ACTIVE TRANSPORT JOURNEY PLANNER

METHODOLOGY

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Abstract

This research aims to define and develop a methodology to assist an individual traveller to select healthier and more sustainable transport routes and modes among admissible transport options and highlight the trade-offs among multiple objectives in terms of health, economic, social and environmental benefits. It aims to assist an individual traveller with multi-objectives to make more informed decisions in route and mode planning. The objectives in the case study were identified as personal energy expenditure, travel time, travel cost, CO\textsubscript{2} emissions and energy resource consumption concerning sustainability.

This research presents procedures for estimating a range of costs and benefits for journeys; procedures for determining the optimal route for an individual’s trip in an urban area based on cost and benefit estimates and preference weights for specific objectives; procedures for undertaking sensitivity analysis for the optimal route; and uses of the cost and benefit estimation and optimal route generation procedures to conduct a case study for a realistic journey in Melbourne.

An active transport journey planner model was developed in MS Excel to allow users to set constraints for most objectives and give their corresponding weightings, respectively. The recommended transport solution (the least total disutility one) and ranking of other options along with their detailed objective-related information are derived. A case study shows that the methodology developed could be applied in selecting more informed transport solutions based on the user’s multi-objective preferences. In addition, transport options incorporating more cycling and walking have the higher probability to deliver healthier and more sustainable solution to users if social, environmental concerns were considered beyond economic issues. Meanwhile, in sensitivity analysis, the tornado diagrams and spiderplots diagrams are used for demonstrating how sensitive each transport option’s disutility is to the weightings of objectives.
Declaration

This is to certify that

(i) the thesis comprises only my original work towards the Master,

(ii) due acknowledgement has been made in the text to all other material used,

(iii) the thesis is less than 30,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Wenqi Hu
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Chapter 1

INTRODUCTION

Almost everyone is involved in some form of transport every day. Especially, travelling to work or study, transport is a necessity for most people on workdays. However, the over reliance on private motorised vehicles, particularly for single person journeys, has led to many severe issues, such as physical inactivity, air and noise pollution, energy shortage, etc. Switching to more active and sustainable forms of transport is an effective way to reduce these negative impacts and move people towards a sustainable future.

In this chapter, firstly, the common problems of current transport systems are defined in general. Then, their negative impacts will be introduced statistically in detail from the aspects of health, greenhouse gas emissions and energy consumption. Meanwhile, the concept and benefits of active transport will be introduced. Based on the detailed background, the need for more information to switch to active transport is demonstrated. Secondly, the aim and objectives of the research of active transport journey planner methodology are identified. Finally, the structure of this thesis is outlined.

1.1 Problem Definition

In the 12 months ended 31 October 2007 there were an estimated 14.8 million vehicles registered in Australia, where passenger vehicles (78.0%) made up the largest group. The 14.8 million vehicles represented an increase of 1.6 million vehicles (12.1%) compared with the 12 months ended 31 October 2003 (ABS 2007).

Although there has been a slight increase in walking, cycling and using public transport over the past 10 years, it is demonstrated in ‘Australian Social Trends 2008’ that three-quarters (75%) of adults living in capital cities travelled to their usual place
of work or study using private motor vehicles as their main form of transport in March 2006 (ABS 2008). In addition, 19% of adults used public transport, and a further 5% either walked or cycled as their main form of transport to work or study (ABS 2008).

Woodcock et al. (2007) stated that, ‘…fossil-fuel energy use in transport leads to many adverse effects, including climate change, physical inactivity, urban air pollution, energy insecurity, and environmental degradation…’

As in many other industrialized nations, the level of physical activity among Australians is insufficient. It is demonstrated that in 2004-05, 70% of Australians aged 15 years and over were classified as sedentary or having low exercise levels (ABS 2006). There is consistent epidemiological evidence that demonstrates the role that physical activity plays as a major modified risk factor in the reduction of mortality and morbidity from many chronic diseases. These diseases include cardiovascular disease, several cancers, Type 2 diabetes, mental health and the risk of falls and injuries in the elderly (USHHS 1996; Stephenson, Bauman & Davies 2000; Armstrong, Bauman & Davies 2000).

Expert groups, focusing primarily on the outcome of all-cause mortality, annual number of deaths, have concluded that the minimum physical activity recommendation for the adult population is 30 minutes of moderately vigorous physical activity on most days of the week (USHHS 1996). In recent years the focus of physical activity research has moved away from vigorous physical activity to moderate-intensity activities such as walking or cycling for transport. This has resulted from the epidemiological evidence that regular moderate-intensity activity can provide similar health benefits as vigorous activity (USHHS 1996; Blair & Connelly 1996; Pate et al. 1995). This move is reflected in the National Physical Activity Guidelines that recommend that adults accumulate, on most days, 30 minutes or more of moderate-intensity physical activity that can be accumulated in bouts of approximately 10-15mins (USHHS 1996; Pate et al. 1995; ADHA 2007).

The term 'active transport' relates to ‘physical activity undertaken as a means of transport. This includes travel by foot, bicycle and other non-motorized vehicles. Use of public transport is also included in the definition as it often involves some walking
or cycling to pick-up and from drop-off points. Active transport does not include walking, cycling or other physical activity that is undertaken for recreation’ (NPHP 2001).

So increases in active transport are likely to lead to significant direct health benefits. Indirect health benefits may also accrue from reduced environmental pollution and increased community cohesion through increasing physical activity and use of public transport or by walking or cycling. In addition, physical activity is not just a public health issue; it also addresses the well-being of communities, protection of the environment and investment in future generations.

The third high-level meeting on transport, health and environment (THE), organized in collaboration with the World Health Organization, United Nations Economic Commission for Europe (UNECE) and the Ministries of Transport, Environment and Health of the Netherlands in Amsterdam, was held in Netherlands in January 2009. Three key challenges are addressed (World Health Organization 2009):

(i) How to manage sustainable mobility, promote clean and efficient public transport systems and encourage walking and cycling?
(ii) How to reduce emissions of transport-related greenhouse gases and other air pollutants as well as noise?
(iii) How to promote a healthier and safer environment, particularly in urban settings?

Walking and cycling as means of daily transport can be a most effective strategy to achieve large health gains through increased levels of routine physical activity. The benefits of walking and cycling go beyond those of physical activity, as they encompass decreasing air and noise pollution and improving the quality of urban life. Use of public transport is also included, as it often involves some walking or cycling to pick-up and from drop-off points.

In capital cities, public transport use is considerably higher than in other parts of Australia. This is in part due to their relatively large populations and extensive public transport infrastructure. Increased use of public transport in capital cities has the potential to reduce traffic congestion and pollution, including greenhouse gas emissions from motor vehicle exhausts. Public transport systems supply a social
welfare service by providing a relatively low cost method of travel for those who are unable to drive or do not have access to a private motor vehicle.

Meanwhile, switching to physically active modes of transport, such as walking and cycling, can make a significant difference to physical wellbeing. Research shows that people who are physically active or have higher levels of cardio respiratory fitness have better moods, higher self-esteem and better cognitive functioning than those who are physically less fit (Dora & Phillips 2000).

In order to reduce the usage of private motorized vehicles, the background of transport-related problems and their negative impacts will be introduced from the following three aspects: health, greenhouse gas emissions and energy consumption. The benefits of reducing motorized vehicle usage through active transport will also be addressed.

1.1.1 Health

Motor vehicle traffic is the main source of ground level concentrations of air pollutants in urban areas with recognized hazardous properties. In northern Europe it contributes practically all CO, 75% of nitrogen oxides (NOx), and about 40% of the PM10 concentrations (Dora & Phillips 2000).

In addition, levels of CO and benzene inside cars are around 2–5 times higher than at the roadside, and car users are exposed to more pollutants than pedestrians, cyclists or users of public transport sharing the same road (Van Wijnen & Van der Zee 1998). About 36 000–129 000 adult deaths a year can be attributed to long-term exposure to air pollution generated by traffic in European cities. This is based on applying a conservative estimate of exposure–response found in the follow-up studies of adults in the United States to estimates of particulate matter exposure in European cities. The same analysis also estimates that particulate matter accounts for 6000–10 000 additional admissions to hospital for respiratory diseases in European cities every year (Dora & Phillips 2000).
Meanwhile, traffic-related air pollution contributes most to morbidity and mortality from cardiovascular and respiratory diseases, several components of diesel and petrol engine exhausts are known to cause cancer in animals (Health Effects Institute 1995) and there is evidence of an association between exposure to diesel and cancer in human beings. A recent analysis of many studies showed a 40% increase in lung cancer risk for long-term, high level occupational exposure to diesel. On that basis, the California Environmental Protection Agency adopted, in August 1998, the legal definition of ‘toxic air contaminant’ for particles emitted from diesel engines (Air Resource Board 1998). Two large longitudinal studies of exposure to ambient air pollutants found an increase in the risk of developing lung cancer for the general population, of a similar magnitude to the risk for cardiopulmonary diseases (Dora & Phillips 2000).

Moreover, half of the adult population in the western world is sedentary or minimally active, and levels of physical activity are declining. Obesity is increasing in western countries in spite of a decrease in calorie intake, and this is mostly due to increasingly sedentary lifestyles. Physical inactivity is now more prevalent than tobacco smoking, and together, these risk factors account for the greatest number of deaths and years of life lost in developed countries (Murray & Lopez 1996).

In Finland it was estimated that a 3–7% reduction in deaths from coronary heart disease could be expected if another 8% of the working population chose to walk or cycle to work (Vuori 1994). The Finnish transport ministry estimated that savings worth about US $80–235 million a year would result from the doubling of cycling distances travelled (Ministry of Transport and Communications 1996).

Choosing to walk or cycle for one’s daily transport needs offers two important kind of benefits. The first, with the reduced use of motorized transport – noise, air pollution and accident rates – would all fall. The second is the benefits to health from regular physical exercise.
1.1.2 Greenhouse Gas Emissions

Transport is the second largest source of greenhouse emissions, contributing about 16% of Victoria's total emissions. Emissions in this sector are growing rapidly, and without further action, will continue to increase (State Government of Victoria 2006).

In 2005, Victoria’s total net greenhouse gas emissions were 121.87 million tonnes (CO2-e). Victoria’s total emissions are higher than some nations, including other industrialised countries with significantly higher populations, such as Austria, Hungary, Portugal, Slovakia, Sweden and Switzerland (State Government of Victoria 2007). Focusing on the transport sector, it accounts for about 14% of Australia’s net greenhouse gas emissions. Between 1990 and 2005, the carbon dioxide equivalent emissions (CO2-e) from the transport sector grew by 30% or 18.5 million tonnes (Australian Greenhouse Office 2007). The Australian Government has introduced initiatives such as the National Travel Behaviour Change Project, which is due to run from 2008 to 2012 (AGO 2006). Such programs seek to encourage people to reduce their reliance on private motor vehicles and consider using more sustainable modes of travel, such as public transport.

A majority of the world’s scientists agree that human activities have resulted in an observed increase in global average temperatures, particularly since the middle of the 20th century. Recent data indicate that the global mean temperature has increased by between 0.2 and 0.6°C since the late 19th century, while Australian average temperatures have increased by 0.8°C. Earth’s average temperature might increase by up to 5.8°C over the next 100 years, if greenhouse gas concentrations continue to increase (State Government of Victoria 2009).

As the average global temperature rises, it will lead to other changes in weather. ‘Storm patterns and severity might increase, sea levels will rise, and floods and drought may become more frequent and more severe. Some changes to the climate are inevitable – even if we stop emitting greenhouse gases now, the gases we have already released will have an effect. However, we must do everything we can to avoid further changes and to adapt to the impacts of climate change’ (State Government of Victoria 2009).
The Victorian Government is working to reduce emissions from the transport sector. Emissions from transport arise from the combustion of fossil fuels in vehicles. Consequently, there are two directions Victorian can pursue to lower these emissions. Firstly, to reduce vehicle use through sound, sustainable urban planning to minimise the need for cars and encourage more sustainable forms of transport. Secondly, to reduce vehicle emissions through new technologies, such as petrol-electric hybrids or by exploring alternative fuels, like biofuels.

1.1.3 Energy Consumption

In Victoria in 2001 total energy expenditure by end-users was about $12 billion. This comprised $5 billion for stationary energy and $7 billion for transport (Department of Natural Resources & Environment 2002). Energy resource consumption runs through the whole life-cycle of a motorized vehicle, as energy is consumed both in the manufacturing and operation stages. In operation, for example, registered motor vehicles in Australia consumed 30,047 million litres of fuel in the 12 months ended 31 October 2007. Of the total fuel consumed by motor vehicles in this period, 62.8% was petrol and 31.2% was diesel. Passenger vehicles used 15,910 million litres of petrol in the 12 months ended 31 October 2007. This was 87.9% of all fuel used by passenger vehicles (ABS 2007).

In 2004-05, Australia’s end-users of energy, comprising households and industries, used 3,822 petajoules (1 PJ = 10^{15} J) of energy. This is an increase of 7.9% since 1999-2000. And the transport sector, including household transport, is the largest end-user of energy, using 1,339 PJ in 2004-05. In 2004-05, road transport accounted for 78% (1,044 PJ) of the transport sector’s energy use, with the remaining contributors being air transport (178 PJ), water transport (58 PJ), rail transport (38 PJ) and other (21 PJ). The manufacturing sector was the second highest user of energy (1,247 PJ) in 2004-05. Together with the transport sector, these two sectors account for 68% of total energy end-use (ABS 2007).

In terms of fossil fuel energy, none is used in walking, little for cycle manufacturing, and less during manufacturing and operation for public transport, in comparison to
private motor vehicles. Thus, switching to active transport can significantly reduce the energy consumption in the transport sector, either in the manufacturing or the operation stages. Moreover, it can further contribute to the sharp reduction of greenhouse gas emissions and consequently bring a large amount of benefits to people’s health.

1.1.4 Need for provision of more information

From the above reviews of the negative effects of current transport systems, especially derived from private motorized vehicles through the perspectives of health, greenhouse gas emissions and energy consumption, the challenge is to promote healthy and sustainable transport alternatives to reduce their impacts. An important way to do this is to ensure that health costs as well as sustainability impacts are estimated when transport decisions are being made and policies formulated. One reason this has not always happened is that, ‘the analytical tools required have been unavailable, inadequate or poorly understood. Methodologies need to be developed, promoted and used to make integrated assessments, monitor progress, account fully for social and environmental costs and identify the strategies with the greatest net benefits’ (Dora & Phillips 2000).

Public and non-motorized transport offers opportunities for regular physical activity, integrated into daily life at minimal cost, for large segments of the population. Modal shifts to physically active transport are likely to bring major benefits to public health, the environment and quality of life, and to decrease congestion. Strategies designed to engineer such shifts should be energetically pursued, especially in urban areas, and their effects monitored and evaluated (Dora & Phillips 2000).

Transport-related physical activity has great potential to promote overall physical activity, as a recent review (Ogilvie et al. 2004) concluded, obtaining more and stronger evidence on the effectiveness of interventions that promote physical activity in transport settings is crucial. Understanding of the relationships between physical activity, transport and health effects is increasing as more research has been carried out in recent years (Badland & Schofield 2005; Sallis et al. 2004). Interdisciplinary
collaborative approaches seem to be important to effectively promote active transport (Sallis et al. 2004).

Ideally, the promotion of physically active travel as a means to increase physical activity levels in populations should be integrated into an overall public health strategy at the national and international levels (Dora & Racioppi 2003). Behaviour change campaigns, such as personalized travel planning, should be easily fit into people’s daily transport (Dombois, Kahlmeier, Martin-Diener, Martin, Racioppi & Braun-Fahrländer 2006).

A report on the ROMANSE project, which provides real-time information, stated that the greatest potential impact on travel behaviour was the provision of ‘pre-trip in-home information’ (Powell 1993). In many capital cities, people can use online transport planning system to acquire public transport information about timetables, services, fares and ticketing, such as ‘metlink’ (see metlinkmelbourne.com.au) in Melbourne. In terms of the trend to switch to more active and sustainable forms of transport, there is a need to design an improved transport planning information system involving active transport options as well as more detailed information regarding sustainability for an individual traveller to easily select their travel preferences in daily transport to potentially change people’s travel behaviour in urban areas towards healthier and more sustainable options.

1.2 Aim, objectives and scope of the research

Aim

This research aims to define and develop a methodology to assist an individual traveller to select healthier and more sustainable transport routes and modes among admissible transport options and highlight the trade-offs among multiple objectives in terms of health, economic, social and environment benefits.
Objectives

There are four objectives to be achieved:

1. To develop procedures for estimating a range of costs and benefits for journeys, including:
   
   (i) Personal energy expenditure (benefit)
   (ii) Direct financial cost (cost)
   (iii) Travel time (cost)
   (iv) Greenhouse Gas Emissions (cost)
   (v) Energy resource consumption (cost)

2. To develop procedures for determining the optimal route and mode for an individual’s trip in an urban area based on cost and benefit estimates and preference weights for specific objectives.

3. To use the cost and benefit estimation and optimal route generation procedures to conduct a case study for a realistic journey in Melbourne.

4. To undertake sensitivity analysis using the case study.

1.3 Thesis Structure

To achieve the above aim and objectives outlined in this chapter, Chapter 2 presents a literature review in the area of active transport, sustainable transport, behavioural change models, current journey planners, trip planning, transport modelling, GIS and local initiatives. Firstly, it describes the historic trends of active transport, followed by demonstrating the impacts of active transport on health and sustainable development. Then, it describes behavioural change models and the potential of journey planners to modify current transport behaviour as well as identifies the current functions and limitations of existing journey planners. Based on this, some basic concepts and factors affecting trip planning are presented and then developments of transport modelling are further explored and discussed. In addition, the application of GIS in
transport planning is indicated. Lastly, some local journey planning initiatives in Australia, especially in Melbourne are described.

Chapter 3 defines and develops a methodology and associated procedures for estimating a range of cost and benefit estimates for journeys to determine the optimal route for an individual’s trip based on cost and benefit estimates and preference weights for specific objectives for assisting multi-objectives decision making for selected objectives in terms of health and sustainability during the route and mode selection process. This chapter highlights the strengths of multi-criteria analysis as an appropriate method for developing the active transport journey planner.

Based on Chapters 2 and 3, Chapter 4 uses the cost and benefit estimation and optimal route generation procedures to conduct a case study for a realistic journey in Melbourne and introduces procedures for undertaking sensitivity analysis. Then the procedures are tested in an active transport journey planner model set up in Excel. Lastly, conclusions, discussions and future work are presented in Chapter 5.
Chapter 2

LITERATURE REVIEW

Introduction

This Chapter begins by introducing the concept, current situation and trends associated with active transport. Then its benefits in health and sustainability are identified in sections 2.2 ‘Health and Transport’ and 2.3 ‘Sustainable Transport’, respectively. Meanwhile, the advantages of active transport for the environment, people and economy are further discussed in section 2.3. Based on the above background, the role of information in changing people’s behaviour switching to active transport is highlighted in section 2.4 ‘Behavioural Change Models’, and the need to develop an active transport journey planner is advised. In section 2.5 ‘Journey Planner’, we look at existing journey planners worldwide. Their current functions and limitations are presented. The use of ‘metlink’ is described as an example. In order to develop an active transport journey planner, transport modelling is reviewed in Section 2.6, where the concepts of trip assignment, modal split and utility is reviewed. As we know, data collection is an important part in model development, the application of GIS in transport for collecting data is introduced in section 2.7 ‘GIS and Transport’. Lastly, some local initiatives in Australia, especially in Melbourne are described, including the Principle Bicycle Network (PBN) and SmartBus. For other cities of Australia, the achievement of TravelSmart in Perth will also be introduced.

2.1 Active Transport

What is active transport? As mentioned in Chapter 1, it relates to, ‘physical activity undertaken as a means of transport. This includes travel by foot, bicycle and other non-motorized vehicles. Use of public transport is also included in the definition as it often involves some walking or cycling to pick-up and from drop-off points. Active
transport does not include walking, cycling or other physical activity that is undertaken for recreation’ (NPHP 2001).

What percentage of the population is currently taking active transport? Much depends on the interaction of social and environmental factors with individual goals and intentions. A study in Copenhagen found that about 10 years ago, 20-30% of adults cycled to work, spending 3 hours per week on their bicycles; the proportion of cyclists dropped from 28% in the least educated to 20% in the best educated (Andersen et al. 2000). In Denmark as a whole, 46% of 25-year-old men and women used a bicycle to travel to work every day throughout the year, and this rose to about 70% during the summer months (Andersen et al. 1994). In the Netherlands, 19% of workers walked and 27% cycled to work, and in Sweden the corresponding figures were 39% and 10% (Campbell et al. 2004).

In some European developed countries, the Organisation for Economic Co-operation and Development (1999) indicated, the percentage of adults who are presently cycling is small. For example, daily cycling trips among adults in six European countries with more detailed information range from about 1 in the Netherlands to as low as 0.1 in the United Kingdom. Although these are the countries in Europe with the most cycling and walking, cars are used to make 30-65% of short trips (under 5 km).

On average, 5% of all trips in EU countries were made by bicycle in 1995 (European Commission 1999). Cycling habits vary widely. Cycling is much more common in northern countries; in Denmark and the Netherlands, for example, people make 18% and 27% of trips, respectively, by bicycle, and cycle on average 850 km per year. In Mediterranean countries, by contrast, only 1-4% of trips are made by bicycle and average annual cycling distances are 20-70 km (Dora & Phillips 2000).

What about the situation in Australia? Recently published by ABS, in March 2006, 80% of Australian people aged 18 years and over used a private vehicle to travel to work or study, 14% took public transport and 6% either walked or cycled since 1996. More than 14% of all people reported using public transport to get to their place of work or study in March 2006, up from 12% in 1996. The proportion of people who usually walk or cycle to their place of work or study has remained unchanged since 2000 (about 6%). However, more people were walking or cycling to work or study in the
Australian Capital Territory (up from 5% in 2000 to 10% in 2006) and the Northern Territory (up from 7% in 2000 to 12% in 2006) (ABS 2008).

Why gain physical activity through transport? Physical activity is defined as any body movement that results in energy expenditure (Casperson et al. 1985). More than 30% of adults in Europe are not sufficiently active in their daily life (HEPA Network 2000), and levels of physical activity are continuing to decline. Where data are available, as in the United Kingdom, obesity is increasing although calorie intake remains largely stable, and this may also apply to other European countries. In most European countries, the prevalence of obesity is estimated to have increased by 10–40% from the late 1980s to the late 1990s (Brown 2000). In Australia, it is demonstrated that in 2004-05, 70% of Australians aged 15 years and over were classified as sedentary or having low exercise levels (ABS 2006). Physical inactivity is the second most important risk factor for poor health, after tobacco smoking, in industrialized countries (Murray & Lopez 1996).

During the mid-1990s, an international consensus was established on the value of regular moderate physical activity. The World Health Organization (WHO) was among many international and national agencies that highlighted the importance of moderate activity for health, encouraging at least 30 minutes of physical activity daily. The 30 minutes can be built up over a day, so that two or three bouts of 10 or 15 minutes each provide important health benefits. The following captures much of the message for this new consensus (WHO 1995):

‘Daily activity should be accepted as the cornerstone of a healthy lifestyle. Physical activity should be reintegrated into the routine of everyday living. An obvious first step would be walking and cycling for short journeys.’

Is it reasonable to take active transport instead of car for journeys? Many journeys are short: less than 2 kilometres which is suitable for walking and less than 8 km which is suitable for cycling. In England, for example, about 25% of journeys are shorter than 1.6 km in length, and 80% of these are travelled on foot. Cars, however, are the dominant mode of travel for distances over 1.6 km (Department of Transport, Local Government and the Regions 2000). More than 30% of trips made in cars in Europe
cover distances of less than 3 km and 50% less than 5 km (European Commission 1999). These distances can be covered within 15–20 minutes by bicycle or within 30–50 minutes by brisk walking, providing the recommended amount of daily physical activity.

In addition, policies promoting a shift towards more walking and cycling as transport modes should concentrate on the trips for which motorized modes are often used but whose length easily permit their completion on foot or by bicycle; this applies to many trips shorter than 5 km (zone B in Figure 2.1) (WHO Regional Office for Europe 1998).

Figure 2.1 Number of trips made by different means of transport over different distances (Source: WHO Regional Office for Europe 1998)

In Europe the average trip taken on foot (to reach work or for leisure or shopping) is currently about 2 km and the average cycling trip is about 3–5 km (Hydén 1998). Each takes around 15 minutes, enough to provide the above-mentioned health benefits. Walking is declining as a means of transport. In the United Kingdom, miles walked fell 20% between the early 1970s and the early 1990s; the decline was larger among children (British Medical Association 1997). In Finland during the same period, the number of trips on foot dropped from 25% to around 10% and cycling trips from 12% to 7%, while trips by car increased from 45% to 70% (Henkilöliikennetutkimus 1992).
While in Australia, the most average distance travelled by persons living in Victoria to work or study was 10km to less than 20km (28%), followed by 5km to 10km (20%) and less than 5km (19%) (ABS 2006). Based on these data and research, it can be seen that many trips to work or study can be adequately switched to walking and cycling according to the distance.

What other benefits can active transport bring? Both walking and cycling as regular activities can also contribute to controlling weight. This is especially important given the rising trends of obesity in the population and the need for people to take effective action to control their weight. Obesity is defined as having a body mass index (weight in kg divided by (height in m)$^2$) (Better Health Channel 2007) over 30. It is one of the most important avoidable risk factors for several life-threatening diseases and serious ill health, including heart disease, diabetes and joint problems. Changes in body weight result from an imbalance between energy intake and expenditure. Reduced levels of physical activity appear to be the dominant factor causing the trend of increasing obesity (Prentice & Jebb 1995). A viable public health strategy is to target improving the health of those with excess weight through the beneficial effects of physical activity (Pescatello & Vanheest 2000).

In the United Kingdom, a National Audit Office (2001) study on obesity identified transport as a key area in which further action needs to be taken to encourage and assist people in being physically active in their travel routines. Among its recommendations, the National Audit Office highlighted the importance of both the health and transport sectors in tackling this epidemic (National Audit Office 2001):

‘The Department of Health and the Department of the Environment, Transport and the Regions should continue to encourage other potential partners, in particular local authorities and health authorities, to adopt local targets for cycling and walking which provide clear incentives to support healthy modes of travel. They should also put in place arrangements to monitor centrally progress towards achieving these targets.’

In order to have a more detailed and complete background about the benefits of active transport, the advantages and benefits of incorporating active transport into daily life, especially studies in walking and cycling are further reviewed.
Walking

Walking is a form of physical activity and a means of transport accessible to the vast majority of people (disabled people being an exception) regardless of age, gender and social status, provided that appropriate environmental conditions exist for making it safe, enjoyable and convenient. Walking is the dominant form of transport for journeys under 1.6 kilometres and can become an important part of intermodal transport in urban settlements if linked with efficient public transport. Walking is convenient and may also be included in occupational and domestic routines. It is self regulated in intensity, duration and frequency and is inherently safe. Walking has been associated with a lower risk of death in middle-aged men (Paffenbarger 1986) and specifically with a reduced risk of heart disease and colon cancer (Hardman 1999). Morris & Harman (1997) said:

‘Walking is a rhythmic, dynamic, aerobic activity of large skeletal muscles that confers the multifarious benefits of this with minimal adverse effects. Walking is the nearest activity to perfect exercise.’

A systematic review of strategies that promote physical activity (Hillsdon & Thorogood 1996) concluded that walking is the most important form of physical activity that should be encouraged to improve public health given that it is the activity most widely available. The authors noted that (Hillsdon & Thorogood 1996):

‘Interventions that encourage walking and do not require attendance at a facility are most likely to lead to sustainable increases in overall physical activity.’

Cycling

Compared with walking, the health benefits of cycling are somewhat greater because the intensity of effort is greater (Oja et al. 1998). Cycling uses the large skeletal muscles of the body in a rhythmic pattern, with periods of active work alternating with rest periods. In addition, longer periods of rest occur in normal urban cycling, determined by such factors as traffic lights and other road users. Rest periods allow recovery from high levels of activity when in motion. These factors make it a highly
suitable activity to provide aerobic exercise and thereby to improve physical fitness (Pearce 1998).

Several recent field experiments have included cycling to test the effects of physical activity on health. For example, the Copenhagen Heart Study, which involved 13,375 women and 17,265 men aged 20–93 years, found that cycling has a strong protective function. Assessed by self-reported health, blood pressure, cholesterol, body mass index and risk factors such as smoking, it concluded that (Andersen 2000):

‘even after adjustment for other risk factors, including leisure time physical activity, those who did not cycle to work experienced a 39% higher mortality rate than those who did.’

Research in the Netherlands (Hendriksen 1996) has demonstrated that cycling as part of normal daily activities can yield improvements in physical performance similar to those of specific training programmes. The higher the total distance cycled during the 6-month trial period of activity, the higher the gain in maximal external power and maximal oxygen uptake. For those with a low initial fitness level, a single trip distance of 3 km per day on at least 4 days per week is enough to improve physical performance (Hendriksen 1996).

This confirms that the greatest health gains can be achieved when the least active individuals become moderately active (Blair & Connelly 1995). Similarly, a study of non-exercisers in the United Kingdom who agreed to take up cycling on at least 4 days per week (Department of Environment, Transport and the Regions 1999) found the greatest benefits were near the beginning of the intervention, and the more the volunteers cycled, the fitter they became. Body fat also declined significantly among 59% of the volunteers who were overweight or obese at the outset. The extent of the fat loss, typically 2–3 kg of fat mass over the period of the trial, should mean that they achieve a change in energy balance, making it easier for them to control their weight while they continue to cycle.

From the review of studies on walking and cycling, it can be concluded that walking and cycling clearly provide the opportunity for regular, moderate physical activity. This includes local journeys to schools and workplaces, especially for the majority of
Europeans who live in urban areas, where trip distances are often short. For example, practical trials have demonstrated this for commuting and concluded that (Oja et al. 1998): ‘Walking and cycling during work trips currently provide the possibility for regular physical activity for a considerable proportion of the working population, and there is potential for a substantial increase of actively commuting people.’

Based on this conclusion, it can be similarly expanded to Australia, for those who live in urban areas, walking or cycling to work or study is a good way to bring significant health benefits to individual travellers. Whereas, for those who live in suburban areas, taking public transport, such as train, tram or bus and then transferring to cycling or walking, can also bring many positive impacts on people’s health.

On the basis of the review of the concept and benefits of active transport, it can be seen that active transport plays a significant role in people’s daily life. Then, how about the promotion of active transport so far? Are there any constraints or opportunities? With several events, campaigns or projects introduced, organized and held in Australia, such as ‘TravelSmart’ (see travelsmart.gov.au), ‘Walk to Work Day’ and ‘Ride to Work Day’ initiated by ‘Go for your Life’, (see goforyourlife.vic.gov.au), active transport has been gradually introduced to people from concept to action. However, the public health efforts to increase physical activity have so far focused largely on education and skill development in individuals, as well as physical activity as leisure. Rarely have they considered environmental determinants of people’s choice of and ability to maintain regular physical activity, and built on these to design interventions to promote physical activity (Dora & Phillips 2000). Constraint factors such as the availability of public transport, high housing density and street connectivity have all been shown to be associated with higher levels of physical activity (Dora & Phillips 2000). In addition, evidence shows that people are more likely to take up activities that are easy to fit into the daily schedule and have reasonable cost (Dora & Phillips 2000). These can be regarded as an opportunity to involve more and more people in using active transport for individual trips.

In addition, Dombois et al. indicated, behaviour change campaigns, such as personalized travel planning, should be easily incorporated into people’s daily life (Dombois, Kahlmeier, Martin-Diener, Martin, Racioppi & Braun-Fahrländer 2006). Meanwhile, a report on the ROMANSE project, which provides real-time information,
stated that the greatest potential impact on travel behaviour was the provision of 'pre-trip in-home information' (Powell 1993). Therefore, it will be a great opportunity to plan an individual’s journey which includes more active transport modes and potentially change people’s travel behaviour towards a more active and healthier lifestyle.

2.2 Health and Transport

Although the general description of health benefits brought by active transport is reviewed above, in order to have a more informed knowledge of the relationship between health and transport, as well as the necessity of switching to active transport under current circumstances, the aspect of health and transport is going to be reviewed further in detail below.

In Australia, the Government is concerned about the increasing prevalence of obesity and chronic diseases. Research shows approximately 3.3 million Australians are obese, with another 5.6 million overweight (Australian Institute of Health and Welfare 2003). In Victoria, obesity is ranked second as a cause of premature death and disability, contributing to 8% of the overall burden of disease (Department of Human Services 2005). Disturbingly, the prevalence of overweight Australian children almost doubled during the last decade, while levels of obesity more than tripled.

Conservative estimates indicate that 23% of Australian children are overweight or obese (Booth et al 2001). Over the last two decades obesity rates among adults have also increased. Between 1980 and 2000, rates of obesity or overweight among males aged 25 to 64 years increased from 47.3% to 65.7%. Among women, the rate increased from 27.2% in 1980 to 46.5% in 2000 (Department of Human Services 2005). Due to the low rates of activity levels in Australia, it is suggested that no one group is more ‘at risk’ from inactivity and the whole community should be targeted, as there is a need to increase physical activity levels across most groups.

WHO recently reviewed the evidence for the health effects of physical activity (Grundy et al. 1999). It is summarized here:
CVD

The strongest evidence indicates that the greatest benefit of physical activity is in the reduction of CVD risk (Berlin & Colditz 1990; Powell et al. 1987). Inactive people have up to twice the risk of heart disease of active people. Physical activity also helps to prevent stroke (Ellekjaer et al. 2000; Wannamethee & Shaper 1999) and improves many of the risk factors for CVD, including high blood pressure and high cholesterol (Hardman & Stensel 2003).

Overweight and obesity

Low levels of physical activity are a significant factor in the dramatic increase in obesity prevalence in the European Region. Obesity occurs when energy intake (dietary intake) exceeds total energy expenditure, including the contribution of physical activity (Bull et al. 2004). Body weight normally increases with age, but habitual, lifetime physical activity can reduce weight gain. Participation in appropriate amounts of activity can support healthy weight maintenance or even weight loss (Grundy et al. 1999). It is also extremely important for people who are already overweight or obese (Department of Health 2004).

Diabetes

Diabetes is an increasing concern in the Region, as rates of type 2 (non-insulin-dependent) diabetes increases. Type 2 diabetes typically occurs in adults aged over 40, although cases are emerging among children and young people as obesity rates rise. Strong evidence indicates that physical activity helps to prevent type 2 diabetes (Ivy, Zderic & Fogt 1999); the risk for active people is about 30% lower than that for inactive people (Tuomilehto et al. 2001). Both moderate and vigorous-intensity physical activity reduces the risk (Hu et al. 1999; Folsom & Kushi 2000; Okada et al. 2000; Colditz), but it must be undertaken regularly.

Cancer

Physical activity is associated with a reduction in the overall risk of cancer. Numerous studies have shown the protective effect of physical activity on the risk of colon cancer (Cannuscio & Frazier 1997; IARC 2002; Thune & Furberg 2001); the risk for
active people is around 40% lower. Physical activity is also associated with a reduced risk of breast cancer among postmenopausal women (Gammon et al. 1998; Latikka, Pukkala & Vihko 1998; Verloop et al. 2000; Tehard et al. 2006), and some evidence shows that vigorous activity may provide a protective effect against prostate cancer in men (Giovannucci et al. 1998).

Musculoskeletal health

Participation in physical activity throughout life can increase and maintain musculoskeletal health, or reduce the decline that usually occurs with age in sedentary people (Brill et al. 2000). Participation by older adults can help maintain strength and flexibility, helping older people to continue to perform daily activities (Brill et al. 2000; Huang et al. 1998; Simonsick et al. 1993). Regular activity can also reduce older adults’ risk of falls and hip fractures (Grisso et al. 1997; Gillespie & McMurdo 1998; Kujala et al. 2000; Gregg, Pereira & Caspersen 2000). Participation in weight-bearing activities (such as jumping or skipping) helps to increase bone density (Gutin & Welten D et al. 1994) and prevent osteoporosis (Department of Health 2004). This is particularly important for the development of bone density in adolescents (Kasper1992) and for middle-aged women (Zhang, Feldblum & Fortney 1992).

Psychological well-being

Physical activity can reduce symptoms of depression and, possibly, stress and anxiety (Dunn, Trivedi, & O’Neal 2001; Glenister 1996; Hassmen, Koivula & Utela 2000; Paffenbarger et al. 1994). It may also confer other psychological and social benefits that affect health. For example, it can help build social skills in children (Evans & Roberts 1987), positive self-image among women (Maxwell & Tucker 1992) and self-esteem in children and adults (Sonstroem 1984), and improve the quality of life (Laforge et al. 1999; Morans & Mohai 1991). These benefits probably result from a combination of participation itself and the social and cultural benefits of physical activity.

It was previously thought that only vigorous, uninterrupted exercise, such as jogging, could provide health benefits (Pate et al. 1995). While the benefits of physical activity increase with the intensity and frequency of exercise, the greatest come from when
people who have been sedentary or minimally active engage in moderate activity. In addition, moderate physical activity is a more realistic goal for most people and carries a lower risk of cardiovascular or orthopaedic complications than vigorous activity. It is therefore safer to recommend for the general population.

A total of 30 minutes of brisk walking or cycling a day, on most days, even if carried out in ten to fifteen-minute episodes, reduces the risk of developing cardiovascular diseases, diabetes and hypertension, and helps to control blood lipids and body weight (Murphy & Hardman 1998). Also, physical activity has major beneficial effects on most chronic diseases. These benefits are not limited to preventing or limiting the progression of disease, but also include improving physical fitness, muscular strength and the quality of life (Pedersen & Saltin 2006). This is particularly important for older people, as regular physical activity can increase the potential for independent living.

Convincing scientific evidence now shows the substantial health benefits of physical activity (US Department of Health and Human Services 1996; Morris & Hardman 1997). Walking and cycling to work have been shown to meet metabolic criteria for achieving health benefits from exercise (Oja et al 1998). The health benefits of regular sustained physical activity include (Vuori & Oja 1998):

- a 50% reduction in the risk of developing coronary heart disease (a similar effect to not smoking);
- a 50% reduction in the risk of developing adult diabetes;
- a 50% reduction in the risk of becoming obese;
- a 30% reduction in the risk of developing hypertension;
- a 10/8-mmHg decline in blood pressure in people with hypertension (a similar effect to drugs);
- reduced osteoporosis;
- relief of symptoms of depression and anxiety; and
- prevention of falls in the elderly.

As the Victorian Government’s ‘Go for your life’ strategic plan 2006-2010 addressed, the objectives for improving physical activity are increasing physical activity levels, reducing sedentary behaviour as well as increasing active transport (Victorian
Increases in active transport are likely to have significant direct health benefits. By improving physical activity through active transport, the development of chronic diseases like diabetes and cardiovascular disease can be prevented, with significant personal, social and economic benefits. There is strengthening evidence around the benefits of physical activity for the community as a whole.

Tackling healthy issues, such as physical inactivity, is not solely an individual responsibility. Society is responsible for creating conditions that facilitate active living. Consequences for communities and societies of sustainable transport will be significant. The Australian Government recognises that the entire community needs to be involved in these activities and will work together with industry organisations, businesses, research institutions, community groups and schools to develop and deliver the active transport program (Victorian Government 2006), such as ‘ride to work day’ (see ride2work.bv.com.au/home) and ‘walk to work day’ (see goforyourlife.vic.gov.au/hav/events.nsf/pages/Walk_to_Work_Day?Open).

The National Public Health Partnership update on evidence for physical activity and health, Getting Australia Active II (Bull et al 2004) quotes a recent Danish study that showed cycling to work reduces mortality risk, providing clear and positive evidence regarding active commuting.

2.3 Sustainable Transport

Besides its health benefits, active transport can also bring significant impacts towards a sustainable future. Thus, active transport can also be regarded as sustainable transport. Besides considering the health impacts for journey planning, sustainable factors can also be included into the trip planning stage. Therefore, the benefits and necessity of active transport in terms of environmental, social and economic sustainability are reviewed.

In many large cities throughout the world, residents and administrators are realizing that our reliance on cars, particularly for single personal journeys, is becoming unsustainable. As TravelSmart (2006) indicated, traffic congestion and delays, the
extremely high cost of advanced road systems, air and noise pollution and our increasing dependence on non-renewable fuels are some of the more readily recognized reasons that people are concerned. In addition, studies are now showing that there are serious personal health and social consequences of high levels of car travel. There is a further concern that Australians may be ‘building in’ car dependency into children, making the problems much worse in the future (TravelSmart 2006).

TravelSmart Australia brings together the many community and government based programs that are asking Australians to use alternatives to traveling in their private car; asking people to make voluntary changes in their travel choices, encouraging people to use other ways of getting about rather than driving alone in a car. For example, trains, trams, buses, cycling or walking (TravelSmart 2006).

All the travel modes recommended by TravelSmart for sustainability are active transport modes. Active transport, or say sustainable transport can bring significant benefits in environmental, social and economic sustainable development. Each of these areas is discussed in detail below.

**Environment**

In addition to the health benefits derived directly from physical activity, replacing some motorized trips by walking and cycling brings additional and important health benefits by reducing air pollution and noise and contributing to improve the quality of urban life. Improvements in the quality of life include creating more protected space for pedestrians and cyclists.

In Australia, in 2005, Victoria’s total net greenhouse gas emissions were 121.87 million tonnes (CO2-e). Victoria’s total emissions are higher than some nations, including other industrialised countries with significantly higher populations, such as Austria, Hungary, Portugal, Slovakia, Sweden and Switzerland (State Government of Victoria 2009). Focusing on the transport sector, it accounted for about 14% of Australia's net greenhouse gas emissions. Between 1990 and 2005, the carbon dioxide equivalent emissions (CO2-e) from the transport sector grew by 30% or 18.5 million
tonnes (Australian Greenhouse Office 2007). The Australian Government has introduced initiatives such as the National Travel Behaviour Change Project, which is due to run from 2008 to 2012 (AGO 2006). Such programs seek to encourage people to reduce their reliance on private motor vehicles and consider more sustainable modes of travel, such as public transport, walking or cycling.

In 2005, transport accounted for about 14% of Australia’s net emissions (80.4 megatons (Mt) of carbon dioxide equivalent), 30% higher than the 1990 level, with an annual growth of almost 2%. Road transport was the main source of transport emissions in 2005 (87.9% or 70.7 Mt), of which passenger cars contributed nearly two-thirds (43.7 Mt) (ABS 2008). The transport sector (including household transport) is the largest end user of energy, using 1,264 petajoule (1 PJ = 10^{15} J) in 2000-01. In 2000-01, road transport accounted for 77% (975 PJ) of the sector’s energy use, of which over 40% can be attributed to household activity. Air transport energy use has increased by 87% since 1989, to 204 PJ in 2000-01 (ABS 2004).

The data flow of transport emissions and total emissions from 1988 to 2008 are illustrated in Figure 2.2. Climate change is one of the greatest environmental, economic and social challenges of our time, and the way we choose to travel impacts on greenhouse pollution (Victorian Government 2008). Two ways to save our environment are: to use less polluting forms of transport more often; and to ensure that all forms of transport are as environmentally friendly as possible.

![Figure 2.2 Victorian Transport and Total GHG Emissions](Source: Department of Climate Change 2006)
A majority of the world’s scientists agree that human activities have resulted in observed increase in global average temperatures, particularly since the middle of the 20th century. Recent data indicates that the global mean temperature has increased by between 0.2 and 0.6°C since the late 19th century, while Australian average temperatures have increased by 0.8°C. Earth’s average temperature might increase by up to 5.8°C over the next 100 years, if greenhouse gas concentrations continue to increase (State Government of Victoria 2009).

As the average global temperature rises, it will lead to other changes in weather. Storm patterns and severity might increase, sea levels will rise, and floods and drought may become more frequent and more severe. Some changes to the climate are inevitable – even if we stop emitting greenhouse gases now, the gases we have already released will have an effect. However, we must do everything we can to avoid further changes, and to adapt to the impacts of climate change (State Government of Victoria 2009).

How can we solve the problem or stop it moving to a worse situation? Over the past decade, it has become clearer that environmental interventions may be a key to promoting physical activity (Owen 2000). Improving local environments so that they are perceived as being attractive and safe and can meet everyday travel needs is important (ADONIS 1998). The importance of walking and cycling as means to achieve greater sustainability and attain health gains from transport was recognized in the Charter on Transport, Environment and Health adopted by Member States of the European Region of WHO in 1999 at the Third Ministerial Conference on Environment and Health (WHO Regional Office for Europe 1999).

In Australia, the Victorian Government is working to reduce emissions from the transport sector. Emissions from transport arise from the combustion of fossil fuels in vehicles. Consequently, there are two directions Victoria can pursue to lower these emissions: firstly, to reduce vehicle use through sound, sustainable urban planning to minimise the need for cars and encourage more sustainable forms of transport; secondly, to reduce vehicle emissions through new technologies, such as petrol-electric hybrids or by exploring alternative fuels, like biofuels (Victorian Government 2008).
Before the relative long-term discovery, research, development and application of new technologies, enabling people to walk, choose public transport, ride motor bikes, scooters and bicycles will reduce emissions more quickly. This vision builds on the Government’s long term strategies for building a more efficient and less polluting transport system. Since 1999, significant investment in public transport, walking and cycling has enabled a shift in behaviour towards increased use of these more efficient modes of travel (Victorian Government 2008).

From an energy perspective, in terms of fossil fuel energy, none is used in walking, little for cycle manufacturing, and less during manufacturing and operation for public transport, compared with private motor vehicles. Thus, switching to active transport, which is also sustainable transport, can significantly reduce the energy consumption in the transport sector, which consequently contributes to the sharp reduction of greenhouse gas emissions.

In conclusion, active transport can contribute to a more efficient and sustainable transportation system. Increasing the number of people using active transport can reduce road congestion benefiting all road users, especially during peak hours. Active transport is non-polluting and is among the most environmentally friendly forms of transport. Substituting motorized transport with active transport can therefore bring about reductions in greenhouse gas emissions, air pollution, water pollution, noise and land used for transport. The primary environmental benefit of active transport is improved air quality and decrease global warming.

**Social**

In addition to the direct effects on health and environment, physical activity can benefit society, the economy and, indirectly, other health behaviour. Positive social effects active living offers people include the opportunity to interact with others, the community and the environment.

From an individual’s perspective, personal factors that are positively associated with physical activity (Sallis & Owen 1999; Trost et al. 2002) include:
• self-efficacy (belief in one’s own ability to be active);
• intention to exercise;
• level of perceived health or fitness;
• self-motivation;
• social support;
• expectation of benefits from exercise; and
• perceived benefits.

In conclusion, increasing the use of active transport can provide benefits both at the individual level and the social level. It can create more liveable cities and increase people’s mobility. When people use active transport they are more likely to have personal contact with others, leading to a greater sense of community. Active transport modes are also inexpensive compared to personal vehicles. Since not everyone can afford a car, making investments to accommodate active transport can increase the population’s mobility as well as the overall equity of the transportation system.

**Economic**

Besides the costs in terms of mortality, morbidity and quality of life mentioned above, physical inactivity extracts high financial costs from countries across the Region. For example, the annual costs in England – including those associated with the health system, days of absence from work and loss of income due to premature death – have been estimated to be €3–12 billion (Department for Culture, Media and Sport (DCMS) and Strategy Unit 2002). This excludes the contribution of physical inactivity to overweight and obesity, whose overall cost might run to €9.6–10.8 billion per year (The Stationery Office 2001).

In addition, the economic costs of physical inactivity affect national economies, as shown by the following examples taken from studies of particular policies. In one United States study, costs associated with inactivity were between US $24.3 billion (2.4% of total health care costs) and US $37.2 billion (3.7%) for direct health care (Colditz 1999). Direct costs comprise diagnosis and treatment related to any disease.
(including hospital stay, nursing home, medication and physician services). When obesity costs are included (Colditz 1999):

‘...a minimum of 9.4% of all direct costs incurred in delivering health care in the U.S. are attributable to insufficient energy expenditure which directly leads to medical conditions or alternatively the accumulation of adiposity [excess fat] which then contributes to excess morbidity and mortality.’

In Europe, a study in Switzerland (Davis 2002) estimated that insufficient levels of physical activity cause 1.4 million cases of disease and 2000 deaths and cost about Swiss Franc 2.4 billion per year. In England, the estimated annual direct and indirect costs of obesity in 1998 amounted to £2.6 billion, and if present trends continue these costs may increase by a further £1 billion per year by 2010 (National Audit Office 2001).

Conversely, the potential reduction in the costs of treating heart disease if sedentary adults walked regularly has been calculated in the United States (Jones & Eaton 1994); US $5.6 billion would be saved annually if 10% of adults began a regular walking programme. The cost savings from walking would be especially high for men aged 35–64 years and for women aged 55–64 years (Jones & Eaton 1994).

Similarly, a Swiss study estimated the direct treatment costs of physical inactivity at €1.1–1.5 billion (Cavill, Kahlmeier & Racioppi 2006). On the basis of these two studies, physical inactivity can be estimated to cost a country about €150–300 per citizen per year. Increasing current levels of activity could significantly reduce the costs to society, but even maintaining them can result in savings. For example, the Swiss study estimated the savings on direct treatment costs for the physically active at about €1.7 billion (Cavill, Kahlmeier & Racioppi 2006).

In Australia, the Bureau of Infrastructure, Transport and Regional Economics (BITRE) estimates that the ‘avoidable’ costs of traffic congestion totalled approximately $9.4 billion in 2005 across Australian capital cities (BTRE 2007).

Based on the previous reviews, it can be acknowledged that the transport system can strongly influence opportunities to be physically active, both by facilitating walking
and cycling and by enabling people to get to places to be active. A recent systematic review of walking and cycling as an alternative to using cars (Ogilvie et al. 2004) found evidence that targeted programs can change the behaviour of motivated subgroups. For example, the TravelSmart study in Perth, Australia found a shift of 5.5% of all trips from car travel to walking, cycling or public transport in the intervention area after six months, compared with a 2% shift towards the car in a neighboring control area (Department for Planning and Infrastructure 2003). These projects also promoted increased use of public transport, which can often result in increased walking compared to trips by car.

In conclusion, many of the economic benefits of active transport accrue to the individual since significant cost savings are possible when using active transport instead of a car for short trips. Reduced health care costs, however, benefit society as a whole through a less costly medical system and fewer sick days taken from work.

It can be concluded that, active transport or say sustainable transport can be significantly beneficial to the environmental, social and economic aspects as an integral system.

2.4 Behavioural Change Models

On the basis of the awareness of the benefits of active or sustainable transport from health, environment, social and economic aspects, the next step is to consider how to change people’s travel behaviour to take active or sustainable transport modes. Some behavioural change models will be reviewed here.

Changing people’s behaviour is a complex and long term challenge. But with levels of obesity among children increasing at an alarming rate, it is a challenge that cannot be ignored (Victorian Government 2006). Action is required now to ensure that Victoria has the healthy workforce and population required to build a strong economy and maintain our high standard of living, and to ensure that current and future generations of Victorians enjoy the benefits of long, healthy and active lives (Victorian Government 2006). An earlier review (National Institute for Health and Clinical Excellence 2005) identified using theories of behaviour change to teach skills and
tailor interventions to individual needs. In addition, a report on the ROMANSE project, which provides real-time information, stated that the greatest potential impact on travel behaviour was the provision of ‘pre-trip in-home information’ (Powell 1993). Thus, it is an effective way to provide detailed information regarding active and sustainable transport options to an individual traveller which can potentially change personal travel behaviour.

Why are some people active and others not? A complex range of factors – in the individual and the micro and macro environments (Figure 2.3) – influences the likelihood that an individual, group or community will be physically active.

Based on Figure 2.3, factors in the macro environment include general socio-economic, cultural and environmental conditions. Influences from the micro environment include the conduciveness of living and working environments to physical activity, and the supportiveness of social norms and local communities. Individual factors such as attitudes towards physical activity, belief in one’s ability to be active or awareness of opportunities in daily life can influence the likelihood that someone will try a new activity (Sallis & Owen 1999; Trost et al. 2002).

![Figure 2.3 Determinants of Physical Activity](Source: Cavill, Kahlmeier & Raciopp 2006, p 12)

Considering the direct impacts on health from active transport, for over four decades, the Health Belief Model (HBM) has been one of the most widely used conceptual frameworks in health behaviour. HBM has been used both to explain change and maintenance of health behaviour and as a guiding framework for health behaviour
interventions. In general, it now is believed that individuals will take action to ward off, to screen for, or to control an ill-health condition if they regard themselves as susceptible to the condition, if they believe it to have potentially serious consequences, if they believe that a course of action available to them would be beneficial in reducing either their susceptibility to or the severity of the condition, and if they believe that the anticipated barriers to (or costs of) taking the action are outweighed by its benefits (Strecher et al. 1996).

In the trip planning stage, besides macro and micro impacts to the decision maker, individual factors play a key role. Aiming to understand what influences personal choices and predict population choice, behavioural (or discrete) choice models are introduced to quantify in a meaningful way a relationship between discrete choice and a set of explanatory variables. During the trip planning, if people have clear ideas of how many benefits can be achieved and how many costs can be saved, as well as their trade-offs in taking active transport, it will help people make good decisions towards a healthier life style based on HBM theory.

It is acknowledged that the probability of an individual choosing a given option is related to their socioeconomic characteristics and the relative attractiveness of the option, which can be further aggregated to estimate overall demand and estimate the significance and importance of exploratory variables for compromising numerous components and interactions that influence choice. Within the ‘Conceptual Model of the Transport Choice Process’, the following key concepts are introduced by Thompson (Richardson 1982):

*System Characteristics*

Physical and operational characteristics of the system in order to accurately represent the choice environment.

*Decision Maker Characteristics*

Decision maker characteristics are characteristics that influence individuals’ choices. It is assumed that individuals possess a set of attitudes relating to the importance of the various attributes of alternatives, e.g. the income, time budget, etc.
Choice Set Generation

The set of alternatives being considered when making a choice, which is based on the assumptions that each alternative is independent and available. Information can help people consider other alternatives, e.g. bike availability or ownership.

Constraints

Including: voluntary constraints; perceptual constraints; regulatory constraints; physical constraints; system constraints; personal constraints; e.g. health, fitness, time and financial budget.

Importance Hierarchy

Importance that an individual associates with particular attributes of alternatives; market segmentation techniques can identify difference rankings of importance for different groups (or homogeneous sub-population) within the population, e.g. travel time is critical for travelling to work in the morning.

Attribute Set Generation

Set of attributes of alternatives being considered.

Attribute Perception

Decision makers base on their perception of the values of the attributes of alternatives rather than the real or objective values. Trip planning software can assist in changing people’s perceptions of energy expenditure, carbon emissions and energy resource consumption, etc.

Attribute Evaluation

That is individual feeling about the perceived level of an attribute.

Composite Evaluation

Combine attribute perceptions and evaluations with an importance hierarchy to
represent the overall worth of an alternative, which is beneficial to determine a generalized benefit or utility.

*Behavioural Intent*

Identifying how the preferred alternative is determined, given a measure of worth for each alternative.

*Choice inertia*

Many factors that tend to maintain the status quo and mitigate against change, e.g. feedback, habit, reinforcement.

On the basis of these individual factors in the decision-making process, as mentioned previously, the percentage of active transport users mainly depends on social and environmental factors interacting with individual’s intention and goals. Green and Kreuter (1991) classify these factors as predisposing, reinforcing, and enabling and note that collectively, they increase the likelihood that behavioural and environmental change will occur. Predisposing factors are the antecedents that provide the rationale or motivation for a behaviour. They include an individual’s knowledge, attitudes, beliefs, personal preferences, existing skills, and self-efficacy beliefs. Reinforcing factors are those elements that appear subsequent to the behaviour and that provide continuing reward or incentive for the behaviour to become persistent. Enabling factors are antecedents that enable motivation to be realized; they can affect behaviour directly or indirectly through an environmental factor. They include the programs, services, and resources necessary for behavioural and environmental outcomes to be realized and, in some cases, the new skills needed to enable behaviour change (Green and Kreuter 1991). Based on this, regarding promoting behavioural change towards active transport, it is not only important that the individual has an intention to improve or maintain personal physical or psychological health as well as contributing to the international or national sustainable development, but also the attraction of the reliability, availability, convenience and easy access to the active and sustainable transport environment and services could play an important role to assist people in changing towards a healthy and sustainable future.
Thus, the role of information is a significant key in decision making. For someone who does not intend to be active, lack of information or resources may be unimportant. However, if a person had strong intentions to be active, access to adequate information or resources might determine whether a traveller’s attempt was successful. Intention can interact with access to information or resources. Therefore, an on-line active transport journey planning system can play an important role in providing active transport options and detailed information on health and sustainability concerns. With an easily accessible active transport planning system wherever and whenever the internet is connected, it can meet people’s needs for acquiring the information they want, such as transport modes, travel distances or times, related health and sustainability benefits which can facilitate changing travel behaviour towards a healthier and more sustainable travel option.

In many capital cities, people can use an online transport planning system to acquire public transport information about timetables, services, fares and ticketing, such as ‘metlink’ (see metlinkmelbourne.com.au) in Melbourne. In terms of the trend to switch to active and more sustainable forms of transport and the existing technology of journey planner on-line systems, it will be very helpful to have an improved system involving active transport options as well as more detailed information regarding sustainability for an individual traveller to easily select their travel preferences in daily transport which can potentially change people’s travel behaviour towards a healthier and more sustainable future.

How may information assist in encouraging persons to try more active transport? Seethaler & Rose summarized (2003) that appealing to deeply seated human needs, the six persuasion principles of Reciprocity, Consistency, Social Proof, Authority, Liking and Scarcity can be translated into practical communication strategies that will increase the personal involvement of a target population and secure a lasting change in behavioural patterns.

2.5 Journey Planners

As discussed earlier, behaviour change campaigns, such as personalized travel planning, could easily be fit into people’s daily transport (Dombois, Kahlmeier,
Martin-Diener, Martin, Racioppi & Braun-Fahrländer 2006). A real-time online information system such as journey planner has the greatest potential impact on travel behaviour with the provision of ‘pre-trip in-home information’ (Powell 1993).

The Existing journey planners (see theaa.com or thetrainline.com) typically concentrate on one mode of transport, providing information on mileage and directions, or number of stages and the time each will take. Transport Direct (see transportdirect.gov.uk), a national journey planning service, extends this across routes combining all forms of transport including bus, train, air and car. So has the similar function of the journey planner in Chicago, USA (see tripsweb.rtachicago.com). In Australia, there are also several journey planners available for users in the major cities, such as ‘metlink’ in Melbourne (see metlinkmelbourne.com.au), ‘131500 Transport Infoline’ in Sydney, (see 131500.info/realtime/newjourney.asp), ‘TRANSLink’ (see jp.transinfo.qld.gov.au) in Brisbane, ‘Transperth’ in Perth (see transperth.wa.gov.au), and ‘Adelaide Metro’ in Adelaide (see adelaidemetro.biz/planner.php). Their simple functions include providing users with transport information based on start/end location and departing/arriving time. Advanced functions include users being able to choose their preferences for transport mode, trip and other special requirements, such as fewest changes, use only services with wheelchair accessible vehicles, etc.

How do journey planners work? Many are similar. Let’s take ‘metlink’ for example here. According to the user document of ‘metlink’ journey planner (2007), it enables you to plan journeys throughout Melbourne and Victoria. There are four steps followed (metlink 2007):

Step 1 – enter your origin and destination

The origin and destination are entered in the ‘From’ and ‘To’ fields. You can enter an address, station or stop, or a landmark.

Step 2 – choosing the departure or arrival preference

Select ‘Departing’ if you want to specify the date and time that you want to leave. Or select ‘Arriving’ if you want to specify the date and time you want to get to your destination.
Step 3 – Entering the date and time of the journey

The journey planner search screen, displays the current date and time. If you want to plan your journey in advance, you must change the date or select a date using the calendar function.

Step 4 – Click Search

Click Search to begin searching for a travel plan. If you wish to clear the form and start again, click Reset.

Although existing journey planners provide schedule and duration information effectively, realistic transport decisions involve many constraints, such as weather, safety, fitness and environmental concerns. However, instead of developing a brand new technology, some work can be done based on existing journey planning systems, such as using its current database including travel distance, schedule and duration as well as its related public transport modes and route numbers. The next step is however to analyze the journey planning system and address the lack of constraints or multiple objectives involving health and sustainability concerns. Under the current circumstances, it is necessary to include health and sustainability factors in journey planning. Thus, this research extends the existing journey planner concept to allow users to choose between available active transport routes based on their multi-objective preferences and priorities for transport options.

2.6 Transport Modelling

This review has provided a background of the concepts and implementation issues of active transport. The necessities of switching to active transport as well as its significant health, environmental, social and economic benefits have been identified. From behavioural change models, it is acknowledged that information can play an important role in changing travel behaviour. Furthermore, journey planners, which provide information to individual travellers, have a potential to change person’s travel behaviour. Although existing journey planners provide schedule and duration information effectively, realistic transport decisions involve multiple objectives. Thus,
there is a need to improve current journey planners to allow users to choose between available active transport options regarding their multi-objective preferences for journeys. In order to develop an active transport journey planner, transport modelling will be reviewed.

What is a journey? A journey is a one-way movement from a point of origin to a point of destination. Now, although the word ‘trip’ is literally defined as ‘an outward and return journey, often for a specific purpose’ (Ortuzar & Willumsen 1990, p94), in transport modelling both terms are used interchangeably.

Are there any factors affect the decision-making during the journey planning stage? Many factors affect journey planning. The following factors have been proposed for consideration in many practical studies (Ortuzar & Willumsen 1990, p 97): income, car ownership, household structure, family size, value of land, residential density, and accessibility. Other factors, identified from the previous reviews, such as increased concerns on health and sustainability may also impact trip planning.

Years of experimentation and development have resulted in a general structure which has been called the classic transport model, see Figure 2.4. The structure is, in effect, a result from practice in the 1960s but has remained more or less unaltered despite major improvements in modelling techniques during the 1970s and 1980s (Ortuzar & Willumsen 1990, p 23).

The general form of the model is depicted in Figure 2.4. The approach developed by Ortuzar & Willumsen (1990, p 23) starts by considering a zoning and network system, and the collection and coding of planning, calibration and validation data. These data would include base-year levels for populations of different types in each zone of the study area as well as levels of economic activity including employment, shopping space, educational and recreational facilities. These data are then used to estimate a model of the total number of trips generated and attracted by each zone of the study area, which is called trip generation. The next step is the allocation of these trips to a particular destination, in other words their distribution over space, thus producing a trip matrix. The following stage normally involves modelling the choice of mode and this results in modal split, i.e. the allocation of trips in the matrix to different transport modes.
Finally, the last stage in the classic model requires the assignment of the trips by each mode to their corresponding networks: typically private and public transport.

However, transport planning models on their own do not solve transport problems. To be useful they must be utilized within a decision process adapted to the chosen decision-making style. The classic transport model was originally developed for an idealized normative decision-making approach. Its role in transport planning can be presented as contributing to the key steps in a ‘rational’ decision-making framework as in Figure 2.5, (Ortuzar & Willumsen 1990, p 26).
Before describing Figure 2.5, there is a need to understand what the ‘rational’ decision-making approach is and how it can help transport modelling. Normative decision theory is a rational decision-making approach. The decision problem is seen as one of choosing options from a complete set of alternatives and scenarios; the utility of each alternative is quantified in terms of benefits and costs and other criteria like environmental protection, safety, and so on. In some cases it may be possible to cast a decision problem into a mathematical programming framework. This means that the objectives function is well understood and specified, and that the same applies to the constraints defining a solution space. Behavioural decision theory is an attempt to soften the edges of the normative decision-theory approach by recognizing that often decision makers are not utility maximisers but simply satisfiers (Ortuzar & Willumsen 1990, p 10).

With active transport journey planners, an individual traveller is going to choose from a set of feasible transport alternatives based on their defined constraints, the utility or disutility of each alternative is quantified in terms of its cost and benefit estimates on multiple objectives or criteria as well as their corresponding preferences or priorities. A mathematical model is presented in Chapter 3.

The rational decision making procedure with models as indicated by Ortuzar & Willumsen (1990, p 26) in Figure 2.5 includes:

1. Formulation of the problem

A problem can be defined as a mismatch between expectations and perceived reality. The formal definition of a transport problem requires reference to objectives, standards and constraints. Objectives reflect the values implicit in the decision-making process, a definition of an ideal but achievable future state. Standards are provided in order to compare, at any one time, whether minimum performance is being achieved at different levels of interest. Constraints can be of many types, financial, temporal, geographical, technical, etc. In reality, an active transport journey planner is needed to assist an individual traveller obtain information on active transport regarding health and sustainability. Thus, the objectives, standards and constraints relate to health, environmental, social and economic factors.
2. Collection of data

Details of the present state of the system of interest are required in order to support the development of the analytical model. Of course, data collection is not independent from model development, as the latter defines which types of data are required: data collection and model development are closely interrelated. Thus, besides corresponding data of the objectives, standards or constraints to be collected during the development of an active transport journey planner, the decision variables and parameters are going to be generated as well.
3. Construction of an analytical model of the system of interest

The tool-set can be used to build transport models including demand and system performance procedures from a tactical and strategic perspective. In general, one would select the simplest modelling approach which makes possible a choice between schemes on a sound basis. The construction of an analytical model involves specifying it, estimating or calibrating its parameters and validating its performance with data not used during calibration.

4. Generation of solutions for testing

This can be achieved in a number of ways, from tapping the experience and creativity of local transport planners and interested parties, to the construction of a large-scale design model. Active transport options, including route and modes are generated for testing. For public transport, the information could be generated from local journey planners or local residents; for walking and cycling options, the information could be collected from interviewing frequent walkers or cyclists in the study area or even using GIS.

5. Forecasting planning variables

In order to test the solutions or schemes proposed in the previous step it is necessary to forecast the future values of the planning variables which are used as inputs to the model. This requires the preparation of consistent quantified descriptions, or scenarios, about the future of the area of interest, normally using forecasts from other sectors and planning units. This could include changing the value of energy resource consumption for each mode per kilometre to see if the route ranking results vary or not, then determine how much effort is required in the energy resource section to promote active or sustainable transport.

6. Testing the model and solution.

The performance of the model is tested under different scenarios to confirm its reasonableness; the model is also used to simulate different solutions and estimate their performance in terms of a range of suitable indicators. These must be consistent with the identification of objectives and problem definition above. Since the active
transport journey planner has not been practically applied yet, the results will need to be discussed with the local residents with transport experience to test its reasonableness.


This involves an operational, economic, financial and social assessment of alternative courses of action on the basis of the indicators produced by the models. A combination of skills is required here, from economic analysis to political judgment. The active transport journey planner model can be used to evaluate the effects of different combinations of transport modes and routes for planning or strategy or policy purposes.

8. Implementation of the solution and searching for another problem to tackle; this requires recycling through this framework starting again at point 1.

The active transport journey planner requires network modelling, involving trip assignment and modal split.

**Assignment**

During the standard traffic assignment stage, a set of rules or principles is used to load a fixed trip matrix onto the network and thus produce a set of links flows. Each assignment method has several steps which must be treated in turn. One of the basic functions is to identify a set of routes which might be considered attractive to users (Ortuzar & Willumsen 1990, p 246). With the promotion of active transport, the routes involving active or sustainable transport modes, such as walking, cycling or public transport should be included in the active transport journey planner options. The assignment of route and time on public transport are based on the local journey planner. For walking or cycling, the assignment is based on interviews of local residents or frequent travellers in the study area.
Modal Split

Ortuzar & Willumsen (1990, p161) addressed the issue of mode choice as being probably the single most important element in transport planning and policy making. It affects the general efficiency with which we can travel in urban areas, the amount of urban space devoted to transport functions, and whether a range of choices are available to travellers (Ortuzar & Willumsen 1990, p 161). Initially, it is important to find the attributes of travel that influence individual choices of mode. These factors may be classified into three groups (Ortuzar & Willumsen 1990, p162):

1. Characteristics of the trip maker. The following features are generally believed to be important:
   - car availability/ownership
   - possession of a driving license
   - household structure
   - income
   - decisions made elsewhere, e.g. taking the children to school
   - residential density

2. Characteristics of the journey. Mode choice is strongly influenced by:
   - trip purpose
   - time of the day when the journey is undertaken

3. Characteristics of the transport
   - relative travel time
   - relative monetary costs
   - availability and cost of parking
   - comfort and convenience
   - reliability and regularity
   - protection and security

Based on the classification of these characteristics, with the active transport journey planner, firstly, for the trip maker, it is assumed that an individual is willing to take
active transport and consider its benefits in terms of health and sustainability. Secondly, the journey is limited to the trip from home to work or study, or vice versa during day time. Thirdly, for transport, it is assumed that all transport modes are available and on time, based on their current timetables and monetary costs.

Utility Theory

In the real world, travellers choose the best transport option by considering not only route-based criteria but also non-route based factors, which could affect their transport choice, such as frequency along the path, total number of transfer points along the path, and total path cost, such as time and cost. With the trend towards active and sustainable transport, travellers may also consider health, environment, social or economic factors, such as personal energy expenditure, carbon emissions and energy resource use.

Is there a common unit of measurement for all these criteria? If there is, the problem would still be complex, since the calculation of trade-offs would remain. Assuming all the criteria to be expressible in money, one would still have to decide how much money would be saved for every minute spent cycling to and from work. However, contrary to a common assumption in the business world, many desirable aspects of objects are not reducible to monetary gains or losses; one can assume that objects can be evaluated on one’s personal utility scale, which can serve as a common denominator of value (Rapoport 1998). Also, Rapoport (1998) indicated, ‘the utility of an object possessing several aspects can be assumed to be the sum of the utilities of aspects.’ It is written as $u(x_1, x_2, \ldots, x_n) = u_1(x_1) + u_2(x_2) + \ldots + u_n(x_n)$ (Rapoport 1998).

Under what circumstances, can this assumption be used? Decisions often involve multiple objectives. Multi-criteria analysis refers to a set of procedures designed to help decision makers choose between alternative plans or options in such circumstances.

Multi-criteria analysis has three main components: a finite number of alternative plans or options; a set of criteria by which the alternatives or options are to be judged; and a
method for ranking the alternatives or options according to how well they satisfy the criteria (Resource Assessment Commission 1992).

The most common theoretical base, framework or paradigm for generating discrete choice models is the random utility theory (Domencich & McFadden 1975; Williams 1977), which basically postulates that:

1. Individuals belong to a given homogeneous population \( Q \), act rationally and possess perfect information, i.e. they always select that option which maximizes their net personal utility subject to legal, social, physical and/or budgetary (both in time and money terms) constraints.

2. There is a certain set \( A = \{A_1, ..., A_j, ..., A_N\} \) of available alternatives and a set \( X \) of vectors of measured attributes of the individuals and their alternatives. A given individual \( q \) is endowed with a set of attributes \( x \in X \) and in general will face a choice set \( A(q) \in A \). In what follows it is assumed that the individual’s choice set is predetermined; this implies that the effect of the constraints has already been taken care of and does not affect the process of selection among the available alternatives.

3. Each option \( A_j \in A \) has associated a net utility \( U_{jq} \) for individual \( q \). Usually, the modeler does not possess complete information about all the elements considered by the individual making a choice; therefore, it assumes that \( U_{jq} \) can be represented by two components:

   - a measurable, systematic or representative part \( V_{jq} \) which is a function of the measurable attributes \( x \); and

   - a random part \( \epsilon_{jq} \) which reflects the particular tastes of each individual, together with any measurable or observational errors made by the modeler.

Thus, the modeler postulates that: \( U_{jq} = V_{jq} + \epsilon_{jq} \) and a popular and simple expression for \( V \) is: \( V_{jq} = \sum_k \theta_{jq} x_{ik} \), where the parameters \( \theta \) are assumed to be constant for all individuals but may vary across alternatives. It is important to emphasize the existence of two points of view in the formulation of the above problem: firstly, that of the individual who weighs all the elements of interest and selects the most convenient option; secondly, that of the modeler who by observing only some of the
above elements needs the residuals $\epsilon$ to explain what otherwise would amount to non-rational behaviour.

4. The individual $q$ selects the maximum-utility alternative.

Multi-criteria analysis provides a structured, yet flexible, approach to decision making; it is particularly useful when the problem is complex and the amount of information exceeds the integrative capacity of the human brain. The technique can take into account different points of view by varying the weight applied to each criterion (Resource Assessment Commission 1992). Thus, for multi-objective trip planning regarding health, environment, social and economic concerns, multi-criteria analysis is a good method to evaluate transport alternatives based on the weightings of each criteria contributed by the traveller regarding the corresponding utility or disutility, similarly.

As there are mostly costs incurred rather than benefits in transport systems, the concept of disutility is used in active transport journey planner development. The disutility is often assumed to be minimized in travel behaviour. The methodology of the active transport journey planner is based on the concept of disutility and the method of multi-criteria analysis. The development process and details are presented in Chapter 3. As mentioned earlier, for walking and cycling options, some data can be acquired using GIS. Thus, the application of GIS in transport is reviewed in the next section.

2.7 GIS and Transport

As the procedure of rational decision making with models indicated by Ortuzar & Willumsen shows (see Figure 2.5) data collection is important in supporting the development of an analytical model.

Data are an essential component of transport modelling. The collection of data is therefore a significant activity of the transport planner. Transport problems are getting more and more dynamic due to changes in the complex social, economical, and physical world. Decisions must now take account of social, economic, and
environmental pressures, the interaction between them, and the possible consequences for all interested groups. The implication is that the information requirements will change significantly, with clear identification of costs and performance measures being required. The range of models that needs to be employed has expanded rapidly and the integration of transport models and technologies such as the geographical information system (GIS) has become a major requirement in any process of transport planning (Hensher & Button 2000).

In general, GIS consists of data, software, personnel, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the Earth (Dueker & Kjerne 1989).

There are four functions of GIS summarized here (Hensher & Button 2000). With these four important functions, GIS can be used as an important tool for supporting transport studies.

GIS allows digital mapping, showing information in an electronic version of a paper map.

- GIS data management: To help users manage the information in their maps;
- GIS data analysis: GIS data analysis functions allow us to set up queries for analyzing relationships between information from databases.

GIS data presentation: GIS allows users to extract and/or present data that go with a map layer using thematic mapping.

GIS is proving to be effective in integrating the data required to support transport modelling and data management. The term GIS-T, which stands for GIS for transportation, emerged in the 1990s (Hensher & Button 2000). GIS-T is an encompassing concept. It needs to support a broad range of applications from planning to operations. Planning applications are characterized by a low level of spatial accuracy that only need to be updated or forecasted infrequently, whereas operational systems are characterized by real-time data needs and a high level of spatial accuracy so that vehicle operations can be related to the correct road or lane as represented in the database. In planning, the role for GIS-T is mainly in support of
travel-demand modelling, consisting of processing and validating input data, and in processing and visualization of output data. In operations, the role for GIS-T is more real-time and integrated, rather than ‘what if’ as in planning (Hensher & Button 2000).

Some studies have been done using GIS in transport modelling. For example, Li and Kurt developed a GIS-based itinerary planning system for a multi-modal and fixed-route transit network.

The application of GIS for active transport journey planner development is mainly at the route generation and data collection stages. Based on the interviews of local residents or frequent travellers in the study area, some active transport options, such as walking or cycling, or even swift transfer from car to public transport, walk or cycle at interval, etc. can be generated by GIS map analysis. In addition, data about the distances for specific modes can be calculated using GIS.

2.8 Local Initiatives in Australia

What about active transport initiatives in Australia? An experiment in Melbourne using four modes of transport: a car, a motorbike, a bicycle and a train, revealed that the quickest way to get from Sandringham to the central city is by cycling, reported by Sexton (2008) in the Sunday Age. With overcrowding on public transport now reaching a dangerous level and with the price of petrol even less affordable in the current economic climate, The Sunday Age asked four commuters to time their journeys to the city during the morning peak. After 17 kilometers of bayside views, the bicycle rider arrived first in 32 minutes with no direct financial cost and nil emissions. The cyclist suggested, ‘it should definitely show people that they should think about getting on their bikes. There is nothing dangerous about it if you use bike paths as much as possible.’ The result was welcomed by sustainable energy activists, as bicycles emit no greenhouse gases. The train was the next most eco-friendly mode of transport used in the test. Motorbikes emit three times less carbon than driver-only cars, according to recent Transport Department figures, and based on the Sunday Age test, are a time efficient way to get to work (Sexton 2008).
In this report, Elliott Fishman, from the Institute for Sensible Transport, said the success of the bicycle rider should send a message to commuters and government. ‘Bicycles can help the individual get from A to B faster and it also minimizes greenhouse gas emissions and traffic congestion.’ He also said, ‘Government needs to do everything they can to make cycling an easy option. People aren’t using bikes here on the level they do in Euro cities because it hasn’t been made as safe here as it could be.’ But the rate of people cycling to work is growing steadily in Melbourne. In 2006, around 7,200 cyclists commuted daily into the city centre, a jump of almost 75% in five years. Bicycle Victoria president Harry Barber says worsening traffic congestion will make cycling an even more attractive option in the future, ‘It’s becoming relatively faster and faster to ride a bike during the peak periods,’ he says (Sexton 2008).

According to the media release by the Victorian Government, The Victorian Transport Plan includes more than $38 billion in projects to meet the demands of a growing state. Major initiatives include (Victorian Government 2008):

(i) New trains and new tracks – an investment of more than $2.6 billion
(ii) More trams and buses – $1.5 billion for 50 new low-floor trams and up to 270 new low-floor buses

Taking practical steps for a Sustainable Future, a $100 million increase in funding for bicycle lanes and shared walking and cycling paths on priority bicycle routes is planned (Department of Transport 2008):

(i) A $5 million public bicycle hire scheme for inner Melbourne
(ii) A focus on improving safety, awareness and parking for motorcycles and scooters to enhance their potential as an alternative to cars

There are many significant innovative projects in Melbourne, Victoria which bring us significant health, environmental, social and economic benefits towards a sustainable future, such as the Principle Bicycle Network and SmartBus. For other Australian cities, the achievement of TravelSmart in Perth will be introduced.
**Principal Bicycle Network (PBN)**

The Principal Bicycle Network (PBN) is a network of arterial cycling routes in metropolitan Melbourne (VicRoads 2007).

The PBN currently consists of approximately 3500 kilometers of existing and proposed on-road and off-road bicycle routes. So far, approximately 1200 kilometers of the network have been completed. VicRoads has primary responsibility for managing the development of the PBN. Bicycle facilities on the PBN are implemented by VicRoads and local councils depending on whether they are on an arterial or local road.

**Public Transport, Smart Bus**

The Victorian Government is rolling out a network of SmartBus routes across Melbourne to greatly improve the quality of public transport services in suburban communities.

SmartBus is a premium bus service that has been designed to complement Melbourne's radial train network by providing 'cross-town' connections along major arterial roads to train stations, tram lines, schools, universities, hospitals, shopping centres and other activity centres (Department of Transport 2008).

It was developed following extensive research involving both existing and potential bus passengers. This research identified nine priorities to improve bus services (Department of Transport 2008):

(i) more bus services (more trips)
(ii) more services at night and on weekends
(iii) a more reliable service
(iv) more information and marketing of services
(v) quicker travel times
(vi) better design of routes so that passengers don’t have as far to walk to bus stops
(vii) linking bus timetables to connecting rail services
TravelSmart pilot project

Individualized marketing is an approach that has been applied successfully to road transport in Western Australia to try and change travel behaviour away from car use. After piloting, a large-scale programme involving 35,000 people in 15,300 households was conducted in 2000 by the company Socialdata, which devised an individualized marketing program. This resulted in a 35% increase in walking from a baseline of 12% modal share in 1997–1998 and a 61% increase in cycling (James & Brog 2001). The programme involves enhancement to bus stops, providing clear information on large ‘finger posts’ and distribution of local bus timetables. In addition, district walking, cycling and public transport maps are widely distributed. The process is focused on helping those who indicate they are willing to try to change their travel behaviour, through communication, motivation and information.

The method for TravelSmart involves in-depth dialogue with households contacted and willing to attempt some change in travel behaviour. Particular suburbs are targeted for the programme. During this process, information is gathered about reasons for the choice of transport mode. In Perth, in-depth research identified that up to 15% of car trips are in principle changeable to walking without the need for additional infrastructure (James & Brog 2001).

In conclusion, ideally, the promotion of physically active travel as a means to increase physical activity levels in populations should be integrated into an overall public health strategy at the national and international levels (Dora & Racioppi 2003), as well as broader sustainability concerns.

Many studies have been done for meeting multiple objectives mostly concerned about cost and time. This research incorporates active transport into daily travel between work or study place and home in fixed-route in terms of multi-objective from both health and sustainability perspectives, based on the previous reviews that identified
important factors, such as personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption. A ranking of the informed travel options including modes and routes will be given according to a user’s travel preferences.

This chapter has identified the need to develop an active transport journey planner involving multi-objectives in the pre-trip planning stage, regarding health, environment, social and economic sustainability. This research will focus on trips in an urban area during peak hour to work or study, which can significantly assist a large number of people incorporate active transport into daily life, having more informed travel solutions considering multiple objectives as well as stating their preferences regarding multiple objectives, and making transport decisions towards a healthier and more sustainable future.
Chapter 3

METHODOLOGY

Introduction

This Chapter develops a methodology for modelling the active transport journey planner. It starts by introducing a model development process, followed by identifying each step in developing an active transport journey planner. These include problem definition, objectives, criteria, systems analysis and synthesis, data collection and resources, software development, verification, validation and application in sequence.

3.1 Model Development Process

Normally, there are six steps in modelling decision-making by an individual (Render, Stair & Hanna 2006):

(1) Clearly define the problem at hand
(2) List the possible alternatives
(3) Identify the possible outcomes or states of nature
(4) List the payoff of each combination of alternatives and outcomes
(5) Select one of the mathematical decision theory models
(6) Apply the model and make the decision

In stage (5), there are a number of advantages to using mathematical models (Render, Stair & Hanna 2006).

(i) Models can accurately represent reality. If properly formulated, a model can be extremely accurate. A valid model is one that is accurate and correctly represents the problem or system under investigation.

(ii) Models can help a decision maker formulate problems. In the active transport journey planner model, for example, a decision maker can determine the
important factors or contributors to personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption.

(iii) Models can give us insights and information. For example, using the active transport journey planner model, we can see what parameters would change the result of best solution. As discussed in the previous section, studying the impact of changes in a model is called sensitivity analysis.

(iv) Models can save time and money in decision making and problem solving. It usually takes less time, effort, and expense to analyse the results of a model. We can use the active transport journey planner model to analyse the impact of a new active transport campaign that notifies travellers concerning the impact of their transport decisions in planning process before into action. In most cases, using models is faster and less expensive than actually developing a new campaign in a real world setting and observing the results.

(v) A model may be the only way to solve large or complex problems in a timely fashion. An individual, for example, may want to set up the maximum energy expenditure possible given its transport solution constraints, a maximum travel cost or travel time, etc. A mathematical model may be the only way to determine the best transport solution the individual can take under these circumstances.

(vi) A model can be used to communicate problems and solutions to others. A decision analyst can share their work with other decision analysts. Solutions to a mathematical model can be given to decision makers to help them make final decisions.

This research aims to develop a methodology to assist an individual traveller to select a healthier and more sustainable transport route and mode among feasible transport options, and highlight the trade-offs among multi-objectives trip planning in terms of health, economic, social and environmental benefits. It is a decision-making aid. A model is required to achieve the demonstrated function. This research follows the model development process, which provides a flexible, structured and logical approach. The model development process (Figure 3.1) consists of a number of stages, problem definition, objectives, criteria, system analysis, system synthesis, data collection and resources, software development, verification, validation and application. One step does not have to be finished completely before the next is started. In most cases, one or more of these steps will be modified to some extent.
before the final results are implemented. Thus, it is an iterative process which requires every step to be carefully defined, analysed and executed.

The identification and function of each step in the model development process of an active transport journey planner is discussed in the following sections.

### 3.2 Problem Definition

The first step in developing the active transport journey planner is to develop a clear, concise statement of the problem. The statement will give direction and meaning to the subsequent steps.

In many cases, defining the problem is the most important and the most difficult step. It is essential to go beyond the symptoms of the problem and identify the true causes. One problem may be related to other problems; solving one problem without regard to other related problems can make the entire situation worse. Thus, it is important to analyse how the solution to one problem affects other problems or the situation in

---

**Figure 3.1 Model Development Process (Source: Thompson 2007)**
general. A research objective is to use the combination of ideas from active transport and journey planning to assist people in making more informed transport decisions which can bring health and sustainability benefits into people’s life during daily travel. Such benefits include maximising health gains, maximising environmental, social benefits and minimising economic costs for the journey.

This pre-trip planning tool is required to assist an individual traveller:

(i) to make more informed transport decisions that consists of route and mode information for common urban travel (e.g. from home to work or study);
(ii) to rank reasonable transport alternatives involving active and sustainable transport options which have direct physical active health benefits and indirect sustainable benefits, such as reduced congestion, carbon emissions and energy resource consumption, into daily transport;
(iii) and to highlight the best transport option in terms of total disutility derived from the user’s stated preference of each objective concerning health, environmental, social and economic issues.

It can be further concluded that the principle problem is concerned with how to identify the least disutility route option based on the user’s stated preferences in terms of multi-objectives of different measurement units. In addition, there is a need to provide objective estimates of the costs and benefits compared with people’s perceptions. Because people are sometimes not aware of what objectives are needed to estimate a journey’s costs and benefits and their related trade-offs in complex situations due to finite information and knowledge. As soon as people are informed and consider the specific costs and benefits objectives, they may be more likely to use this information in the decision-making process.

3.3 Objectives

The next step is to identify the objectives which can help solve the problem. When the problem is difficult to quantify, it may be necessary to develop specific, measurable objectives. It is important to avoid objectives that may not solve the real problems.
On the basis of the problem identified in Section 3.2, the objectives are to develop a procedure for:

- estimating a range of cost and benefit elements of the disutility-related objectives for journeys;
- determining the optimal route for an individual trip based on cost and benefit estimates and preferences (weightings) for specific objectives.

### 3.4 Criteria

Criteria are the measures of a model performance, which is attributed to the accuracy and reliability of the information delivered by the active transport journey planner to trip planners. That is, the developed model can produce accurate results to assist an individual traveller in the pre-trip planning process. To ensure the accuracy of the active transport journey planner, required information and data will be collected on the local public transport sector and from GIS, such as public transport timetables from ‘metlink’ and travelling distances from GIS maps. Meanwhile, in order to make sure that the time required for calculation of this model is reasonable, a limited number of active transport options are to be provided. However, the number of options is not a major issue, as this research’s emphasis is not on implementation but developing a methodology.

### 3.5 Systems Analysis

The next step is to analyse the active transport journey planning system. Simply stated, a model is a representation, usually mathematical, of a system.

In the active transport journey planner, the generalised benefit and cost elements are personal energy expenditure, travel cost, travel time, CO₂ emissions and energy resource consumption, according to the report of ‘Energy and Transport’ (Woodcock, Banister, Edwards, Prentice & Roberts 2007). The hierarchical relationship of transport related objectives and issues are illustrated in Figure 3.2. As presented in
Figure 3.2, the disutility will be generated due to less energy consumption, more emissions and resource consumption.

![Figure 3.2 Relationship between Energy and Transport](source)

Formulating a mathematical program involves developing a mathematical model to represent the system. Once the problem of the active transport journey planner is understood, one can be used to develop the mathematical statement of the problem. However, the shortcoming of mathematical programming techniques such as linear and integer programming is that their objective function is measured in the same unit only. With the active transport journey planner, the sub-objectives concerning health, environment, social and economic are in different units. It is not possible for mathematical programming to have multiple goals unless they are all measured in the same units, such as dollars, a highly unusual situation. Before introducing a method that can measure multiple objectives in different units, mathematical programming can be applied to establish the objective function of minimising the total disutility for journey, and an individual’s value of expectations or requirements for objectives can be set as constraints to eliminate infeasible transport options.
3.6 Systems Synthesis

Based on the system analysis, mathematical program concepts can be used to formulate the model. Mathematical modelling is developed principally based on multi-objective analysis to evaluate and rank different transport alternatives in terms of their total disutility in different measurement units, including personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption. Whereas, mathematical programming is applied to establish objective function, and set up constraints to eliminate infeasible alternatives.

A mathematical model is a set of mathematical relationships. In most cases, these relationships are expressed in equations and inequalities. Although there is considerable flexibility in the development of models, most of the models contain one or more variables and parameters. A variable, as the name implies, is a measurable quantity that may vary or is subject to change. Variables can be controllable or uncontrollable. A controllable variable is also called a decision variable. A parameter is a measurable quantity that is inherent in the problem. In most case, variables are unknown quantities, while parameters are known quantities. All models should be developed carefully. The active transport journey planner should be solvable, realistic, and easy to understand and modify, and the required input data should be obtainable.

In today’s transport decision-making environment, travel cost minimization is not always the only objective that an individual has. Often, minimising travel time is just one of several goals, including such contradictory objectives as maximising travel speed, minimizing travel distance, maximising transport safety, minimising travelling through congestion areas, etc (Render, Stair & Hanna 2006).

Moreover, a monetary value is not always a true indicator of the overall value of the result of the decision. The overall worth of a particular outcome is called utility, and rational people make decisions that maximize their expected utility (Render, Stair & Hanna 2006). Similarly, the generalised cost or disutility is often assumed to be minimised in travel behaviour. Considering there are numerous cost elements in the transport system, the idea of minimising the total disutility is applied in the active transport journey planner’s mathematical model.
Regarding maximising or minimising an objective, it is natural to consider linear programming. In the past 50 years, mathematical programming has been applied extensively worldwide. Linear programming can be used to formulate the objective function. Even though the applications are diverse, all linear programmes have four properties in common (Render, Stair & Hanna 2006, p 364):

(1) All problems seek to maximise or minimise some quantity, usually total benefit or cost. In the active transport journey planner, the objective is to minimise the total disutility including health, environmental, social and economic sustainability for a journey.

(2) The second property that problems have in common is the presence of restrictions, or constraints, that limit the degree to which we can pursue the objective. In the active transport journey planner, the constraints are the estimates or limits set up by an individual traveller for each sub-objective. For example, deciding a limit on how many kilojoules a traveller expects to expend, or the maximum amount of time, or how much energy should be consumed, such as fuel, electricity.

(3) There must be alternative courses of action to choose from. For example, the transport options involve active transport modes, such as walking, cycling, or taking train, tram, bus to work or study; or include reasonable multi transport modes to into one journey.

(4) The objective and constraints in mathematical programming must be expressed in terms of linear equations or inequalities. Linear mathematical relationships mean that all terms used in the objective function and constraints are linear, i.e. not higher order polynomials, with respect to the decision variables.

The steps followed in formulating the mathematical program of the active transport journey planner were:

1. Understanding the transport decisions being faced.

With the active transport journey planner, the objective transport problem is to minimise the total disutility of health, environmental, social and economic issues for journeys.

That is, \[ \text{Min} \sum_{r=1}^{N} (R_r \times DU_r) \]
• \( R_r \): route option \( r \), if route option \( r \) is selected, \( R_r = 1 \), otherwise, \( R_r = 0 \);
• \( DU_r \): total value of disutility in route option \( r \);
• \( r \): route option number, \( r \in R \{1,2,\ldots,N\} \);
• \( R \): the set of route options;
• \( N \): total number of route options.

2. Identifying the objectives and constraints.

The objective is to minimise the total disutility. However, there are countless factors associated with health and sustainability concerns. The total disutility minimisation objective can be decomposed here into several sub-objectives to be minimised. This research selects five sub-objectives derived from the report, ‘Energy and Transport’ (Woodcock, Banister, Edwards, Prentice & Roberts 2007), to minimise the disutility of:

1) personal energy expenditure  
2) travel time  
3) travel cost  
4) \( CO_2 \) emissions  
5) energy resource consumption

Thus, \( DU_r = \sum_{o=1}^{5} DU_{o,r} \)

• \( DU_{o,r} \): value of disutility with regard to cost or benefit objective \( o \) in route option \( r \);
• \( o \): subscript number, where,

1 represents personal energy expenditure  
2 for travel time  
3 for travel cost  
4 for \( CO_2 \) emissions and  
5 for energy resource consumption
Constraints are to be setup in Step 4 regarding the above sub-objectives.

3. Define the decision variables.

In transport systems, the transport distance is highly favoured as a decision variable due to its relatively constant and stable character compared with travel speed or travel time. As there are seven transport modes in the active transport journey planner, the decision variable is the travelled distance by travel mode m in route option r, written as $X_{m,r}$, and the unit is km.

4. Use the decision variables to write mathematical expressions for the objective function and the constraints.

So, the objective function is:

$$\text{Min} \sum_{r=1}^{N} (R_{r} \times DU_{r})$$

- $DU_{r}$: total value of disutility in route option r; $DU_{r} = \sum_{o=1}^{5} DU_{o,r}$
- $R_{r}$: route option r, if route option r is selected, $R_{r} = 1$, otherwise, $R_{r} = 0$.

Constraints are: $0 \leq O_{\text{min}} \leq O_{r} \leq O_{\text{max}}$

- $O_{r}$: set of objectives achieved in route option r;
- $O_{\text{min}}$: minimum value of constraints for the set of objectives in route option r;
- $O_{\text{max}}$: maximum value of constraints for the set of objectives in route option r.

For example, with sub-objective, personal energy expenditure, $O_{r}$ is the value of kilojoules expended for route option r, while $O_{\text{min}}$ and $O_{\text{max}}$ are the values of expected minimum and maximum energy expenditure setup by a user for selecting feasible a route, respectively.

In addition,

$$DU_{o,r} = \sum_{m=1}^{M} a_{o,m,r} \lambda_{m,r} X_{m,r}$$
• m: travel mode number, m ∈ M;
• M: the set of travel modes;
• \( \lambda_{m,r} \): availability of travel mode m in route option r, if travel mode m is available in route option r, \( \lambda_{m,r} = 1 \); otherwise, \( \lambda_{m,r} = 0 \);
• \( a_{o,m,r} \): the disutility (for cost objective) or utility (for benefit objective) conversion factor with regard to the extent of objective o achieved by travel mode m per person per km in route option r.
• \( X_{m,r} \): the travelled distance by travel mode m in route option r; the unit is km.

As addressed previously, the shortcoming of mathematical programming is that its objective function is measured in the same unit only. However, the active transport journey planner includes multi objectives in trip planning. Fortunately, ‘multi-criteria analysis’ refers to a set of procedures designed to help decision makers choose between alternative plans or options in such circumstances. There is no precise definition of ‘multi-criteria analysis’. A variety of terms, such as ‘multi-objective decision support’, ‘Multi-criterion decision making’ and ‘multiple-criteria decision aid’, appear in the literature and are used in slightly different ways by different authors. This research will use the term, ‘Multi-criteria analysis’ to refer to these techniques. It provides a structured, yet flexible approach to decision making. It is particularly useful when the problem is complex and the amount of information exceeds the integrative capacity of the human brain, such as the trade-off among health, environment, social and economic concerns. The technique can take into account different points of view by varying the weightings applied to each criterion, ‘a review of selected applications of multi-criteria analysis suggests that the major benefits of the technique are a more rational structuring of the decision-making process and better understanding of different options and the effects of divergent social values upon their evaluation’ (Resource Assessment Commission 1992, p V).

Based on the review report of the Resource Assessment Commission (1992) on multi-criteria analysis, this method has three main components: a finite number of alternative plans or options; a set of criteria by which the alternatives or options are to be judged; and a method for ranking the alternatives or options according to how well they satisfy the criteria.
The main strengths of multi-criteria analysis are listed as follows (Resource Assessment Commission 1992, p 10):

(i) provides structure for decision making while still allowing flexibility;
(ii) particularly useful for complex problems where the amount of information exceeds the integrative capacity of the human brain;
(iii) follows naturally from the way people tend to approach problems with multiple objectives;
(iv) flexible data requirements, methods are available for qualitative data, quantitative data, or a mix of both;
(v) allows different points of view to be dealt with explicitly through the use of weightings;
(vi) allows information that is agreed upon by all parties to be distinguished from areas of contention, indicated by different weightings;
(vii) amenable to sensitivity analysis to determine how robust the final results are to changes in the underlying assumptions and methods;
(viii) does not require assignment of a monetary value to all quantities;
(ix) can identify where additional data would be useful and where additional data would have little impact on the final decision.

The ability of multi-criteria analysis to deal with measurements on a variety of scales may provide an advantage over benefit-cost analysis in some situations. Individuals who have a fundamental objection to placing a monetary value on some amenities, particularly environmental ones, may find multi-criteria methods that use qualitative scores or rankings more acceptable. Although multi-criteria analysis does not eliminate the difficulty of ultimately reducing all scores to a comparable basis through a combination of standardisations, weightings and an evaluation method, it does provide more flexibility in exploring different ways of reflecting different points of view through different weightings than is available with a strict economic analysis.

Multi-criteria analysis is intended to assist this decision making. It has been applied to a wide range of planning problems in urban and regional planning, such as transport planning. There appear to be three ways in which multi-criteria analysis can contribute to decision making:
(1) It can provide a ranking of alternatives, allowing the decision maker to choose the ‘best’, that is, the highest ranked alternative.

(2) It can help to structure the planning process in a more rational way, by helping to define the information needs of a particular problem at an early stage through a comprehensive consideration of criteria and alternatives, and by fostering a learning process in which decision makers and others can contribute to the analysis and refine the information needs as the multi-criteria analysis proceeds.

(3) It can improve decision makers’ understanding of different options and of the various ways in which the options may be evaluated. In particular, the effects of divergent social or environmental values upon the evaluation of different options can be highlighted through the use of multiple weighting sets or through the construction of ideal or extreme options, and questions concerning factual information can be distinguished more clearly from matters of social or environmental value.

Again, it was based on these issues that substantive claims of such analysis to provide various ‘points of view’ on options suggest that it is particularly appropriate for controversial problems in which divergent social or environmental values are central to the issue and complex factual determinations are involved. Multi-criteria analysis can help clarify how values and factual information interact in the assessment of options in the active transport journey planner concerning health, environmental, social and economic, thus it can help identify the precise areas of disagreement and agreement.

Multi-criteria analysis is an approach rather than a single well-defined procedure. Multi-criteria analysis does, however, have the potential to identify those views and values of the active transport journey planner in ways that can help an individual traveller understand the implications of a particular decision.

3.6.1 The Multi-Criteria Model

As indicated previously, criteria used to judge alternatives in the active transport journey planner include personal energy expenditure, travel time, travel cost, CO₂
emissions and energy resource consumption. Once the infeasible transport options are eliminated from alternatives due to the user’s defined criteria, the feasible alternatives are evaluated based on the user’s stated preference on each criteria using multi-criteria analysis.

Multi-criteria analysis compares the advantages and disadvantages of each option one against the other, thereby assisting decision makers in reaching a decision. Table 3.1 shows how the alternatives and criteria can be conveniently displayed. This form of display is called an ‘effects table’ or ‘effects matrix’ (Bana & Vinke 1990). The columns of the effects table represent the alternative plans or options and the rows represent the criteria by which the alternatives are to be evaluated. The entries in the effects table indicate how well each alternative scores with respect to each criterion. With I alternatives and J criteria, the effects table is a matrix X of size J by I. The entry in the jth row ith column of X, x_{ji}, represents the performance of alternative i with respect to criterion j (Bana & Vinke 1990).

| Table 3.1 General Example of an Effects Table (Source: Bana & Vinke 1990) |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Criterion                  | Alternative                | Alternative                | Alternative                |
| Criterion I
| I                           | ...                         | I                           | ...                         | I                           |
| x_{11}                      | ...                         | x_{j1}                      | ...                         | x_{11}                      |
|  ...                        |  ...                       |  ...                       |  ...                       |  ...                       |
| Criterion j
| j                           | ...                         | j                           | ...                         | j                           |
|  ...                        |  ...                       |  ...                       |  ...                       |  ...                       |
| Criterion J
| J                           | ...                         | J                           | ...                         | J                           |
| x_{1J}                      | ...                         | x_{jJ}                      | ...                         | x_{1J}                      |
|  ...                        |  ...                       |  ...                       |  ...                       |  ...                       |
|  ...                        |  ...                       |  ...                       |  ...                       |  ...                       |
| x_{JJ}                      | ...                         | x_{jJ}                      | ...                         | x_{JJ}                      |

Some multi-criteria methods require scores to be measured quantitatively; that is, with numerical values. For others, qualitative scores such as ranks or pluses and minuses are sufficient. The ability of some multi-criteria methods to deal with qualitative scores or a mixture of quantitative and qualitative scores provides greater flexibility.
compared with techniques such as benefit-cost analysis that require all values to be quantified.

The process of assembling each effects table and determining the scores makes a major contribution to the decision-making process and might be sufficient to produce a clear ranking of the alternatives.

When this is not the case, the next step is to apply to the table a mathematical procedure that results in a ranking or partial ranking of the alternatives. This requires some measurement of relative importance to be attached to the criteria, either by ranking the criteria from most to least important or by assigning specific numerical weights to each criterion. The assignment of different rankings or sets of weightings allows the effect of different points of view to be explored.

### 3.6.2 Steps in Multi-Criteria Analysis

(1) Specifying alternatives

Alternatives are courses of action that may be chosen by a decision maker. Whatever method is used to arrive at the set of alternatives, the selection of these alternatives is critically important to the success of the analysis.

Technical discussions of multi-criteria analysis often assume that the alternatives to be considered are already well-defined. Computer programs can assist planners in formulating alternatives by generating all possible combinations of a set of factors. A long list of alternatives may be reduced to a manageable set by eliminating those that do not satisfy an initial criterion (Belton & Vickers 1990).

With the active transport journey planner, the transport alternatives are generated from an online public transport journey planner, such as ‘metlink’, that includes the detailed information of the time, duration, distance of train, tram and bus. Other active transport alternatives can be generated from interviews or surveys of local residents and frequent car users, cyclists or walkers. Accurate or precise geographical data,
such as distances, can be estimated with the aid of a Geographical Information System (GIS).

(2) Specifying the criteria

Multi-criteria analysis is founded on the notion that decision makers usually attempt to satisfy more than one objective simultaneously. These objectives are likely to be quite general and conflicting, and involve concepts such as economic well-being, environmental quality and quality of life.

The label ‘criterion’ covers a continuum from relatively well defined and easily measured quantities, such as personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption.

The hierarchical structure of criteria is recognized in a number of multi-criteria methods and is dealt with explicitly in the ‘analytical hierarchy process’ (Forman 1990; Satty 1980). Criteria are subdivided into groups of sub-criteria and possibly into groups of sub-subcriteria. When a criterion consists of several subcriteria, the process of evaluating the subcriteria and deriving a score for the parent criterion can be regarded as a multi-criteria analysis in its own right.

In order to make the criteria more concise and focused, Figure 3.3 shows a hierarchical structure for the active transport journey planner. There are three possible groups of objectives: maximizing social benefits, minimizing economic costs, minimizing environmental issues. Maximizing social benefit involves maximizing personal energy expenditure; while minimizing economic costs involve minimizing travel costs and travel time; and with environmental issues, CO₂ emissions and energy resource consumptions are minimised.
Based on these criteria, including personal energy expenditure, travel time, travel cost, CO\textsubscript{2} emissions and energy resource consumption, for alternative 1 to alternative \textit{I}, the Effects table is shown in Table 3.2.

Table 3.2 Effects Table for the Active Transport Journey Planner

<table>
<thead>
<tr>
<th>No.</th>
<th>Criterion</th>
<th>Alternative</th>
<th>Alternative</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Personal Energy Expenditure</td>
<td>$x_{11}$</td>
<td>...</td>
<td>$x_{1i}$</td>
</tr>
<tr>
<td>2</td>
<td>Travel Time</td>
<td>$x_{21}$</td>
<td>...</td>
<td>$x_{2i}$</td>
</tr>
<tr>
<td>3</td>
<td>Travel Cost</td>
<td>$x_{31}$</td>
<td>...</td>
<td>$x_{3i}$</td>
</tr>
<tr>
<td>4</td>
<td>CO\textsubscript{2} emissions</td>
<td>$x_{41}$</td>
<td>...</td>
<td>$x_{4i}$</td>
</tr>
<tr>
<td>5</td>
<td>Energy Resource Consumption</td>
<td>$x_{51}$</td>
<td>...</td>
<td>$x_{5i}$</td>
</tr>
</tbody>
</table>
Keeney and Raiffa (1976, p XI) state that the set of criteria used in a multi-criteria analysis should be:

(i) Complete (If two alternatives have the same score for each criterion then it must be agreed that the two alternatives are equivalent. In other words, there should not be any additional basis for distinguishing between alternatives.)

(ii) Operational (The set of criteria should be able to be used in some meaningful manner in the ensuing analysis.)

(iii) Decomposable (It should be possible to simplify the analysis by disaggregating the decision problem.)

(iv) Non-redundant (No aspect of the problem is accounted for more than once.)

(v) Minimal (There should be no other smaller set of criteria satisfying the proceeding conditions.)

(3) Scoring alternatives in relation to each criterion

To complete the effects table, a value or score must be assigned to each alternative indicating its performance for each criterion. Based on the hierarchical arrangement of objectives or criteria, the unit of each criterion is assigned in Table 3.3, according to common measurement units. Thus, the scores from alternative 1 to alternative \( I \) with regard to each criterion should be assigned in the form of the corresponding unit shown below.

### Table 3.3 Criteria and Corresponding Units

<table>
<thead>
<tr>
<th>Sustainability</th>
<th>Criteria</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social(Health)</td>
<td>Personal Energy Expenditure</td>
<td>kJ</td>
</tr>
<tr>
<td></td>
<td>Travel Time</td>
<td>hr</td>
</tr>
<tr>
<td></td>
<td>Travel Cost</td>
<td>$</td>
</tr>
<tr>
<td>Economic</td>
<td>CO(_2) Emissions</td>
<td>g</td>
</tr>
<tr>
<td></td>
<td>Energy Resource Consumption</td>
<td>MJ</td>
</tr>
</tbody>
</table>

The objective function established previously is influenced by a set of independent sub-objectives. The scores can be collected based on the disutility of each criterion, which is a function of travelled distance by travel mode \( m \) in route option \( r \), written as \( X_{m, r} \) and score values in terms of travel distance can be generated by multiplying corresponding parameters shown in Table 3.4. Furthermore, the meaning of each parameter and its unit is summarised in Table 3.5.
Table 3.4 Relationship of Criteria and Disutility; Generation of Value for Each Criterion

<table>
<thead>
<tr>
<th>Sustainability</th>
<th>Criteria</th>
<th>Disutility (DU)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social(Health)</td>
<td>Personal Energy Expenditure (EE)</td>
<td>Inverse proportion (i.e. ↓ EE ⇒ DU_{EE}↑)</td>
<td>kJ/person/km × km</td>
</tr>
<tr>
<td></td>
<td>Travel Time (TT)</td>
<td>Direct proportion (i.e. ↓ TT ⇒ DU_{TT}↓)</td>
<td>hr/person/km × km</td>
</tr>
<tr>
<td>Economic</td>
<td>Travel Cost (TC)</td>
<td>Direct proportion (i.e. ↓ TC ⇒ DU_{TC}↓)</td>
<td>$/person/km × km</td>
</tr>
<tr>
<td>Environmental</td>
<td>CO₂ Emissions (CE)</td>
<td>Direct proportion (i.e. ↓ CE ⇒ DU_{CE}↓)</td>
<td>g/person/km × km</td>
</tr>
<tr>
<td></td>
<td>Energy Resource Consumption (EC)</td>
<td>Direct proportion (i.e. ↓ EC ⇒ DU_{EC}↓)</td>
<td>MJ/person/km × km</td>
</tr>
</tbody>
</table>

Table 3.5 Criteria and Parameters

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Parameter</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Energy Expenditure</td>
<td>How much personal energy a person spends by each travel mode</td>
<td>kJ/person/km</td>
</tr>
<tr>
<td>Travel Time</td>
<td>How long a person spends by each travel mode</td>
<td>hr/person/km</td>
</tr>
<tr>
<td>Travel Cost</td>
<td>How much money (direct cost) a person spends by each travel mode</td>
<td>$/person/km</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>How much emissions a person produces by each travel mode</td>
<td>g/person/km</td>
</tr>
<tr>
<td>Energy Resource Consumption</td>
<td>How much energy (energy resource consumption during manufacturing and operation, such as fuel, electricity) a person consumes by each travel mode.</td>
<td>MJ/person/km</td>
</tr>
</tbody>
</table>

Before applying some evaluation methods, in particular those in which the numerical value of the score is used directly to rank alternatives, it is necessary for all criteria scores to be reduced to a comparable or standardised basis. Standardisation should not be confused with weighting: standardisation is intended to eliminate effects of scale.
that would otherwise introduce a weighting. The aim is to avoid introducing weightings at any place in the analysis other than explicitly through the weighting vector provided by the user.

Janssen (1991) suggests one procedure for standardising the $x_{ji}$ is based on the position of the value between the lowest and highest value. The standardised scores are given by $x_{ji} = \frac{(x_{ji} - \min_i x_{ji})}{(\max_i x_{ji} - \min_i x_{ji})}$

As can be seen in Table 3.4, the disutility of personal energy expenditure is inversely proportioned to the kilojoules expended while disutility of the other criteria is in direct proportion to each criterion. In multi-criteria analysis, the disutility of benefit criteria can be derived from one minus its utility in standardised form.

i.e. $DU'_{o, r} =$

$$\begin{align*}
DU_{o, r} - \text{Min}_r \{DU_{o, r}\} \bigg/(\text{Max}_r \{DU_{o, r}\} - \text{Min}_r \{DU_{o, r}\}), \text{ if } o \text{ is a cost objective;} \\
1 - U'_{o, r} = 1 - \left((U_{o, r} - \text{Min}_r \{U_{o, r}\}) \bigg/(\text{Max}_r \{U_{o, r}\} - \text{Min}_r \{U_{o, r}\})\right), \text{ if } o \text{ is a benefit objective.}
\end{align*}$$

Where,

- $DU'_{o, r}$: standardised value of disutility with regard to cost objective $o$ for route option $r$;
- $DU_{o, r}$: value of disutility with regard to cost objective $o$ for route option $r$;
- $\text{Min}_r \{DU_{o, r}\}$: minimum value of disutility with regard to cost objective $o$ with route options;
- $\text{Max}_r \{DU_{o, r}\}$: maximum value of disutility with regard to cost objective $o$ with route options;
- $U_{o, r}$: value of utility with regard to benefit objective $o$ for route option $r$;
- $\text{Min}_r \{U_{o, r}\}$: minimum value of utility with regard to benefit objective $o$ for route options;
- \( \text{Max}_i \{U_{o,r}\} \): maximum value of utility with regard to benefit objective \( o \) for route options.

(4) Assigning weightings to the criteria

Assigning weightings to the criteria is possibly the most valuable aspect of multi-criteria analysis because it allows different views and their impact on the ranking of alternatives to be expressed explicitly. The weightings defined in this step are referred to as ‘explicit weightings’ to distinguish them from implicit weightings that enter the analysis unintentionally and possibly unnoticed.

Weightings represent social preferences, and therefore the question of who specifies the weightings becomes important. In the active transport journey planner, the weightings are generated from the user’s stated preferences of the criteria. Normally only the relative value of weightings impacts results. Therefore, all weightings are to be assigned to each of the criteria and the total value adds up to one. The weighting assigned to criterion \( j \) is designated by \( w_j \) and the set of weightings is given by the weighting vector \( \mathbf{w} \).

Given the matrix \( \mathbf{X} \) and the weighting vector \( \mathbf{w} \), all that remains is to specify some decision rule that operates on \( \mathbf{X} \) and \( \mathbf{w} \) and produces a ranking of the \( I \) alternatives.

(5) Evaluating alternatives

The alternatives are evaluated by applying a mathematical procedure to the effects table and the criteria weightings, to produce a ranking of alternatives. The choice of evaluation method is dictated to some extent by the nature of the effects table and the type of weighting information. Some methods require quantitative data, some are designed for qualitative data, and some can deal with a mixture of quantitative and qualitative data. For the active transport journey planner, all data are quantitative. All alternatives will be evaluated and ranked according to their total disutility, respectively. In the end, the least disutility option will be delivered to the active transport journey planner user as the recommended transport solution. The rank of all options will be presented as well. More details are presented in the Case Study in Chapter 4.
3.7 Data Collection & Resources

Data are required for three main purposes: to decide the present situation, input to program development and use of active transport journey planner models, and to monitor the effects of the implementation of policies, strategies, and investments.

The first purpose of data is to describe the current transport situation, such as transport start/stop/end location, travel duration, distance and transport timetables, and how much money (direct cost) a person spends by each travel mode, etc.

The second main purpose for the data are as input to the development of forecasting models, used to provide a forecast to some point in the future, either without any changes being made to the system, or in response to various possible changes that could be made. Such testing could be for a new sustainability friendly transport mode, say an electric car.

The third main purpose of data is to monitor the results of certain actions taken in response to the transport system.

Once we have developed an active transport journey planner, the data used in the model must be obtained. Obtaining accurate data for the model is essential; even if the model is a perfect representation of reality, improper data will result in misleading results. Collecting data can be one of the most difficult steps in developing a model.

There are a number of sources for data collection. In some cases, government reports and documents can be used to obtain the necessary data, local public transport on-line systems can be used to collect detailed information of the times, locations, durations of public transport, such as ‘metlink’ in Melbourne. Another source of data is from interviews or surveys of local residents or transport users related to the research scope. Individuals can sometimes provide excellent information, and their experience and judgements can be invaluable. Sampling and direct measurement provides other sources of data for the model.
### 3.8 Software Development

Developing a solution, testing the solution, and analysing the results are important steps in the model development process. Because mathematical models are being used, these steps require mathematical calculations. Fortunately, the computer can make these steps easier. Excel can be used to solve many of these problems.

The accuracy of the solution depends on the accuracy of the input data and the model. If the input data are accurate to only two significant digits, then the results can be accurate to only two significant digits.

An active transport journey planner was developed in Microsoft Excel to allow users to set their constraints for objectives and give their weightings, respectively. Constraints include the minimum and maximum kilojoules of personal energy a person wants to expend during travel, the maximum travel cost and time budget; whether to take account of CO\textsubscript{2} emissions and energy resource consumption or not is due to limited public knowledge on the precise values they want to save. The total weightings add up to one. The spreadsheet determines the optimal route (the least disutility one) and produces a ranking of other transport options along with their detailed objective-related information.

Figure 3.4 and Figure 3.5 present the general work flow of the active transport journey planner and structure of user’s data input (constraints) and weightings input interface.
The procedures of the Active Transport Journey Planner include identifying possible solutions, applying constraints, eliminating infeasible solutions, and ranking solutions. All three boxes in Figure 3.4 describe the procedures of the active transport journey planner, i.e. input, calculation (optimization) and output.

![Figure 3.5 User’s Data Input (Constraints) and Weightings Entry Interface](image)

There are four spreadsheets in the active transport journey planner. Their names are input, parameter, ATJP (abbreviation of Active Transport Journey Planner), and output.

(i) The input spreadsheet is a user input interface, where an individual traveller can enter the travel information, including start/end location, travel type (arriving end location or departing start location), travel date and arrive/depart time, personal weight, expectations or requirements for each objective (such as maximum or minimum value for personal energy expenditure, maximum direct cost of time and money, whether to consider CO₂ emissions and energy resource consumption or not). Meanwhile, preferences for multiple objectives are entered as relative values, so all weightings add up to one. The input spreadsheet layout is shown in Figure 3.6.
(ii) The parameter spreadsheet is a database for storing active transport journey planner data and information. It consists of two parts, ‘Reference’ and ‘Parameter’. The ‘Reference’ part includes information relating to personal weight-based energy expenditure, maximum or minimum travel speed, travel direct cost (such as parking and public transport ticketing), grams of CO₂ emitted and MJ of energy resource consumed per kilometre per person, with regard to different travel modes. The ‘Parameter’ part includes the data actually used in calculation in the model, that is, the data selected from ‘Reference’ and then exported to ATJP spreadsheet for calculation. The parameter spreadsheet layout described in Appendix 2. The detailed data and information is presented in Appendix 3.

(iii) The ATJP spreadsheet is an inner model calculation environment using the method introduced above. It imports data from the parameter spreadsheet, and does all the calculations inside automatically, then determines the minimal disutility transport option and ranks all options based on their disutility. Lastly, the recommended option (least disutility one) and the final ranking are exported to the output interface. Details of the ATJP spreadsheet are presented in Appendix 3.
The output spreadsheet is a results interface, which presents the recommended transport option, a ranking of all options as well as each option’s detailed information regarding personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption. It also indicates the feasibility of each option depending on an individual traveller’s expectations or requirements for multiple objectives. Details of output spreadsheet are presented in Figure 3.7.

![Figure 3.7 Output Spreadsheet Interface](image)

**3.9 Verification**

Before a solution can be analysed and implemented, it needs to be tested completely. Because the solution depends on the input data and the model, both require testing. Testing the input data and the model includes determining the accuracy and completeness of the data used by the model. Inaccurate data will lead to an inaccurate solution. There are several ways to test the input data. One method of testing the data is to collect additional data from a different source. If the original data were collected using interviews, perhaps some additional data can be collected with the original data, and statistical tests can be employed to determine whether there are differences between the original data and the additional data. If the data are accurate but the results are inconsistent with the problem, the model may not be appropriate. The model can be checked to make sure that it is logical and represents the real situation.

To help detect both logical and computational mistakes, the results should be checked to make sure that they are consistent with the structure of the problem.

Analysing the results starts with determining the implications of the solution. The implications of these actions or changes must be determined and analysed before the results are implemented.
More details of testing the model using provided sample calculations, undertaken by varying input and checking output will be presented in the Case Study in Chapter 4. Consistency with expectations and results will be tested and reviewed then.

3.10 Validation

Before the application of the active transport journey planner, it is important to validate this model. A case study is conducted using the active transport journey planner for a realistic journey in Melbourne in Chapter 4, and the results delivered will be checked with a local resident for validation with different sets of weightings.

3.11 Application

Implement and present the results

The final step is to implement the results. This is the process of incorporating the solution into the system. After the solution has been implemented, it should be closely monitored. Over time, there may be numerous changes that call for modifications of the original solution.

Since the objective of a multi-criteria analysis is to assist in the decision making process, presentation of the results in a form easily understood by the decision maker or makers is extremely important. One of the main advantages of multi-criteria analysis is its potential to simplify a mass of complex information. Decision makers are unlikely to be convinced of its value if they must wade through pages of large effects tables and statistical output. A trade-off has to be made between the researcher’s desire for completeness and the decision maker’s desire to consider a few clear-cut alternatives.

Multi-criteria analysis is most valuable when it is an interactive process involving the decision maker from the very beginning. When this is not possible, ingenuity is needed to show how the results vary with different sets of weightings and to illustrate the results of sensitivity analyses.
The active transport journey planner in Excel allows the decision maker to change inputs such as expectations or constraints for objectives and their corresponding weightings, then immediately see the effect of the changes.

A case study of the application of the active transport journey planner is presented in the Case Study in Chapter 4.

**Sensitivity analysis**

The importance of sensitivity analysis cannot be overemphasized. Because input data may not always be accurate or model assumptions may not be completely appropriate, sensitivity analysis can often be an important part of the model development process.

Because a model is only an approximation of reality, the sensitivity of the solution to changes in the model’s parameters and input data is a very important part of analysing the results. This type of analysis is called sensitivity analysis (Render, Stair & Hanna 2006). It determines how much the solution is sensitive to changes in the input data and the model’s specification.

In keeping with the trend away from the notion of a single ‘correct’ answer, sensitivity analysis has received greater emphasis in multi-criteria analysis (Resource Assessment Commission 1992). In a sensitivity analysis, various aspects of the multi-criteria problem, scores, weightings, standardization methods and evaluation methods and so on, are varied systematically to determine their effect on the ranking of the alternatives. Sensitivity analysis can be a very powerful tool because it reveals the strengths and weaknesses of the multi-criteria analysis. If the ranking of alternatives is insensitive to different sets of weightings of criteria, the choice of weightings is unimportant. If, on the other hand, the assignment of sets of weightings influences the ranking, more attention to the corresponding criterion is required.

Sensitivity analysis, supported by computer hardware and software, can easily overwhelm an analyst or decision maker with data. However, this data can be organized in a readily understandable way using well-designed graphs. Two graphical techniques, spiderplots and tornado diagrams, are commonly used by decision
analysts. Their advantages are complementary. The simpler tornado diagram can summarize the total impact of many independent variables. An individual spiderplot displays more information about a smaller number of variables. This includes the limits for each independent variable and the impact of each on the dependent outcome (Exchenbach 1992).
Chapter 4

CASE STUDY

Introduction

In this chapter, a case study is presented as a practical application use of the active transport journey planner, which is developed based on the methodology introduced in Chapter 3. Particular attention is focused on the application of multi-criteria analysis in the active transport journey planner. Moreover, applications in the ‘real world’ were sought, where multi-criteria analysis was an input to the decision process and not just an illustration or hypothetical example.

4.1 Background

An active transport journey planner is required to rank admissible travel alternatives involving active transport and identify the one with the least disutility in terms of the multi-objectives concerning personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption based on the user’s preferences (weightings).

A number of assumptions have been made:

(i) All travel modes (train, tram, bus, car, motorcycle, bicycle & walking) are available for selected travel routes at all times before 9am.
(ii) Good traffic conditions, no waiting time to, from and during travel.
4.2 Scope, Objectives and Criteria

Scope

(1) Geographic & Temporal

Daily transport from a resident home (296 Hope St, Brunswick West VIC 3055, Australia) to work or study at the University of Melbourne (Parkville Campus) during the morning peak to arrive no later than 9am.

(2) Organizational

Six reasonable travel routes including active transport, with seven available modes, including train, tram, bus, car, motorcycle, bicycle and walk, were identified to represent the transport system in the study area. Since the train station is far away from both the residence and the university compared with other modes according to a local resident, in the case study, the travel options exclude train.

(3) Functional

An individual traveller selects their travel objectives/criteria, as well as enters their expectations for these objectives and states their preferences. Then the active transport journey planner selects and ranks all the feasible transport options and identifies the one with the least disutility in terms of the selected multi-objectives based on the user’s preferences within the current health, economic, social and environmental system.
Objectives and Criteria

In the case study, there are five objectives including: personal energy expenditure, travel time, travel cost, CO₂ emissions and energy resource consumption, associated with health, environmental, social and economic benefits. For these objectives, their corresponding criteria are presented in Table 3.3.
4.3 Systems Analysis and Synthesis

The active transport journey planner workflow is illustrated in Figure 4.2. An individual traveller selects transport objectives or criteria, and then sets expectations as constraints for the multi-objectives as well as states corresponding preferences (weightings). After collecting the information, the active transport journey planner evaluates the generated alternatives by comparing the values of each objective with the user’s expectations or requirements. Based on those requirements, infeasible alternatives will be eliminated, such as the value of kilojoules expended for a journey if it is not within the minimum and maximum value set by the user. If the range of non-inferior solutions is adequate, the active transport journey planner will recommend the least disutility transport option and rank all the feasible transport options and present detailed information regarding the objectives for all options.

In this case study, the journey planner evaluates and ranks alternatives based on each option’s total disutility. In disutility analysis, a function is assessed for each criterion separately in terms of each specific characteristic. As presented in Table 3.4 in Chapter 3, personal energy expenditure is inversely proportion to disutility, which means the less energy you spent during the journey, the more disutility it incurs. Whereas, the other four objectives, travel time, travel cost, CO₂ emission and energy resource consumption, are in direct proportion to disutility, which means the less travel time it takes, the less disutility it has and so on. Meanwhile, the value of each criterion can be generated from the objective-related parameter based on distance as indicated in Table 3.4 of Chapter 3.
Select Objectives or Criteria.
Setup Expectations as Constraints.
State Preferences.
Generate Active Transport Journey Planner Options
Evaluate Options by Comparing Value of Each Objective/Criteria with Expectations (Constraints)
Eliminate Infeasible Options
Is The Range of Non-Inferior Solutions Adequate?
YES
NO
Recommend the Least Disutility Transport Option.
Rank All the Feasible Transport Options.
Present Detailed Information Regarding Objectives for All Options.

Figure 4.2 Active Transport Journey Planner Logic Work Flow

4.4 Data Collection

4.4.1 Generation of Routes

Based on an investigation of the public transport system and consultation with a traveller within the study area, six transport solutions including active transport were generated. The corresponding transport modes for each route are presented in Figure 4.3 according to their sequence during the journey from home to the university.
4.4.2 Generate Variables

Travel distance (unit: km) by each transport mode \( m \) in route option \( r \) is indicated as \( X_{m,r} \), which are the key variables in the objective function. It represents the travel distance by travel mode \( m \) in route option \( r \). For each transport route, the distance travelled by each mode is presented in Table 4.1.

4.4.3 Generate parameters

The parameters for each objective are presented in Table 3.5. The values of parameters for each objective are presented in Appendix 1.
4.5 Model
The model interface and functions are to be introduced in this section.

4.5.1 Model Interface

Users can enter information and requirements for the objectives through the active transport journey planner input interface (Figure 4.4), such as personal weight which is used for calculating personal energy expenditure during the journey, 86kg; expected achieved minimum or maximum value of personal energy expenditure, 0~8000kJ; expected travel time, 50 mins, travel cost, $15. Since users may not have a clear idea of the amount of CO$_2$ and energy resource consumption they are expected to save, they can select whether to take these two elements into account or not. All the information and requirements will be calculated within the model as well as setting the constraints to determine the feasible transport options and to eliminate the infeasible ones.

The feasible transport solutions will then be evaluated based on the user’s specified weightings for each objective. The final ranking of all feasible options will be provided according to their total disutility. The least disutility option will be recommended as the transport solution in the end. In addition, a ranking of all feasible
options and detailed objective-related information will also be presented as output, which is shown as Figure 4.5.

Figure 4.4 User Input Interface

Figure 4.5 User Output Interface

4.5.2 Model Function

In the case study, it is assumed that all the transport options are feasible given the regarding user’s multi-objective requirements. The value of each objective for transport options are presented in Table 4.2 according to the method and objective function introduced in Chapter 3.
Table 4.2 Values of each Objective for Transport Options

<table>
<thead>
<tr>
<th>Objective</th>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>Route 4</th>
<th>Route 5</th>
<th>Route 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>WTWBW</td>
<td>WBWTW</td>
<td>CW</td>
<td>CB</td>
<td>B</td>
<td>MC</td>
</tr>
<tr>
<td>Personal Energy Expenditure (kJ)</td>
<td>602.40</td>
<td>502.00</td>
<td>25.10</td>
<td>4062.96</td>
<td>7724.64</td>
<td>0.00</td>
</tr>
<tr>
<td>Travel Time (hr)</td>
<td>0.71</td>
<td>0.75</td>
<td>0.22</td>
<td>0.31</td>
<td>0.41</td>
<td>0.21</td>
</tr>
<tr>
<td>Travel Cost ($)</td>
<td>1.53</td>
<td>1.53</td>
<td>11.65</td>
<td>1.91</td>
<td>0.06</td>
<td>0.74</td>
</tr>
<tr>
<td>CO₂ Emission (g)</td>
<td>277.10</td>
<td>308.60</td>
<td>1066.40</td>
<td>481.60</td>
<td>0.00</td>
<td>768.80</td>
</tr>
<tr>
<td>Energy Resource Consumption (MJ)</td>
<td>5.59</td>
<td>10.94</td>
<td>29.14</td>
<td>13.42</td>
<td>0.49</td>
<td>17.36</td>
</tr>
</tbody>
</table>

During the normalization procedure, the performance, measures of alternatives are modified to be comparable, thus ensuring the applicability of preference or disutility aggregation under consideration for all criteria. Table 4.4 shows the value of weighted summation using interval standardization and quantitative weights. The weighted summation method requires quantitative information on values and weightings. As Janssen (Janssen & Herwijen 1991) suggested for standardization, the extreme value is one method. The equation $x'_{ij} = \frac{x_{ij} - \min_j \{x_{ij}\}}{\max_j \{x_{ij}\} - \min_j \{x_{ij}\}}$ is based on the position of the value between the minimum and maximum values. Because only the relative values of this information are used in the evaluation. The method provides a complete ranking and information on the relative differences between alternatives. As presented in Table 4.3c, the responding standardized value is given for each objective, respectively from routes 1 to 6. Whereas, the weightings are provided by a local resident as presented for the case study, which depend on the preferences of objectives that all add up to one. Then, the total disutility for each route is calculated as the sum of each standardized objective-related value multiplied by its corresponding weighting.

For example, the value of personal energy expenditure (kJ) for routes 1 to 6 is acquired using the above equation in Table 4.3, respectively. As the objective function is to minimize the total disutility, while personal energy expenditure is a benefit objective, its standardized value is $1 - x'_{ij} = \frac{x_{ij} - \min \{x_{ij}\}}{\max \{x_{ij}\} - \min \{x_{ij}\}}$. For other cost objectives, the standardize values are calculated as $x'_{ij} = \frac{x_{ij} - \min \{x_{ij}\}}{\max \{x_{ij}\} - \min \{x_{ij}\}}$. An
example of travel time calculation is presented in Table 4.3. Meanwhile, according to disutility standardization introduced in Chapter 3, the application of the active transport journey planner methodology is presented in Table 4.4.
\[
\text{DU}'_{o,r} = \begin{cases} 
(DU_{o,r} - \min_r \{DU_{o,r}\}) / (\max_r \{DU_{o,r}\} - \min_r \{DU_{o,r}\}), \text{ if } o \text{ is a cost objective;} \\
1- U'_{o,r} = 1- [(U_{o,r} - \min_r \{U_{o,r}\}) / (\max_r \{U_{o,r}\} - \min_r \{U_{o,r}\})], \text{ if } o \text{ is a benefit objective.}
\end{cases}
\]

Table 4.3 Standardized Values (personal energy expenditure and travel time as examples)

<table>
<thead>
<tr>
<th>Objective</th>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>Route 4</th>
<th>Route 5</th>
<th>Route 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>WTWBW</td>
<td>WBWTW</td>
<td>CW</td>
<td>CB</td>
<td>B</td>
<td>MC</td>
</tr>
<tr>
<td>Personal Energy Expenditure (kJ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Value</td>
<td>602.40</td>
<td>502.00</td>
<td>25.10</td>
<td>4062.96</td>
<td>7724.64 (max)</td>
<td>0.00 (min)</td>
</tr>
<tr>
<td>Standardized Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(benefit objective)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WTWBW</td>
<td>1- [(602.40 - 0.00) / (7724.64 - 0.00)] = 0.923</td>
<td>1- [(502.00 - 0.00) / (7724.64 - 0.00)] = 0.936</td>
<td>1- [(25.10 - 0.00) / (7724.64 - 0.00)] = 0.996</td>
<td>1- [(4062.96 - 0.00) / (7724.64 - 0.00)] = 0.474</td>
<td>1- [(7724.64 - 0.00) / (7724.64 - 0.00)] = 0</td>
<td>1- [(0.00 - 0.00) / (7724.64 - 0.00)] = 1</td>
</tr>
<tr>
<td>WBWTW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>B</td>
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<tr>
<td>MC</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time (hr)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real Value</td>
<td>0.71</td>
<td>0.75 (max)</td>
<td>0.22</td>
<td>0.31</td>
<td>0.41</td>
<td>0.21 (min)</td>
</tr>
<tr>
<td>Standardized Value</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(cost objective)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WTWBW</td>
<td>(0.71 - 0.21) / (0.75 - 0.21) = 0.899</td>
<td>(0.75 - 0.21) / (0.75 - 0.21) = 1.000</td>
<td>(0.22 - 0.21) / (0.75 - 0.21) = 0.031</td>
<td>(0.31 - 0.21) / (0.75 - 0.21) = 0.208</td>
<td>(0.41 - 0.21) / (0.75 - 0.21) = 0.414</td>
<td>(0.21 - 0.21) / (0.75 - 0.21) = 0.000</td>
</tr>
<tr>
<td>WBWTW</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CW</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>CB</td>
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<td></td>
<td></td>
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<tr>
<td>B</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

94
The total disutility of each option equals the summation of the standardized values of each objective multiplied by its weighting. It should be noted that the weightings entered in this case study are not necessarily representative. The individual with more concerns in health would put more interests or weights on the objective of personal energy expenditure. Take route option 1 for example.

Total disutility (Route 1)

\[ = \sum [(\text{Standardized Value of each objective}) \times (\text{each objective Weighting})] \]

\[ = (0.923 \times 0.3) + (0.899 \times 0.3) + (0.180 \times 0.2) + (0.260 \times 0.1) + (0.178 \times 0.1) = 0.621. \]

The disutility of other routes can be calculated similarly in Table 4.4.

<table>
<thead>
<tr>
<th>Objective</th>
<th>Route 1</th>
<th>Route 2</th>
<th>Route 3</th>
<th>Route 4</th>
<th>Route 5</th>
<th>Route 6</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Symbol</td>
<td>WTWBW</td>
<td>WBWTW</td>
<td>CW</td>
<td>CB</td>
<td>B</td>
<td>MC</td>
<td>0.3</td>
</tr>
<tr>
<td>Personal Energy Expenditure (kJ)</td>
<td>0.923</td>
<td>0.936</td>
<td>0.996</td>
<td>0.474</td>
<td>0.000</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Travel Time (hr)</td>
<td>0.899</td>
<td>1.000</td>
<td>0.031</td>
<td>0.208</td>
<td>0.414</td>
<td>0.000</td>
<td>0.3</td>
</tr>
<tr>
<td>Travel Cost ($)</td>
<td>0.180</td>
<td>0.180</td>
<td>1.000</td>
<td>0.159</td>
<td>0.000</td>
<td>0.059</td>
<td>0.2</td>
</tr>
<tr>
<td>CO₂ Emission (g)</td>
<td>0.260</td>
<td>0.289</td>
<td>1.000</td>
<td>0.452</td>
<td>0.000</td>
<td>0.721</td>
<td>0.1</td>
</tr>
<tr>
<td>Energy Resource Consumption (MJ)</td>
<td>0.178</td>
<td>0.365</td>
<td>1.000</td>
<td>0.451</td>
<td>0.000</td>
<td>0.589</td>
<td>0.1</td>
</tr>
<tr>
<td>Total Disutility</td>
<td>0.621</td>
<td>0.678</td>
<td>0.705</td>
<td>0.289</td>
<td>0.053</td>
<td>0.443</td>
<td>1.0</td>
</tr>
</tbody>
</table>

4.6 Model Results

According to the user expected attainments and weightings allocated to each objective described above in the model interface, it can be seen from Figure 4.5 that the Active Transport Journey Planner identifies route 5, cycling from home to the university as the best solution, followed by routes 4, 6, 1, 2, 3. Route 5 involves around 7725kJ of energy expenditure, 25 minutes of travel, 0.06 dollars, no CO₂ emission and 0.49 MJ energy resource consumption which only occurs at the bicycle manufacturing stage.
4.7 Sensitivity Analysis

If the ranking of alternatives is insensitive to different sets of weightings of criteria, the choice of weightings is unimportant. If, on the other hand, the assignment of sets of weightings influence the ranking, more attention to the corresponding criterion is required.

The base case weightings for each objective are: personal energy expenditure (0.3), travel time (0.3), travel cost (0.2), CO$_2$ emissions (0.1), and energy resource consumption (0.1). The consistency of results delivered from several evaluation approaches can be reviewed using sensitivity analysis, which aims to investigate the influence of modified input data on the calculated results and tests. In principle, all parameters can or should be subject to sensitivity analysis, but usually only criterion weights are examined. Tornado diagrams and spiderplots based on the equations of the model were constructed to aid the sensitivity analysis (Exchenbach 1992) and are shown in Figure 4.6 and Figure 4.7, respectively.

To construct a tornado diagram (Figure 4.6), it investigates the effects of change to the independent variables whose limits have the widest range for the dependent outcome at the top of the vertical axis. It also shows the other variables in descending order of effect on the dependent outcome. The limits of these variables could be expressed as percent change. Tornado diagram quickly highlights those variables which have the most influence on the outcome (Exchenbach 1992).
It can be concluded, this travel time weighting has the most impact on the total disutility, while carbon emissions and energy consumption have the least.

The spiderplot’s greater complexity can convey more information. A tornado diagram shows only the outcome values (y-coordinates) at the end of each spiderplot curve. The x-coordinates of these endpoints in the spiderplot curves depict the limits for each independent variable. The slopes of the spiderplot curve depict the relative change in the outcome for a unit change in the independent variable. The shape of the spiderplot curve also shows whether linear or nonlinear relationships are present. Tornado diagrams can be easier to produce and can be constructed for more variables (Exchenbach 1992).

The base-case outcome is the deterministic result. This defines the vertical axis of the tornado diagram and the center of the spiderplot. One at a time, each variable is set to its upper and lower limits and the base-case outcome is calculated, while the other variables remain at their base-case values.

The base case total disutility is the deterministic result. It defines the vertical axis of the tornado diagram and the center of the spiderplot. One at a time, each objective-related weighting variable is set to its upper (200% of the base case value) and lower (50%) limits and the total disutility is recalculated, while the other objective-related
weightings change in proportion, to ensure all weightings add up to one. As indicated in Figure 4.6, the travel time weighting has the most impact on total disutility, whereas CO$_2$ emission and energy resource consumption have the least. Personal energy expenditure and travel cost weightings are in between; with total disutility being more sensitive to personal energy expenditure than CO$_2$ emissions.

(1) Route 1 with symbol: WTWBW

(2) Route 2 with symbol: WBWTW
(3) Route 3 with symbol: CW

(4) Route 4 with symbol: CB

(5) Route 5 with symbol: B

(6) Route 6 with symbol: MC

Figure 4.7 Spiderplots for Routes weighting variables (distribution sensitivity analysis)
As indicated in Figure 4.7, for consistency, the x-axis measures each objective-related weighting variable as a percentage of its base case, while other weightings change in relative proportion to ensure the total weightings add up to one.

Route 1 involves 4.8km on the tram, 1.25km by bus and 0.99km walking. As presented in Figure 4.7, the personal energy expenditure has the most negative impact on total disutility, i.e. more weight on personal energy expenditure, the more disutility the route 1 has. This criterion is followed by travel time, which also has a negative impact but less steep as indicated in Figure 4.7 (1). Whereas, the travel cost has the most positive impact, i.e. more weights on travel cost, the less disutility the route 1 is, which is followed by energy resource consumption and then CO₂ emissions.

Route 2 involves 3.47km on the tram, 5.83km by bus and 0.83km walking. Travel time has the most negative impact on total disutility, followed by personal energy expenditure. Whereas, travel cost has the most positive impact, followed by CO₂ emissions and then energy resource consumption.

Route 3 involves 6.2km by car and 0.05km walking. Travel time sensitivity has the only positive impact on total disutility. Whereas, the personal energy expenditure has the most negative impact, followed by travel cost, CO₂ emissions and then energy resource consumption.

Route 4 involves 2.8km by car and 3.24km on bicycle. Personal energy expenditure has the most negative impact on total disutility, followed by energy resource consumption and CO₂ emissions. Whereas, the travel time has the most positive impact, followed by travel cost.

Route 5 involves 6.16km on bicycle. Travel time has the only negative impact on total disutility. Whereas, personal energy expenditure has the most positive impact, followed by travel cost, CO₂ emissions and then energy resource consumption.

Route 6 involves 6.2km on motorcycle. Travel time has the only positive impact on total disutility. Whereas, personal energy expenditure has the most negative impact, followed by travel cost, CO₂ emissions and then energy resource consumption.
It is concluded that transport options incorporating more physical activity such as cycling and walking have a higher probability to deliver as the least total disutility to the user if social and environmental concerns were taken into account beyond economic issues.

Other Applications

Assume the weighting for each objective is even, that is, 0.2 is given to each objective. Therefore, the ranking is route 5, 4, 6, 1, 2, 3 based on the total disutility from the least to the highest. At extreme situations, when total weightings are only given to one objective, i.e. 1 for one objective, 0 for all others each. The results are presented in Table 4.5.

Table 4.5 Result of Extreme situation in Weightings

<table>
<thead>
<tr>
<th>Rank</th>
<th>Disutility</th>
<th>Personal Energy Expenditure</th>
<th>Travel Time</th>
<th>Travel Cost</th>
<th>CO₂ Emissions</th>
<th>Energy Resource Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Least</td>
<td>5</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>4</td>
<td>3</td>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>2</td>
<td>5</td>
<td>1 (or 2)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>3</td>
<td>1</td>
<td>2 (or 1)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>6</td>
<td>Most</td>
<td>6</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Key

<table>
<thead>
<tr>
<th>Route</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WTWBW</td>
</tr>
<tr>
<td>2</td>
<td>WBWWTW</td>
</tr>
<tr>
<td>3</td>
<td>CW</td>
</tr>
<tr>
<td>4</td>
<td>CB</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>MC</td>
</tr>
</tbody>
</table>
For other situations, assume in Case 1, an uncaring or unthinking individual who is not interested in health, CO₂ or resource consumption, would input 0.5 on travel time and other 0.5 on travel cost, the result would favour motorcycle (Route 6). The ranking is presented in Table 4.6.

Assume in Case 2, weights of the five criteria, including personal energy, travel time, travel cost, CO₂ emissions and energy resource consumption, are given as 0.1, 0.4, 0.3, 0.1 and 0.1. The results still favour bicycle same as the base case (Route 5). The ranking is presented in Table 4.6.

Table 4.6 Result of other situation in Weightings

<table>
<thead>
<tr>
<th>Rank</th>
<th>Disutility</th>
<th>Rank (if weighting of criteria in the column=1, others=0 in sequence)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Base Case</td>
</tr>
<tr>
<td>1</td>
<td>Least</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Most</td>
<td>3</td>
</tr>
</tbody>
</table>

Key

<table>
<thead>
<tr>
<th>Route</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WTWBW</td>
</tr>
<tr>
<td>2</td>
<td>WBWTW</td>
</tr>
<tr>
<td>3</td>
<td>CW</td>
</tr>
<tr>
<td>4</td>
<td>CB</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>MC</td>
</tr>
</tbody>
</table>
Chapter 5

CONCLUSIONS

Results show that the active transport journey planner methodology developed could be applied for selecting the best transport solution based on an individual user’s multi-objective preferences and weightings. In addition, transport options that incorporate more cycling and walking have a higher probability to deliver as the best solution for the user if social and environmental concerns were taken into account beyond financial issues.

Future Work

Further research is needed to extend and test this model in order to take into account other criteria, such as weather and safety. This could be undertaken through survey or stakeholder workshops. In addition, it is suggested that the value of parameter for each objective should involve time and location considerations for its wider and more flexible update and utilization.

In addition, during the weighting generation stage, research in assisting an individual to generate weights certainly deserves further investigation and application. As it represents social preferences, and therefore the question of who specifies the weights becomes important. Weights can be assigned directly by the individual carrying out the analysis to represent hypothetical points of view: they can be based on data collected from opinion polls, focus groups or other direct forms of sampling public or expert opinion; or they can be generated mathematically from limited information on rankings.

Davis (1984) suggested that the need to assign weights is a disadvantage because it is unclear whether it should be done by the analyst or by politicians. However, with the active transport journey planner, all weights are assigned by an individual. The active transport journey planner can be used by politicians, to simulate what route options different groups of people will take. More recent attributes to multi-criteria analysis,
however, have tended to move away from the idea of an analysis based on a single ‘correct’ set of weights.

In their review of multi-criteria analysis, Romero and Rehman (1987, p75) concluded, ‘[the] greatest difficulty in the widespread use of the [multi-criteria decision making] paradigm is the availability of substantial information required from the decision maker on his objectives, goals, targets, weights and pre-emptive ordering of preferences.’

This concern is echoed by Jelassi (1991), who suggests that participants be offered support from the philosophy of ethics in order to elucidate their weightings and preferences. Some work for finding out the way to generate weightings should be done, such as online tests or surveys, since weightings directly determines the result of the best transport route and mode as well as the ranking of the others. Also knowledge of health, environmental, social and economic sustainability should be promoted and disseminated, which could help individuals to enter their expectations for selecting routes and modes effectively.

The principal barriers to active transport are distance, time, weather, inconvenience, lack of infrastructure and facilities, traffic safety and road conditions, personal safety, health and disability, and a car culture. Future work is needed to remove these barriers to benefit the implementation of active transport.

*Distance and time:* For many people, a barrier to using active transport, especially for commuting, is distance. The longer the trip takes, the less likely it is that the average person will choose to use active transport. People also tend to value their time and if physical activity is not a priority or is accommodated in some other way, many will choose to drive to get to their destination in order to have more time for their set priorities.

*Weather:* Melbourne’s climate varies frequently, bringing cold and hot temperatures, rain, dry and other challenging conditions. Different weather conditions will be a factor for different people, with their impact depending on the form of active transport on individual perceptions.
Inconvenience: Many people enjoy the convenience that personal vehicles offer and may feel that using active transport would not suite them due to their chosen lifestyle. Active transport may also not be convenient for different types of jobs (i.e. some require the use of personal vehicles to do the job).

Lack of infrastructure and facilities: Many people choose not to use active transport because of a lack of infrastructure such as bike lanes, off-road paths and trails, sidewalks and ramps. Another factor is whether appropriate facilities such as on-site sidewalks or pathways, bike parking, showers and change rooms are available at the destination.

Traffic safety and road conditions: Active transport often involves sharing the road with motorized vehicles. A major concern for cyclists is safety in traffic, and other forms of active transport have similar concerns (e.g. pedestrian safety at road crossings or on roads without sidewalks). Driver, cyclist and pedestrian education is also a major factor. On top of the traffic safety concerns, road conditions including rain, flood can be a deterrent to certain forms of active transport. This includes conditions for sidewalks and paths, which need to be maintained during winter months in order to make active transport feasible.

Personal safety: Personal safety as a barrier to active transport includes fear of crime, such as bicycle theft, child abductions, and muggings, among others.

Health and disability: Another barrier to active transport is health. Some people cannot use active transport for health reasons. On smog days in particular, people who are vulnerable to asthma or other respiratory disorders are advised to be cautious when it comes to physical activity and outdoor activities. In addition, persons with disabilities may not be able to use active transport for long distances and some cannot use it at all.

Car Culture: Other barriers to active transport stem from what has been referred to as a `car culture`. Active transport lacks credibility and respect as a form of transport since our present urban design evolved with personal motor vehicle use as the norm. For many, using a personal vehicle to run errands or go to work is simply second
nature. In addition, a car can also be seen as a status symbol, which dissuades the substitution of other forms of transportation.

In addition, there is a need to highlight health benefits and environmental costs. Providing other information for routes, especially, percentage of energy expenditure according to the physical activity guidelines for one trip and estimating the physical active level (PAL) would be good to include.

It would be useful to extend the scope to trips over an entire day to ensure that linked trips and travel time budgets can be incorporated, including trips from home to work or school, then onto shops or other places and finally going back home.

All in all, active transport is a trend leading Australia to a more healthy and sustainable future. Individuals, communities and governments should work together to facilitate the wide promotion and implementation of active transport. An active transport journey planner can be a component of this process.

**Discussion**

From the sensitivity analysis, it can be seen that energy resource consumption has the most disutility, as all transport modes except walking are involved, either at the manufacturing or operating stage. Other objectives such as personal energy expenditure only exist for cycling and walking. So transport options incorporating more cycling and walking have a higher probability to deliver healthier and more sustainable solution to users if social, environmental concerns were taken into account beyond economic issues.

Further research is needed to extend and test this model in order to incorporate other objectives, such as weather, and safety through surveys or stakeholder workshops.

In summary, this research has completed a number of tasks and achieved its objectives. The active transport journey planner methodology has been planned, designed and developed. The application of the active transport journey planner is demonstrated in a case study.
The procedures for estimating a range of costs and benefits for journeys have been developed; the procedures for determining the optimal route and mode for an individual’s trip in an urban area based on cost and benefit estimates and preference weights for specific objectives have been developed; the cost and benefit estimation and optimal route generation procedures to conduct a case study for a realistic journey in Melbourne has been used; and sensitivity analysis have been undertaken using the case study.
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Appendices

Appendix 1: Objective Function

Objective Function

$$\text{Min } \sum_{r=1}^{N} (R_r \times DU_r)$$

$$= \text{Min } \sum_{r=1}^{N} [R_r \times \sum_{o}^{O} \omega_o DU'_{o,r}]$$

$$= \text{Min } \sum_{r=1}^{N} \{R_r \times \{\sum_{o}^{O} \{\omega_o [(DU_{o,r} - \text{Min}_r \{DU_{o,r}\})/(\text{Max}_r \{DU_{o,r}\} - \text{Min}_r \{DU_{o,r}\})]})} \}$$

$$DU'_{o,r} = (DU_{o,r} - \text{Min}_r \{DU_{o,r}\})/(\text{Max}_r \{DU_{o,r}\} - \text{Min}_r \{DU_{o,r}\}), \text{ if } o \text{ is a cost objective;}$$

$$DU'_{o,r} = 1 - U'_{o,r} = 1 - [(U_{o,r} - \text{Min}_r \{U_{o,r}\})/(\text{Max}_r \{U_{o,r}\} - \text{Min}_r \{U_{o,r}\})], \text{ if } o \text{ is a benefit objective.}$$

Where $DU_{o,r}$ or $U_{o,r} = \sum_{m=1}^{M} a_{o,m,r} \lambda_{m,r} X_{m,r}$, for either cost or benefit objectives.
**Constraints**

\[ 0 \leq O_{\text{min}} \leq O_r \leq O_{\text{max}} \]

Where, \( O_r \) is the set of objectives achieved in route option \( r \);

\( O_{\text{min}}, O_{\text{max}} \) are the minimum or maximum value of constraints for set of objectives in route option \( r \), respectively.

**Decision Variables**

- \( R_r \): Route option \( r \);
  \[
  \begin{align*}
  R_r &= 1, \text{ if route option } r \text{ is selected;} \\
  R_r &= 0, \text{ otherwise.}
  \end{align*}
  \]

- \( r \): Route option number, \( r \in R \{1,2,\ldots,N\} \); where \( R \) is the set of route options, and \( N \) is the total number of route options;

- \( X_{m,r} \): Distance travelled by travel mode \( m \) in route option \( r \); (km)

**Parameters**

- \( \omega_o \): Weighting of objective \( o \);

- \( m \): Travel mode number; \( m \in M \{1,2,\ldots,7\} \); where \( M \) is the set of travel modes, and \( M \) is the total number of travel mode options; *In the case study, 7 travel modes totally, i.e. 1-train, 2-tram, 3-bus, 4-car, 5-motorcycle, 6-bicycle, 7-walk;*

- \( \lambda_{m,r} \): Availability of travel mode \( m \) in route option \( r \);
\[ \lambda_{m, r} = 1, \text{ if travel mode } m \text{ is available in route option } r; \]
\[ \lambda_{m, r} = 0, \text{ otherwise.} \]

- \( a_{o, m, r} \): Disutility (for cost objective) or utility (for benefit objective) conversion factor with regard to the extent of objective \( o \) achieved by travel mode \( m \) per person per km in route option \( r \);

**Terminology**

- \( \text{Min}_r \{ \text{DU}_o, r \} \): Minimum value of disutility with regard to cost objective \( o \) in route options;
- \( \text{Max}_r \{ \text{DU}_o, r \} \): Maximum value of disutility with regard to cost objective \( o \) in route options;
- \( \text{DU}_r \): Total value of disutility in route option \( r \);
- \( \text{DU}_o, r \): Value of disutility with regard to cost objective \( o \) in route option \( r \);
- \( \text{DUV}_{o, r} \): Standardised value of disutility with regard to cost objective \( o \) in route option \( r \);
- \( \text{Min}_r \{ \text{U}_o, r \} \): Minimum value of utility with regard to benefit objective \( o \) in route options;
- \( \text{Max}_r \{ \text{U}_o, r \} \): Maximum value of utility with regard to benefit objective \( o \) in route options;
- \( \text{U}_r \): Total value of utility in route option \( r \);
- \( \text{U}_o, r \): Value of utility with regard to benefit objective \( o \) in route option \( r \);
- \( \text{U}_{o, r} \): Standardised value of utility with regard to benefit objective \( o \) in route option \( r \);
- \( o \): Objective, either cost objective or benefit objective; *in the case study*, where \( o \in O \{ EE, TT, TC, CE, EC \} \);
- \( O \): Set of objectives;
**Standardisation**

Objective scores are generally mutually incompatible since most of the measurement units are different. Therefore, there is a need to transform costs and benefits for each objective for each mode option into one (dimensionless) unit.

**Extreme Value**

\[
DU'_{o,r} = \frac{DU_{o,r} - \min_{r}\{DU_{o,r}\}}{\max_{r}\{DU_{o,r}\} - \min_{r}\{DU_{o,r}\}}, \text{ if } o \text{ is a cost objective;}
\]

\[
1 - U'_{o,r} = 1 - \frac{(U_{o,r} - \min_{r}\{U_{o,r}\})}{\max_{r}\{U_{o,r}\} - \min_{r}\{U_{o,r}\}}), \text{ if } o \text{ is a benefit objective;}
\]

\(DU'_{o,r}\) or \(U'_{o,r}\) indicates relative position on interval between the lowest & highest values.
## Appendix 2: Parameter Spreadsheet

### Reference

#### Personal Energy Expenditure

<table>
<thead>
<tr>
<th>Physical Activity</th>
<th>Velocity (km/hr)</th>
<th>Energy Expenditure (L/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>3.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Cycling</td>
<td>15.5</td>
<td>0.7</td>
</tr>
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### Parameter

#### Personal Energy Expenditure

<table>
<thead>
<tr>
<th>Physical Activity</th>
<th>Velocity (km/hr)</th>
<th>Weight (kg)</th>
<th>Energy Expenditure (L/hr)</th>
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</thead>
<tbody>
<tr>
<td>Walking</td>
<td>3.2</td>
<td>70</td>
<td>0.8</td>
</tr>
<tr>
<td>Cycling</td>
<td>15.5</td>
<td>60</td>
<td>0.7</td>
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### Travel Velocity

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<th>m3</th>
<th>m4</th>
<th>m5</th>
<th>m6</th>
<th>m7</th>
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</thead>
<tbody>
<tr>
<td>Slow</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
<td>66</td>
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<tr>
<td>Fast</td>
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</tbody>
</table>

### Travel Cost

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<th>Travel Mode</th>
<th>m1</th>
<th>m2</th>
<th>m3</th>
<th>m4</th>
<th>m5</th>
<th>m6</th>
<th>m7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
</tr>
<tr>
<td>Bus</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
<td>2.95</td>
</tr>
</tbody>
</table>

### CO₂ Emission

<table>
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<th>Travel Mode</th>
<th>m1</th>
<th>m2</th>
<th>m3</th>
<th>m4</th>
<th>m5</th>
<th>m6</th>
<th>m7</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Emission (g/km/person)</td>
<td>14</td>
<td>52</td>
<td>22</td>
<td>172</td>
<td>124</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Energy Resource Consumption

<table>
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<tr>
<th>Travel Mode</th>
<th>m1</th>
<th>m2</th>
<th>m3</th>
<th>m4</th>
<th>m5</th>
<th>m6</th>
<th>m7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Resource Consumption (MWh/km/person)</td>
<td>0.2</td>
<td>0.8</td>
<td>1.4</td>
<td>6.7</td>
<td>2.8</td>
<td>0.08</td>
<td>0</td>
</tr>
</tbody>
</table>

## 128
# Appendix 3: Parameter Reference Table

## I. Personal Energy Expenditure Table

<table>
<thead>
<tr>
<th>Weight</th>
<th>50 kg</th>
<th>68 kg</th>
<th>77 kg</th>
<th>86 kg</th>
<th>91 kg</th>
<th>100 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m=6 Bicycle</td>
<td>15-16 (km/hr)</td>
<td>577</td>
<td>786</td>
<td>890</td>
<td>991</td>
<td>1045</td>
</tr>
<tr>
<td>m=7 Walk</td>
<td>3.3 (km/hr)</td>
<td>276</td>
<td>376</td>
<td>426</td>
<td>477</td>
<td>502</td>
</tr>
<tr>
<td>m=7 Walk</td>
<td>4.8 (km/hr)</td>
<td>368</td>
<td>502</td>
<td>568</td>
<td>635</td>
<td>669</td>
</tr>
</tbody>
</table>

(Source: Bauman 2004)

Note:

EE: Personal energy expenditure of travel mode m based on weight index w (kg) and velocity index v (km/hr); (kJ/hr)

V: Velocity of alternative v of travel mode m; (km/hr)

Parameter of personal energy expenditure = EE/V; (kJ/person/km)

## II. Travel Velocity Table

<table>
<thead>
<tr>
<th>Travel Mode</th>
<th>Train</th>
<th>Tram</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Velocity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow</td>
<td>60'</td>
<td>16''</td>
<td>25'''</td>
<td>45'''</td>
<td>30'''</td>
<td>15''''</td>
<td>3.3''''</td>
</tr>
<tr>
<td>Fast</td>
<td>60'</td>
<td>16''</td>
<td>35'''</td>
<td>50'''</td>
<td>50''''</td>
<td>21''''</td>
<td>4.8''''</td>
</tr>
</tbody>
</table>

(Source: ': Data from Melbourne Connex Train website (Connex 2008), ''': Data from Melbourne Yarra Tram website (Yarra Tram 2008), ''''' (Tranter 2004 ); ''''''': consultation form traveller Asif within case study scope (Zaman 2008); ''''''': (Bauman 2004))
Parameter of travel time = $1/V$ (hr/person/km)

### III. Travel Cost Table

<table>
<thead>
<tr>
<th>Travel Mode</th>
<th>Train</th>
<th>Tram</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Cost</td>
<td>1.53* ($/trip)</td>
<td>1.53* ($/trip)</td>
<td>1.53* ($/trip)</td>
<td>0.67** ($/km)</td>
<td>0.12*** ($/km)</td>
<td>0.01* ($/km)</td>
<td>0</td>
</tr>
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</table>

(Source: *: data from the calculation based on the assumption that traveller use yearly Metcard($1117) take public transport for return between home and workplace on weekdays in scope($1117/(2*5) (Metlink 2008)); **: (ABS 2008); ***: consultation form traveller Asif within case study scope (Zaman 2008))

### IV. CO₂ Emission Table

<table>
<thead>
<tr>
<th>Travel Mode</th>
<th>Train</th>
<th>Tram</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Emission (g/person/km)</td>
<td>14</td>
<td>52</td>
<td>22</td>
<td>172</td>
<td>124</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

(Source: ABS 2003)

### V. Energy Resource Consumption Table

<table>
<thead>
<tr>
<th>Travel Mode</th>
<th>Train</th>
<th>Tram</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Resource Consumption (MJ/person/km)</td>
<td>0.2</td>
<td>0.8</td>
<td>1.4</td>
<td>4.7</td>
<td>2.8</td>
<td>0.08</td>
<td>0</td>
</tr>
</tbody>
</table>

(Source: ABS 2006)
### Appendix 4: Active Transport Journey Planner Spreadsheet

#### Active Transport Objectives

<table>
<thead>
<tr>
<th>Objective</th>
<th>Weight</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal Energy</td>
<td>0-8000</td>
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</tr>
<tr>
<td>Travel Time</td>
<td>0-50min</td>
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<td>0.11</td>
</tr>
<tr>
<td>CO2 Emission</td>
<td>Y/N?</td>
<td>0.06</td>
</tr>
<tr>
<td>Energy Resource Consumption</td>
<td>Y/N?</td>
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#### Mode Availability

<table>
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<th>Waiting Time (h)</th>
<th>Train</th>
<th>Tram</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
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<tbody>
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<td>1</td>
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<td>0</td>
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</tr>
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<td>0</td>
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#### Travel Time

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<th>Tram</th>
<th>Bus</th>
<th>Car</th>
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<td>0.25</td>
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<td>0.05</td>
<td></td>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
</tr>
<tr>
<td>5</td>
<td>Home Walking</td>
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<td>0.05</td>
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<td></td>
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<td>0</td>
<td>0</td>
<td>0.25</td>
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<td></td>
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</table>

#### Travel Distance

<table>
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<th>Travel Distance</th>
<th>Train</th>
<th>Bus</th>
<th>Car</th>
<th>Motorcycle</th>
<th>Bicycle</th>
<th>Walk</th>
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<td>8.90</td>
<td>1.25</td>
<td></td>
<td></td>
<td>1.14</td>
<td>0.29</td>
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<tr>
<td>3</td>
<td>Home Walking</td>
<td>8.90</td>
<td>1.25</td>
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<td></td>
<td>1.14</td>
<td>0.29</td>
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<tr>
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<td>1.25</td>
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<td></td>
<td>1.14</td>
<td>0.29</td>
<td></td>
</tr>
<tr>
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<td>8.90</td>
<td>1.25</td>
<td></td>
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<td>1.14</td>
<td>0.29</td>
<td></td>
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<tr>
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<td>8.90</td>
<td>1.25</td>
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<td>0.29</td>
<td></td>
</tr>
<tr>
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<td>Trip Description</td>
<td>Parking Cost ($)</td>
<td>Energy Expenditure (€/h)</td>
<td>Travel Time (hr)</td>
<td>Travel Cost ($)</td>
<td>CO₂ Emission (g)</td>
<td>Energy Resource Expenditure (€/h)</td>
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<tr>
<td>-------</td>
<td>------------------</td>
<td>------------------</td>
<td>--------------------------</td>
<td>-----------------</td>
<td>----------------</td>
<td>----------------</td>
<td>----------------------------------</td>
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</tr>
<tr>
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<td>277.410</td>
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<tr>
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<td>0.24</td>
<td>90.08</td>
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</tr>
<tr>
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<td>0.62</td>
<td>0.000</td>
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<tr>
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<td>0.000</td>
<td></td>
</tr>
</tbody>
</table>

**Extro Value**

<table>
<thead>
<tr>
<th>Energy Expenditure (€/h)</th>
<th>Travel Time (hr)</th>
<th>Travel Cost ($)</th>
<th>CO₂ Emission (g)</th>
<th>Energy Resource Expenditure (€/h)</th>
</tr>
</thead>
<tbody>
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<td>0.997</td>
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<td>0.997</td>
<td>1.000</td>
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</tbody>
</table>

**Standardised (Distility based)**

<table>
<thead>
<tr>
<th>Route</th>
<th>Trip Description</th>
<th>Energy Expenditure</th>
<th>Travel Time</th>
<th>Travel Cost</th>
<th>CO₂ Emission</th>
<th>Energy Resource Expenditure</th>
<th>Distility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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<tr>
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<td>Home Car</td>
<td>0.500</td>
<td>1.063</td>
<td>1.063</td>
<td>1.063</td>
<td>0.083</td>
<td>0.083</td>
</tr>
<tr>
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<td>Home Bicycle</td>
<td>0.500</td>
<td>1.063</td>
<td>1.063</td>
<td>1.063</td>
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<td>1.063</td>
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**Rank**

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**Feasibility Check**

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<tr>
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<th>Trip Description</th>
<th>Parking Cost ($)</th>
<th>Energy Expenditure (€/h)</th>
<th>Travel Time (hr)</th>
<th>Travel Cost ($)</th>
<th>CO₂ Emission (g)</th>
<th>Energy Resource Expenditure (€/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Home Walking</td>
<td>0.00</td>
<td>322.65</td>
<td>0.55</td>
<td>2.98</td>
<td>277.410</td>
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</tr>
<tr>
<td>2</td>
<td>Home Walking</td>
<td>0.00</td>
<td>622.40</td>
<td>0.16</td>
<td>2.89</td>
<td>000.000</td>
<td>3.84</td>
</tr>
<tr>
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<td>Home Car</td>
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<td>25.99</td>
<td>0.21</td>
<td>11.59</td>
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<td>29.180</td>
</tr>
<tr>
<td>4</td>
<td>Home Car</td>
<td>0.00</td>
<td>462.80</td>
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<td>90.08</td>
<td>431.600</td>
<td>17.419</td>
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<td>272.94</td>
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<td>0.62</td>
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<td>0.74</td>
<td>700.000</td>
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</tr>
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</table>

**Energy Expenditure (€/h)**

<table>
<thead>
<tr>
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**Utility**

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**Feasibility**

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Author/s:
Hu, W.

Title:
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Date:
2009

Citation:

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