	181	237	298
Station 02	285		52	111	218	372	424	483	466	522	583
Station 03	233	292		59	166	320	372	431	414	470	531
Station 04	174	233	285		107	261	313	372	355	411	472
Station 05	67	126	178	237		154	206	265	248	304	365
Station 06	281	340	392	451	214		52	111	94	150	211
Station 07	229	288	340	399	162	316		59	410	466	527
Station 08	170	229	281	340	103	257	309		351	407	468
Station 09	332	391	443	502	265	419	471	530		56	117
Station 10	276	335	387	446	209	363	415	474	293		61
Station 11	215	274	326	385	148	302	354	413	232	288	
Station 12	501	560	612	671	434	588	640	699	169	225	286
Station 13	439	498	550	609	372	526	578	637	107	163	224
Station 14	379	438	490	549	312	466	518	577	47	103	164
Station 15	470	529	581	640	403	557	609	668	487	194	255
Station 16	412	471	523	582	345	499	551	610	429	136	197
Station 17	365	424	476	535	298	452	504	563	382	89	150
Station 18	717	776	828	887	650	804	856	915	734	441	502
Station 19	632	691	743	802	565	719	771	830	649	356	417
Station 20	535	594	646	705	468	622	674	733	552	259	320

Mean demand-weighted passenger trip time: 181s

Close

APPENDIX 6.

1.1. AM PEAK – 10 HOURS SIMULATION

Simulation results

Output

Sim Results | Network Distance | Straight Line Distance | Trip Time

Passenger waiting times by station (with 10.00 hours of simulation data):

Station	Mean (s)	% <= 60s	N (groups)
Station 01	1	100	2675
Station 02	11	99	633
Station 03	13	96	199
Station 04	32	80	2482
Station 05	1	99	2701
Station 06	0	0	0
Station 07	0	0	0
Station 08	0	0	0
Station 09	6	100	1805
Station 10	10	100	2398
Station 11	25	86	1262
Station 12	0	0	0
Station 13	0	0	0
Station 14	0	0	0
Station 15	69	42	822
Station 16	0	0	0
Station 17	0	0	0
Station 18	79	40	1029
Station 19	18	90	90
Station 20	52	66	611
Total	**20**	**88**	**16707**

Estimated fleet size: 219 vehicles.

Close

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