Modelling Walking Accessibility to Public Transport Terminals

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SUMMARY

Walking accessibility is defined as how easy it is to access public transport terminals by walking. The public transport terminals are Mass Rapid Transit (MRT) stations. Walking effort instead of walking distance or walking time is used to represent the utility of walking as access mode. This effort is expressed by an equivalent walking distance, which consists of actual walking distance and generalised walking effort. The main objective of this research is to develop walking accessibility measure using equivalent walking distance.

There are two research stages that were carried out in this study. The first one is the development of walking mode share function in Walking Access Model (WAM) and the second one is development of Equivalent Walking Distance (EWD). Most of data were obtained from on-site interview surveys and walking route assessments.

WAM was developed to investigate walking mode share to access public transport terminals. The model is built based on two access modes, walking and non-walking mode. Feeder modes such as bus and Light Rapid Transit (LRT) are considered as non-walking modes. Unlike other cities in Canada and USA, Singapore operates LRT as a feeder mode to the main public transport system, MRT.

Nine study areas were selected around MRT stations in residential areas. They are: Clementi and Bedok on East-West Line; Bukit Batok and Choa Chu Kang on North-South Line; and Sengkang, Hougang, Kovan, Serangoon, Boon Keng along the North-East Line.

Observations from 9 stations show that the average proportion of walking and taking bus or LRT to access MRT stations is 61.6% and 34.8%.The other access modes are car (3%), taxi (0.23%), and bicycle (0.38%).According to respondents' characteristics, there is a higher proportion of walking for compulsory trips

(working and educational) and for respondents with age between 26 and 50 years old.

Results form interview survey show that the two top *very important* factors affecting choice of walking to access MRT stations are rain shelters (weather protection) and walking distance. It is also shown that more than 50% of respondents are comfortable with walking distance up to 1000 metres. The average walking distance to access MRT stations is about 630 metres and the average walking speed, which was derived from measured walking distance divided by respondent's reported walking time, is 70.6 m/min. Statistical analysis shows that characteristics of walking are not significantly influenced by gender.

The development of WAM showed that walking probability to access MRT station is influenced by walking distance, number of road crossings, ascending steps and traffic conflicts. Within a subset of data, weather protection becomes another significant factor in the model. The model also shows that the effort of crossing a road is equal to 55.40 metres of walking. The effort to climb one step is equal to 2.81 metres of level walking or 90 metres for a pedestrian bridge (32 steps). The effort to cross a car park or access road is equal to 36.31 metres of walking. The effort of walking for 100 metres is equal approximately to walking of 115 metres on route with weather protection or 80 metres on route without.

On average, EWD value is 1.28 times higher than the average measured walking distance. It implies that effort of walking related to walking route characteristics is comparable with additional 28% of walking distance. There were two types of catchment areas that were used in walking accessibility measure: based on airline distance (ADIST) and EWD. Number of housing blocks was used to show the population inside a catchment area. As a new approach of walking accessibility measure, the walking probability is incorporated into the population ratio between the catchment areas. This measure is called Walking Accessibility Index (WAI) and the values for some areas are: Clementi (65.2%), Bukit Batok (51.9%), Choa Chu Kang (46.9%),and Bedok (44.6%).

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List of Abbreviations

ADIST = Airline Distance (straight line distance)

ASTEP = Number of Ascending Steps

BART = Bay Area Rapid Transit

CBD = Central Business District

EWD = Equivalent Walking Distance

EWT = Equivalent Walking Time

GIS = Geographical Information System

GPS = Global Position System

HCM = Highway Capacity Manual

IIA = Independence of Irrelevant Alternatives

LOS = Level of Service

LRT = Light Rapid Transit

LTA = Land Transport Authority

MNL = Multinomial Logit

MRT = Mass Rapid Transit

NS = National Service

PEF = Pedestrian Environmental Factor

PLOS = Pedestrian Level of Service

RXING = Number of Road Crossings

SLRT = Singapore Light Rapid Transit

TCONF = Number of Traffic Conflicts (i.e. access roads, etc)

TFF = Transit Friendliness Factor

WAI = Waking Accessibility Index

WAM = Walking Access Model

WDIST = (Measured) Walking Distance

WPDI = Walking Permeability Distance Index

WPTI = Walking Permeability Time Index

Chapter 1 Introduction

1.1 Background

There are many ways to access public transport terminals, such as by foot (walking), bicycle, car (drop-off and park-and-ride), taxi, and bus. Many studies on public transport have shown that walking is the most natural and important mode to access public transport (for example: Stringham, 1982; Mitchell and Stokes, 1982; Loutzenheiser, 1997; Meyer and Miller, 2001; and Cervero, 2001). Walking accessibility to public transport is applied to indicate the quality or performance of public transport service (Henk and Hubbard, 1996; Rudnicki, 1999; Polzin et al., 2000; and FDOT, 2001).

In recent public transport studies, public transport accessibility is associated with a certain number that is related to walking distance or walking time. The number of 400 to 800 metres of walking distance or 10 to 15 minutes of walking time is often applied. Inaccessibility or bad accessibility of public transport means that the distance or time to walk to access public transport terminal is longer than these numbers.

Singapore Mass Rapid Transit network (known as MRT Lines) is planned to be the backbone of its transportation system. At the end of 2003, there were 65 operating MRT stations and 20 of Light Rapid Transit (LRT) stations. To promote and increase MRT ridership, good accessibility to access the stations is needed. The Land Transport Authority of Singapore (LTA) provides some facilities to make MRT stations more accessible, such as building walking paths to the station, providing feeder services, taxi stands, park and ride facilities and so on. As a result, there are many alternative ways to reach MRT stations. In terms of access mode choice, a person who walks to the station could be seen as the person who chooses walking as his/her access mode.

Since walking to reach public transport is the result of mode selection process, walking share model could be developed to capture characteristics of the access mode choice to reach public transport terminal. Equivalent walking distance would be derived from the walking share model.

Characteristics of walking routes could not be derived from examining only walking distance or walking time. However, these characteristics influence the walking effort and hence the qualities of public transport accessibility. Equivalent walking distance will be introduced to express walking effort to access public transport terminal based on walking route characteristics.

1.2 Problem Statement

In most urban areas, public transport is the key to transport system efficiency. To make public transport as the main transport mode in Singapore, LTA applies high restraints on car ownership and strives to improve the quality of public transport. Consequently, the ease of walking access to public transport terminals could be an important factor in achieving the highest possible ridership.

Most of the recent research studies on walking accessibility use qualitative approach to measure accessibility. The result of this measure indicates how easy it is for people to access public transport. Since walking is the most important access mode, Equivalent Walking Distance (EWD) concept is proposed to provide 'a measurement tool' of walking accessibility. In developing the measures of walking accessibility, this research will attempt to answer the following questions:

- How to quantify the characteristics of walking route in the term of walking effort?
- How to model the share of walking as an access mode to public transport terminals?

- How to develop unique accessibility measures that incorporate walking route characteristics and the walking share relationship?

1.3 Research Objectives and Scope of Study

Walking accessibility, in terms of how easy it is to reach public transport terminal by walking, is one of important factors in public transport attractiveness. Previous studies on walking as access mode to public transport defined walking catchments in terms of acceptable walking distance or walking time, such as 400 metres or 5 minutes (Halden et al., 2000; Pikora et al., 2001; and from Ker and Ginn, 2003). Catchment areas of public transport terminals are developed based on these numbers. Recent applications using Geographical Information System (GIS) software still use this approach (e.g. Hsiao et al., 1997; Hilman, 1997; and Spear and Weil, 1999). On the other hand, walking route characteristics are usually applied in the modelling of walking travel demand (FHWA, 1999).

Walking effort to access public transport terminal could be expressed in Equivalent Walking Distance (EWD). A public transport accessibility measure is developed using this concept. Characteristics of walking route are incorporated in EWD. Using this new approach of accessibility assessment, public transport accessibility can be calculated more precisely. The influence of walking facilities, walking obstacles (such as number of road crossings and crossing delay), and walking effort can be estimated easily to show their role in public transport accessibility.

The main objective of this research, related to the research questions, is to develop a model of walking accessibility using equivalent walking distance. Thus, the term walking accessibility is based on how much walking effort in needed to access public transport terminal by walking.

There are two stages to be carried out in this study. The first one is the development of walking mode share in Walking Access Model (WAM) and the second one is development of Equivalent Walking Distance (EWD).

This research focuses on walking as access mode, especially to access from home to public transport terminal. Accessibility for people with disability would not be considered in detail. However, some circumstances related to facilities for disabled people are also considered.

1.4 Report Structure

This report is divided into nine chapters. The first chapter is the introduction chapter. It describes the background, problem statement and research objectives. The organisation of the report is also presented in this chapter.

The second chapter discusses literature related to this research. This chapter focuses on the concept of accessibility, characteristics of walking and details of walking as access mode. Previous studies related to modelling walking are also discussed.

Research framework, one of the important parts of this report, is covered in the third chapter. The theoretical framework of walking mode share is discussed, followed by the concept of walking access mode. The introduction to the concept of equivalent walking distance is given in the last part of this chapter.

The fourth chapter discusses pilot survey and preliminary analysis. This part led to preliminary findings, which are furtherdeveloped in the main research. Discussion on data collection continues in the fifth chapter. The main survey and data collection process are reported in this chapter. Characteristics of the study areas are also discussed. Characteristics of walking as access mode captured as the result of the survey are discussed in the sixth chapter.

Development of walking access model and equivalent walking distance are presented in seventh and eighth chapters, respectively. The last chapter of this report, the ninth chapter, shows the findings and conclusions obtained in this research. To support data and analyses presented in this report, some appendices are attached.

Chapter 2 Literature Review

This chapter summarised firstly the general concept of accessibility, accessibility measures, and public transport accessibility as well. Secondly, walking characteristics and walking as an access mode were discussed. Lastly, related studies on walking measures such as walking index and walking modelling were then reviewed. The concept of walking accessibility measure was derived from the understanding between the general concept of accessibility and walking characteristics and measures. Some findings in previous walking modelling studies were adopted into modelling walking accessibility to public transport terminals.

2.1 Basic Concepts of Accessibility

The uses of the term ‘accessibility’ are very wide and varied. Many researchers have given a definition or a concept of accessibility but still there is no commonly agreed meaning. The simple way to understand the term is to look into its application and how to measure it.

Hansen (1959) defined accessibility in general terms as a measurement of the spatial distribution of activities about a point, adjusted for the ability and the desire of people to overcome spatial separation.

The Dictionary of Public Transport (UIPT, 1981) explains accessibility as *“an index of relative ease of travel between two or more areas in terms of distance, time, and cost”*. The term also implies the number of opportunities available for a given amount of travel cost. For transport modelling purpose, this term can be understood as *“the sum of the travel time from one zone to all other zones in a region, weighted by the relative attractiveness of the destination zone involved”*.

Handy and Niemeier (1997) determined accessibility by the spatial distribution of potential destinations, the ease of reaching each destination, and the magnitude, quality, and the character of activities found there. Swedish National Road Administration noted that accessibility is *"the ease with which various activities, including the needs of citizens, trade and industry and public services, can be reached"* (Makri and Folkesson, 1999).

Makri (2001) explained some of the different aspects that might be included in the concept of accessibility, such as:

- Physical accessibility – being able to reach a destination point in spite of any physical hindrances;
- Mental accessibility – understanding and being able to use a given area and its facilities;
- Social accessibility – being able to get to and from work, meet friends and participate in social activities;
- Organisational accessibility – having access to travel opportunities, information and service regarding a journey;
- Financial accessibility – being able to afford available public or private means of transport;
- Virtual accessibility – being able to access information and people without moving from a certain place, by using electronic facilities.

Tyler (1999) gave a different meaning of accessibility, especially the public transport accessibility. He considered that accessibility is the result of the interaction between the public transport element and people when they attempt to use it. According to this view, accessibility means the ease of using public transport related to the given facilities of the public transport. For example, an escalator gives better accessibility to enter a bus station but it could be a barrier for wheelchair users. In his view, accessibility is not measured in terms of grades or degrees, but as a binary condition; either the public transport facilities are a barrier or not. Accessibility for people with disability (e.g. Zaworski and Hron, 1999; Dejeammes, 2000) could be applied in this concept.

Almost all of the accessibility concepts consist of the term 'ability' (ease to reach, ease to travel), opportunities of available activities (and their spatial distribution), and transport system or transport connection (expressed by distance, time, cost, or the combination of them such as generalised cost). To understand more about accessibility, it is necessary to consider how to measure it.

2.2 Accessibility Measures

There are many ways to measure accessibility. Most of the measures are based on quantitative approach and mathematical modelling. The result indicates how easily an individual gets to his/her desired location. In some public transport studies, accessibility measures are based on how people with disabilities can access and use a public transport. The qualitative approach may also be used to present level accessibility using Geographic Information System (GIS).

2.2.1 Distance-based Accessibility Measures

Distance-based measures are simplest accessibility measures, which are a function of distance, time, or cost only. The measurement can be achieved analytically by examining connections in a transport network. This is the kind of aggregate approach for accessibility measurement. Examples of these measures are:

- The Shimbel measure (Jones. 1981)

  This measure considers the node in relation to all other nodes in the network. It states that accessibility of node i is the sum of travel cost (or travel time) to all the other nodes, or

$$A_i = \sum_j c_{ij} \text{ and } \mathbf{j} \neq i \tag{2.1}$$

where : A_i = accessibility of node i
c_{ij} = travel cost (or travel time) from node i to node j

This is the simplest measurement method, but for certain purposes, it is still applicable.

- <u>Ingram Measure</u>

  According to Ingram (1971), the distance separating two points affects the degree of relative accessibility between these points. This effect may be felt in a number of ways including travel time and travel cost. Ingram generalised the Shimbel measure by recognising that the deterrent effect on travel or the cost of difficulty of travel cannot necessarily be identified with the travel cost directly but rather it is a function of the travel cost (Jones, 1981). This measure also extended the Shimbel measure by dividing the study area into zones rather nodes. Thus, Ingram proposed that the relative accessibility of zone i to all other zones is:

$$A_i = \sum_j f(c_{ij}) \qquad (2.2)$$

where : A_i = accessibility of zone i
c_{ij} = travel cost (or travel time) from zone i to zone j
$f(c_{ij})$ = function to represent the deterrence effect of travel cost

Ingram (1971) suggested that the deterrent effect of travel cost could be expressed by negative exponential function, as follows:

$$f(c_{ij}) = \exp(-c_{ij} / \gamma) \qquad (2.3)$$

where γ is a parameter reflecting the cost deterrence

2.2.2 Potential-based Accessibility Measures

Potential-based accessibility measures refer to the number of opportunities located within a certain travel distance, time or cost from a given location. There are two types of measures: simple measures and gravity-based measure. The simple measure (Halden et al., 2000) or cumulative opportunities (Handy and Niemeier,

1997) treats all destinations as being equal opportunities. For example, a small store and a big store will contribute equally to accessibility if they are located in the same place. The differences of accessibility are determined only by spatial distribution. On other hand, the gravity-based measure considers that every opportunity has its own attractiveness. Thus, a small store and a big store should represent different opportunity value although they are located in the same place.

a. Simple Measures

The simple measures can be considered as distance-based accessibility measure, where accessibility only depends on the distance. Some examples of these measures are, as follows:

- Catchments or contour indices (Halden et al., 2000)
  The catchments show the number jobs, shops or other activities that can be reached within a threshold travel cost (distance or time) from a defined location. One application is the access to public transport. The catchments show the acceptable walking distance or walking time to reach a public transport station.

- Time-space geographic measures (or space-time prisms)
  The measure simplifies travel behaviour and choice in terms of the opportunities available within a limited travel time budget. The threshold is therefore the travel time available for a particular individual.

  Hagerstrand was the first to introduce the space-time prism accessibility measures, which included all locations in space that can be reached by an individual in a given time (Miller and Wu, 2000).

  Miller and Wu (2000) measured accessibility in space-time prism relative to mandatory (main) activities with known stop and start times. These activities are relatively fixed in space and time and can be applied as frame events in any accessibility measure with space-time constraints. According to them, for example, accessibility to retail opportunities can be measured based on stopping to shop when travelling from home to work.

GIS is applied to evaluate the space-time accessibility measures. Miller and Wu (2000) added computational tools required for calculating the measures. Their current implementation employs three interfaced components: GIS software, computational module, and graphical user interface.

b. Gravity-based Measures

Gravity-based measures or weighted measures are derived from the denominator of the gravity model for trip distribution. Hansen (1959) first introduced the basic formula of gravity-based measures. The accessibility to a particular type of activity j (number of jobs, for example) from zone i (employees) is directly proportional to the size of the activity at the zone j and inversely proportional to some function of the distance separating zone i to zone j. In other words, the accessibility of zone i can be calculated as:

$$A_i = \sum_j \frac{a_j}{c_{ij}^{\alpha}}, \alpha > 0 \qquad (2.4)$$

where: a_j = activities at zone j

Hansen recommended that α must be the same as the one used in the gravity model. He expected α to be between 0.5 and 3.0 for urban and between 2.5 and 3.0 for interurban travel. For travel time with the terminal time, the α value would be 2.2 for work trip, 2.35 for social trip, and 3.0 for shopping trip.

Using the deterrence function is very common in transport planning. Jones (1981) defined the deterrence function as difficulty of travelling. There are many formulas to describe the deterrence function, for example:

Exponential function: $f(c_{ij}) = \exp(-\beta c_{ij})$

Power function: $f(c_{ij}) = c_{ij}^{-\alpha}$

Combined function: $f(c_{ij}) = c_{ij}^{\alpha} \exp(-\beta c_{ij})$

Gaussian function: $f(c_{ij}) = \exp\left(-\frac{c_{ij}^2}{\beta}\right)$

where α and β are parameters

Parameter α is the exponent of the power function. The value of β is a calibration parameter from gravity model (Ortuzar and Willumsen, 2001). This value is unique to a specific area and cannot be transferred directly from one place to another.

2.2.3 Utility-based Accessibility Measures

Utility-based accessibility measures are based on random utility theory. They consist of the denominator of the multinomial logit model, which is also known as logsum (Handy and Niemeier, 1997). Random utility theory is based on the assumption that individuals maximise their utility. Every individual gives each destination a utility value and the choosing of the destination depends on the utility of that destination compared to the utility of all the other alternatives. The utility function contains variables representing the attributes of each choice, reflecting the attractiveness of the destination, the travel impedance, and the socio-economic characteristics of the individual or household. The measure can be expressed as follows (Handy and Niemeier, 1997):

$$A_n = \ln\left|\sum_{\forall c \in C_n} \exp(V_{nc})\right| \tag{2.5}$$

where: A_n = accessibility for individual n;
V_{nc} = observable component of indirect utility of choice c for individual n;
C_n = the choice set for individual n.

Ben-Akiva and Lerman (1985) gave a measure of accessibility with multinomial logit model:

$$A_n = \frac{1}{\mu}\ln\sum_{i\in C_n}\exp(\mu V_{in}) \tag{2.6}$$

where: V_{in} = deterministic (or systematic) part of the utility for choice i;
C_n = the choice set for individual n;
μ = positive scale parameter related to individual characteristic.

2.2.4 Public Transport Accessibility Measures

Jones (1981) introduced a concept to measure public transport accessibility, which was derived from the Hansen (1959) formula. The idea of this concept is to compare accessibility using public transport and private car in reaching the destination. The general expression of this, as follows:

$$A_i = \frac{\sum_j a_j \cdot f^{pt}(c_{ij})}{\sum_j a_j \cdot f^{pc}(c_{ij})} \tag{2.7}$$

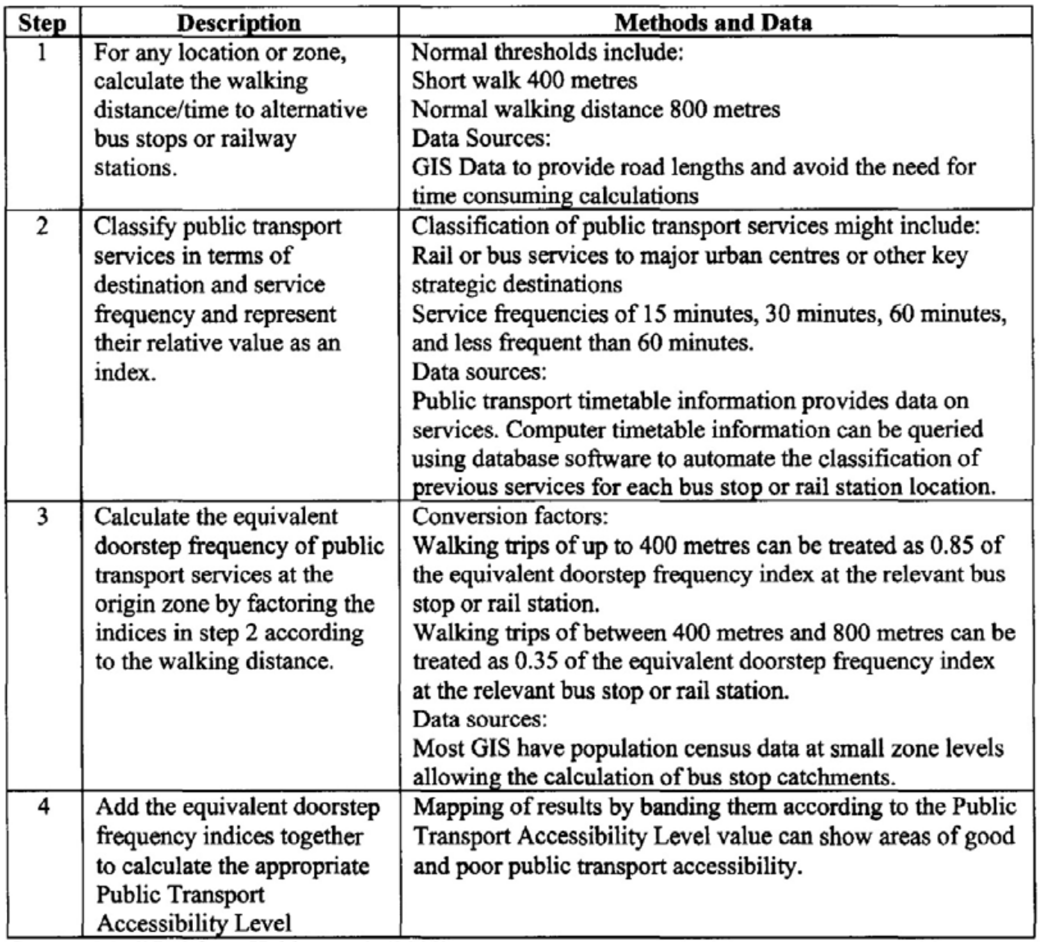
where : $f^{pt}(c_{ij})$: deterrence function from i to j using public transport
$f^{pc}(c_{ij})$: deterrence function from **i** to **j** using private car

Equation (2.7) shows the effects of mode choice. The deterrence function is not a function of travel distance and time only. Walk access and egress costs values are also included in the deterrence values.

Halden et al. (2000) introduced a procedure to measure public transport accessibility, as shown in Table 2.1. Eventually, this procedure is a study on accessibility with walking to public transport as a special case. The numbers of 400 metres and 800 metres are used as the "rule of thumb" of maximum acceptable walking distance. These numbers are commonly used in many studies on public transport.

Research on walking and biking as transport modes can be done together with public transport accessibility studies. This has been used increasingly in UK within development planning, for a number of purposes including the definition of parking standards, site selections, and determining development plot ratio (Halden et al., 2000).

Table 2.1 General Procedure to Measure Public Transport Accessibility



Step	Description	Methods and Data
1	For any location or zone, calculate the walking distance/time to alternative bus stops or railway stations.	Normal thresholds include: Short walk 400 metres Normal walking distance 800 metres Data Sources: GIS Data to provide road lengths and avoid the need for time consuming calculations
2	Classify public transport services in terms of destination and service frequency and represent their relative value as an index.	Classification of public transport services might include: Rail or bus services to major urban centres or other key strategic destinations Service frequencies of 15 minutes, 30 minutes, 60 minutes, and less frequent than 60 minutes. Data sources: Public transport timetable information provides data on services. Computer timetable information can be queried using database software to automate the classification of previous services for each bus stop or rail station location.
3	Calculate the equivalent doorstep frequency of public transport services at the origin zone by factoring the indices in step 2 according to the walking distance.	Conversion factors: Walking trips of up to 400 metres can be treated as 0.85 of the equivalent doorstep frequency index at the relevant bus stop or rail station. Walking trips of between 400 metres and 800 metres can be treated as 0.35 of the equivalent doorstep frequency index at the relevant bus stop or rail station. Data sources: Most GIS have population census data at small zone levels allowing the calculation of bus stop catchments.
4	Add the equivalent doorstep frequency indices together to calculate the appropriate Public Transport Accessibility Level	Mapping of results by banding them according to the Public Transport Accessibility Level value can show areas of good and poor public transport accessibility.

Source: Modified from Halden et al. (2000)

Some public transport accessibility studies examine how people with disability access and use public transport services. The focus on these studies is on development and application of public transport facilities for disabled people, such as how people with cognitive disabilities can reach public transport (Zaworski and Hron, 1999) or how to develop heavy rail boarding aid device for disabled passengers (Dejeammes, 2000).

Tyler (1999) suggested that public transport accessibility could be seen as a result of the interaction between public transport element and people when they attempt to use it. Since his focus was on public bus services, he noted that accessibility to public transport depends mainly on accessibility to the bus system. His proposed method was to investigate how the elements of public transport system become obstacles. Furthermore, he mentioned that accessibility is affected by the design of public transport infrastructure such as bus stops or bus terminal facilities. He also introduced the stages in his method to measure public transport accessibility, which was summarised as follows:

- Identifying the barriers
- Checking the public transport system
- Checking the ways in which barriers apply
- Checking public transport system with users
- Analysing data, concluding and recommending

2.2.5 Discussion on Accessibility

The term accessibility can be defined as how easily a place or a destination can be reached. Accessibility contains two components. One is related to the connection system between zones and the other is related to opportunities and their attractiveness. Commonly, the connection quality is valued by time, cost, or in terms of generalised cost. A better connection implies that people can go faster, cheaper, more comfortably, more safely, and the destinations can be reached more easily.

There are many ways to measure the quality of the connection system. The simplest way is to use distance in expressing the quality of a connection. The distance can be obtained directly from road distance between origin point and destination point or measured as the actual travelled distance. Straight-line distance or airline distance can be obtained from the map. Global Position System (GPS) can be used to obtain the actual travelled path distance.

Another way is to use time to express the quality of a connection, in which case time is the measured travelled time. Cost can also be used to express the connection quality. Using value of time concept, time can be converted to cost.

One point to note here is that people do not travel without a reason. Travel is carried out to meet people's needs. There may be many places to go to but not all of them are reachable (such as being too far, too expensive, no bus connection, no parking space available, etc) and/or they are not worth to be visited (such as the price is too expensive, inconvenient, unsafe, etc). People choose their destination rationally. Only places that are attractive and easy to reach will be chosen as the destination. Therefore, people will go to the place that has good accessibility.

According to Jones (1981), there were some factors to be considered in developing accessibility indices:

- the location and characteristic of the individual or type of person;
- the locations and characteristics of opportunities for relevant activities;
- the connecting transport system;
- if the number of opportunities for an activity increases anywhere, then the accessibility to that activity from any place should improve or remain constant;
- if the travel by any mode is made quicker or cheaper in an area, then the accessibility to any activity in that area, or from any point within that area should improve or remain constant;
- improvements to one mode of transport should not alter the mobility (and hence accessibility to any activity) of any individual or type of person not able to use that mode.

There are many types of activities and their attractiveness. A particular activity should be considered to assess accessibility of a particular land use. Work accessibility and shopping accessibility, for example, should not be mixed directly. Besides that, the attractiveness of a destination should be considered properly. Table 2.2 shows some activities and some possible attraction variables that can be used to assess accessibility.

Table 2.2 Determination of Attractiveness of Activities

Activities	Attractiveness Value	Remark
Work	Number of jobs; people employed; centres of employment	May be classified by type of job
Shopping	Total retail employment; floor area; Number of shops;	Classified by type of shop or commodity
Social	Number of residents; retired persons, Number of households	
Education	Number of school places; school intake; School facilities	Classified by type of school
Medical	Number of doctors; health facilities; hospital beds;	
Recreation	Number of recreational facilities; seats in theatres	Including park, cinema, or library

2.3 Characteristics of Walking

Walking is the basic and original mode of transportation. It constitutes important component in the transportation system, especially in public transport. The usage of walking as a transport mode varies between land use, travel purpose, time when travel is carried out, and other individual characteristics such as age, sex, income, car ownership, and so on.

Walking trip demand refers to how much people would use the walking mode under various circumstances. A list of specific factors that can affect demand for walking trips in a particular situation could be stated, as follows (FHA, 1999; Porter, et al., 1999; Moudon, 2001):

- ***Attractions.*** Certain activity centres tend to be major attractors for walking. These include: commercial districts, school-college-university campuses, recreation centres, parks, and employment centres.
- ***Trip distance.*** Most walking trips are less than 1.6 kilometres long, although recreational trips are often much longer.
- ***Demographics.*** Young persons (10-20 years), elderly, and low-income people tend to rely more on walking as transport mode.

- ***Land use patterns (density and mix).*** Walking as transport mode tends to increase with density (i.e. number of residents and businesses in a given area) because higher density makes this mode more efficient.
- ***Travel conditions.*** Wide roads with heavy, high-speed vehicle traffic can form significant barriers to walking trips. Special walking facilities and their condition can have a significant impact on the amount of walking that occurs.
- ***Topography and climate.*** These factors can affect walking trips, but not as much as might be expected.

According to ***Amsterdam Juarbook 1994*** (in Hass-Klau, 2001), about 43% of residents living in the historic part of Amsterdam walked for shopping. However, the number dropped to 21% in housing areas built in 1900-1940 and fell to only 11% in modem housing estates. This case shows the relationships between land use and walking behaviour.

Mitchell and Stokes (1982) claimed that overall walking has declined in United States, Canada, Australia, and Europe. In Britain, there has been a 5% decline in the total number of walking trips over a 20-year period (1975 to 1995). In Germany, in 1976, there were about 36% of walking trips but in 1989 the percentage had declined to 26% (as cited by Hass-Klau, 2001).

2.3.1 Walking Trips

In Britain, teenagers walked more often than adults and women did so more often than men (Mitchell and Stokes, 1982). Table 2.3 shows the walking trips per person per day by sex and age group. Moreover, Table 2.4 shows walking trips for different trip purposes in Britain. As shown in the table, there is a higher proportion of walking trips for educational purpose. It can be seen from the table that shopping and social trips are the next trip category with high walking share. Work trips have the lowest percentage of walking.

Table 2.3 Walking Trip Rates

Sex and Age Group	Trips per Person per Day
Children (3 – 15 years old)	1.22
Male (16 – 64 years old)	0.66
Female (16 – 64 years old)	0.98
Retired (more than 65 years)	0.75
All	0.91

Source: National Travel Survey 1975/1976(Mitchell and Stokes, 1982)

Table 2.4 Walking Trips for Different Purpose

Trip Purpose	Percentage of Trip by Walking
To/from work	19
Education	60
Shopping and Personal Business	43
Social	26
All Day Trips	54
All Purpose	35

Source: National Travel Survey 1975/1976 (Mitchell and Stokes, 1982)

Table 2.5 shows the classification of walking trip related to age, gender and trip purpose for Singapore, based on the 1991 Home Interview Survey (carried out by Public Works Department for 2500 households or 0.3% of the total population). Similarly to what occurred in Britain, teenagers did walk more than adults and women walked more than men. It is also similar that there is a small proportion of walking trips to work.

Table 2.5 Walking Trips by Age, Sex and Purpose in Singapore

Age Group	Walking Trips per person		
	Female	Male	All
4 – 15	1.10	1.14	1.12
16 – 60	1.08	0.67	0.88
> 60	0.92	0.85	0.88
All	1.03	0.76	0.89
Trip Purpose	**Percentage of Walking Trips**		
Home-based work	9.1		
Home-based school	38.7		
Home-based others	59.8		
Non home-based	47.6		
All	38.9		

Based on origin-destination (O-D) surveys that was conducted by Beijing Traffic Safety Bureau in 1987, walking trips accounted for about 13.8% of the total trips made in Beijing (Tanaboriboon and Jing, 1994). Table 2.6 shows the distribution of walking trip purposes in Beijing. This result was obtained from a total of 1,500 questionnaire forms distributed randomly to pedestrians at 70 locations in Beijing.

Table 2.6 Distribution of Walking Trips by Purpose in Beijing, China

Trip Purpose	Percentage
Work	22.7
School	15.2
Shopping	22.8
Business	1.3
To/ From Transit Stations	15.1
Returning Home	3.1
Recreation	9.8
Social Activities	2.9
Others	7.1
All	100.0

2.3.2 Walking Distance and Walking Time

Table 2.7 shows the proportion of walking trips in different walking distance intervals. As shown in the table, over 70% of all walking trips were shorter than 1.6 km. It can also be seen that percentage of walking trip in rural area was higher than in urban areas within that distance.

Table 2.7 Walking Distances by Type of Area (UK)

Walking Distance (m)	Percentage of Walking Trips		
	Urban area	Rural Area	Total
0 – 800	41.8	49.0	42.6
800 – 1600	29.2	29.5	29.2
1600 – 3200	21.2	17.7	23.4
> 3200	4.9	3.8	4.8
Total	97.1	100.0	100.0

The maximum and mean value of walking distance and walking time obtained from the 1991 Singapore's Travel Survey is showed in Table 2.8. It is shown that the average walking distance and walking time are 740 metres and 10.1 minutes, respectively.

Table 2.8 Walking Time and Distance in Singapore

Trip Purpose	Walking Time (min)		Walking Distance (m)	
	Mean	Max	Mean	Max
Home-based work	14.02	60.0	1038	4140
Home-based school	12.33	35.0	918	2765
Home-based others	9.54	55.0	689	4345
Non home-based	8.47	40.0	631	3160
All	10.10	60.0	740	4345

Source: Olszewski and Tan (1999)

Table 2.9 shows the average walking time and maximum tolerable walking time by age in Beijing, China. The average walking time and the maximum tolerable walking time in Beijing was about 22.5 minutes and 36.5 minutes, respectively (Tanaboriboon and Jing, 1994).

Table 2.9 Average Walking Time and Maximum Tolerable Walking Time By Age (Beijing, China)

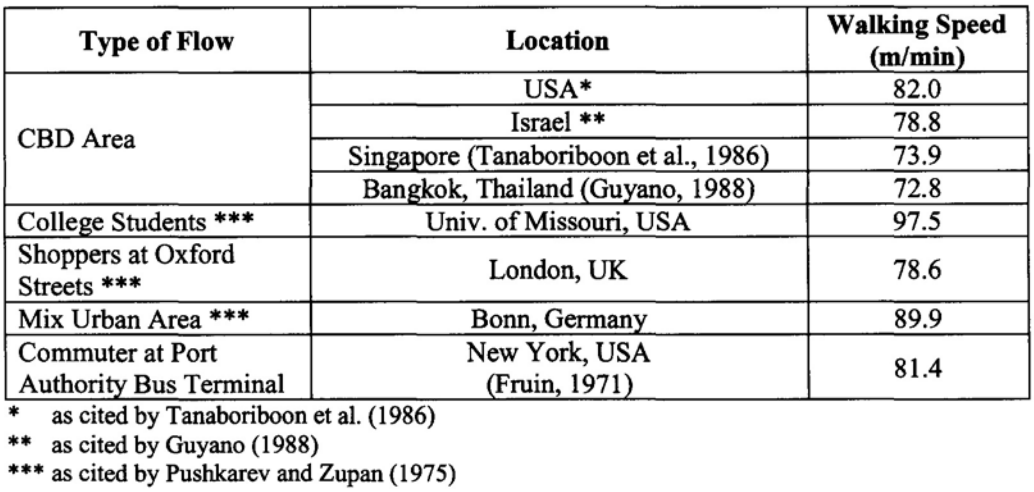
Age Group	Number of Respondents	Average Walking Time (min)	Maximum Tolerable Walking Time (min)
< 15	86	19.6	38.8
16 – 20	154	24.0	41.0
21 – 25	131	21.9	35.8
26 – 35	205	21.1	35.1
36 – 45	143	22.6	35.1
46 – 55	147	24.3	35.7
56 – 65	46	24.4	35.2
> 65	18	22.6	26.7
All ages	930	22.5	36.5

2.3.3 Walking Speed

According to Allan (2001), pedestrians in Australia may be able to maintain a steady walking speed of 6 km/h (100 m/min) for 20 minutes. After 30 minutes, the speed might decrease to 5 km/h and over an hour it will drop to 4 km/h. He noted that 6 km/h for 20 minutes, or 2000 metres, was a reasonable value in many Australian urban environments for walking.

Table 2.10 shows the summary of walking speeds from different studies and locations. These speeds were based on the assumption that pedestrians can walk on their desired path without reducing their average speed in response to other pedestrians. In other words, using the concept of speed-density-flow relationship, the speed in the table is the free-flow walking speed.

Table 2.10 Comparison of Maximum Walking Speed (Free Flow Conditions)



Type of Flow	Location	Walking Speed (m/min)
CBD Area	USA*	82.0
	Israel **	78.8
	Singapore (Tanaboriboon et al., 1986)	73.9
	Bangkok, Thailand (Guyano, 1988)	72.8
College Students ***	Univ. of Missouri, USA	97.5
Shoppers at Oxford Streets ***	London, UK	78.6
Mix Urban Area ***	Bonn, Germany	89.9
Commuter at Port Authority Bus Terminal	New York, USA (Fruin, 1971)	81.4

* as cited by Tanaboriboon et al. (1986)
** as cited by Guyano (1988)
*** as cited by Pushkarev and Zupan (1975)

In Singapore, it was found that the walking speeds for men and women were 79 dmin and 69 m/min, respectively (Tanaboriboon et al., 1986). In Bangkok, they were 76.4 m/min and 70.2 m/min for men and women, respectively (Tanaboriboon and Guyano, 1989). Fruin (1971) noted that walking speeds above 140 m/min could be deemed as running.

According to Fruin (1971), there was no measurable effect on walking speeds due to grades up to 5%, but there was a gradual linear decline in speed for steeper grades. A controlled study of soldiers walking on a variable grade showed that walking speed decreased by 11.5 per cent for grade 5% - 10%. The walking speed continued to decrease to 25 per cent for grade up to 20%, which is the slope that should not be encountered in urban areas.

2.3.4 Road Crossings

In this research, the main consideration for pedestrian crossings is the walking delay. Other aspects such as safety, space available, and level of service for crossing will not be discussed in detail. There are four possible combinations of type and location of crossings, i.e. signalised intersection, unsignalised intersection, signalised midblock, and unsignalised midblock crossing. Theoretically, pedestrians can cross at any point of a roadway. However, for safety reasons, crossing facilities are provided to encourage pedestrians to cross in certain points.

Highway Capacity Manual (HCM) 2000 (TRB, 2000) gives a simple formula to calculate crossing delay at a signalised intersection, as follows:

$$d_p = \frac{0.5(C-g)^2}{C} \qquad (2.8)$$

where: d_p = average pedestrian delay (seconds)
g = effective green time for pedestrian (seconds)
C = cycle time (seconds)

At an unsignalised intersection or midblock crossing, pedestrians cross a road that is not controlled by a traffic light. They cross in available gaps between vehicles. The critical gap is the time in seconds, at which a pedestrian will not attempt to begin crossing the street (TRB, 2000). Pedestrians use their own judgement to determine whether the available gap is sufficient to cross a road safely. HCM 2000 assumed that pedestrian will cross the road when the available gap is greater than the critical gap.

A delay will occur if there is no gap available when a pedestrian is approaching. Pedestrians expect and tolerate smaller delays at an unsignalised intersection than at a signalised one (TRB 2000). HCM 2000 considered that pedestrians would have high probability of taking a higher risk for crossing when the average delay was 30 to 45 seconds. A different situation occurs if a zebra crossing is provided. In this case, pedestrians have the right of way. All vehicles have to stop if pedestrians approach the zebra crossing. Therefore, delay at such a crossing is negligible.

Overpass (pedestrian bridge) and underpass (tunnel) are constructed to eliminate the conflict between pedestrian flow and vehicle movements. Therefore, there is no delay at these pedestrian crossings. However, according to Tanaboriboon and Jing (1994), close to 50% of pedestrians in Beijing did not use overpasses or underpasses. Some reasons given for their objections were: “too tired for walking up and walking down”, “inconvenience”, and “too many steps”.

2.3.5 Walking as an Access Mode

Figure 2.1 shows the walking access and egress to rail transit for home-based trips compared with other access modes.

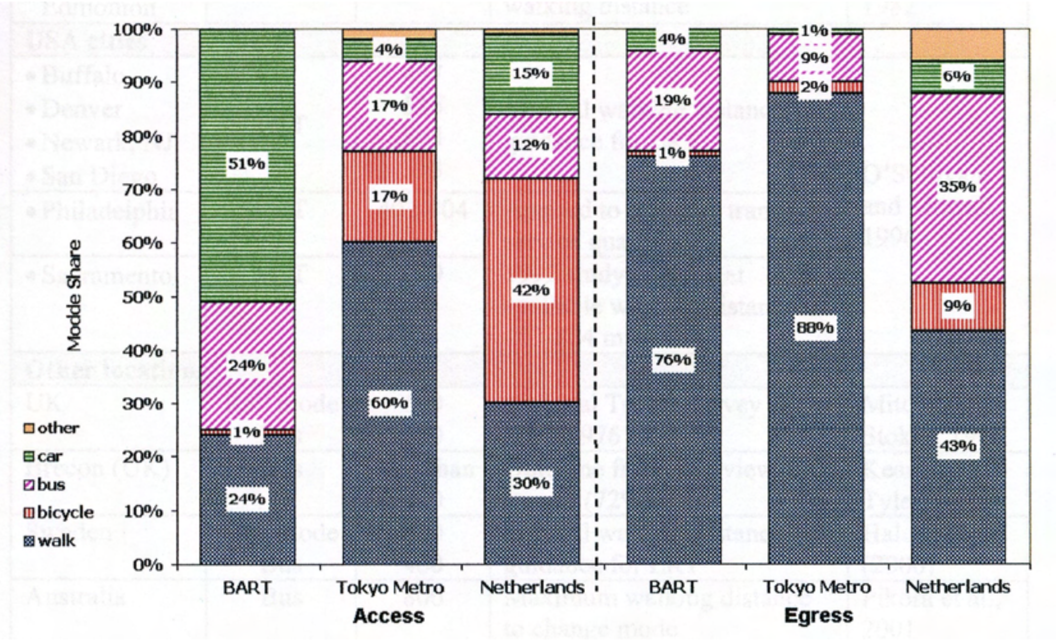


Figure 2.1 Access and Egress Mode Share

Source: Loutzenheiser (1997); BART = Bay Area Rapid Transit, San Francisco

As shown in the figure, walking is the basic and important mode to rail transit. Most of public transport studies assumed that walking as an access mode occurred up to

400 to 800 metres of walking distance or 10 to 15 minutes of walking time. Table 2.11 shows some examples of walking distance to access public transport terminal in many cities in the world.

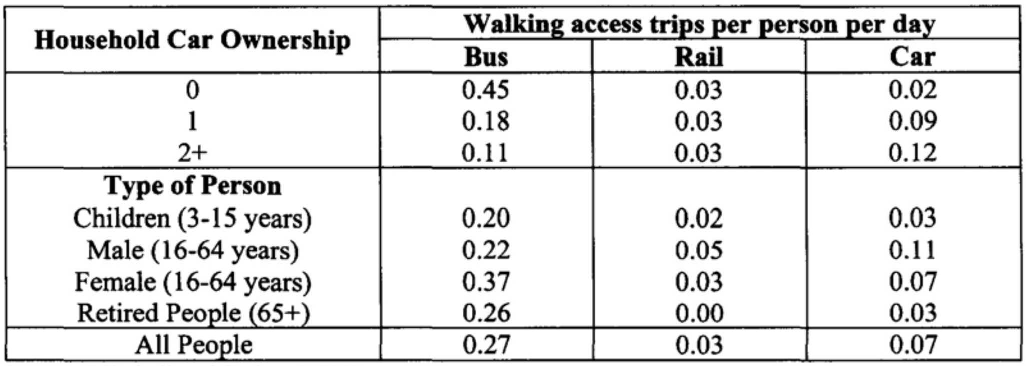
Table 2.11 Walking Distance to Access Public Transport

Location	Type of Public Transport	Walking Distance (m)	Remarks	Source
Canadian cities				
• Calgary	LRT	649 326	Sub urban area CBD area	O'Sullivan and Morrall, 1996
• Calgary • Vancouver • Montreal • Ottawa • Edmonton	LRT	400 900 400-500 400-600 400	General walking distance guidance for LRT	
• Toronto	LRT	300	General walking distance guidance for surface transit	
• Toronto and Edmonton	LRT	1200	Maximum acceptable walking distance	Stringham, 1982
USA cities				
• Buffalo • Denver • Newark, NJ • San Diego	LRT	457 536 804 538	General walking distance guidance for LRT	O'Sullivan and Morrall, 1996
• Philadelphia	LRT	402-804	Applied to consider transit service quality	
• Sacramento	LRT	609	1992 study found that available walking distance is 403-804 m	
Other locations				
UK	Rail mode Bus	640 390	National Travel Survey 1975/1976	Mitchell and Stokes, 1982
Brecon (UK)	Bus	Less than 400	Outcome from interview survey (72%)	Kean and Tyler, 1999
Sweden	Rail mode Bus	800 400	General walking distance guidance for LRT	Halden et al. (2000)
Australia	Bus	800	Maximum walking distance to change mode	Pikora et al., 2001

Actually, there is no fixed value of maximum walking distance. As a rule of thumb, many researchers agree that acceptable maximum walking distance is 1600 metres. In Great Britain, based on National Travel Survey 1975/1976, over 70% of all walk journeys were shorter than 1600 metres (Mitchell and Stokes, 1982). Shriver (1996) used 1290 metres as the average walking distance in measurement of the structure of individual walk-activity patterns as a way to indicate ease to movement. Halden et al. (2000) also suggested that 1600 metres should be the maximum distance. Pikora et al. (2001) used 400 metres as walking distance to the final destination and 800 metres as the maximum walking distance to change mode (for example, walking to a bus stop).

Table 2.12 shows the walking trip rates to access different modes related to car ownership and type of person. As can be seen from the table, the trip rate to access bus is very high for household with no car. However, the rate is still high for households with one car and slightly decreases for 2 and more cars. It can also be seen that women did walk to access bus more frequently than men and conversely for men to access car (Mitchell and Stokes, 1982). In China, according to Tanaboriboon and Jing (1994), the average walking time to and from transit station in Beijing is about 16 minutes.

Table 2.12 Walking to Access Different Modes



Household Car Ownership	**Walking access trips per person per day**		
	Bus	**Rail**	**Car**
0	0.45	0.03	0.02
1	0.18	0.03	0.09
2+	0.11	0.03	0.12
Type of Person			
Children (3-15 years)	0.20	0.02	0.03
Male (16-64 years)	0.22	0.05	0.11
Female (16-64 years)	0.37	0.03	0.07
Retired People (65+)	0.26	0.00	0.03
All People	0.27	0.03	0.07

Source: Mitchell and Stokes (1982)

Fruin (1971) noted that walking distances to access a plane-side from curb side at major airports were reported to be 520 m at O'Hare Airport, Chicago; 519 m at Atlanta; 495 m at Dallas, 390 m at San Francisco International; and approximately 330 m at the Los Angeles International, John F Kennedy International, Miami, and Detroit Airport. Inter-terminal distances at these airports were found to vary from 600 to almost 2400 m. The maximum curb-to-plane walk distances represent a normal 5 – 7 minutes walk for most people. However, these distances were that given by design. Further investigations were needed to see whether these were acceptable or not for many passengers.

Seneviratne and Fraser (1987) determined that the average walking distance between public transport terminals and final destinations in CBD areas was approximately 250 m. They also noted that the main reasons of pedestrians choosing a particular route in CBD from terminal to the final destinations were:

- Quickest
- Always use the route
- Only the route is available
- Less of street crossing
- More attractive
- Less crowded
- Protection from weather
- Security

Acceptable walking distance to access and egress a car park (parking lot) is affected by many factors, such as weather protection, climate, line of sight (whether the driver can see the destination) and road crossing (Parking Today, 2000). The distance ranges reported for different types of walkways were, as follows:

- Weather Protection: 300 m - 1560 m
- Outdoor/Covered: 150 m - 600 m
- Outdoor/Uncovered: 120 m - 480 m
- Through Surface Lot: 105 m - 420 m
- Inside Parking Facility: 90 m - 360 m

2.4 Walking Quality Measures

Many methods were developed to evaluate the quality of walking environment. Level of service, walking index, and walkability measures, are several examples how to assess the walking experience.

2.4.1 Pedestrian Level of Service (PLOS)

Level of service (LOS) is one way to express quantitative performance measure in terms of a quality indicator. The well known level of service concept has been introduced in Highway Capacity Manual by the US Transportation Research Board. There are six levels of service of traffic flow, which are related to service volume, lane capacity and driver convenience. The degree of freedom to choose desired operating speed, ability to pass other vehicles, and changing lanes are expressed in a 6-point scale as letters A to F. Level of service A is the ideal condition and the level of F is the worst. It is suggested that level of service C should be applied as a minimum condition for design.

The pedestrian Level of Service concept provides a useful model for designing pedestrian space. Fruin (1971) introduced the concept of pedestrian LOS that was adopted from Highway Capacity Manual 1965 and then be incorporated into HCM 1994 and 2000. This concept was based on the freedom to select walking speed, the ability to pass slow-moving pedestrians, and relative ease of reverse and crossing movements under various pedestrian volumes. This concept also considered the pedestrian walking speed, density and flow relationships.

The letters of A, for the best condition, to F, for the worse condition, were applied to express level of service. Figure 2.1 shows an illustration of the different levels. As shown in the figure, each dot represents one pedestrian and the dash box represents pedestrian space per metre width of a walkway.

Pedestrian LOS criteria based on available space and flow rate had also been recommended in many studies such as in Tanaboriboon and Guyano (1989) and HCM 2000 (TRB, 2000). Table 2.13 shows the comparison of the level of service criteria for walkways, which are based on pedestrian space and flow rate.

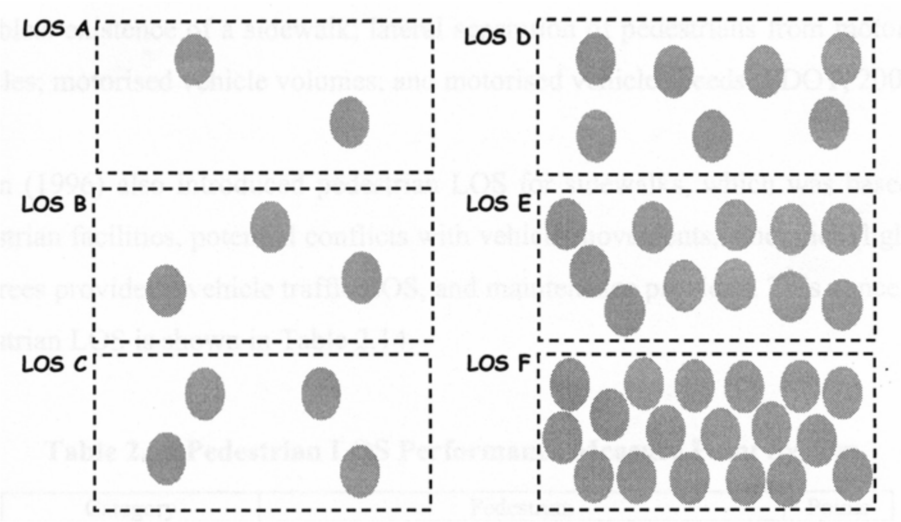


Figure 2.2 Illustration of Pedestrian Level of Service for Walkways

Source: Modified from Fruin (1971)

Table 2.13 Pedestrian LOS for Walkway based on Space and Flow Rate

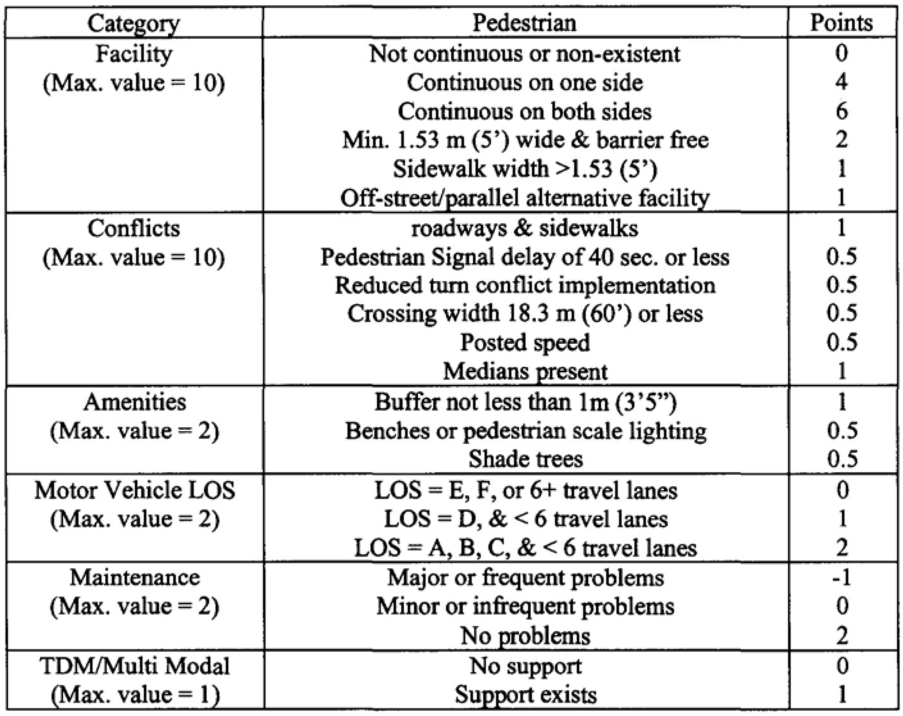
LOS	USA		Thailand
	HCM 2000	Fruin (1971)	Tanaboriboon and Guyano (1989)
Pedestrian LOS threshold for walking space (m2/pedestrian)			
A	> 5.6	> 3.2	> 2.38
B	3.7 – 5.6	2.3 – 3.2	1.60 – 2.38
C	2.2 – 3.7	1.4 – 2.3	0.98 – 1.60
D	1.4 – 2.2	0.9 – 1.4	0.65 – 0.98
E	0.75 –1.4	0.5 – 0.9	0.37 – 0.65
F	< 0.75	< 0.5	< 0.37
Pedestrian LOS threshold for flow rate (ped/min/m)			
A	< 16	< 23	< 28
B	16 – 23	23 – 33	28 – 40
C	23 – 33	33 – 50	40 – 61
D	33 – 49	50 – 66	61 – 81
E	49 – 75	66 – 83	81 – 101
F	variable	> 85	> 101

Pedestrian LOS in Pushkarev and Zupan (1975) used 'Open', 'Unimpeded', 'Impeded', 'Constrained', 'Crowded', and 'Jammed' instead of letters A to F.

Pedestrian LOS for sidewalks considers potential conflicts between pedestrian flow and vehicle movements. The Florida Department of Transportation, USA (FDOT) developed a pedestrian LOS using an analytical approach, which is based on four variables: existence of a sidewalk; lateral separation of pedestrians from motorised vehicles; motorised vehicle volumes; and motorised vehicle speeds (FDOT, 2002).

Dixon (1996) also introduced pedestrian LOS for sidewalks, which was based on pedestrian facilities, potential conflicts with vehicle movements, amenities (lighting and trees provided), vehicle traffic LOS, and maintenance provided. This concept of pedestrian LOS is shown in Table 2.14.

Table 2.14 Pedestrian LOS Performance Measure Point System



Category	Pedestrian	Points
Facility (Max. value = 10)	Not continuous or non-existent	0
	Continuous on one side	4
	Continuous on both sides	6
	Min. 1.53 m (5') wide & barrier free	2
	Sidewalk width >1.53 (5')	1
	Off-street/parallel alternative facility	1
Conflicts (Max. value = 10)	roadways & sidewalks	1
	Pedestrian Signal delay of 40 sec. or less	0.5
	Reduced turn conflict implementation	0.5
	Crossing width 18.3 m (60') or less	0.5
	Posted speed	0.5
	Medians present	1
Amenities (Max. value = 2)	Buffer not less than 1m (3'5")	1
	Benches or pedestrian scale lighting	0.5
	Shade trees	0.5
Motor Vehicle LOS (Max. value = 2)	LOS = E, F, or 6+ travel lanes	0
	LOS = D, & < 6 travel lanes	1
	LOS = A, B, C, & < 6 travel lanes	2
Maintenance (Max. value = 2)	Major or frequent problems	-1
	Minor or infrequent problems	0
	No problems	2
TDM/Multi Modal (Max. value = 1)	No support	0
	Support exists	1

Source: Dixon (1996)

As can be seen from the table, the total score for a particular corridor is obtained, as follows:

- Segment Score = sum of points in six categories (maximum 21)
- Segment Weight = segment length / corridor length
- Adjusted Segment Score = segment score x segment weight
- Corridor Score = sum of the adjusted segment scores in the corridor

Another concept of pedestrian LOS was introduced by Gallin (2001). She defined LOS for pedestrians as:

> *"An overall measure of walking conditions on a route, path or facility. This is directly linked to factors that affect pedestrian mobility, comfort and safety. It reflects the pedestrians' perceptions of the degree to which the facility is pedestrian friendly".*

Gallin (2001) identified three categories of factors affecting LOS. Unlike other previous pedestrian LOS concepts, this concept used only letters A to E to describe the levels of service. The letter 'A' is the best LOS and 'E' is the worst. LOS A indicates the best operating conditions and environment for pedestrians, which may include a wide path with a good quality surface, no obstructions, limited opportunities to conflict with vehicles, few cyclists to compete for space and a safe, pleasant, open environment with adequate lighting. LOS E, on the other hand, is at the lowest end of the scale and may be allocated to a narrow path in an unsafe environment, which is close to moving vehicles and has many potential vehicle conflict points.

2.4.2 Walkability and Walking Index

Walkability reflects the overall support for pedestrian travel in an area. Walkability takes into account the quality of pedestrian facilities, roadway conditions, land use patterns, community support, security and comfort for walking. Walkability can be evaluated at various scales, such as:

- At a site scale, walkability is affected by the quality of pathways, building access road and related facilities.
- At a street or neighbourhood level, it is affected by the existence of sidewalks and crosswalks, and roadway conditions (road widths, traffic volumes and speeds).
- At the community level, it is also affected by land use accessibility, such as the relative location of common destinations and the quality of connections between them.

Bradshaw (1993) introduced four characteristics to determine walkability. These factors are as follows:

- ***Foot-friendly:*** wide walkway, few intersections and narrow streets to cross, lots of litter containers, good lighting, and an absence of obstructions;
- ***Full range of useful,*** attractive destinations within walking distance: shops, services, employment, professional offices, recreation, libraries, etc.
- ***Natural environment:*** no excessive noise, air pollution, or the dirt, stains, and grime of motor traffic.
- ***Social interaction:*** increases contact between people and the conditions for social interaction.

Allan (2001) considered that walkability was related to connectivity in road network. He was concerned that many cities have a coarse urban road grid that had large blocks impermeable for pedestrian access. How easily pedestrians can penetrate some blocks in the city centre was expressed by pedestrian permeability. This concept is called Walking Permeability Distance Index (WPDI), which can be expressed by the following formula:

$$\mathrm{WPDI} = \frac{\text{Shortest practical distance though the network}}{\text{Airline Distance between origin and destination}} \tag{2.9}$$

Allan (2001) also suggested that as an analytical planning tool, the WPDI could be used to explore trip characteristics among origins and destinations in a local area, with WPDI=1.5 being set as the limit of accessibility for a development. The walking permeability index could also be expressed in terms of time. The equation is called Walking Permeability Time Index (WPTI):

$$\mathrm{WPTI} = \frac{\text{Actual distance time (including delay)}}{\text{Direct distance time}} \tag{2.10}$$

A higher value of WPTI of 2 may be needed to indicate the practical limit of pedestrian accessibility (Allan, 2001). Using the WPTI value and walking speed of

6 km/h for time endurance of 20 minutes, the maximum direct distance to a destination to be reached by walking would be 1 km.

VTPI (2003) describes how to evaluate urban roadway pedestrian conditions based on Pedestrian Environmental Factors (PEF). The four criteria below are each rated on a scale from 1 to 3 and the total represents the PEF. These factors are as follows:

- ***Ease of road crossings.*** This is based on street width, traffic volumes, and speeds.
- ***Sidewalk continuity.*** Discontinuous sidewalks create barriers to pedestrian travel. A pedestrian network is only as good as its weakest link, particularly for people with physical disabilities. Even problems that appear minor to able-bodied pedestrians may be a major barrier to people with significant mobility constraints.
- ***Local street characteristics.*** A grid street system provides continuity, allowing more direct access to destinations.
- ***Topography.*** Steps or slopes create barriers to pedestrians.

Evan IV et al. (1997) introduced a method for representing the transit access environment in travel forecasting models. It is called Transit Friendliness Factor (TFF), which is defined as a function of the characteristics of the area surrounding a transit stop. These characteristics include the quality of pedestrian facilities, the character of nearby streets, the presence of amenities at the stop and the proximity to potential destinations.

The composite TFF is a linear combination, with equal weight given to each of four elements. Thus, there are 50 percent for the sidewalk rating and street-crossing rating, 25 percent for patron proximity rating, and the rest for transit amenities (25 percent). The elements of transit fiiendliness factor are sidewalks, street crossings, transit amenities, and proximity of destinations. Each element is valued with rating system for 1 (worse) to 5 (best). The criteria of TFF can be seen in Figure 2.2.

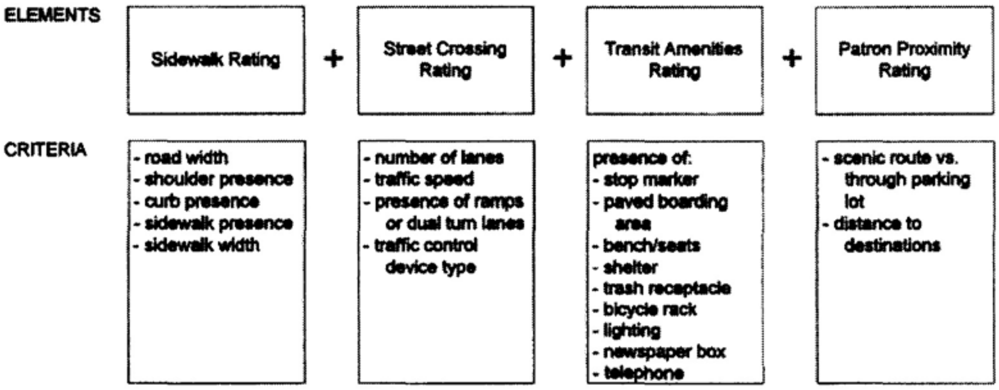


Figure 2.3 Elements of Transit Friendliness Factor (TFF)

Source: Evan IV et al. (1997)

2.5 Walking Modelling

Walking models have been developed to examine walking as transport mode (e.g. Clark, 1997; Eash, 1999, Greenwald and Boarnet, 2001) and also walking as an access mode (e.g. Loutzenheiser, 1997; Cervero, 2001; Beimborm et al, 2003).

Eash (1999) noted that the decision to make a walking trip and the choice of a destination that can be reached by walking may have more to do with the safety or attractiveness of available walking routes than travel time or cost. The methodology was primarily developed to evaluate alternative longer-range development scenarios rather than non-motorised transport facilities. He also used PEF for pedestrian land use environment. The models are stratified by household vehicle ownership for most trip types. For households without vehicles, a binary variable corresponds to whether transit is located within 0.40 km (0.25 mi) of the household.

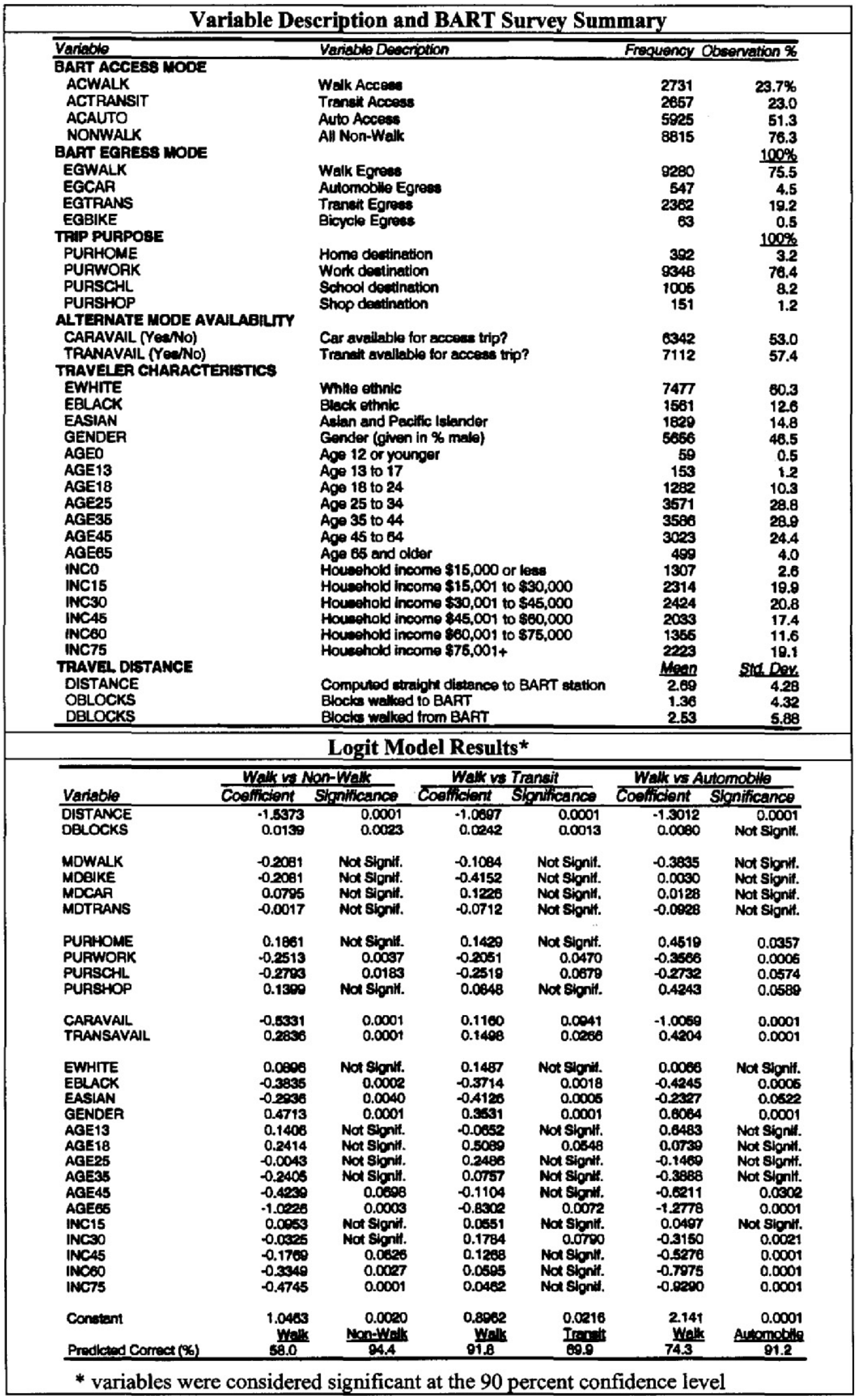
Loutzenheiser (1997) introduced a model of walk trips for pedestrian access to transit. The role of urban form, urban design and station characteristics in choosing of walking were examined in the model. Three binomial logit models were used. Table 2.15 shows variable descriptions and logit model result. Data from Bay Area Rapid Transit (BART) Passengers Survey (carried out in 1992) was used to develop the model.

Some significant findings can be summarised as follows:

- The most significant variables, those with the greatest effect on the choice to walk rather than take other modes, were: walking distance, gender, ethnicity, age, and car availability.
- Distance had a negative effect on walking to a station. The longer the distance from a station, the less likely one was willing to walk.
- Men were much likely to walk than women due to the likely safety and security concerns. As shown in the table, women were the majority of BART users (53.5 percent).
- Ethnicity was surprisingly significant in the choice to walk. Blacks and Asians were uniformly less likely to walk. Asians in particular were more likely to take feeder bus than walking. Blacks were more likely to drive than to walk, and the white population was more likely to walk (although this is not significant).
  Blacks and Asians were approximately 25 percent of BART users.
- Among age groups, those older than 65 were less likely to walk. However, senior citizens composed only 4 percent of the survey respondents.
  Almost 75 percent of passengers were people between 25 and 64 years old.
- Car availability, not surprisingly, was a strong deterrent to walking to BART among those who drove and among the aggregate total BART users.
- Income was most significant to those who drove versus those who walked, particularly among incomes greater than $45,000 per year.
- Those taking work and school trips were more likely to take feeder bus or drive than to walk.

Cervero (2001) also found that built environments (density, land use type and diversity, transit provision) influenced pedestrian access to rail transit station. BART data was also used in his study. Furthermore, Beimborn, et al. (2003) showed that captivity as defined by lack of car ownership was a key factor in public transport choice.

Table 2.15 Variable Description and Model Results



Variable Description and BART Survey Summary

Variable	Variable Description	Frequency	Observation %
BART ACCESS MODE			
ACWALK	Walk Access	2731	23.7%
ACTRANSIT	Transit Access	2657	23.0
ACAUTO	Auto Access	5925	51.3
NONWALK	All Non-Walk	8815	76.3
BART EGRESS MODE			100%
EGWALK	Walk Egress	9280	75.5
EGCAR	Automobile Egress	547	4.5
EGTRANS	Transit Egress	2362	19.2
EGBIKE	Bicycle Egress	63	0.5
TRIP PURPOSE			100%
PURHOME	Home destination	392	3.2
PURWORK	Work destination	9348	76.4
PURSCHL	School destination	1005	8.2
PURSHOP	Shop destination	151	1.2
ALTERNATE MODE AVAILABILITY			
CARAVAIL (Yes/No)	Car available for access trip?	6342	53.0
TRANAVAIL (Yes/No)	Transit available for access trip?	7112	57.4
TRAVELER CHARACTERISTICS			
EWHITE	White ethnic	7477	60.3
EBLACK	Black ethnic	1561	12.6
EASIAN	Asian and Pacific Islander	1829	14.8
GENDER	Gender (given in % male)	5656	46.5
AGE0	Age 12 or younger	59	0.5
AGE13	Age 13 to 17	153	1.2
AGE18	Age 18 to 24	1282	10.3
AGE25	Age 25 to 34	3571	28.8
AGE35	Age 35 to 44	3586	28.9
AGE45	Age 45 to 64	3023	24.4
AGE65	Age 65 and older	499	4.0
INC0	Household income $15,000 or less	1307	2.6
INC15	Household income $15,001 to $30,000	2314	19.9
INC30	Household income $30,001 to $45,000	2424	20.8
INC45	Household income $45,001 to $60,000	2033	17.4
INC60	Household income $60,001 to $75,000	1355	11.6
INC75	Household income $75,001+	2223	19.1
TRAVEL DISTANCE		Mean	Std. Dev.
DISTANCE	Computed straight distance to BART station	2.69	4.28
OBLOCKS	Blocks walked to BART	1.36	4.32
DBLOCKS	Blocks walked from BART	2.53	5.88

Logit Model Results*

	Walk vs Non-Walk		Walk vs Transit		Walk vs Automobile	
Variable	Coefficient	Significance	Coefficient	Significance	Coefficient	Significance
DISTANCE	-1.5373	0.0001	-1.0697	0.0001	-1.3012	0.0001
DBLOCKS	0.0139	0.0023	0.0242	0.0013	0.0080	Not Signif.
MDWALK	-0.2081	Not Signif.	-0.1084	Not Signif.	-0.3835	Not Signif.
MDBIKE	-0.2081	Not Signif.	-0.4152	Not Signif.	0.0030	Not Signif.
MDCAR	0.0795	Not Signif.	0.1226	Not Signif.	0.0128	Not Signif.
MDTRANS	-0.0017	Not Signif.	-0.0712	Not Signif.	-0.0928	Not Signif.
PURHOME	0.1861	Not Signif.	0.1429	Not Signif.	0.4519	0.0357
PURWORK	-0.2513	0.0037	-0.2051	0.0470	-0.3566	0.0006
PURSCHL	-0.2793	0.0183	-0.2519	0.0679	-0.2732	0.0574
PURSHOP	0.1399	Not Signif.	0.0848	Not Signif.	0.4243	0.0589
CARAVAIL	-0.5331	0.0001	0.1160	0.0941	-1.0059	0.0001
TRANSAVAIL	0.2836	0.0001	0.1498	0.0266	0.4204	0.0001
EWHITE	0.0896	Not Signif.	0.1487	Not Signif.	0.0066	Not Signif.
EBLACK	-0.3835	0.0002	-0.3714	0.0018	-0.4245	0.0006
EASIAN	-0.2936	0.0040	-0.4126	0.0005	-0.2327	0.0522
GENDER	0.4713	0.0001	0.3531	0.0001	0.6064	0.0001
AGE13	0.1406	Not Signif.	-0.0652	Not Signif.	0.6483	Not Signif.
AGE18	0.2414	Not Signif.	0.5089	0.0548	0.0739	Not Signif.
AGE25	-0.0043	Not Signif.	0.2486	Not Signif.	-0.1469	Not Signif.
AGE35	-0.2405	Not Signif.	0.0757	Not Signif.	-0.3888	Not Signif.
AGE45	-0.4239	0.0698	-0.1104	Not Signif.	-0.6211	0.0302
AGE65	-1.0226	0.0003	-0.8302	0.0072	-1.2778	0.0001
INC15	0.0953	Not Signif.	0.0551	Not Signif.	0.0497	Not Signif.
INC30	-0.0325	Not Signif.	0.1784	0.0790	-0.3150	0.0021
INC45	-0.1769	0.0626	0.1268	Not Signif.	-0.5276	0.0001
INC60	-0.3349	0.0027	0.0595	Not Signif.	-0.7975	0.0001
INC75	-0.4745	0.0001	0.0462	Not Signif.	-0.9290	0.0001
Constant	1.0463	0.0020	0.8962	0.0216	2.141	0.0001
	Walk	Non-Walk	Walk	Transit	Walk	Automobile
Predicted Correct (%)	58.0	94.4	91.8	69.9	74.3	91.2

* variables were considered significant at the 90 percent confidence level

Source: Loutzenheiser (1997)

Application GIS in analysis of public transport accessibility (e.g. Hsiao et al., 1997 and Hilman, 1997) calculated a ratio of population between area along the street and total population in buffer zone of public transport accessibility. They used bus stop as centre and distance of 400 metres as radius of the zone. The distance of 400 metres is assumed as the reasonable walking distance to reach a bus stop.

2.6 Discussion

It is known that people do walking for many reasons. Walking as a transport mode should be different from walking for health or recreation. In undeveloped areas or isolated regions, some people depend on walking for their travel. It might be that there are no other alternative modes or they have no ability to access alternative modes. There are many reasons why people choose to walk (to MRT stations). The key reason is that walking mode is flexible and often direct. Walking mode is not necessary free – cost of shoes, pollution, and security may have to be considered.

There are many ways to measure walking and many factors can be considered in the measurement. Walking can be measured using qualitative approach, which is related to how easy it is to do (walk). A quantitative approach applies an index to expresses the quality of walking environment.

Walking has a role for access trip to public transport terminals, such as bus interchanges or rail stations. To capture access trip to public transport, an in-detail investigation on walking should be carried out. Interview survey and walking route assessment could be used to investigate walking effort to access public transport terminals.

Chapter 3 Research Framework

This chapter discusses the methodology of this research, corresponding to the research objectives. First part of this chapter is the theoretical framework of walking mode share model followed by the concept of walking access model. The concept of equivalent walking distance and its application in walking accessibility measurement is explained in the last part.

3.1 Introduction

This research is carried out in two research stages. The first stage is to develop the walking access mode or walking mode share model and the second one is to calibrate the equivalent walking distance model. The whole process of this research is illustrated in Figure 3.1.

In the first stage, some study areas were selected based on preliminary analysis in the pilot survey and literature review. Each study area has one MRT station as the main public transport terminal. On-site interview survey was carried out in station area to obtain actual access mode. In this survey, respondents who did walk to access the station were asked to point out their walking route on the map provided in the survey form. According to this information and some prescriptions on walking route to access MRT station, walking route assessments were conducted. These assessments produced data related to walking route characteristics, such as the actual walking distance, number of road crossings, walking delay due to road crossing, number of ascending and descending steps, and so on.

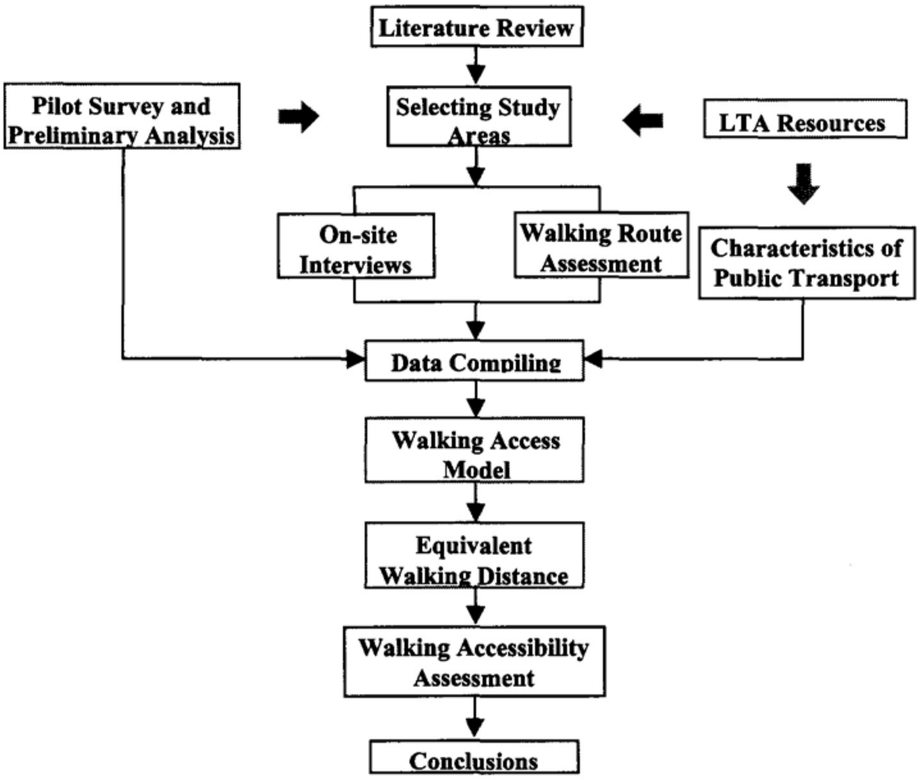


Figure 3.1 Research Framework

Walking mode share relationship was developed as a Walking Access Model (WAM), the model to predict walking mode share to access a public transport terminal, i.e. MRT station. This model can show the significance of factors affecting the choice of walking. Each component in the model that is related to characteristics of walking route can be converted to equivalent walking distance. Since walking accessibility is defined as how easy it is to access public transport by walking, walking effort would be expressed by equivalent walking distance, which is similar to the concept of generalised cost. The relevant characteristics of walking route would be incorporated in the equivalent walking distance formula.

Discrete choice modelling is applied to develop the Walking Access Model (WAM). A limited range of distances from stations should be applied to obtain good variability of access mode choice. According to the previous studies (such as

Stringham, 1982; Loutzenheiser, 1997; and Cervero, 2001) the airline distance of up to 2000 metres from the station was applied.

3.2 Walking Access Model

3.2.1 Theoretical Framework

Discrete choice framework is applied to build the walking share model. The model is a mathematical function, which predicts an individual's choice based on the utility or relative attractiveness of competing alternative modes. The principle of utility maximisation is used in discrete choice model, which means that an individual would select the alternative (transport mode) with the highest utility among the alternatives available at the time of making the choice. Regarding the theoretical framework of random utility theory, there are some basic assumptions in this research:

- Each trip maker is a person in a household. It is assumed that he or she can make a trip and have a free choice of available alternative modes for his or her trip.
- Several categories will be considered, e.g. gender group, within each group the population is homogenous. Each individual in that group selects and chooses an alternative rationally, and has perfect information about all his or her available alternatives.
- Let C be the ***universal set*** of alternatives and C_n be the set of available alternatives for individual n. Each alternative $i \in C_n \in C$ has utility function of U_{in} for individual n. Because the model cannot capture all information completely about all the elements considered by individual n to choose alternative i, the utility function of U_{in} would have two components, as follows:

$$U_{in} = V_{in} + \varepsilon_{in} \tag{3.1}$$

V_{in} is a measurable component and is called a systematic or representative component of the utility function and ε_{in} is the random component which is called a disturbance term of the utility function. Observational error is also included in the random component.

- The measurable component of utility function is expressed by:

$$V_{in} = \Sigma_k \beta_k x_{ikn} = \beta' \mathbf{x}_{in} \qquad (3.2)$$

Variable $\mathbf{x}_{ikn}$ is a set of k measured attributes of alternative i for individual n and β_k is a set of parameters, which are assumed to be constant for all individuals and across alternatives. To simplify notation, β_k is expressed by vector of parameters, β', and x_{ikn} is expressed by vector of attributes, $\mathbf{x}_{in}$.

- In order to estimate the walking share model, it is assumed that all individuals have *the same set of available alternatives and face similar constrains in choosing the alternatives.*
- Probability of individual n choosing an alternative i instead of alternativej :

$$P_n(i|C_n) = P(U_{in} \geq U_{jn}, \forall j \in C_n) \qquad (3.3)$$

or,

$$P_n(i) = P(V_{in} - V_{jn} \geq \varepsilon_{jn} - \varepsilon_{in}) \qquad (3.4)$$

Equation (3.4) is an expression for the joint cumulative distribution function of the random variable $\varepsilon_{jn} - \varepsilon_{in}$, evaluated at the point $V_{in} - V_{jn}$. So, if the distribution of ε is known, equation (3.4) can be used to predict the probability of an individual choosing an alternative.

As discussed in Ben-Akiva and Lerman (1985), if the alternative i is chosen, then:

$$P_n(i) = P[V_{in} + \varepsilon_{in} \geq \max(V_{jn} + \varepsilon_{jn}), j \in C_n, i \neq j] \qquad (3.5)$$

- If the random component ε is (1) independently distributed, (2) identically distributed, and (3) Gumbel-distributed, then:

$$P_n(i) = \frac{e^{V_{in}}}{\sum_j e^{V_{jn}}}, j \in C_n \tag{3.6}$$

which is known as multinomial logit model (MNL).

3.2.2 Characteristics of Multinomial Logit (MNL) Model

MNL model is the most popular practical discrete choice model. The model has tractable and convenient functional form. The parameters can be estimated relatively simple using standard maximum likelihood techniques. Two major characteristics of this model are:

- Independence of Irrelevant Alternatives (IIA), which can be explained as follows:

  When any two alternatives have a non-zero probability of being chosen, the ratio of one probability over the other is unaffected by the presence or absence of any additional alternatives in the choice set (as cited by Ortuzar and Willumsen, 2001), or mathematically:

$$\frac{P(i)}{P(l)} = \frac{e^{V_i} \Big/ \sum_{j \in C_n} e^{V_j}}{e^{V_l} \Big/ \sum_{j \in C_n} e^{V_j}} = \frac{e^{V_i}}{e^{V_l}} = e^{V_i - V_l} \tag{3.7}$$

  The IIA property in MNL is the strength and also the weakness of the model. One of the advantages of this property is that the model can be estimated based on one choice set and then used to predict choices from a modified choice set, e.g. a new alternative mode can be estimated from the previous model.

The problem with IIA property occurs if there are alternatives not independent of each other or a model with too many alternatives. In this case, the hierarchical logit model or nested logit model should be applied. Ben-Akiva and Lerman (1985) and also Manski and McFadden (1981) did more investigation on the IIA property, which can be applied in model development.

- Elasticity of Logit Model

  As shown mathematically by Ben-Akiva and Lerman (1985), the direct elasticity of the probability of an individual n choosing alternative i with respect to a change in some attribute x_k is:

$$\text{Direct Elasticity} = (1 - P_{in})(x_{ink})(\beta_k) \qquad \textbf{(3.8)}$$

  The cross elasticity of the probability that alternative i is selected with respect to a change in attribute x_k of alternative j is:

$$\text{Cross Elasticity} = -P_{in}(x_{jnk})(\beta_k) \qquad (3.9)$$

  To be noted here, they are disaggregate point elasticity, which must be applied with caution (Ben-Akiva and Lerman, 1985).

3.2.3 Estimation and Statistical Analysis

Maximum likelihood and least square method can be applied to estimate the multinomial logit (MNL) model. In this research, the econometric software LIMDEP (version 7.0, 1998) was used for the estimation process.

Maximum likelihood estimator is the value of the parameters for which the observed sample is ***most likely*** to occur (Ben-Akiva and Lerman, 1985). Let N denote the sample size and $y_{in} = 1$ if individual n chooses alternative i and 0 otherwise. The likelihood function for general multinomial logit is:

$$\ell = \prod_{n=1}^{N} \prod_{i \in C_n} P_n(i)^{y_{in}} \tag{3.10}$$

where,

$$P_n(i) = \frac{e^{\beta' x_{in}}}{\sum_{j \in C_n} e^{\beta' x_{jn}}} \tag{3.11}$$

Taking the logarithm of equation (3.10), it is obtained:

$$L = \log \ell = \sum_{n=1}^{N} \sum_{i \in C_n} y_{in} \left(\beta' x_{in} - \ln \sum_{j \in C_n} e^{\beta' x_{jn}} \right) \tag{3.12}$$

Carrying the first derivatives of equation (3.12) with respect to zero:

$$\frac{\partial L}{\partial \beta_{ik}} = \sum_{n=1}^{N} \sum_{i \in C_n} y_{in} \left(x_{ink} - \frac{\sum_{j \in C_n} e^{\beta' x_{jn}} \cdot x_{jnk}}{\sum_{j \in C_n} e^{\beta' x_{jn}}} \right) = 0\text{, for } k = 1, \ldots, K \tag{3.13}$$

or in general terms:

$$\sum_{n=1}^{N} \sum_{i \in C_n} [y_{in} - P_n(i)] \cdot x_{ink} = 0, \quad \text{for } k = 1, \ldots, K \tag{3.14}$$

The L function in equation (3.12) is globally convex, which means that if the solution of equation (3.14) exists, it would be unique (Manski and McFadden, 1981; and Ben-Akiva and Lerman, 1985). LIMDEP version 7.0 (1998) uses this approach to estimate model parameters.

The method of least squares estimation is rarely used in discrete choice models. Gujarati (2002) used transformation procedure to convert equation (3.6) into a linear form. He used MNL model with only two alternatives (binomial logit model).

Berkson-Theil method can be applied to estimate model’s parameters using least squares method. However, it is very difficult except when database is large or when repeated observations on individual’s choices are available (Ben-Akiva and Lerman, 1985).

Statistical analysis is performed to obtain the most satisfactory model. Two types of tests would be conducted. One is the significance test of the coefficient estimation and the other is the test on the structure of the model itself. The most common significance tests for coefficient estimation are t-test, likelihood ratio test, and goodness-of-fit. The t-test is the most important test that should be carried out. The significance level of 5% is applied in this test. The t-test is carried out together with the examination of the coefficient sign. To accept a variable into the model, the correct sign is compulsory even it fails any significance test. The failure in significance test may just be caused by the lack of sufficient data.

The application of likelihood ratio test in MNL model is similar to the F-test used in regression model. Two tests of null hypotheses can be carried out. One **is** the null hypothesis of all coefficients equal to zero and the other is a null hypothesis for constant equal to zero.

The informal goodness-of-fit or pseudo-R^2 (ρ^2 in Ben-Akiva and Lerman, 1985 or McFadden’s ρ^2 in Limdep, 1998) is employed to test the model. In discrete choice model, the goodness-of-fit is less important than other previous tests. The ρ^2 value is an informal goodness-of-fit index that measures the fraction of an initial log likelihood value explained by the model. It is analogous to R^2 in regression but most useful in comparing two specifications of a model with similar data.

3.2.4 Choice Set Determination

Each individual has his own choice set of available modes to make his or her trip. The easiest way to capture the choice set is to ask directly. An interview survey is needed to obtain this information. How many transport modes are available to each individual is one of the difficult points in determination of the choice set. There are at least three main access modes used to reach mass rapid transit stations (O'Sullivan and Morrall, 1996; Loutzenheiser, 1997; Cervero, 2001; Meyer and Miller, 2001). These modes are car (private car and taxi), bus (feeder bus), and non-motorised mode (walking and using bicycle). In Singapore case, Light Rapid Transit (LRT) is also used as feeder mode to access mass rapid transit stations (MRT stations).

In this research, it is assumed that each individual has at least two alternative modes to access public transport terminal (access mode). The theoretical set of alternative access modes (choice set) can be described below, which is then will be modified based on survey data.

- Walking: available to all individuals within 1500 metres straight distance from his/her origin point (e.g. home) to the public transport terminal.
- Feeder Bus or Light Rapid Transit (LRT): available to all individuals within 500 metres straight distance from bus stop or LRT station and they have sufficient money to pay the fare.
- Car and Motorcycle: to be driven (drop off), if there is at least one vehicle available for the trip.
- Taxi: available to all individuals and they have sufficient money to pay the fare.
- Using bicycle: available to all individuals who have available bicycle for the trip and there is available bicycle parking facility at the terminal.

3.2.5 Utility Function

Let i = w for the walking mode. According to equation (3.6), the probability of choosing walking, can be written as:

$$P_n(w) = \frac{e^{V_w}}{\sum_j e^{V_j}}, j \in C_n \tag{3.15}$$

The measurable component of V_w can be expressed as follows:

$$V_w = \beta_1 + \beta'_2\,\mathbf{x}_{\mathbf{mode}} + \beta'_3\,\mathbf{x}_{\mathbf{individual}} \qquad \textbf{(3.16)}$$

From equation (3.16), $\mathbf{x}_{\mathbf{mode}}$ is the vector of measured attributes related to alternative mode of walking. The characteristics of walking route would be included in these attributes. The components of vector $\mathbf{x}_{\mathbf{individual}}$ are measured attributes related to individual characteristics. Table 3.1 shows all components for the utility function that will be incorporated in WAM.

Table 3.1 Possible Components of Utility Function for WAM

Mode	**Attributes**	**Remark**
Walking	• No of road crossing and Average delay	Along walking route
	• No of ascending and descending steps	Elevated road crossing (escalators are excluded)
	• Weather protection	% of walking route
	• No of traffic conflict	Access road and carpark
	• Walking comfort	Subjective rating
	• No of obstruction	along walking route
Feeder Mode (Bus or LRT)	• Time and distance	• Walking time and distance to bus stop or LRT station • Waiting time for bus or LRT (out-vehicle time) • In-vehicle time • Walking time and distance from bus stop, bus terminal, or LRT exit to MRT entrance
Car or taxi	• Time and Distance	• In-vehicle time • Walking time and distance from taxi stand or car park to terminal
Individual Characteristic: • Gender • Age • Income		

3.3 Equivalent Walking Effort

Walking accessibility to public transport is examined in this research using the effort of individual to access public transport terminal by walking. It is presumed that besides walking distance or time, this effort is affected by the characteristics of walking route. To quantify the effort of walking, a concept of equivalent walking effort is introduced. An increase of equivalent walking effort indicates that walking to access the terminals becomes more difficult. It is hoped that application of this concept to walking accessibility measure would produce a more precise and comprehensive measurement. Moreover, the beneficial improvement of access facilities to terminal can be examined more easily.

There are two possibilities of the concept of equivalent walking effort, i.e. Equivalent Walking Time (EWT) and Equivalent Walking Distance (EWD). Pilot survey and preliminary analysis, which will be discussed in the next chapter, has examined EWT in detail. It was found that EWT varies with individual characteristics. Thus, application EWT into walking accessibility, for example, could not produce the unique number of the measure. Consequently, EWD is developed in the main research.

The following paragraphs discuss the development of EWD, which can also be applied to EWT. EWD model has two components, which are related to the characteristics of the walking route. The first component is the actual walking distance. This component is directly measurable and can be easily obtained. The second component of EWD is the ***generalised distance*** related to characteristics of the walking route. Eventually, all components of walking route would be converted to equivalent distance.

There are three main types of walking routes to access public transport, i.e. walkways, sidewalks and road crossings. Each type might have some elements that influence the effort of walking. Road crossings, steps (ascending and descending), conflicts with vehicles, and so on, are several examples of how the components of walking route increase the effort of walking.

An elevated road crossing, such as an overpass (pedestrian bridge) and underpass (tunnel), are not counted as level road crossings but their influence is considered in

EWD model. An escalator in elevated road crossing would not cause any extra effort. In general, the EWD model can be expressed as follows:

$$EWD = WDIST + f(\text{characteristic of walking route}) \qquad (3.17)$$

WDIST is the measurable walking distance. The second component of EWD is a quantitative value for the components of walking route, such as number of road crossing, delay due to crossing, number of ascending and descending steps, and so on. It is assumed that a linear function can be used to express the relationship between these components and EWD, as shown in equation (3.18).

$$EWD = WDIST + \alpha_1 u_1 + \alpha_2 u_2 + \ldots + \alpha_k u_k = WDIST + \boldsymbol{\alpha}' \mathbf{u_i} \qquad (3.18)$$

WDIST could be obtained from the survey directly. The vector of variables **u** are related to the characteristics of walking route with their vector of coefficients α', which can be derived from the Walking Access Model (WAM). Unit of distance, i.e. metre, is used as the common unit.

3.4 Walking Accessibility Measure

3.4.1 Walking Probability

In some public transport studies, acceptable walking distance to public transport terminals is assumed to be between 400 and 800 metres. However, as will be shown in pilot survey and preliminary analysis, individuals might choose to walk over much longer distances.

In this research, the probability of walking is introduced to show acceptable walking distance to public transport terminal. This concept assumes that for every distance to the terminal, there is a probability of walking. To illustrate, Figure 3.2

shows the relationship between walking probability and the distance from the terminal.

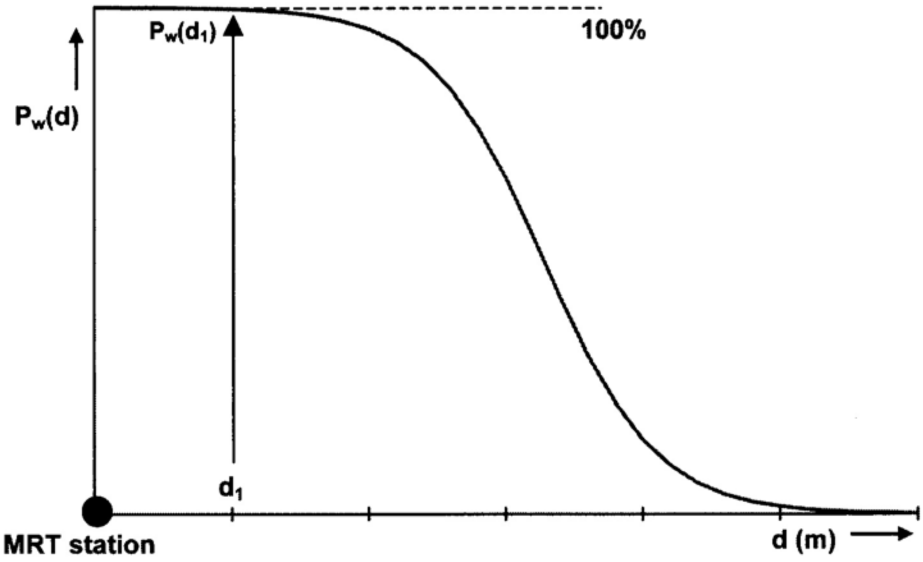


Figure 3.2 Walking Probability related to Distance from MRT station

As can be seen in the figure, up to the distance of d_1, the walking probability, $P_w(d_1)$ ≈ 100%. It can be said that at the distance d_1, all individuals would walk to access the terminal. The maximum acceptable walking distance could be determined by defining reasonable minimum walking probability.

The simple model to develop walking probability is the logit model. Walking probability could be expressed as a function of EWD. The general form of the model is as follows:

$$P_w(d) = \frac{1}{1 + e^{-(\phi - \theta \cdot d)}} \tag{3.20}$$

where: $P_w(d)$ = walking probability for distance d
$\phi; \theta$ = constant coefficients

3.4.2 Walking Accessibility Index

It should be stated here that the concept of walking accessibility measure is an improvement from what has been known from the literature and developed in the pilot survey and preliminary analysis, which will be discussed in Chapter 4.There are two main differences with the previous work. One is that equivalent walking distance is used instead of walking time and the other is using walking probability as a weightage.

The index uses two types of coverage areas, which are defined as the population covered within a certain distance. First type is the coverage area drawn based on airline distance. It was assumed that in this area an individual could access MRT station without any resistance to walking. The walking route is a straight line and has no road crossings, no steps or slopes to climb, and so on. This is called an "ideal walking environment".

The second type is drawn based on EWD values. Based on field observations, each origin point of individual (i.e. housing block) has its specific EWD value related to the walking route available. A contour of EWD would be drawn and the coverage area of EWD constructed for a certain distance range.

The index is developed as the ratio of number of housing block covered within EWD distance and the "ideal walking environment".

Walking accessibility index can be calculated as the ratio between number of housing blocks covered in EWD contour and the corresponding airline distance contours. As walking share decreases with distance from terminal, a walking probability is also incorporated into the calculation as a weightage. Thus, general expression of the index is, as follows:

$$\mathrm{WAI} = \frac{\sum_{i}^{n} N_i^{EWD} P_{wi}}{\sum_{i}^{n} N_i^{ADIST} P_{wi}} \tag{3.21}$$

where: **WAI** = walking accessibility index
P_{wi} = walking probability for distance band i
N_i^{EWD} = number of housing blocks located within EWD contour band i
N_i^{ADIST} = number of housing blocks located within airline distance (ADIST) contour band i

The procedure to calculate WAI can be described as follows:

- First at all, contours with interval of 100 metres of airline distance are drawn. These contours will be circles with MRT station as the centre. The EWD contour was drawn based on EWD value at respondent's origin points and along walking routes. The interval of 100 metres is also used for EWD contours. Typical ADIST and EWD-based catchment areas can be seen in Figure 3.3.

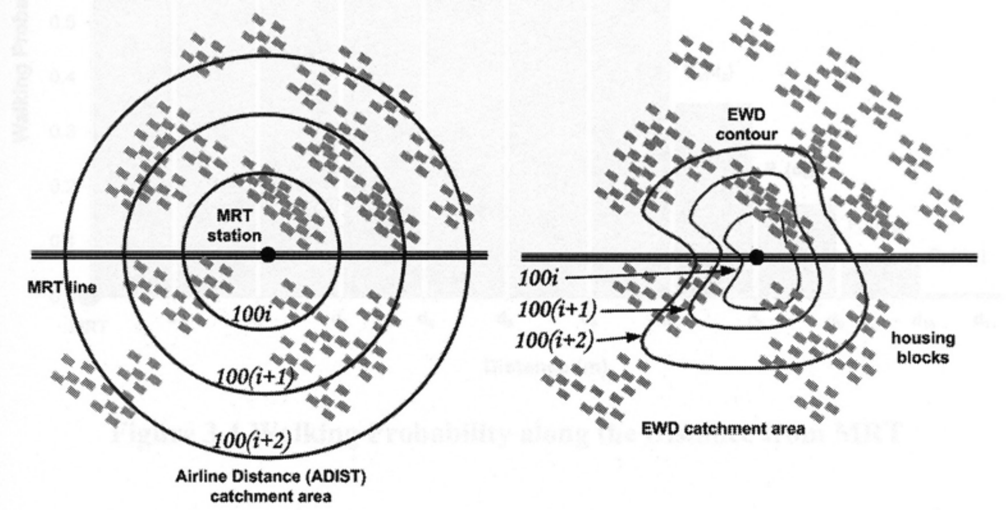


Figure 3.3 An Illustration of Catchment Area for ADIST and EWD

- Next, number of housing blocks located within airline distance (ADIST) and EWD contour bands (i+1) are calculated as the number of housing blocks located between ring 100i and 100(i+1).

- Then, walking probability is calculated based on equation (3.20) for each contour interval. It is assumed that walking probability for each point in the contour band is the same. Figure 3.4 gives an illustration of walking probability distribution along the distance from MRT station based on contour intervals. As shown in the figure, d_i is the interval contour of 100i metres. Walking probability for i, $\mathbf{P_w(d_i)}$, is the ***average*** walking probability for distance between d_{i-1} and d_i. Figure 3.4 was drawn based on equation (3.20), with the value of ϕ and θ being 7.00 and 0.005, respectively.
- Finally, walking accessibility index is calculated using equation (3.21).

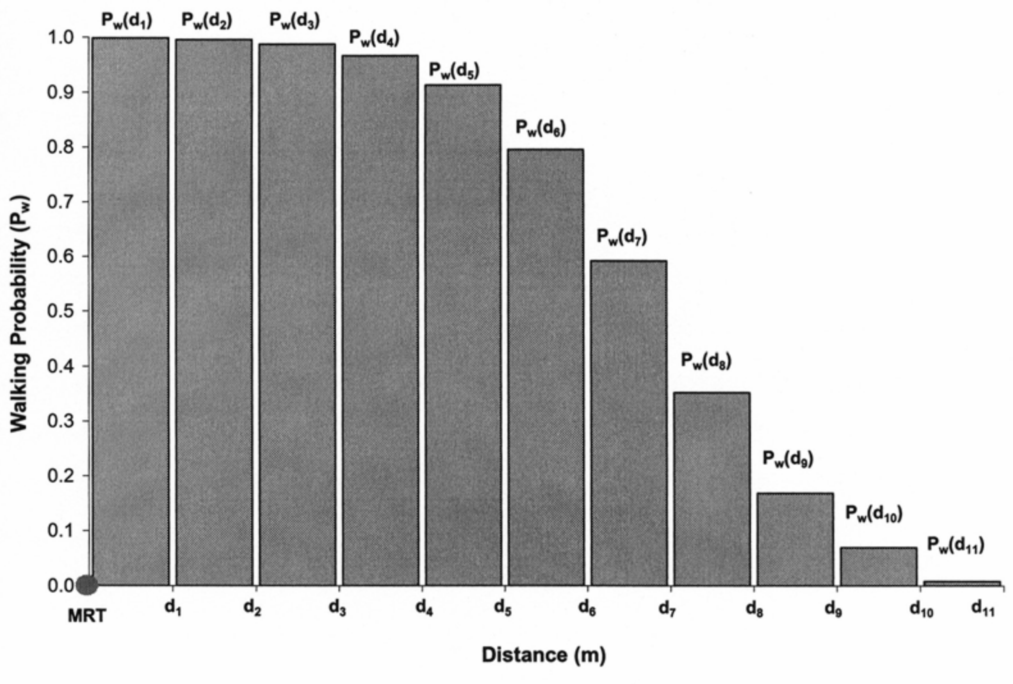


Figure 3.4 Walking Probability along the Distance from MRT

This new method of walking accessibility assessment is more precise and comprehensive. Some advantages of this method are as follows:

- The effort of walking is incorporated in the assessment. The influence of some barriers to walking could be incorporated.

- Land use pattern, which influences walking route diversions, can be captured. Most of the paths of walking routes were result from the land use characteristics.
- Some improvements in walking facilities to access a station can be accommodated. Replacing ascending steps with an escalator, for example, would reduce the EWD value and consequently increase the value of WAI.

Chapter 4 Pilot Survey and Preliminary Analysis

This chapter focuses on pilot survey and preliminary analysis. In this part, the prototype of walking access model and equivalent walking time were obtained. Some findings in the preliminary analysis were extended in the main research.

4.1 Data Resources

4.1.1 Study Areas

Five locations were selected initially for the pilot analysis, i.e. Tampines, Chinese Garden, Hougang, Bedok and Clementi. Chinese Garden area has only an MRT station as the main public transport terminal. All trunk bus routes in that area have origin or destination at Jurong East Interchange and Boon Lay Interchange. Mixed residential and commercial buildings are located in the vicinity of the station. No feeder buses operate to access the station and the most common mode to access the station is by walking.

Tampines, Hougang, Bedok and Clementi have the typical characteristics of a Singapore public housing new town. They have an integrated MRT station and bus interchange and residential areas built around the terminal up to 800-1000 metres. Activity centres, such as malls and offices, are concentrated close to the stations. Feeder buses are operated to access the MRT station.

However, the new MRT line (North-East Line) was not operational yet when the pilot survey was conducted. Hence, for Hougang, there is only a bus interchange. Mixed residential and commercial buildings are located surrounding the bus terminal. Feeder buses are operated as alternative mode to access the terminal but most of the passengers have the final destination nearby the terminal.

4.1.2 Survey

On-site interviews and walking route assessments were carried out in the study areas, which were conducted over twenty days between November and December 2002 by Yip (2003) and Fock (2003). Additional surveys were carried out by the author at Bedok and Clementi MRT stations. The data summary from the survey can be seen in Table 4.1.

Table 4.1 Data Summary of Pilot Survey

Location	**Number of data**		**Type of Public Transport Terminal**
	Interview	**Walking Assessment**	
Tampines	133	34	MRT station
Chinese Garden	82	21	MRT station
Hougang	113	22	Bus Interchange
Additional Data:			
Bedok	32	11	MRT station
Clementi	33	14	MRT station
Total	**393**	**102**	

In the on-site interview survey, respondents were the passengers who took MRT or bus to go to their final destination. Less than 20 questions were given related to information such as access mode used to reach terminal, trip purpose, walking time (for those who walked to terminal), and respondent's characteristics, i.e. their location (their housing block number), occupation, age (in ranges), and combined monthly income of their family (in ranges). An example of on-site interview survey form can be seen in Appendix A. 1.

The interview took approximately 1-3 minutes to complete. Specific questions were asked on the mode used to go to the terminal, such as the elapsed time, the reason of choosing the mode, and waiting time (for bus and taxi). Respondents who walked to access the terminal were asked to point out their route on the map provided with the survey form.

Based on the walking route pointed by the respondent, walking route assessments were carried out. The objective of this survey was to obtain walking route characteristics in detail, such as measured walking distance, number of road crossings and delay time due to road crossing, number of ascending and descending steps (especially for elevated road crossings), conflict points (access road and car park), and other characteristics of walking facility. An example of walking assessment form can be seen in Appendix A.1.

Walking route assessment was carried out on many attributes of the walking route, as shown in Table 4.2. An electronic device was used to measure walking distance: pedometer is an electronic digital instrument, which can count the number of steps in normal walking or running. Using stride length adjustment, pedometer converted number of steps into the length of walking path.

Table 4.2 Attributes of Walking Route

Attribute	Unit	How to measure
Walking distance	step	Pedometer
Walking time	minute	Pedometer
Walking path width	M	Roller measurement
Obstruction	per 100 m	Manual counting
Support facilities	per 100 m	Manual counting, e.g. refuge median, ramp, etc
Barrier	per 100 m	Manual counting, e.g. no ramp for wheelchair
Weather protection	%	Roller measurement, reported as %-walking route
Conflict point	per 100 m	Manual counting, e.g. access road
No of road crossing	-	Manual counting, excluding elevated road crossings
Total delay	second	Stopwatch
No of Steps	-	Manual counting, separately between ascending and descending steps, excluding escalators.

4.2 Characteristics of Walking as Access Mode

Based on the interviews, walking and bus were the most frequent modes to access MRT station and bus interchange. Car was also another alternative mode with a small proportion. No taxi, motorcycle, and bicycle trips were captured in the pilot interviews. Thus, the modal split from the pilot survey is as shown in Table 4.3.

Table 4.3 Mode Choice to Access Public Transport Terminal

Location	Walking	Bus	Car	Total Data
Tampines	63	68	2	133
Chinese Garden	75	5	3	82
Hougang	110	2	1	113
Bedok	11	20	1	32
Clementi	14	17	2	33
Total	**273**	**112**	**9**	**393**

4.2.1 Walking Distance

Walking distance to access public transport can be differentiated by access to rail station and to bus stop, as shown in Table 4.4. Many studies on non-motorised trip and public transport suggested that walking distance to rail stations is longer than to bus stops (Mitchell and Stokes, 1982; O'Sullivan and Morrall, 1996; Halden et al, 2000; Ker and Ginn, 2003; etc). The characteristics of access trips to bus stops would not be discussed in detail in this pilot analysis.

Table 4.4 Walking Distance to Access Public Transport (Pilot Study)

Descriptive Statistics	to bus stop			to bus interchange			to MRT station		
	Men	Women	All	Men	Women	All	Men	Women	All
Average, m	163.7	184.9	175.8	531.9	468.8	500.4	612.2	646.8	628.3
Std. Dev., m	88.1	117.5	106.0	177.5	179.0	180.2	275.5	220.7	251.3
Minimum, m	35	35	35	119	145	119	162	170	162
Maximum, m	418	526	526	882	931	931	1350	1151	1350
No. of Data	47	63	110	55	55	110	87	76	163

Statistical analysis:

Descriptive Statistics	to bus stop		to bus interchange		to MRT station	
	Men	Women	Men	Women	Men	Women
Mean	163.7	184.9	531.9	468.8	612.2	646.8
Variance	7760.2	13800.6	31502.9	32029.2	75882.7	48717.1
Observations	47	63	55	55	87	76
Hypothesized Mean Difference	0		0		0	
Degree of freedom (df)	108		108		160	
t_o (Observed)	-1.082		1.856		-0.8895	
t_{cr} (Critical) for two-tail	1.982		1.982		1.9749	
$P(\|t_o\| \le t_{cr})$ for two-tail	0.282		0.066		0.3751	

For walking distance to access bus stop, it is shown that $|t_o| = 1.082 < t_{cr} = 1.982$. The null hypotheses of average walking distance for men equals to the one for women cannot be rejected at 5% level of significance. It means that characteristics of walking between men and women are not different. Same result is obtained for access to bus interchange and MRT station.

4.2.2 Walking Time

There are two types of walking time obtained in the surveys. One is measured walking time, captured by surveyors during walking route assessment, and the other is reported walking time from the interview survey. Comparison of these walking times is shown in Figure 4.1. It is expected that the differences would be normally distributed (bell shape) to indicate that there is no bias between measured walking time and respondents' perception.

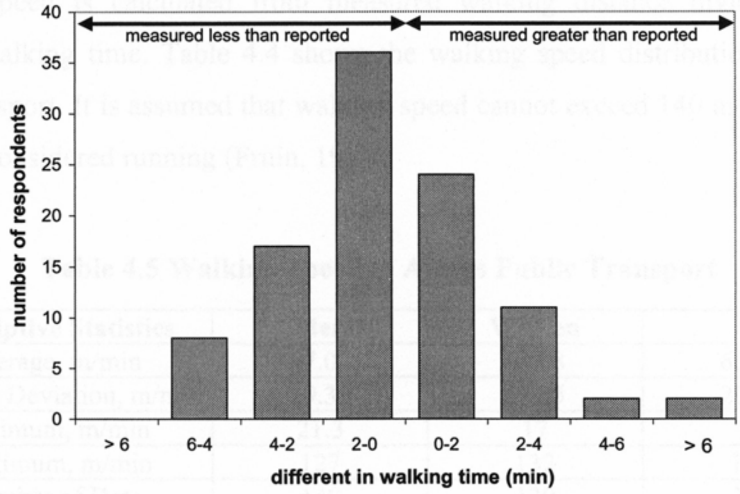


Figure 4.1 Measured and Reported Walking Time

It can be seen from the figure, there is a higher proportion of ***measured less than reported.*** It indicates that most of respondents reported their walking time higher than what was measured.

Most of the respondents reported their walking time rounded up to the nearest five minutes. Reported walking time could be the total journey time that comprised walking from home to the station gate. Some walking delay due to road crossing or obstructions such as ascending steps might be included in the reported time.

The null hypotheses that average measured walking time equal to average reported walking time can be rejected at 10% level of significance. It is meant that average measured walking time was statistically different with the average reported walking time. It is possible because for same walking path, respondent and surveyor might have had different walking speed, which produced different walking time. To obtain reported walking time more precisely, O'Sullivan and Morrall (1996) suggested selecting only commuters as respondents.

4.2.3 Walking Speed

Walking speed is calculated from measured walking distance divided by the reported walking time. Table 4.4 shows the walking speed distribution to access public transport. It is assumed that walking speed cannot exceed 140 m/min, as this would be considered running (Fruin, 1971).

Table 4.5 Walking Speed to Access Public Transport

Descriptive Statistics	**Men**	**Women**	**All**
Average, m/min	67.07	63.08	65.15
Standard Deviation, m/min	19.35	21.55	20.50
Minimum, m/min	21.3	17	17
Maximum, m/min	127	132	132
Number of Data	140	130	270

Statistical analysis:

Descriptive Statistics	**Men**	**Women**
Mean	67.07	63.08
Variance	374.483	464.460
Observations	140	130
Hypothesized Mean Difference	0	
Degree of freedom (df)	259	
t_o (Observed)	1.596	
t_{cr} (Critical) for two-tail	1.969	
$P(\|t_o\| \leq t_{cr})$ for two-tail	0.112	

The null hypotheses that average walking speeds for men and women are equal could not be rejected at 5% level of significance. It indicates that the characteristics of walking speed for men and women are not different.

4.3 Modal Split Observations

4.3.1 Modal Split and Characteristics of Respondents

In the preliminary analysis, two types of access mode were examined in detail, i.e. walking mode and motorised mode (bus and car). To examine relationship between modal split and age, respondents' were classified into three age groups. They are: under working-age group for all respondents with age up to 21 years, the working-age-adult group between 21 and 50 years old, and older persons of 50 years and more. Table 4.5 shows the modal split between walking and non-walking by age group. As shown in the table, 71% of working-age adults chose walking which is more frequent than the other groups. The table also shows that men did walk more than women.

Table 4.6 Proportion of Walking and Non-Walking by Respondents' Age

Age Group	Number of Respondents						Proportion of Respondents					
	Female		Male		All		Female		Male		All	
	Walk	Non-Walk	Walk	Non-Walk	Walk	Non-Walk	Walk	Non-Walk	Walk	Non-Walk	Walk	Non-Walk
< 21	17	16	5	0	22	16	0.52	0.48	1.00	0.00	0.58	0.42
21-50	111	50	133	48	244	98	0.69	0.31	0.73	0.27	0.71	0.29
> 50	3	4	4	2	7	6	0.43	0.57	0.67	0.33	0.54	0.46
Total	131	70	142	50	273	120	0.65	0.35	0.74	0.26	0.69	0.31

Effect on modal split between walking and non-walking of other respondents' characteristics could not be examined due to insufficient data, especially for income and occupation. For income data, some respondents thought it was confidential information and refused to answer the question.

4.3.2 Mode Choice Related to Distance and Time

The proportion choosing walking and non-walking can be classified by walking distance and walking time. It is presumed that respondents would choose walking for short walking distance (or walking time) and they would shift their mode to non-walking mode (bus and car, for this case) as the walking distance (or walking time) increased.

Figure 4.2 shows the proportion of walking and non-walking related to walking distance. According to the figure, no respondents chose walking for walking distances higher than 1600 metres. For this reason, the distance of 1600 metres might be applied as respondent's maximum acceptable walking distance.

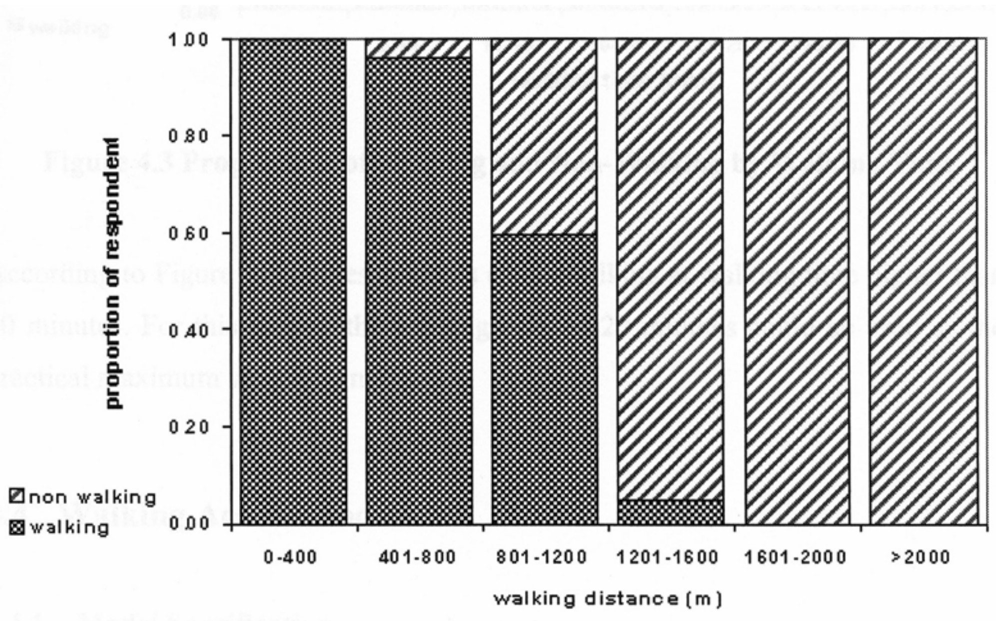


Figure 4.2 Proportions of Walking and Non-Walking by Walking Distance

Similarly, the proportions of walking and non-walking related to walking time are shown in Figure 4.3. It should be noted here that survey data did not provide all the walking times, especially for respondents who chose non-walking mode (bus and car). Thus, some assumptions were made, which meant that for those who chose bus and car, walking time was calculated by dividing walking distance by the average walking speed in Table 4.5.

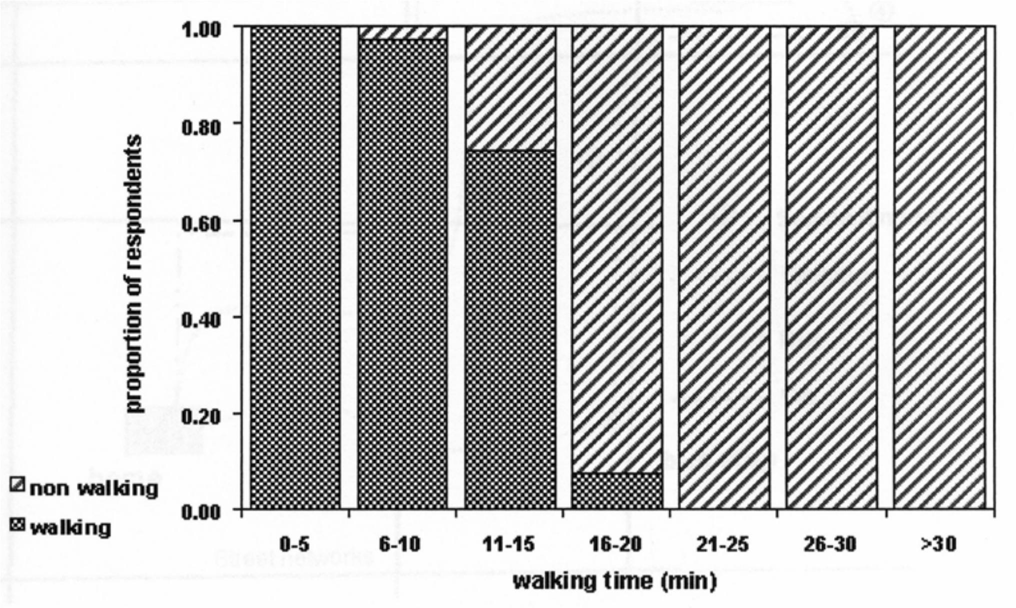


Figure 4.3 Proportions of Walking and Non-Walking by Walking Time

According to Figure 4.3, no respondents chose walking at walking time higher than 20 minutes. For this reason, the walking time of 20 minutes could be used as the practical maximum walking time.

4.4 Walking Access Model

4.4.1 Model Specification

Walking Access Model (WAM) is developedto describe the walking mode share to access public transport terminals. It is assumed that the probability of an individual choosing walking to access public transport is influenced by characteristics of alternative modes (walking and non-walking), walking route, and individual. Figure 4.4 shows the illustration of the choices used to develop Walking Access Model in this pilot analysis. Parameters describing the alternative access modes are shown in Table 4.7.

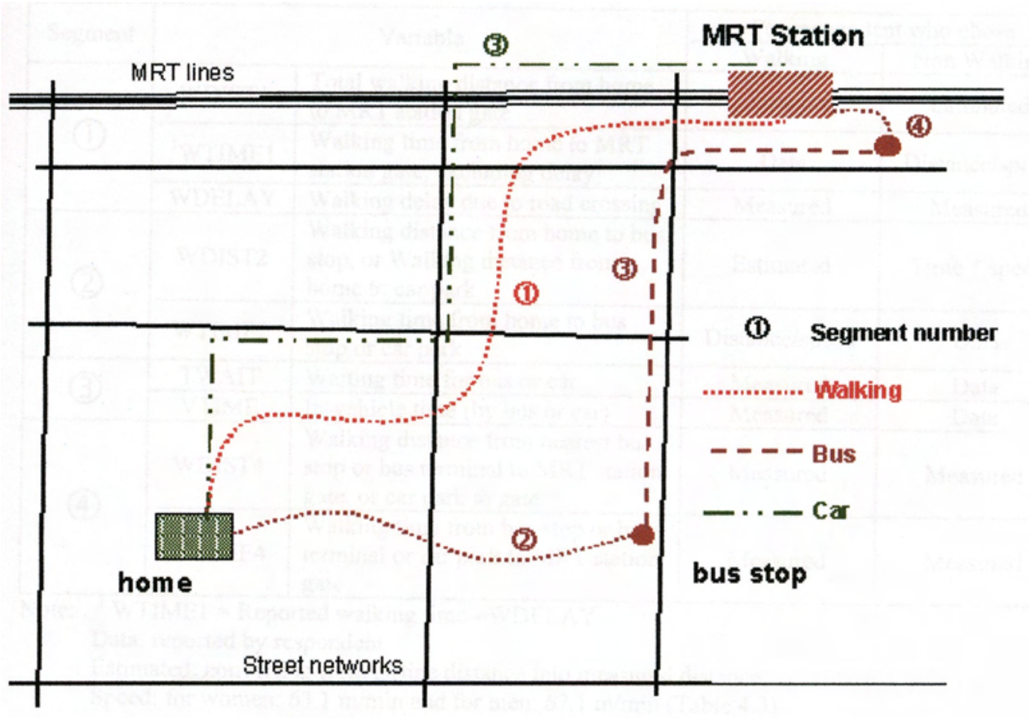


Figure 4.4 Illustration for Walking Access Model

In this preliminary analysis, a binomial logit model is used to develop the prototype of walking access model. The probability of an individual choosing walking mode (P_w) is dependent on the difference of utility of walking (w) and non-walking mode, or,

$$P_W = \frac{1}{1+e^{-(V_w - V_{nw})}} = \frac{1}{1+e^{-Z}} \tag{4.1}$$

where $Z = V_w - V_{nw}$ and V_w and V_{nw} are systematic components of the utility function of walking mode and non-walking mode (i.e. bus and car, for this case), respectively.

$$Z = V_w - V_{nw} = \beta' \mathbf{x_i} = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_K x_K \tag{4.2}$$

where $\mathbf{x_i}$ is the difference of variable values for walking and non-walking modes.

Table 4.7 Variables describing Access Mode Choices

Segment	Variable		For respondent who chose	
			Walking	Non Walking
①	WDIST1	Total walking distance from home to MRT station gate	Measured	Estimated
	[1]WTIME1	Walking time from home to MRT station gate, excluding delay	Data	Distance/speed
	WDELAY	Walking delay due to road crossing	Measured	Measured
②	WDIST2	Walking distance from home to bus stop, or Walking distance from home to car park	Estimated	Time * speed
	WTIME2	Walking time from home to bus stop or car park	Distance/speed	Data
③	TWAIT	Waiting time for bus or car	Measured	Data
	VTIME	In-vehicle time (by bus or car)	Measured	Data
④	WDIST4	Walking distance from nearest bus stop or bus terminal to MRT station gate, or car park to gate	Measured	Measured
	WTIME4	Walking time from bus stop or bus terminal or car park to MRT station gate	Measured	Measured

Note: [1] WTIME1 = Reported walking time - WDELAY
Data: reported by respondent
Estimated: converting from airline distance into measured distance
Speed: for women: 63.1 m/min and for men: 67.1 m/min (Table 4.3)

According to available data from the five study areas, ten variables (with one dependent variable) were used to develop the model. Table 4.8 shows the model specification in detail. The characteristics of the variables can be described as follows:

- The dependent variable (left-hand-side variable) of MODE indicates the mode choice. MODE = 1 is for walking and MODE = 0 is for non walking.

- Variables of mode characteristics, which are expressed in time units (minutes):
  1. DTIME: Time difference between walking time to MRT station and walking time to reach bus stop or car park and from bus stop to MRT station's gate.
     DTIME = WTIME1- (WTIME2+WTIME4)
     DTIME is a generic variable and is expected to be negatively correlated with the probability of choosing walking.

Table 4.8 Model Specification

Variable	Walking Mode, (w)	Non-Walking Mode, (nw)	Data Input
x_1	1	0	MODE
x_2	WTIME1	WTIME2+WTIME4	DTIME
x_3	WDELAY	TWAIT	DWAIT
x_4	0	VTIME	-VTIME
x_5	DIR	0	DIR
x_6	RXING	0	RXING
x_7	ASTEP	0	ASTEP
x_8	TCONF	0	TCONF
x_9	SEX	0	SEX
x_{10}	AGE	0	AGE

2. DWAIT: waiting time difference on waiting i.e. between walking delay due to road crossings (WDELAY) and waiting time for bus at bus stop (TWAIT)

   DWAIT = WDELAY - TWAIT

   DWAIT is also a generic variable and is expected to be negatively correlated with the probability of choosing walking.
3. VTIME: In-vehicle time for bus or car. This variable is alternative specific and is expected to be positively correlated with the probability of walking.

- Variable of walking route characteristics:
  4. DIR: Directness, additional walking distance due to detour in walking route. It is a percentage of additional walking distance compared with direct distance between origin and destination. The minimum value of DIR is 0.0%. DIR is alternative specific and expected to be negatively correlated.
  5. RXING: Number of road crossings on the walking route to access MRT station. Grade separated crossings, such as pedestrian bridge and tunnel, are excluded. This is also an alternative specific variable and is expected to be negatively correlated.

6. ASTEP: Number of ascending steps on the walking route, especially in overhead crossings. Escalators are excluded. This variable is alternative specific and expected to be negatively correlated.
7. TCONF: Number of conflict points on the walking route to access MRT station. Road access and car park are considered as the conflict points. This variable is also alternative specific and is expected to be negatively correlated.

- Respondents' characteristics are also considered in the model.
    8. SEX (1/0): A dummy variable for respondent's gender. 1-male and 0-female. Positive sign of this coefficient indicates that the dummy variable of 1 (male) prefers mode 1 (walking) or it can be said that men have higher probability of walking than women.
    9. AGE (1/0): A dummy variable for respondent's age group. Age data are classified into 6 classes i.e. <21; 21-30; 31-40; 41-50; 51-60, and >60. Thus, for dummy, it is 1 for working-age adult (age group of 21-30; 31-40; and 41-50) and 0 otherwise. The positive sign of its coefficient indicates that working-age-adults have higher possibility of walking than other age groups.

4.4.2 Coefficient Estimation

LIMDEP version 7.0 (1998) was used to estimate the coefficients of the model, as shown in Table 4.9. The signs of these coefficients were examined to obtain the most satisfactory specification of the model.

A stepwise method was used to seek variables that have correct sign, are significant at a certain level of significance and have a reasonable coefficient value, based on some other studies. As can be seen from the table, the coefficient for variable of TCONF (number of conflict points) and DIR (directness) do not have the expected sign. This implies that these variables should be rejected in the next iteration.

Table 4.9 Coefficient Estimation for Walking Access Model

Coefficient	**Variable**	**Estimation**	**t-statistic**	**P-value**
β1	Constant	4.4151	3.433	0.107
β2	DTIME	-0.5332	-6.403	0.000
β3	DWAIT	-0.3462	-1.913	0.056
β4	VTIME	0.1614	2.094	0.036
β5	DIR	1.0209	0.760	0.447
β6	RXING	-0.1824	-0.997	0.319
β7	ASTEP	-0.0415	-3.084	0.002
β8	TCONF	0.0072	0.048	0.962
β9	SEX	-0.3236	-0.692	0.489
β10	AGE	1.7197	2.848	0.004

Statistic Summary	
Number of observations, n	393
Log likelihood at maximum, LogL	-67.6926
Log likelihood for only constant, LogL0	-241.8224
Log likelihood all variable zero, Log0	-241.8199
Chi-squared, χ^2	348.2595
Psudo-R^2, ρ^2	0.7201

Data Summary	**Average**	**Min**	**Max**	**Std.Dev**
Walking distance from home to MRT station, m	857.81	119	3265	540.39
Walking distance from home to bus stop, m	190.04	0	545	102.98
Walking time from home to MRT station, min	13.46	2	51.5	8.39
Walking time from home to bus stop, min	3.11	0.5	8.5	1.58
Walking delay, min	1.25	0	5	1.05
Waiting time for bus or car (out-vehicle time), min	4.46	0	15	1.36
In-vehicle time, min	4.70	1.1	30.8	3.81
Directness	0.29	0.0	1.1	0.20
Number of road crossings to access MRT station	2.21	0	11	1.57
Number of ascending steps to access MRT station	20.77	0	96	21.82
Number of conflict point to access MRT station	3.11	0	10	2.20

As shown in the table, the variable of TCONF, DIR, and SEX have P-value more than 5%. It means that these variables do not significantly affect the probability of walking. These variables were eliminated one by one in the next iterations. After four iterations, the final result and the best coefficient estimation is shown in Table 4.10.

The likelihood ratio test examines the null hypotheses of $\beta_i = 0$ for i = {2,..,6}, all variables are zero except the constant. The critical value of χ^2distribution with 5 degrees of freedom for 5% level of significance is 11.070 (Wapole et al, 2002). Thus the null hypothesis can be rejected with high confidence. Consequently, all values of β_i could not be zero. The P-value shows that estimations are significant at the level of 5%.

Table 4.10 Coefficient Estimation for Walking Access Model (Final Result)

Coefficient	Variable	Estimation	t-statistic	P-value
$\beta 1$	Constant	4.1290	3.699	0.000
$\beta 2$	DTIME	-0.5320	-6.760	0.000
$\beta 3$	DWAIT	-0.3693	-2.052	0.040
$\beta 4$	VTIME	0.1615	2.301	0.021
$\beta 7$	ASTEP	-0.0385	-3.038	0.002
$\beta 10$	AGE	1.6063	2.758	0.006
Statistic Summary				
Number of observations, n			393	
Log likelihood at maximum, LogL			-68.7255	
Log likelihood for only constant, LogL0			-241.8224	
Log likelihood all variable zero, Log0			-241.8210	
Chi-squared, χ^2			346.1937	
Psudo-R^2, ρ^2			0.7158	

The ratio of two coefficients can provide a trade-off between all variables and the walking time, as follows:

- Walking time and delay: $\beta_2/\beta_3 = 1.44$, which means that about 1.44 minutes of delay is equal to approximately of one minute of walking.
- Walking time and in-vehicle time: $\beta_2/\beta_4 = 3.30$, which means that one minute walking is equal to approximately to 3.30 minutes of moving in vehicle.
- Walking time and ascending step: $\beta_2/\beta_7 = 13.8$, which means that 13.8 steps are equivalent to one minute of walking. A pedestrian bridge with 32 steps is equals to approximately 32/13.8 = 2.3 minutes of walking or about 150 metres of walking (for average walking speed of 65.15 m/min, see Table 4.3).

4.5 Equivalent Walking Time (EWT) Model

4.5.1 Model Prototype

Equivalent Walking Time (EWT) model is a comprehensive measure of walking effort, which is derived from the walking access model. The measure is weighted sum of walking time, walking delay, and walking route characteristics. General formula of EWT model is:

$$\begin{aligned} EWT = \ & WTIME + \alpha_1 WDELAY + \alpha_2 DIR + \alpha_3 RXING + \\ & \alpha_4 ASTEP + \alpha_5 TCONF \end{aligned} \quad (4.3)$$

Parameter α_i, for $i = 1$ to 5, is the marginal rate of substitution of variable i for walking time from the WAM. Thus, according to Table 4.10, the EWT model can be formulated, as follows:

$$EWT = WTIME + 0.69\ WDELAY + 0.07 ASTEP \quad (4.4)$$

The relationship between walking probability and walking time can be seen in Figure 4.5. This figure also shows the effect of changing component of EWT on the walking probability. As shown in the figure, the probability of walking decreases for additional one pedestrian bridge, which is assumed to have 32 ascending steps. The probability of walking also decreases for additional crossing delay of 1.0 minute.

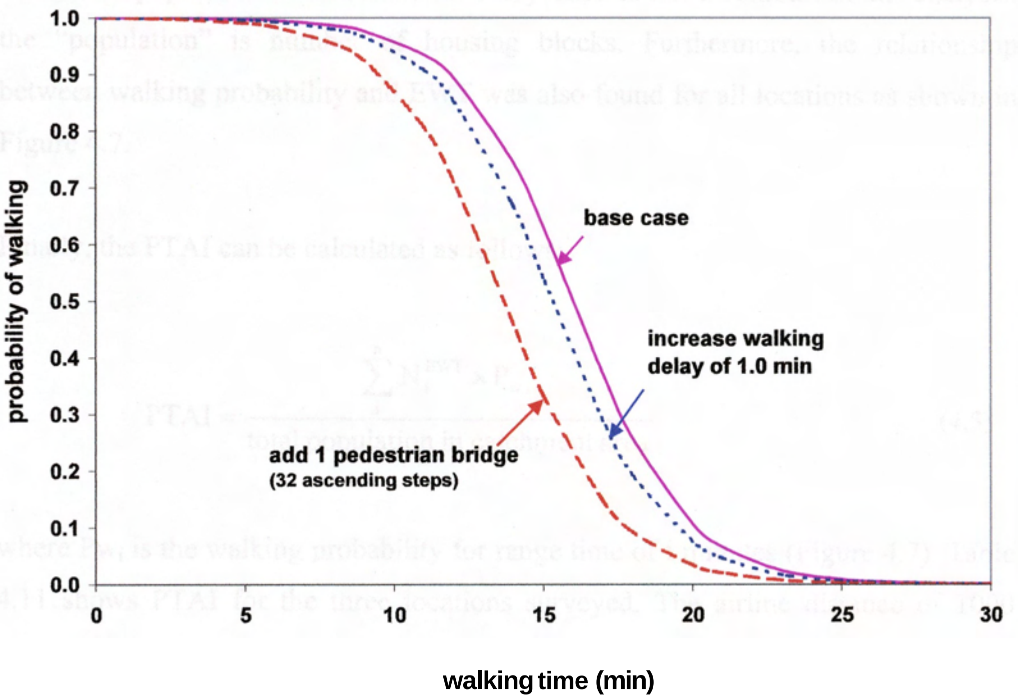


Figure 4.5 Relationship between Probability of Walking and Walking Time

It can also be seen in the figure that walking probability decreases more for additional pedestrian bridge rather than for additional one minute of walking delay. So, this model can be applied to examine the effectiveness of different pedestrian crossing types.

4.5.2 Walking Accessibility Measure

A preliminary method of walking accessibility assessment was developed using the EWT model. Public Transport Accessibility Index (PTAI) is used to express the proportion of population that is located within a walkable catchment area of a public transport terminal. The development of PTAI is as follows:

First at all, for each location, EWT was calculated to housing blocks and then the EWT contour was drawn as shown in Figure 4.6 for Tampines, for example.

Next, total population was counted for every band of EWT contour. In this analysis, the "population" is number of housing blocks. Furthermore, the relationship between walking probability and EWT was also found for all locations as shown in Figure 4.7.

Finally, the PTAI can be calculated as follows:

$$\text{PTAI} = \frac{\sum_{i}^{n} N_i^{EWT} \times P_{wi}}{\text{total population in catchment area}} \qquad (4.5)$$

where Pw_i is the walking probability for range time of i minutes (Figure 4.7). Table 4.11 shows PTAI for the three locations surveyed. The airline distance of 1000 metres was used as the catchment area.

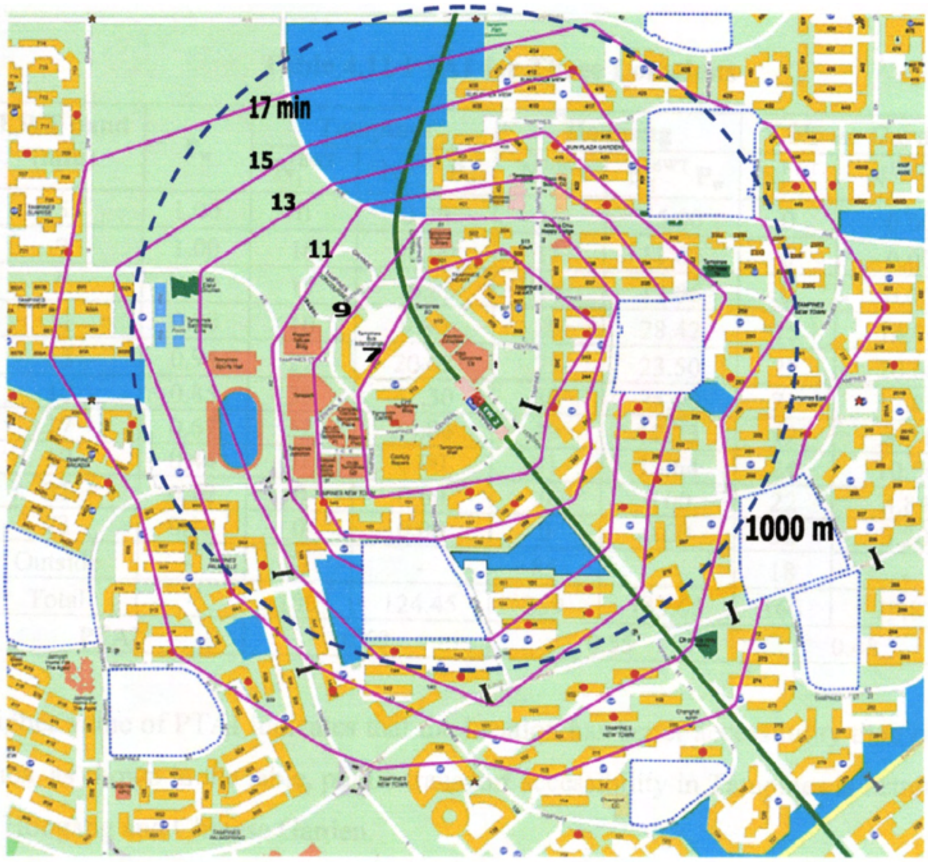


Figure 4.6 EWT Contour for Tampines

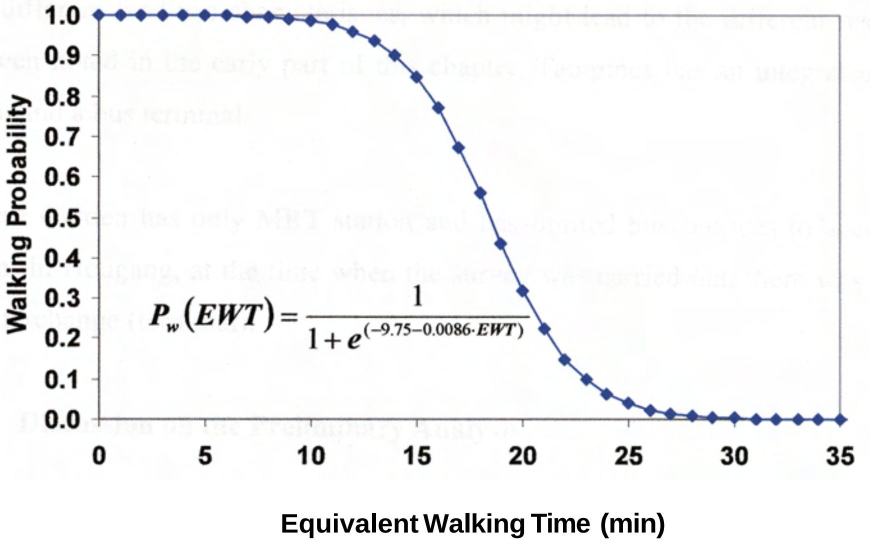


Figure 4.7 Relationship between Walking Probability and EWT

Table 4.11 PTAI for Three Locations

EWT band (min)	P_w	Tampines		Hougang		Chinese Garden	
		N_i^{EWT}	$N_i^{EWT} P_w$	N_i^{EWT}	$N_i^{EWT} P_w$	N_i^{EWT}	$N_i^{EWT} P_w$
5	1.00	0	0.00	15	15.00	0	0.00
7	1.00	10	10.00	11	11.00	0	0.00
9	0.99	17	16.83	14	13.86	0	0.00
11	0.98	10	9.80	29	28.42	15	14.70
13	0.94	22	20.68	25	23.50	22	20.68
15	0.85	38	32.30	30	25.50	21	17.85
17	0.67	52	34.84	19	12.73	12	8.04
19	0.44	0	0.00	31	13.64	24	10.56
21	0.22	0	0.00	0	0.00	22	4.84
23	0.10	0	0.00	0	0.00	32	3.20
Outside	-	31	-	85	-	18	-
Total	-	180	124.45	259	143.65	166	79.87
PTAI		0.69		0.55		0.48	

Higher value of PTAI indicates that the location has better accessibility than others. Thus, as shown in the table, public transport accessibility in Tampines is better than in Hougang and Chinese Garden.

However, one should be careful in interpreting these results. All these locations have different land use characteristics, which might lead to the different results. It has been noted in the early part of this chapter, Tampines has an integrated MRT station and a bus terminal.

Chinese Garden has only MRT station and has limited bus services to access the station. In Hougang, at the time when the survey was carried out, there was only a bus interchange (terminal).

4.5.3 Discussion on the Preliminary Analysis

From the general expression of Equivalent Walking Time (EWT), it can be seen that EWT depends mainly on walking time. Previously, it has been shown (in this chapter) that for the same path of walking route, each individual could have a different walking time. It means that EWT varies according to individual characteristics. Thus, EWT could not be a unique value for each path and EWT contour could be drawn only approximately.

Because of this problem, there is a need to develop another model similar to equivalent walking time. Thus, in the next part of this study, equivalent walking distance is used rather than equivalent walking time. Equivalent walking distance is only dependent on characteristics of the walking route and accordingly every housing block would have a unique value of equivalent walking distance to the public transport terminal.

To obtain a more precise walking accessibility assessment, the catchment area should be divided into several bands. The multiplication between walking probability and population could also be conducted for every contour band.

Chapter 5 Data Collection

This chapter discusses the main survey data collection process, which extends from pilot survey and preliminary analysis that was discussed in the previous chapter.

5.1 Selected Study Areas

To obtain a wide spread of localities and features relevant to walking accessibility, nine study areas were selected for data collection. These areas are based on location of MRT stations. They are Clementi and Bedok on East-West MRT Line, Bukit Batok and Choa Chu Kang on North-South MRT Line, and five stations along North-East Line: i.e. Sengkang, Hougang, Kovan, Serangoon, and Boon Keng. Detail maps of these areas are shown in Appendix B.

Data from all nine stations will be used to describe characteristics of MRT access trip (Chapter 6). The detailed analysis of walking share model and walking accessibility assessment will be limited to the first four stations only due to time limitation. The four study areas are discussed in detail below.

5.1.1 Clementi and Bedok Stations (East-West Line)

East-West MRT Line is the first MRT line built in Singapore. There are 29 stations along this line and Clementi station is one of the main MRT stations in the west part of the line. The station is built over the Commonwealth Avenue West. The station access is through an overhead pedestrian bridge that has two entrances on both sides of the road. These entrances are integrated with bus stops.

The site of Clementi station can be seen in Figure 5.1. There is a bus interchange not far from with the station. The distance between bus alighting point and station entrance point (point A) is around 65 metres.

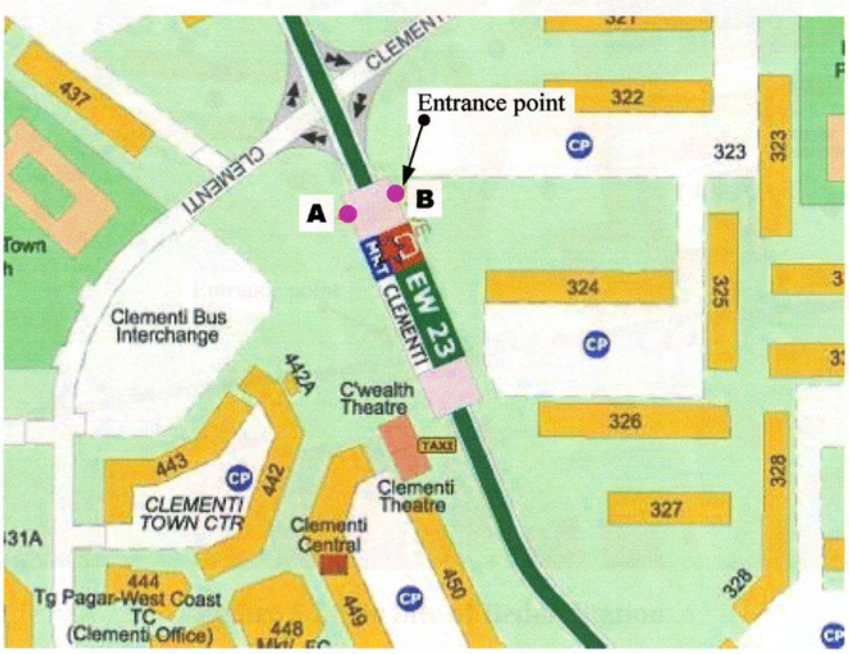


Figure 5.1 The Site of Clementi Station

(picture was captured from www.streetdirectory.com)

As of August 2003, there were 15 bus routes terminating at Clementi Bus Interchange. Three of them were feeder bus services. There were also another 8 and 10 bus routes that stopped at the bus stop in points A and B, respectively.

Park & Ride Scheme is operating at Clementi station. All car parks near housing blocks 322, 324, and 326 are used for this scheme. However, there are only limited spaces for bicycles and motorcycles surrounding the station. A taxi stand is provided close to the station building.

Bedok station is one of the main MRT stations in east part of EW Line. Figure 5.2 shows the site of the station. Similarly to Clementi station, the terminal building of this station is built over the New Upper Changi Road. There are also two entrance points through an underpass at the both side of the road, which are integrated with bus stops.

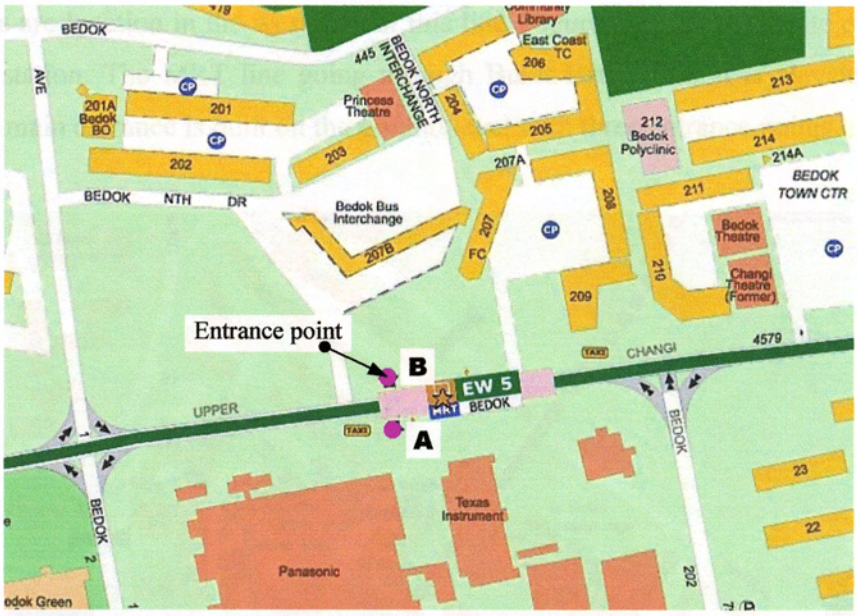


Figure 5.2 The Site of Bedok Station

(picture was captured from www.streetdirectory.com)

The station building is built close to the Bedok Bus Interchange. There is a distance of 201 metres between bus alighting point and the station entrance point (point B). There were 28 bus routes terminating at this terminal (as of August 2003). Four feeder bus services were operated. Besides that, there were another 4 and 7 bus route stopping at the bus stops in points A and B, respectively.

Park & Ride scheme is also operating in Bedok but the car park location is quite far from the station building. The drivers should take bus first to access the station. There are also limited spaces for bicycles and motorcycles. Two taxi stands are provided close to the station building.

5.1.2 Bukit Batok and Choa Chu Kang (North-South Line)

North-South (NS) MRT Line has 25 stations. Bukit Batok and Choa Chu Kang stations are location in the west part of this line. Figure 5.3 shows the site of Bukit Batok station. The MRT line going through Bukit Batok station is elevated. The station main entrance is built on the ground level with three entrance points.

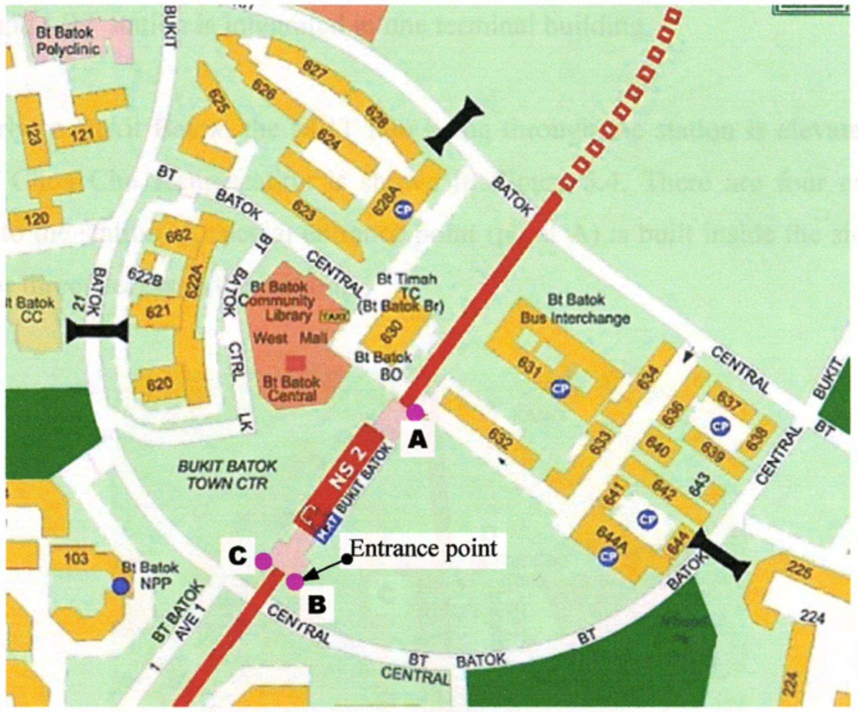


Figure 5.3 The Site of Bukit Batok Station

(picture was captured from www.streetdirectory.com)

Bukit Batok Bus Interchange is located quite far from the entrance point of the station. The walking distance from bus alighting point at the bus interchange to the station main entrance is about 210 metres. There are 13 bus routes terminating at Bukit Batok Bus Interchange. Two of them are feeder bus services. There are another eight bus services stopping at the nearest bus stop, which are 377 metres of walking distance from the station.

Car park facility for Park & Ride Scheme is located close to the station building. There are limited spaces for bicycles and motorcycles but a ***bicycle for*** rent facility is provided at the station. No taxi stand is provided nearby.

In Choa Chu Kang area, an LRT system is in operation, namely the Bukit Panjang LRT Line. Unlike other LRT systems in some cities in USA or Canada, this LRT is operated as a feeder mode to access Choa Chu Kang MRT station. Choa Chu Kang MRT and LRT station is integrated in one terminal building.

Similarly to Bukit Batok, the MRT line going through the station is elevated. The site of Choa Chu Kang station is shown in Figure 5.4. There are four entrance points to the station. A special entrance point (point A) is built inside the shopping mall for direct access to the station.

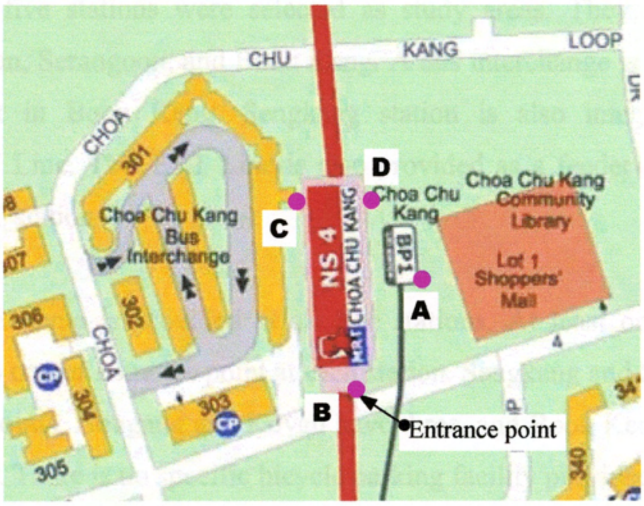


Figure 5.4 The Site of Choa Chu Kang Station
(picture was captured fiom www.streetdirectory.com)

Choa Chu Kang Bus Interchange is located close to the station building. There are only 75 metres of walking distance from the bus alighting point to main entrance (point C). About eleven bus routes terminate at the bus interchange with three of them being feeder bus services. Passengers who used bus to access the MRT station can alight at the nearest bus stop or at the bus interchange. The station can be accessed from two nearest bus stops through point B, which are located at around 220 and 70 metres of walking distance from the station gate.

No Park & Ride scheme and specific taxi stand are provided for the station. The nearest taxi stand is placed in the front of the shopping mall. The station provides parking facilities for bicycles but not for motorcycles.

5.1.3 North- East Line

North-East (NE) Line is the new MRT line operated by SBS Transit. This line is a fully automated mass rapid transit system and 20-km fully underground line. There are 16 stations along the line with two stations not yet open.

In this study, five stations were selected as study areas. They are: Sengkang, Hougang, Kovan, Serangoon, and Boon Keng. A bus interchange is built near these stations except in Boon Keng. Sengkang station is also integrated with the Sengkang LRT Line. This LRT Line is also provided as a feeder mode to access Sengkang MRT station.

Park & Ride Scheme is provided at all five stations. At least one taxi stand is located close to one of entrance point at each station. Sengkang and Serangoon have four entrance points, Hougang and Kovan have three, and Boon Keng only has two entrance points. There is no specific bicycle parking facility provided at the stations. Motorcycle parking slots are incorporated within car parks surrounding the shopping malls and the housing blocks.

5.2 On-Site Interview Survey

Similarly to what was done in the pilot survey, on-site interview surveys were carried out at the platforms of MRT stations. Respondents of these surveys were passengers who took MRT to go to their final destinations. A questionnaire (less than 15 questions) was given to respondents to obtain the following information:

- Respondent's origin point, i.e. his or her housing block;
- Mode used to get to MRT station and time needed to get there (excluding any stops on the way for shopping, eating, etc);
- Trip purpose and its characteristics, and
- Characteristics of respondents, such as age, his or her particulars (such as employed, unemployed, student, housewife, retired, etc), and combined family income per month.

Based on experience in the pilot survey, more detailed questions were given to those who walked to reach MRT stations: they were asked about their perception of walking distance and walking comfort. Again, to obtain detailed path of walking route, respondent was also asked to point out his or her walking route on the map provided with the survey form.

As this research focuses on walking to access MRT stations, all respondents were asked to rate nine factors affecting the choice of walking to the station. These factors were developed from other studies on walking as access mode such as Mitchell and Stokes (1982), Henk and Hubbard (1996), Hass-Klau (2001), Pikora et al (2001), and findings from survey pilot and preliminary analysis. The nine factors are as follows:

A. Walking distance
B. Walking comfort (obstructions, etc)
C. Rain shelters (weather protection)
D. Having to climb stairs or slopes
E. Risk of traffic accident
F. Unnecessary detour
G. Crowded walkways
H. Security
I. Number of road crossings and delays

Based on experience from pilot survey and preliminary analysis, a four-point scale was developed, i.e. (1) ***not important,*** **(2)** ***somewhat important,*** (3) ***important,*** or **(4)**

very important. Thus, based on this scale, respondents were asked to state the importance of each of the factors.

The surveys were carried out during nine days between November and December of 2003. The survey was carried out in the morning peak. An example of on-site interview survey form could be seen in Appendix A.2.

Table 5.1 shows the number of interviews that were obtained from the nine study areas. Incomplete data are the data that contain unknown location or unclear respondent's origin point. Those with origin points more than 2000 metres of airline distance from the station were classified as "outside study area". As can be seen from the table, 54 of 1354 (4%) data could not be used.

Table 5.1 Interview Data Collection Summary

Location (MRT Station)	Code	no. of respondents	incomplete data	Origin outside study area	usable data
Clementi	CLE	155	8	8	139
Bukit Batok	BBT	154	1	7	146
Choa Chu Kang	CCK	153	2	6	145
Bedok	BDK	150	1	5	144
Serangoon	SER	145	4	0	141
Hougang	HGG	154	2	3	149
Sengkang	SKG	150	1	0	149
Boon Keng	BKG	145	0	0	145
Kovan	KOV	148	6	0	142
TOTAL		**1354**	**25**	**29**	**1300**

5.3 Walking Route Assessment

To obtain the characteristics of all the walking routes used, a field assessment on walking route should be carried out from the origin point (housing block) of every respondent. The exact walking path should be obtained from the respondents. This was the reason why the on-site interview survey asked respondents to point out their routes. However, it turned out that not all respondents were able or willing to identify clearly their path of walking route. Some of them could not even point out their origin point or housing block on the map. These problems could be due to the following reasons:

- Respondents were not familiar with the map, especially the map provided in the survey form.
- Some information on the map could not be read clearly.
- Respondent did not have enough time because he or she was in a hurry.

On the other hand, it was very expensive and time consuming to do the walking route assessment on each path. Hence, the assessment was conducted on only several main walking routes spreading out radiantly from the station. Table 5.2 shows the number of origin point of respondents obtained from the on-site interviews and the number of walking routes assessed.

Table 5.2 Summary of Walking Route Assessment Data

Location (MRT Station)	Code	No. of Available Data	No. of different origin points	No. of walking route assessed
Clementi	CLE	139	101	14
Bukit Batok	BBT	146	102	16
Choa Chu Kang	CCK	145	103	16
Bedok	BDK	144	114	17
Serangoon	SER	141	98	19
Hougang	HGG	149	107	19
Sengkang	SKG	149	115	17
Boon Keng	BKG	145	57	15
Kovan	KOV	142	115	16
TOTAL		**1300**	**912**	**149**

As shown in the table, less than 20% locations were investigated. Fortunately, many of origin point of respondents were located close to each other. Thus, one investigated route could cover several points. The remaining origin points were later ‘connected’ to the surveyed routes.

Each walking route was divided into several segments related to the their type, such as walkway, sidewalk, and road crossing. Measurement was conducted for each segment. Table 5.3 shows the data captured during the route assessment surveys.

Table 5.3 Data Captured in Walking Route Assessment

Data Type	Unit	Method	Remark
Segment Type	-	visual	walkway, sidewalk and crossing
Segment length	metres	measured	Using Pedometer
Slope toward MRT station	%	measured	
Ascending/Descending steps	number	count	Toward to MRT station
Weather protection	% length	estimated	
Barriers for wheelchair	YES/NO	visual	Valued as YES or NO
Traffic conflict	number	count	Access road, car park
Obstructions	number	count	Posts, trees, benches
Surface quality	1 to 5	rating	1 for worst and 5 for the best
Continuity	1 to 5	rating	1 for worst and 5 for the best
Congestion	1 to 5	rating	1 for worst and 5 for the best
Overall walking comfort	1 to 5	rating	1 for worst and 5 for the best
Average waiting time	sec	measured	At crossing

Pedometer was used to measure each segment length. Total walking distance was the summation of all segment lengths. Manual counting was used to count the number of steps (ascending and descending), traffic conflicts, and obstructions. The counting was carried out for each segment. Access roads and car parks were considered as traffic conflicts. On the other hand, trees, notice boards, litter bins, and bus stops on walking pathway were counted as obstructions. Street market and stalls were also counted if they influenced movement along the walkway.

Slope was measured manually using levelling bar and ruler. Positive and negative sign was given to show ascending or descending slope towards the MRT. This slope measurement was not done in the pilot survey. To simplify, slope was converted to the number of steps. Average step height of 13 to 15 centimetres was applied.

Weather protection was estimated as percentage of segment length. A weighted average was calculated to have total weather protection along the route, as follows:

$$\mathrm{WPRO} = \frac{\sum_{i=1}^{n} \mathrm{WPRO}_i \cdot \mathrm{WDIST}_i}{\sum_{i=1}^{n} \mathrm{WDIST}_i} \tag{5.1}$$

where: **WPRO** = weather protection for total route (%)
WPRO_i = weather protection, %-length of segment i
WDIST_i = length of segment i (metre)

Some special assessments were carried out for walkways and sidewalks, such as rating of surface quality, continuity, and congestion. A 5-point rating scale was used. Weighted average was also applied to obtain the value for total walking route, as follows:

$$R_{\mathrm{average}} = \frac{\sum_{i=1}^{n} R_i \cdot \mathrm{WDIST}_i}{\sum_{i=1}^{n} \mathrm{WDIST}_i} \tag{5.2}$$

where: R_{average} = rating value for total route (%)
R_i = rating value for segment i
WDIST_i = length of segment i (metre)

Road crossings were classified as: signalised road crossing, zebra crossing, unmarked crossing, and overpass crossing (pedestrian bridge and tunnel). To calculate walking delay at signalised crossings, cycle time and green time were recorded. Cycle time was measured from ***red man*** to another ***red man*** and total time of the ***green man,*** including flashing was counted as the green time. Walking delay at signalised crossings was calculated by HCM 2000 method (equation 2.9). Delay at unsignalised crossing was estimated directly on site.

An example of walking route assessment form can be seen in Appendix A. Figure 5.6 shows an example of walking routes surveyed for Clementi.

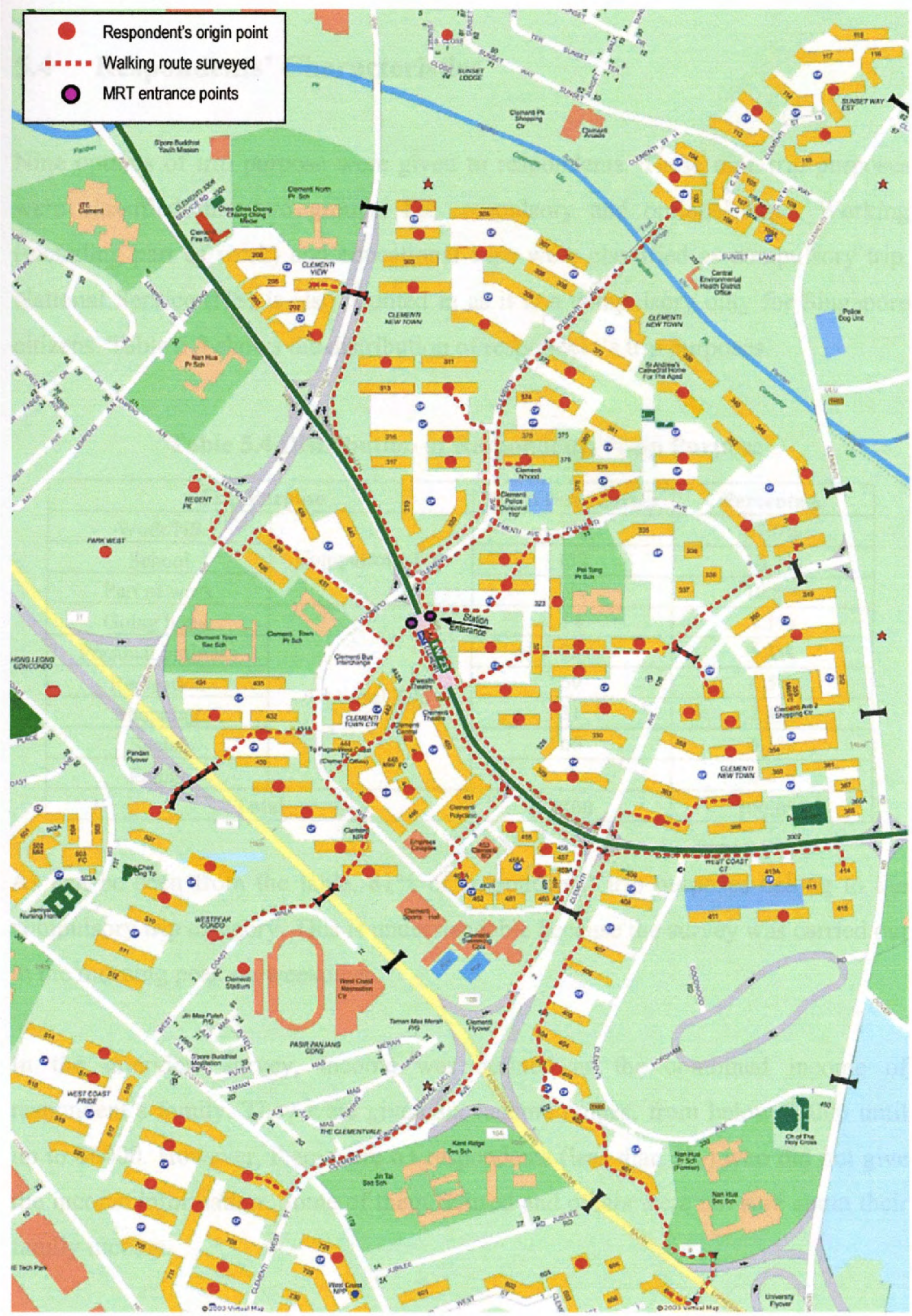


Figure 5.5 Walking Route for Clementi Area

5.4 Respondents' Characteristics

Nine options of trip purpose were given to respondents. These nine trip purposes were classified into two groups, i.e. compulsory and optional trips. Working (including part of work) and educational trips were classified as compulsory trip. National Service (NS) is also counted in as it is a compulsory duty for Singapore citizens. Table 5.3 shows the distribution of respondent's trip purposes.

Table 5.4 Distribution of Respondents' Trip Purpose

Trip Purpose		**No of respondents**	**Percentage**
Work/NS	Compulsory Trip	780	60.0%
School		132	10.2%
Part of work		140	10.8%
Going home	Optional Trip	14	1.1%
Personal business		75	5.8%
Recreation		59	4.5%
Shopping		31	2.4%
Social		66	5.1%
Eating		3	0.2%
Total		**1300**	**100.0%**

As can be seen from the table, 81% of respondents' trip purposes belong to the compulsory trip category. This is understandable because the survey was carried out in the morning peak on weekdays.

In the interview survey, income was defined as the combined income of respondent's family. They were given six income ranges, from below $2000 until up to $8000. However, there were 63 respondents (less than 5%) who did not give the income information. Some of them refused and others were not sure about their family income.

The six ranges of income were grouped into three income groups, i.e. low, medium, and high income. Table 5.5 shows the distribution of respondents' income. As shown in the table, 66.5% of respondents were classified into medium income group.

Table 5.5 Distribution of Respondents' Income

Income Group		No of respondents	Percentage
< $2000	Low Income	177	14.3%
$2001 - 3000	Medium Income	315	25.5%
$3001 - 4000		307	24.8%
$4001 - 6000		201	16.2%
$6001 - 8000	High Income	149	12.0%
> $8000		88	7.1%
Total		**1237**	**100.0%**

The question on respondent's current situation or their status was also asked in the interview. There were six options related to status: ***employed, student, unemployed, housewife, retired,*** and ***others.*** The distribution of respondent's status can be seen in Table 5.6 below. As shown in the table, 95.1% of respondents are employed or students. It is quite different comparing to Table 5.4 in which only 81% of respondent's trip purposes are work and educational.

Table 5.6 Distribution of Respondents' Status

Status	No of respondents	Percentage
Employed	896	68.9%
Student	340	26.2%
Housewife	28	2.2%
Unemployed	20	1.5%
Retired	8	0.6%
Others	8	0.6%
Total	**1300**	**100.0%**

5.5 Reported Time to Access MRT Station

The interview survey asked respondents to provide the time used to get to MRT station, excluding any stops on the way for shopping, eating, etc. This time is called reported access time. For respondents who walked to reach the station, the reported time should be their walking time, which was determined from their origin point (e.g. home) to the MRT entrance point. For those respondents who took a bus to get to the station, the reported time should consist of walking time from their origin point to the bus stop, waiting for the bus (out of-vehicle time), moving time in the bus (in-vehicle time), and walking time from the bus stop (or bus alighting point at the bus terminal) to the MRT entrance point.

Experience from preliminary analysis suggested that it is difficult to rely on reported time for further analysis. Similarly as in the pilot survey, most of the respondents reported their time rounded to the nearest five minutes. Their reported time might be covered some delay due to their activities along the way to get to the station. Figure 5.7 shows the distribution of reported time to access MRT station using different access modes, including walking.

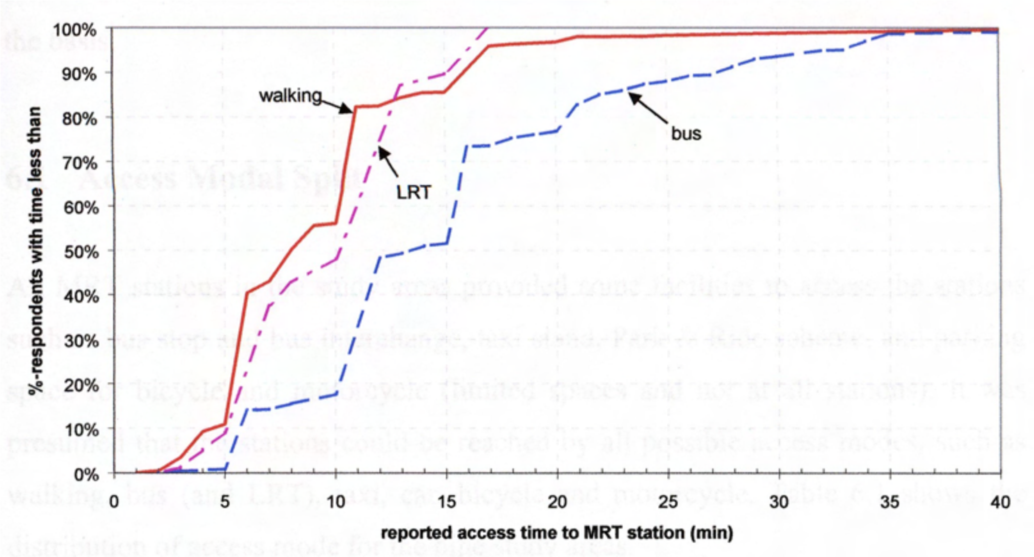


Figure 5.6 Reported Time to Access MRT Station

As shown in the figure, more than 95% of respondents spent less than 20 minutes to access MRT station by walking. On the other hand, less than 80% of respondents who access MRT station by bus spent less than 20 minutes. It can also be seen that LRT gave a shorter time than bus.

Chapter 6 Analysis of MRT Access Trips

This chapter discusses further analysis of data collected through interview surveys. Characteristics of access modal split and walking as access mode are discussed in more detail. The development of walking access model and equivalent walking distance, which will be discussed in the next chapters, used these characteristics as the basis.

6.1 Access Modal Split

All MRT stations in the study areas provided some facilities to access the stations such as bus stop and bus interchange, taxi stand, Park & Ride scheme, and parking space for bicycle and motorcycle (limited spaces and not at all stations). It was presumed that the stations could be reached by all possible access modes, such as walking, bus (and LRT), taxi, car, bicycle and motorcycle. Table 6.1 shows the distribution of access mode for the nine study areas.

Table 6.1 Access Mode to reach MRT Stations

Location (MRT Station)	**Code**	**Access Mode to MRT Station**							**Total**
		walking	**car**	**taxi**	**m-cycle**	**bicycle**	**bus**	**LRT**	
Clementi	CLE	89	9	2	0	0	39	0	139
Bukit Batok	BBT	100	4	0	0	0	42	0	146
Choa Chu Kang	CCK	61	0	0	0	3	50	31	145
Bedok	BDK	57	2	1	0	1	83	0	144
Serangoon	SER	108	8	0	0	0	25	0	141
Hougang	HGG	111	5	0	0	0	33	0	149
Sengkang	SKG	79	0	0	0	0	23	47	149
Boon Keng	BKG	136	2	0	0	0	7	0	145
Kovan	KOV	60	9	0	0	1	72	0	142
TOTAL		**801**	**39**	**3**	**0**	**5**	**374**	**78**	**1300**

However, the results of the on-site interview survey show that walking and taking bus were the most frequent access modes to reach MRT stations. Car, taxi, and bicycle were used in very small proportion and no one used motorcycle. More detailed discussion about respondent's access modal spilt is shown below.

Figure 6.1 shows the access modal split related to respondent's trip purpose. It can be seen in the figure that a higher proportion of respondents walked to access MRT stations for their compulsory trips than for optional trips.

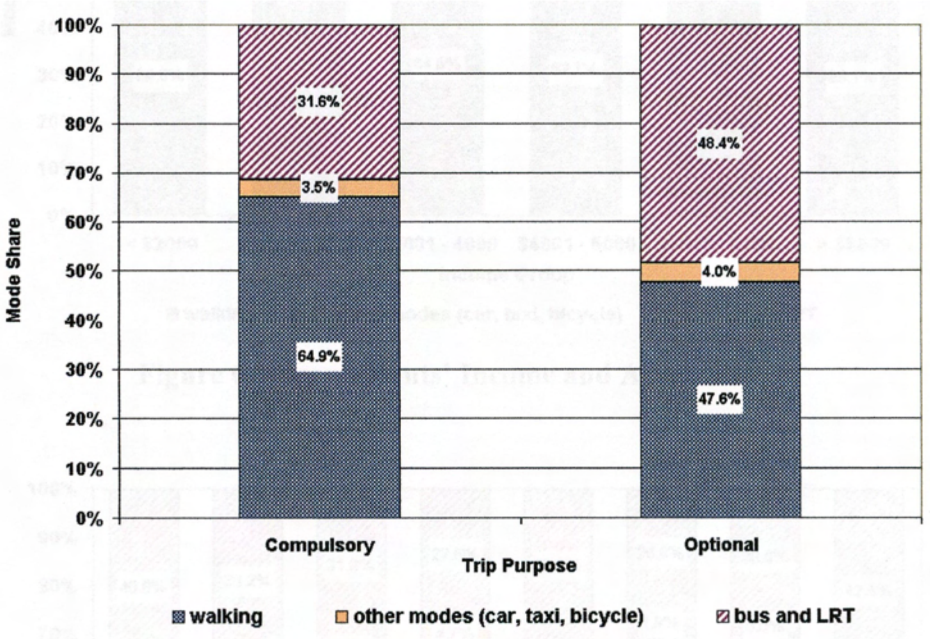


Figure 6.1 Respondents' Trip Purpose and Access Mode

Another view of respondents' access modal split can be seen in Figure 6.2, which shows the relationships between modal split and income. There was a high proportion of walking for every income group. This indicates that income had a major influence on modal split. However, the proportion of car usage for high income group was slightly higher.

The relationship between modal split and respondents' age can be seen in Figure 6.3. As can be seen in the figure, proportion of walking for age group between 26 to

50 years old was higher than for the other age groups. For the age group of over 50 years, there was a large drop in proportion of walking to 45.5%.

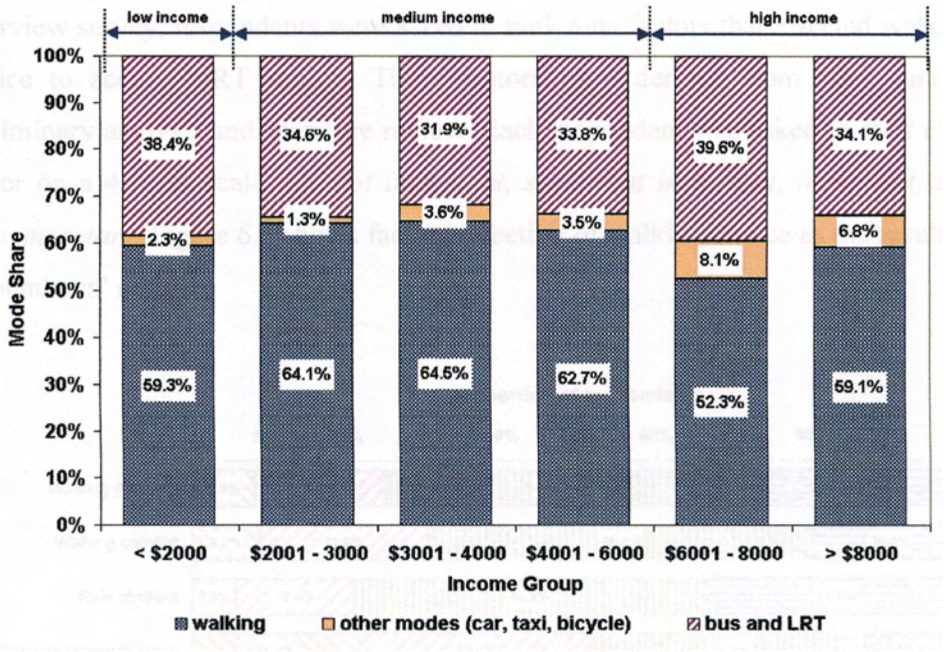


Figure 6.2 Respondents' Income and Access Mode

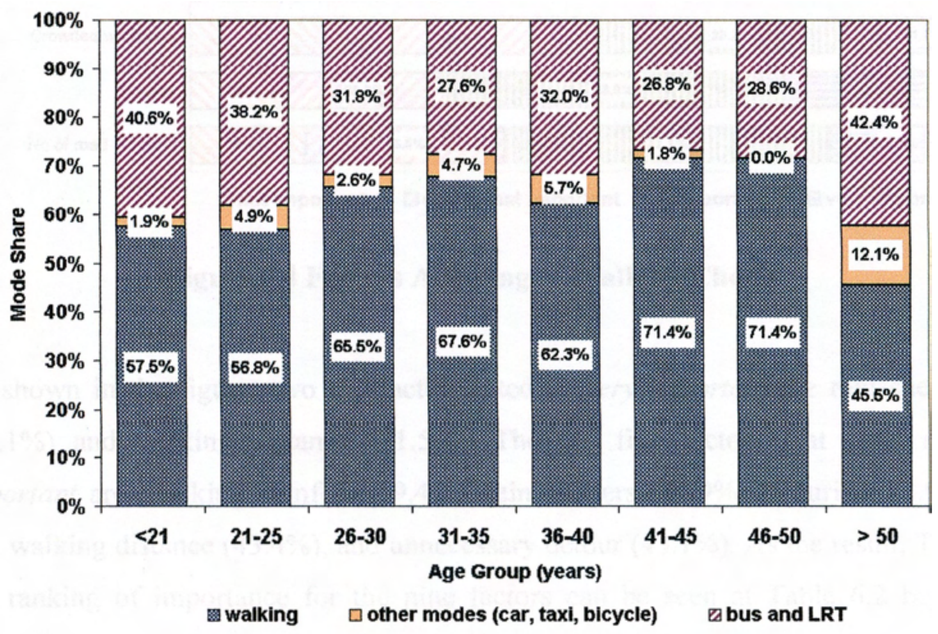


Figure 6.3 Respondents' Age and Access Mode

6.2 Factors Affecting the Choice of Walking

Since the focus on this research is walking to access public transport, in the interview survey, respondents were asked to rank nine factors that affected walking choice to access MRT station. These factors were derived from pilot survey, preliminary analysis and literature review. Each respondent was asked to rank each factor on a 4-point scale, i.e. ***not important, somewhat important, important,*** and ***very important.*** Figure 6.4 shows factors affecting of walking choice as the result of respondents' ranking.

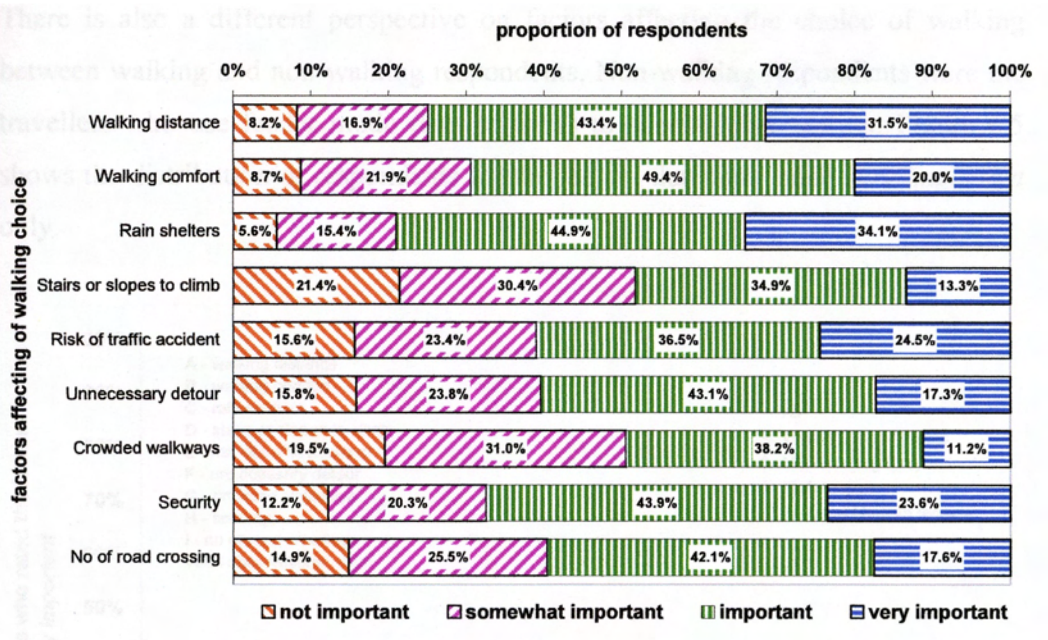


Figure 6.4 Factors Affecting of Walking Choice

As shown in the figure, two top factors rated as ***very important*** are rain shelters (34.1%) and walking distance (31.5%). The top five factors that were rated ***important*** are: walking comfort (49.4%), rain shelters (44.9%), security (43.9%), and walking distance (43.4%), and unnecessary detour (43.1%). As the result, Thus, the ranking of importance for the nine factors can be seen at Table 6.2 below, whereas the five main factors affecting of walking choice are rain shelters, walking distance, walking comfort, security, and risk of traffic accident.

Table 6.2 Ranking of Factors Affecting Choice of Walking

Factors Affecting		%*
C	Rain shelters	79.0
A	Walking distance	74.9
B	Walking comfort	69.4
H	Security	67.5
E	Risk of traffic accident	61.0
F	Unnecessary detour	60.4
I	Number of road crossings	59.6
G	Crowded walkways	49.5
D	Stairs or slopes to climb	48.2

*based on rate of important and very important
Total respondents: 1300

There is also a different perspective on factors affecting the choice of walking between walking and non-walking respondents. Non-walking respondents were the travellers who use feeder mode (bus or LRT) to access MRT station. Figure 6.5 shows the distribution of respondents for the factors that were rated very important only.

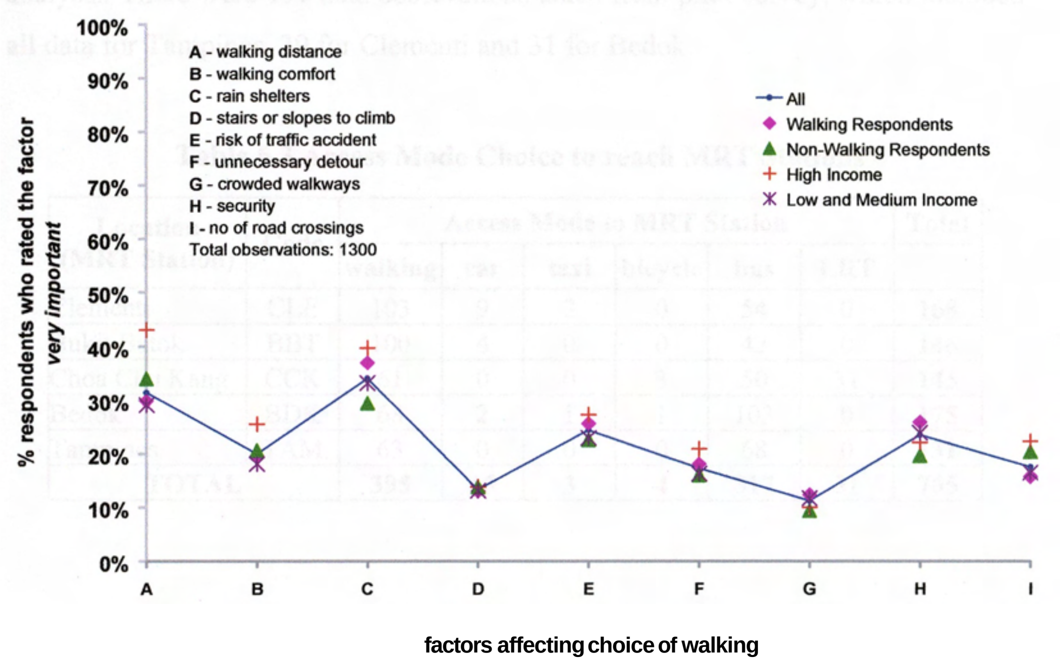


Figure 6.5 Very Important Factors Affecting of Walking Choice

From the figure, it could be seen that non-walking respondents considered factors related to walking effort (i.e. walking distance and number of road crossings) as more important factors. On the other hand, the walking respondents considered factors related to walking convenience, such as rain shelters, detour, and crowded walkways.

High-income respondents attached more importance to all factors except crowded walkways and security.

6.3 Walking Route Characteristics

Due to the limitation of available time, the examination on walking route characteristics was carried out on five stations, which included some data from the pilot analysis. Table 6.3 shows the summary of the data that was used in further analysis. There were 191 data observations taken from pilot survey, which included all data for Tampines, 29 for Clementi and 31 for Bedok.

Table 6.3 Access Mode Choice to reach MRT Stations

Location (MRT Station)	Code	Access Mode to MRT Station						Total
		walking	car	taxi	bicycle	bus	LRT	
Clementi	CLE	103	9	2	0	54	0	**168**
Bukit Batok	BBT	100	4	0	0	42	0	**146**
Choa Chu Kang	CCK	61	0	0	3	50	31	**145**
Bedok	BDK	68	2	1	1	103	0	**175**
Tampines	TAM	63	0	0	0	68	0	**131**
TOTAL		**395**	**15**	**3**	**4**	**317**	**31**	**765**

6.3.1 Respondents' Perception of Walking Distance

The interview survey asked respondents who walked to reach MRT station to rate their walking distance. Four options were given, i.e. ***"short, very convenient";***

"medium, still comfortable"; "long but still acceptable", and ***"too long".*** Table 6.4 shows the summary of respondents' rating of walking distance.

Table 6.4 Respondent's Rating of Walking Distance

Walking Distance	Short, very convenient	Medium, still comfortable	Long but still acceptable	Too long	Total
0 - 200	1.0%	0.0%	0.0%	0.0%	1.0%
201 - 400	20.5%	4.3%	0.3%	0.3%	23.2%
401 - 600	15.7%	9.9%	0.5%	0.3%	26.1%
601 - 800	9.1%	10.9%	0.5%	0.0%	20.9%
801 - 1000	5.6%	8.4%	1.5%	0.3%	17.0%
>1000	2.8%	5.6%	2.8%	0.0%	11.8%
Total	54.7%	39.0%	5.6%	0.8%	100.0%

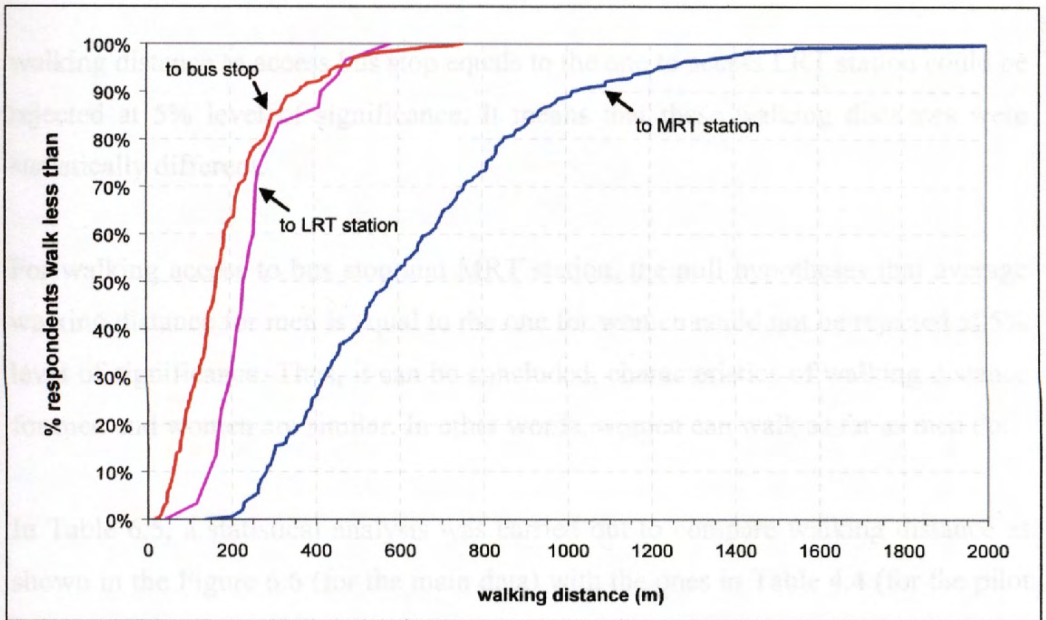
Total: **395 respondents**

As shown in the table, more than 50% (51.9%, precisely) of respondents are comfortable with walking distance up to 1000 metres. It is less than 3% of respondents, which have maximum acceptable walking distance more than 1000 metres. However, Stringham (1982) noted that the walking distance of 1200 metres might be applied as the maximum acceptable walking distance.

To be noted here, respondents did not know the actual walking distance when they rated their distance. He or she might give different value for the same walking distance at a different location. How often he or she uses the route might influence their rating of walking distance.

6.3.2 Walking Distance

Figure 6.6 shows the cumulative distribution of walking distance to access MRT, LRT and bus stop obtained from the data. Many studies on non-motorised trips and public transport suggested that walking distance to rail station may be longer than to bus stop (Mitchell and Stokes, 1982; O'Sullivan and Morrall, 1996; Halden et al, 2000; Ker and Ginn, 2003).



Descriptive Statistics	to bus stop			to LRT station			to MRT station		
	Men	Women	All	Men	Women	All	Men	Women	All
Average, m	190.8	192.2	191.6	206.5	286.2	250.2	643.4	615.5	630.5
Std. Dev., m	122.9	129.8	126.9	66.8	134.9	115.2	333.2	286.2	312.3
Minimum, m	30	15	15	41	115	41	137	198	137
Maximum, m	726	752	752	315	580	580	2028	1722	2028
No. of Data	125	192	317	14	17	31	213	182	395

Statistical analysis:

Descriptive Statistics	access to		to bus stop		to LRT station		To MRT station	
	bus stop	LRT sta	Men	Women	Men	Women	Men	Women
Mean	191.6	250.2	190.8	192.2	206.5	286.2	643.4	615.5
Variance	16115.5	13261.8	15103.5	16856.2	4460.7	18195.4	110994.5	81932.8
Observations	317	31	125	192	14	17	213	182
Hypothesized Mean Difference	0		0		0		0	
Degree of freedom (df)	38		275		24		393	
t_o (Observed)	-2.677		-0.098		-2.138		0.896	
t_{cr} (t Critical) for two-tail	2.024		1.969		2.064		1.966	
$P(\lvert t_o \rvert \leq t_{cr})$ for two-tail	0.011		0.922		0.043		0.371	

Figure 6.6 Walking Distance to Access Public Transport

As shown in the figure, the cumulative distribution of walking distance to access bus stop and LRT are similar. This might be understood because the LRT system is operated as a feeder mode to the MRT. However, the null hypothesis that average walking distance to access bus stop equals to the one to access LRT station could be rejected at 5% level of significance. It means that these walking distances were statistically different.

For walking access to bus stop and MRT station, the null hypotheses that average walking distance for men is equal to the one for women could not be rejected at 5% level of significance. Thus, it can be concluded, characteristics of walking distance for men and women are similar. In other words, women can walk as far as men do.

In Table 6.5, a statistical analysis was carried out to compare walking distance as shown in the Figure 6.6 (for the main data) with the ones in Table 4.4 (for the pilot data). As shown in the table, for walking distance to access bus stop and MRT station, there were not statistically different at 5% level of significant. After merging all data (pilot and main survey), It was obtained that the average walking distance to access bus stop and MRT station were 187.6 and 629.9 metres, respectively.

Table 6.5 Walking Distance from the Pilot and Main Survey

Descriptive Statistics	**to access bus stop**		**to access MRT station**	
	pilot data	**main data**	**pilot data**	**main data**
Mean	175.8	191.6	628.3	630.5
Variance	11236.0	16115.5	63137.4	97556.2
Observations	110	317	163	395
Hypothesized Mean Difference	0		0	
Degree of freedom (df)	225		372	
t_o (Observed)	-1.279		-0.087	
t_{cr} (t Critical) for two-tail	1.971		1.966	
$P(\lvert t_o \rvert \le t_{cr})$ for two-tail	0.202		0.931	
Merging Data				
	to access bus stop		**to access MRT station**	
Average, m	187.6		629.9	
Std. Dev., m	121.97		295.59	
Minimum, m	15		137	
Maximum, m	752		2028	
No. of Data	427		558	

6.3.3 Walking Speed

The on-site interview survey asked the respondents about their elapsed time to access the station. These data reported by respondents who walked could be used as the walking time. The walking time reported is the total journey time, which covered the time from when they started at home until the time when they arrived at the station. Some walking delay due to road crossing or obstructions such as ascending steps is included in the reported time. So, the time that they reported was their perceived time.

Walking speed was calculated from measured walking distance divided by walking time reported by respondents. Figure 6.7 shows the walking speed distribution to access MRT station, based on the following assumptions:

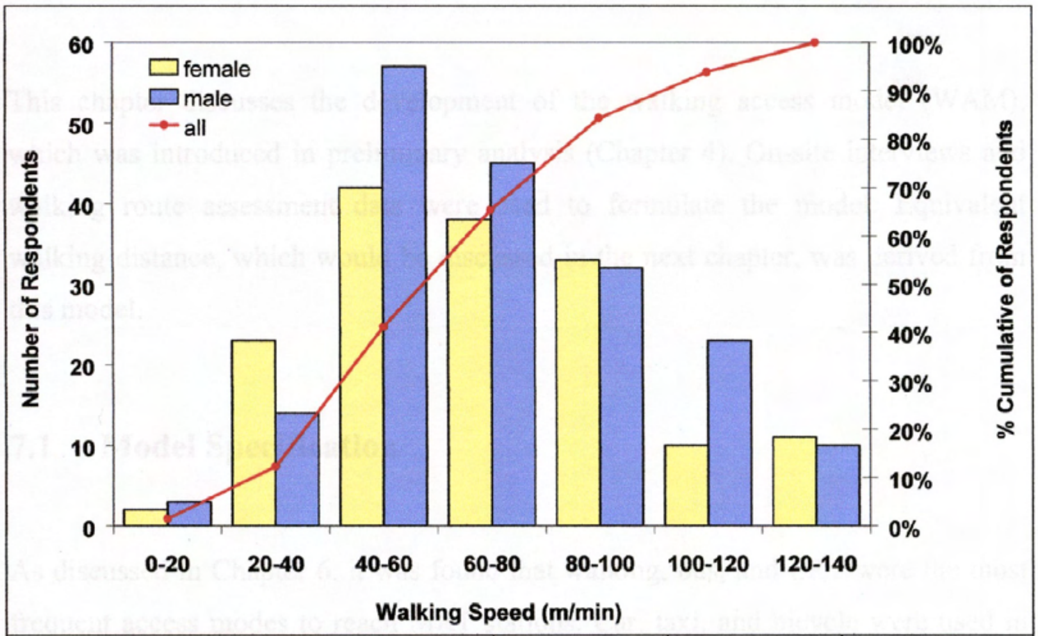
- walking speed of 140 m/min or more was excluded as it can be considered running (Fruin, 1971)
- walking time was not more than 20 minutes (Allan, 2001)
- minimum walking distance used was 200 metres

Statistical analysis shows that the average walking speed for men is equal to that for women at 10% level of significance. It means that the characteristics of walking speed for men and women are similar. As the conclusion, walking characteristics (walking distance and walking speed) are not significantly influenced by gender.

Statistical analysis was carried out to compare walking speed as shown in the Figure 6.7 with the ones in Table 4.5. It was found that they were statistically different at 5% level of significant.

The average walking speed as shown in Figure 6.7 is different from those found previously for Singapore, i.e. 73.9 m/min (Tanaboriboon et al., 1986) or for Bangkok (Thailand), 72.8 m/min (Guyano, 1988). These speeds were based on moving speed only in free flow conditions. However, many walking studies use walking speed of 80 m/min as a ***rule of thumb*** of walking speed (such as in

O'Sullivan and Morrall, 1996; Knoblauch et al., 1996; and Halden et al., 2000) or even 100 m/min for 20 minutes walking in Allan (2001). Walking speeds in this study are expected to be lower as the walking time comprises not only moving time but also delay at road crossing.



Descriptive Statistics	Men	Women	All
Average, m/min	71.72	69.19	70.55
Standard Deviation, m/min	26.27	27.54	26.85
Minimum, m/min	15.10	15.10	15.10
Maximum, m/min	137.40	136.60	137.40
No. of data	184	159	343

Figure 6.7 Walking Speed to Access MRT Station

Chapter 7 Walking Access Model

This chapter discusses the development of the walking access model (WAM), which was introduced in preliminary analysis (Chapter 4). On-site interviews and walking route assessment data were used to formulate the model. Equivalent walking distance, which would be discussed in the next chapter, was derived from this model.

7.1 Model Specification

As discussed in Chapter 6, it was found that walking, bus, and LRT were the most frequent access modes to reach MRT stations. Car, taxi, and bicycle were used in very small proportion and no one used motorcycle. Walking Access Model predicts an individual’s choice of mode for access trip to MRT station. Since there is small number of observation for some access modes, WAM is built based on two access modes only: walking mode and non-walking mode. Feeder modes such as bus and LRT are considered as non-walking mode.

To build the model, it is assumed that each individual has ***a free choice*** to select one of the two alternative access modes to reach the desired MRT station. When choosing walking as an access mode, an individual would walk from his or her housing block (origin point) to MRT station. If a feeder mode (e.g. bus) is chosen, he or she would walk to bus stop, wait for the bus, ride the bus, alight at the bus stop nearest to MRT station or at bus terminal, and walk to the MRT entrance. Walking between LRT exit point and MRT entrance point is still considered, although these points are integrated in one building.

Another assumption for the model is that an individual would definitely choose walking when the distance from home to MRT station is lower than total walking distance of using the feeder mode (summation of walking distance from home to bus stop, or LRT station, and walking distance from the bus or LRT alighting point to MRT entrance point). In other words, the ***difference of walking distance*** between walking and non-walking modes should not be less than zero.

WAM was developed for the catchment area defined by 2000 metres airline distance from MRT station. It was assumed that area was enough to cover the good variability of access mode choice between walking and non-walking mode (feeder mode). The distance was measured between the centre point of housing block, home (origin point) and MRT station (MRT entrance point).

As shown in Table 6.3 (Chapter 6), there were 765 observations obtained from the interview survey. Since the model only considers walking and feeder modes (bus and LRT), this data set was reduced to 743 observations. Based on the assumption that the difference in walking distance should not be less than zero, there are 646 observations that can be used for model estimation. The frequencies of the chosen access modes are as follows:

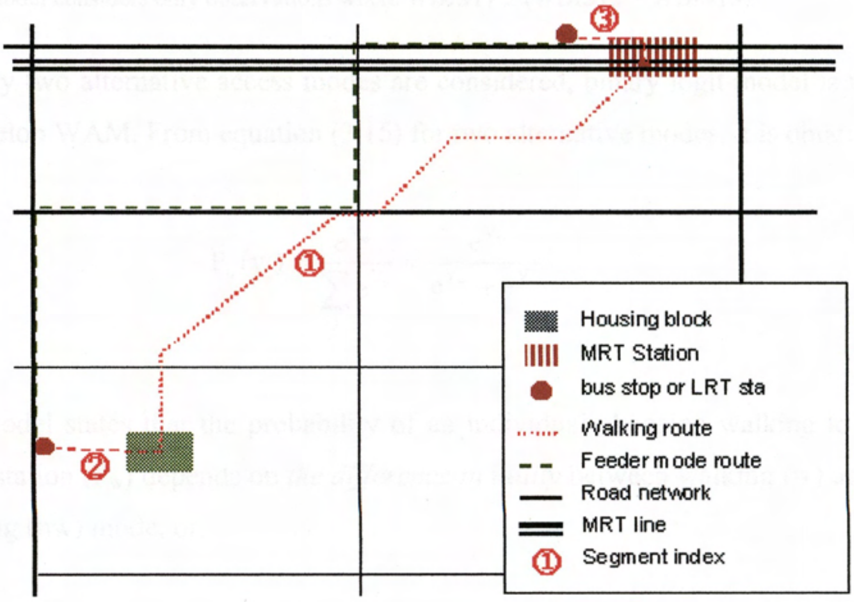
- Walking: 299 (46.3%)
- Bus: 316 (48.9%)
  LRT: 31 (4.8%)
- Total: 646 (100.0%)

The descriptive statistics of the explanatory variables can be seen in Table **7.1.** Signalised and unsignalised (midblock and intersection) crossings are counted together as number of road crossings. Zebra crossings and other unmarked crossings are also counted in. Grade separated crossings, such as pedestrian bridge and tunnel, are excluded. Number of car parks and access roads, which pedestrians should cross on the way to MRT station, are counted as traffic conflict points.

Table 7.1 Variables in Walking Access Model

Variable	Unit	Description	Average	Std. Dev.	Max	Min	Count
WDIST1	min	Walking distance from home to MRT station, segment 1	1140.1	552.2	2954	198	646
WDIST2	min	Walking distance from home to bus stop (LRT station), segment 2	187.1	113.8	752	15	646
WDIST3	min	Walking distance from bus stop (or LRT exit) to MRT entrance point, segment 3	145.7	110.5	377	15	646
NWTIME	min	Total travel time of feeder mode	9.7	3.6	25.1	2.9	646
RXING1	-	Number of road crossings, segment 1	2.5	1.7	11	0	646
RXING2	-	Number of road crossings, segment 2	0.3	0.5	1	0	646
RXING3	-	Number of road crossings, segment 3	0.2	0.4	1	0	646
ASTEP1	-	Number of ascending steps, segment 1	20.2	21.2	115	0	646
ASTEP2	-	Number of ascending steps, segment 2	1.7	7.8	52	0	646
ASTEP3	-	Number of ascending steps, segment 3	3.9	4.1	36	0	646
TCONF1	-	No of traffic conflict along the route, segment 1	3.3	2.5	13	0	646
TCONF2	-	No of traffic conflict along the route, segment 2	0.8	1.0	11	0	646
TCONF3	-	No of traffic conflict along the route, segment 3	0.0	0.0	0	0	646

The scenario of development WAM could be seen at Figure 7.1.



Segment index:
① walking route from home to MRT station
② walking route from home to the nearest bus stop (or LRT station)
③ walking route from bus stop (or LRT exit) to MRT entrance point

Figure 7.1 Illustration for Walking Access Model

As mentioned in discussion on preliminary analysis (Chapter 4), the reported access time, especially the walking time, was highly unreliable. For the same location and same walking route, reported time could be different. Thus, walking distance was used instead of walking time.

Table 7.2 shows the description of mode characteristics. Unlike what had been done in the preliminary analysis, all components were measured. Distance was applied to characterise walking.

Table 7.2 Segment Characteristics

Variable	Unit	Description	For respondent who chose	
			walking	non-walking
WDIST1	m	Walking distance from home to MRT station, segment 1	measured	measured
WDIST2	m	Walking distance from home to bus stop (LRT station), segment 2	measured	measured
WDIST3	m	Walking distance from bus stop (or LRT exit) to MRT entrance point, segment 3	measured	measured
NWTIME	min	Total travel time by feeder mode	measured	measured

Note: Model considers only observations where WDIST1 ≥ (WDIST2 + WDIST3)

As only two alternative access modes are considered, binary logit model is utilised to develop WAM. From equation (3.15) for two alternative modes, it **is** obtained,

$$P_n(w) = \frac{e^{V_w}}{\sum_j e^{V_j}} = \frac{e^{V_w}}{e^{V_w} + e^{V_{nw}}} \qquad (7.1)$$

The model states that the probability of an individual choosing walking to access MRT station (P_w) depends on ***the difference in utility*** between walking (w) and non-walking (nw) mode, or,

$$P_W = \frac{1}{1+e^{-(V_w - V_{nw})}} = \frac{1}{1+e^{-z}}; z = V_w - V_{nw} \qquad (7.2)$$

$$V_w - V_{nw} = \boldsymbol{\beta}'\mathbf{x}_i = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_K x_K \qquad (7.3)$$

where V_w: systematic component of the utility function of walking mode
V_{nw}: systematic component of the utility function of non-walking mode
$\mathbf{x}_i$: is the difference of utility of walking and non-walking mode.

As shown in equation (7.3), the model focuses on the difference in variable (or attribute values) between walking and non-walking mode. Thus, based on available data, ten variables were included in the model, as shown in Table 7.3. These are: one dependent variable, four generic variables of access modes, one alternative specific variable for feeder mode, two dummy variables for socio-economic variables (individual characteristics), and two dummy variables for feeder modes.

Table 7.3 Data Input for Walking Access Model

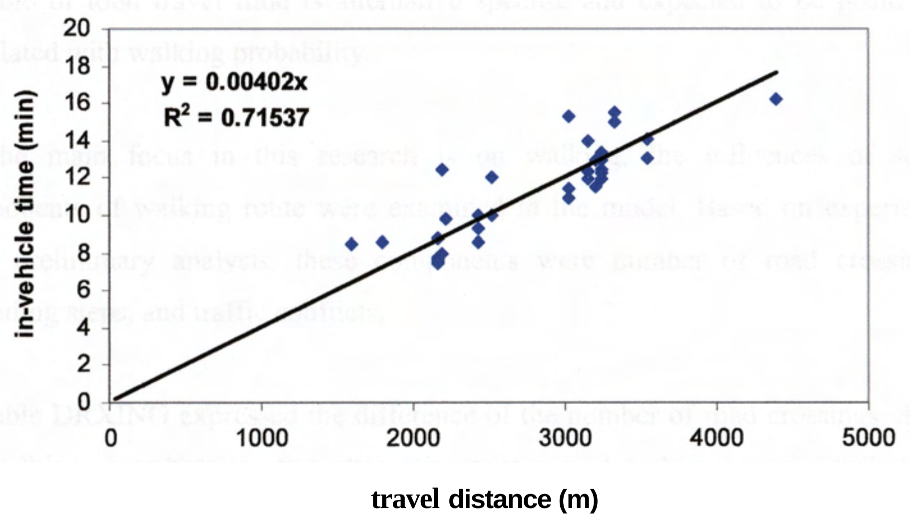
Coeff.	**Walking Mode**	**Feeder Mode**	**Input Variable**	**Remark**
β_1	1	0	**MODE**	
$\beta 2$	WDIST1	WDIST2+WDIST3	**DDIST** = WDIST1-(WDIST2+WDIST3)	Generic
$\beta 3$	0	NWTIME	**-NWTIME**	Alt. specific feeder
$\beta 4$	RXING1	RXING2+RXING3	**DRXING** = RXING1-(RXING2+RXING3)	Generic
$\beta 5$	ASTEP1	ASTEP2+ASTEP3	**DASTEP** = ASTEP1-(ASTEP2+ASTEP3)	Generic
$\beta 6$	TCONF1	TCONF2+TCONF3	**DTCONF** = TCONF1-(TCONF2+TCONF3)	Generic
$\beta 7$	1: male 0: female		**SEX**	Alt. spec. socio
$\beta 8$	1: 21-50 years old 0: otherwise		**AGEGP**	Alt. spec. socio
$\beta 9$	1: feeder mode = LRT; 0: otherwise		**LRT**	Alt. specific feeder
$\beta 10$	1: feeder mode = trunk bus; 0: otherwise		**TBUS**	Alt. specific feeder

The dependent variable (left-hand side variable) of MODE indicates the mode choice. This is the alternative-specific constant that reflected the ***mean*** of (ε_j-ε_i), the difference in the utility of alternative walking mode against feeder mode (non walking mode) when ***'all else being equal'*** (not different at all). The positive sign of the coefficient $\boldsymbol{\beta}_1$ reflected a relative preference for the walking mode.

It was assumed that DDIST should not be less than zero. As a generic variable, DDIST is expected to be negatively correlated with the walking probability.

In this study, total travel time by feeder mode (Bus or LRT) is considered as the attractiveness of the mode. The time can be divided into out-vehicle time and in-vehicle time. Waiting time in bus stop or LRT platform is counted as out-vehicle time.

In-vehicle time is total time spend in the vehicle. Besides moving time, this time includes the delay time caused by alighting and boarding process, traffic signal and traffic conditions. To estimate in-vehicle time of bus, a model was developed from 34 observations of in-vehicle time and distance by bus, as shown in Figure 7.2.



Regression Statistics		**ANOVA**	**df**	**SS**	**MS**	**F**
Multiple R	0.84580	Regression	1	150.058	150.058	**82.940**
R^2	**0.71537**	Residual	33	59.705	1.809	
Adjusted R^2	0.68507	Total	34	209.763		
Std. Error	1.34508					
No. of Data	**34**					

Figure 7.2 Relationship between In-Vehicle Time and Travel Distance

This relationship focused on in-vehicle time of bus approaching the terminal (less than 10 bus stops to terminal). Using the significance level of $\alpha = 1\%$, it is obtained that $F = 82.940 > F_{0.01,1,33} = 7.47$ 1. So, the hypothesis test of the slope equal to zero can be rejected or in other words, the slope is statistically different from zero. From the figure, it was found that average journey speed for bus approaching the terminal was about 14.9 km/hour.

Some measurements were carried out to capture the average speed and headway of LRT. Four LRT stations were selected for the measurement, i.e. South View, Keat Kong, Teck Whye, and Phoenix. Interactive online map was used to measure the distance between these stations. Total in-vehicle time between stations (covering moving and stopping time) was measured on board. As a result, from 8 observations of time, it was found that average journey speed was 23.93 kmihour. This number is close to the one given by the official website of LRT company (SLRT, Singapore Light Rapid Transit)', i.e. 25km/h and average train headway of 3 minutes. The speed of 23.93 km/hour was applied to calculate in-vehicle time of LRT. The variable of total travel time is alternative specific and expected to be positively correlated with walking probability.

As the main focus in this research is on walking, the influences of some components of walking route were examined in the model. Based on experience from preliminary analysis, these components were number of road crossings, ascending steps, and traffic conflicts.

Variable DRXING expressed the difference of the number of road crossings along the walking route between two alternative access modes. As a generic attribute of walking, DRXING is expected to be negatively correlated with the walking probability.

Similar consideration was applied to variables DASTEP and DTCONF. Variable DASTEP is the total difference of the number of ascending steps along the walking route for both alternative modes. Escalators are excluded from this variable. Slope toward MRT on walking path was converted to number of steps. DTCONF is the difference of number of conflict points along the walking route for both alternatives. Access road and car parks are considered as the conflict points. DASTEP and DTCONF were also expected to be negatively correlated with walking probability.

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[1] http://www.slrt.com.sg/system_right.htm (access date: March, 2004)

Variable SEX is a dummy variable for respondent's gender. It was defined as 1 for male and 0 for female. Positive sign of this coefficient indicates that men are more likely to choose walking than women.

Variable AGEGP is a dummy variable for the group of respondent's age. It was defined as 1 for individuals between 21 and 50 years old and 0 otherwise. The positive sign of its coefficient indicates that the group age of 21 to 50 has higher propensity to walk than other age groups.

Variable LRT is a dummy variable to accommodate characteristics of feeder mode, i.e. LRT. The value is 1 for LRT and 0 otherwise. Negative sign of this variable indicates the relative preference of choosing LRT. Similarly, it was also applied into TBUS, with 1 for taking bus and 0 otherwise.

Table 7.5 shows the correlation matrix of WAM variables. Compared to walking distance variable (DDIST), variables related to walking route such as DRXING, DASTEP, and DTCONF have higher correlation than variables related to individual characteristics, such as SEX and AGEGP. This is expected because for longer walking distance, the number of road crossings, ascending steps, or traffic conflicts may increase.

Table 7.4 Correlation Matrix for WAM Variables

	DDIST	NWTIME	DRXING	DASTEP	DTCONF	SEX	AGEGP	LRT	TBUS
DDIST	1.0000								
NWTIME	0.4476	1.0000							
DRXING	0.4503	0.0291	1.0000						
DASTEP	0.3393	0.2507	0.0474	1.0000					
DTCONF	0.5467	0.2797	0.2781	0.2020	1.0000				
SEX	-0.0473	0.0568	-0.0709	-0.0674	0.0090	1.0000			
AGEGP	-0.0471	0.0248	-0.0464	0.0561	0.0464	0.1123	1.0000		
LRT	0.0232	-0.3095	0.2331	0.0065	0.0221	-0.0203	-0.1291	1.0000	
TBUS	-0.0354	-0.0014	-0.1134	0.0046	0.0667	0.0080	-0.0707	-0.1843	1.0000

7.2 Coefficient Estimation and Validation

7.2.1 Coefficient Estimation

LIMDEP version 7.0 (1998) was used to estimate the coefficients of WAM, as shown in Table 7.5. An expectation with respect to sign was employed to select the most satisfactory variables in the model. A stepwise method was applied to eliminate insignificant variables. It can be seen from the table that all coefficients of estimation have expected sign except NWTIME. Variable elimination was carried out firstly on the variable with the wrong sign.

Table 7.5 Initial Coefficient Estimation for Walking Access Model

Coefficient	Variable	Estimation	t-statistic	P-value
β_1	Constant	4.2268	6.997	0.000
β_2	DDIST	-0.0052	-10.053	0.000
β_3	NWTIME	-0.0167	-0.330	0.741
β_4	DRXING	-0.2578	-2.860	0.004
β_5	DASTEP	-0.0140	-2.217	0.027
β_6	DTCONF	-0.1881	-2.984	0.003
β_7	SEX	1.0256	3.721	0.000
β_8	AGEGP	0.2699	0.886	0.375
β_9	LRT	-3.4526	-3.052	0.002
β_{10}	TBUS	-0.3698	-1.344	0.179
Statistic Summary				
Number of observations, n	646			
Log likelihood at maximum, LogL	-191.6807			
Log likelihood for only constant, LogL0	-445.9882			
Log likelihood all variable zero, Log0	-445.9765			
Chi-squared, χ^2	508.6150			
Pseudo-R^2, ρ^2	0.5702			

The variables of VTIME, AGEGP, and TBUS have small t-statistic value or their P-values are higher than 5% significance level. Thus, these variables were eliminated in the next iteration. Variable with the highest P-value was eliminated first.

After other three iterations with step-by-step elimination of insignificant variables, the most satisfactory model was obtained and shown in Table 7.6. Estimation result from iterations can be seen detail in Appendix C.

Similar to what had been done in preliminary analysis, likelihood ratio test was carried out to test the null hypotheses of $\boldsymbol{\beta_i} = 0$ except for the constant β_1. From Wapole et al. (2002), it is found that the critical value of χ^2distribution with *6* degrees of freedom at 5% level of significance is 12.592. Since the χ^2 value in Table 7.5 is very high, the null hypothesis can be rejected with high confidence. It means that all values of $\boldsymbol{\beta_i}$ could not be zero.

Table 7.6 Final Coefficient Estimation for Walking Access Model

Coefficient	Variable	Estimation	t-statistic	P-value
β_1	Constant	4.1712	11.002	0.000
β_2	DDIST	-0.0049	-10.239	0.000
β_4	DRXING	-0.2704	-3.038	0.002
β_5	DASTEP	-0.0137	-2.256	0.024
β_6	DTCONF	-0.1772	-2.904	0.004
β_7	SEX	1.0663	3.996	0.000
β_9	LRT	-3.3146	-3.050	0.002
Statistic Summary				
Number of observations, n		646		
Log likelihood at maximum, LogL		-96.4427		
Log likelihood for only constant, LogL0		-445.8362		
Log likelihood all variable zero, Log0		-445.8325		
Chi-squared, χ^2		498.7869		
Pseudo-R^2, ρ^2		0.5594		

Some interpretations from the model estimation are as follows:

- Walking mode is more preferable than feeder mode to access MRT stations.
- Walking access trips are influenced primarily by attributes of walking route and gender.
- Walking distance is the most significant factor of walking choice to access MRT station, compared with the other walking route attributes.
- Men are much more likely to walk than women.

A ratio of two coefficients appearing in the same utility function provides information about a trade off or marginal rate of substitution (Ben Akiva and Lerman, 1985). For example, the value of the trade-off between parameter of road crossing and walking distance is:

$$\frac{\beta_{DRXING}}{\beta_{DDIST}} = \frac{-0.2704}{-0.0049} = 55.40 \tag{7.4}$$

It means that, for walking route to access MRT station, walking effort of crossing one road (signalised or unsignalised) is equal to 55.40 metres of walking, approximately.

Similarly, using the parameters for ascending steps and traffic conflict:

$$\frac{\beta_{DASTEP}}{\beta_{DDIST}} = \frac{-0.0137}{-0.0049} = 2.81 \tag{7.5}$$

The effort to climb one ascending step is equal to 2.81 metres of level walking, approximately. It means that the effort to climb one pedestrian bridge with 32 ascending steps is equal to 90 metres of walking.

$$\frac{\beta_{DTCONF}}{\beta_{DDIST}} = \frac{-0.1772}{-0.0049} = 36.31 \tag{7.6}$$

The effort to cross a car park or access road is equal to 36, 1 metres of walking approximately.

As discussed in Chapter 5, rain shelter or weather protection is one of important factors affecting of walking choice. Weather protection was recorded from survey as percentage of walking route covered. The recording was done for all walking route segments. The average value of weather protection is shown in Table 7.7.

It can be seen from the table, the average value of WPR03 is close to 100%. It could be said that almost all walking route to access MRT, from bus stop or bus terminal, was covered. In the same way, maximum WPR02 is 100%. It indicates that bus stop was connected to the housing block with a covered walking path.

Therefore, with these weather protected walking facilities, feeder mode might be more attractive than walking.

Table 7.7 Summary of Weather Protection

Notatio	Unit	Description	Average	Std. Dev.	Max	Min	Count
Segment 1: walking route from home to MRT station							
WDIST1	m	Walking distance	1097.0	555.8	2954.0	198	517
WPRO1	%	Percentage route protected	34.9	22.6	100.0	0	517
DPRO1	m	Length of route protected	365.3	301.5	1626.7	0	517
DNPRO1	m	Length of route unprotected	731.7	472.7	2620.2	0	517
Segment 2: walking route from home to bus stop (LRT station)							
WDIST2	m	Walking distance	189.6	117.1	752.0	15	517
WPRO2	%	Percentage route protected	50.0	22.2	100.0	0	517
DPRO2	m	Length of route protected	77.0	29.5	139.2	0	517
DNPRO2	m	Length of route unprotected	112.5	105.0	714.4	0	517
Segment 3: walking route from bus stop or bus terminal (LRT exit point) to MRT entrance							
WDIST3	m	Walking distance	115.6	83.9	377.0	15	517
WPRO3	%	Percentage route protected	99.2	4.3	100.0	75	517
DPRO3	m	Length of route protected	113.7	81.3	377.0	15	517
DNPRO3	m	Length of route unprotected	1.9	10.4	75.4	0	517

To capture the influence of rain shelters or weather protection, model estimation was carried out on a subset of data, which is shown in Table 7.8.

Table 7.8 Coefficient Estimation for Weather Protection in WAM

Variable	Estimation	t-statistic	P-value
Constant	4.52455	10.180	0.000
DDPRO: DPRO1 – (DPRO2+DPRO3)	-0.00424	-6.507	0.000
DDNPRO: DNPRO1 – (DNPRO2+DNPRO3)	-0.00613	-8.882	0.000
Statistic Summary			
Number of observations, n	517		
Log likelihood at maximum, LogL	-176.2232		
Log likelihood for only constant, LogL0	-359.0348		
Log likelihood all variable zero, Log0	-359.0383		
Chi-squared, χ^2	365.6231		
Pseudo-R^2, ρ^2	0.5092		

Thus, the trade off for weather protection is, as follows:

$$\frac{\beta_{DDPRO}}{\beta_{DDIST}} = \frac{-0.00424}{-0.00488} = 0.869$$

or,

$$\text{DDIST} = 0.869\ \text{DDPRO} \tag{7.7}$$

$$\frac{\beta_{\text{DDNPRO}}}{\beta_{\text{DDIST}}} = \frac{-0.00613}{-0.00488} = 1.256$$

or,

$$\text{DDIST} = 1.256\ \text{DDNPRO} \tag{7.8}$$

The interpretation for equations (7.7) and (7.8): the effort of waking for 100 metres is equal approximately to walking of 115 metres (100/0.869 = 115) on route with weather protection or 80 metres (100/1.256 = 80) on route without. In other words, these equations show that one will walk longer in protected walking path.

7.2.2 Model Validation

According to Ben-Akiva and Lerman (1985), Meyer and Miller (2001), and Ortuzar and Willumsen (2001), model validation can use a sub sample of data or another sample that was not used during the estimation process as a validation sample. Thus, in this case, the data from pilot survey was used to validate coefficient estimation of WAM. Detail description of pilot data can be seen in Table 4.3. The data of Tampines, Bedok and Clementi were already used and data for Hougang is for bus terminal only (MRT was not operated yet). Therefore, only data of Chinese Garden can be used to validate the WAM.

Percentage of true prediction was used to examine how well the model predicts the access mode for Chinese Garden data. The frequencies of observed and predicted outcomes of Chinese Garden data using WAM can be seen in Table 7.9.

Table 7.9 Frequencies of Actual and Predicted Outcomes

Observed	**Predicted**		**Total**
	Feeder Bus	**Walking**	
Feeder Bus	4	1	5
Walking	42	33	75
Total	46	34	80

The percentage of true prediction can be calculated as $(4+33)/80 = 43.6\%$. It could be said that using Chinese Garden data, WAM can only predict the correct mode choice in 43.6%of cases which is much lower than expected. This low percentage could be caused by the characteristics of the area of Chinese Garden. It has been explained in Chapter 4 that there are no feeder buses operating directly to access the MRT station and consequently the most common access mode is by walking.

Chapter 8 Equivalent Walking Distance

This chapter discusses the development of Equivalent Walking Distance (EWD). The basic concept of generalised cost is adopted in the model. An application of EWD in public transport accessibility measurement is also introduced.

8.1 Model Development

As discussed in Chapter 3, there are the two elements of EWD, i.e. actual walking distance and generalised walking effort. Walking distance is the measurable component of EWD, which can be obtained directly from walking route measurement. However, walking distance is not the only component of walking effort to access public transport terminal. Crossing roads or climbing stairs constitute an additional effort in walking which should be considered.

EWD is a model to represent the effort of walking as access mode. It is assumed that the total effort can be expressed as a linear function of walking distance and characteristics of walking route. The general formula of EWD is:

$$\text{EWD} = \text{WDIST} + f(\text{characteristics of walking route}) \tag{8.1}$$

The effect of walking route characteristics on walking effort is expressed in the second component of equation (8.1). From the previous chapter, the trade-off or marginal rates of substitution from the walking access model represents the individual perceived ‘weights’ of characteristics of walking route. Then, equation (8.1) can be expressed as follows:

$$EWD = WDIST + \frac{\beta_4}{\beta_2} RXING + \frac{\beta_5}{\beta_2} ASTEP + \frac{\beta_6}{\beta_2} TCONF \tag{8.2}$$

According to Table 6.3, the equation (8.2) becomes:

$$EWD = WDIST + 55.40\ RXING + 2.81\ ASTEP + 36.31\ TCONF \tag{8.3}$$

where: EWD = equivalent walking distance (metre)
WDIST = walking distance (metre)
RXING = number of road crossings
ASTEP = number of ascending steps
TCONF = number of traffic conflict along walking route

As shown in equation (8.3), EWD is the actual walking distance plus the equivalent distance of the number of road crossing, ascending steps, and traffic conflicts.

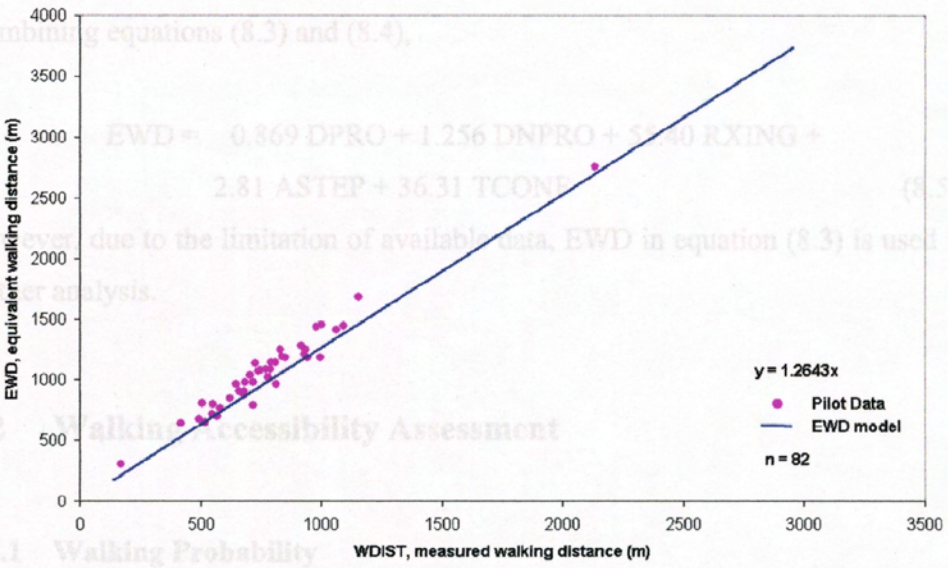
The ratio between EWD and WDIST can indicate the 'an additional' walking distance due to the characteristics of walking route. Higher value of this ratio means that there is more effort of walking. Since airline distance is deemed as the ideal walking route, the ratio between WDIST and ADIST can show the diversion of the walking route. Higher value of this ratio indicates that there is a longer detour to access MRT station. Table 8.1 shows the average values of EWD, WDIST, ADIST and the ratios as well.

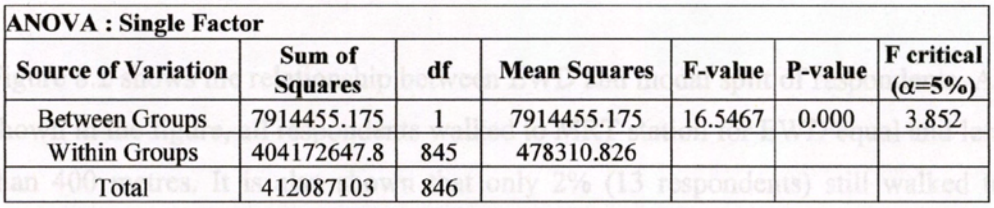
Table 8.1 Ratio of Average EWD, WDIST and ADIST

Location	**No of data**	**$EWD_{ave.}$**	**$WDIST_{ave.}$**	**$ADIST_{ave.}$**	$\frac{EWD_{ave.}}{WDIST_{ave.}}$	$\frac{WDIST_{ave.}}{ADIST_{ave}}$	$\frac{EWD_{ave.}}{ADIST_{ave}}$
Clementi	168	1063.8	852.0	648.2	1.25	1.31	1.64
Bukit Batok	146	1161.3	877.9	673.6	1.32	1.30	1.72
Choa Chu Kang	145	1338.2	964.4	786.8	1.39	1.23	1.70
Bedok	175	1681.0	1404.8	979.0	1.20	1.44	1.72
Tampines	131	1428.4	1091.2	817.3	1.31	1.34	1.75
All	765	1338.0	1045.7	783.9	1.28	1.33	1.71

As shown in the table, for the five study areas, the effort of walking related to characteristics of walking route is equivalent to additional 28% of walking distance on average.

From Table 8.1, the EWD-WDIST relationship can also be achieved. Since model validation can use a sub sample of data or another sample that was not used during the estimation process as a validation sample, in this case, the data from pilot survey (i.e. Chinese Garden) was used to validate EWD using EWD-WDIST relationship. Figure 8.1 shows the EWD-WDIST relationship for the pilot data. An expected EWD-WDIST relationship (based on EWD model) was drawn as a solid line to show *how well* the pilot data fit the model.





ANOVA : Single Factor

Source of Variation	Sum of Squares	df	Mean Squares	F-value	P-value	F critical (α=5%)
Between Groups	7914455.175	1	7914455.175	16.5467	0.000	3.852
Within Groups	404172647.8	845	478310.826			
Total	412087103	846				

Figure 8.1 EWD Validation on Pilot Survey Data

As shown in the figure, since the F-value was higher than F critical, the model was statistically significant at the 5% level. In other words, the similar characteristic of EWD model was also obtained from the pilot data. According to the figure, for pilot data, there is an additional of 26% of walking distance on average for the walking effort related to characteristics of walking route.

The equation (8.3) could be extended to incorporate the influence of weather protection on EWD. According to equations (7.7) and (7.8), walking distance could be divided into parts with and without weather protection, or:

$$\text{WDIST} = 0.869\,\text{DPRO} + 1.256\,\text{DNPRO} \tag{8.4}$$

where: WDIST = walking distance (metre)
DPRO = walking distance with weather protection (metre)
DNPRO = walking distance with no weather protection (metre)

Combining equations (8.3) and (8.4),

$$\begin{aligned}\text{EWD} = {} & 0.869\,\text{DPRO} + 1.256\,\text{DNPRO} + 55.40\,\text{RXING} + \\ & 2.81\,\text{ASTEP} + 36.31\,\text{TCONF}\end{aligned} \tag{8.5}$$

However, due to the limitation of available data, EWD in equation (8.3) is used for further analysis.

8.2 Walking Accessibility Assessment

8.2.1 Walking Probability

Figure 8.2 shows the relationship between EWD and modal split of respondents. As shown in the figure, all respondents walked to MRT station for EWD equal and less than 400 metres. It is also shown that only 2% (13 respondents) still walked to access MRT station for EWD more than 2000 metres. Model estimation was developed to show the relationship between walking probability and EWD.

Coefficient estimation was carried out to obtain the relationship between walking probability and EWD, as shown in Table 8.2. From the table, the walking probability model would be developed as:

$$P_w(\text{EWD}) = \frac{1}{1 + \exp(-\ 6.491 + 0.005.\text{EWD})} \tag{8.6}$$

Table 8.2 Coefficient Estimation for Walking Probability

Variable	Estimation	t-value	P-value
Constant	6.4909	12.740	0.000
EWD (Equivalent Walking Distance)	-0.0049	-13.096	0.000
Statistic Summary			
Number of observations, n	646		
Log likelihood at maximum, LogL	-204.2917		
Log likelihood for only constant, LogL0	-445.9882		
Log likelihood all variable zero, Log0	-445.9836		
Chi-squared, χ^2	483.3930		
Pseudo-R^2, ρ^2	0.5419		

As walking accessibility is defined as how easy it is to access MRT stations by walking, the walking probability and EWD shall be applied into the walking accessibility assessment.

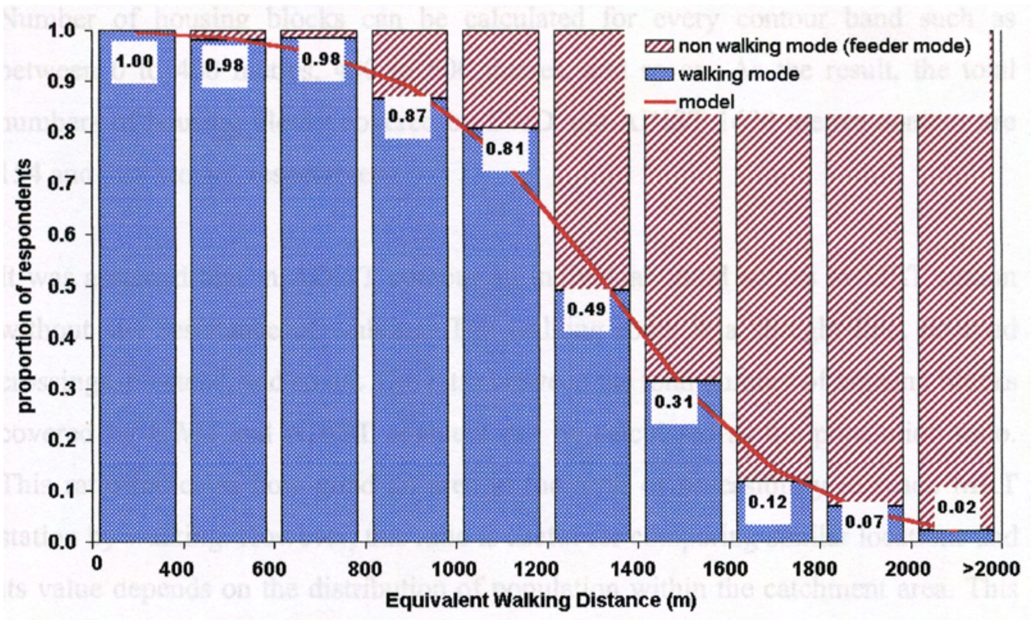


Figure 8.2 Proportion of Walking and Non-Walking related to EWD

8.2.2 EWD Contours and Catchment Area

The basic measurement of accessibility in public transport is to count the population covered within a certain walking distance. EWD value was calculated and drawn for each individual's origin point (i.e. housing block). Total population covered within the area could be calculated to represent the catchment of each interval contour of

EWD. In this research, to simplify computation, the number of housing blocks is used to represent population covered in this area. The contour was drawn based on EWD value at respondent's origin points and along walking routes surveyed.

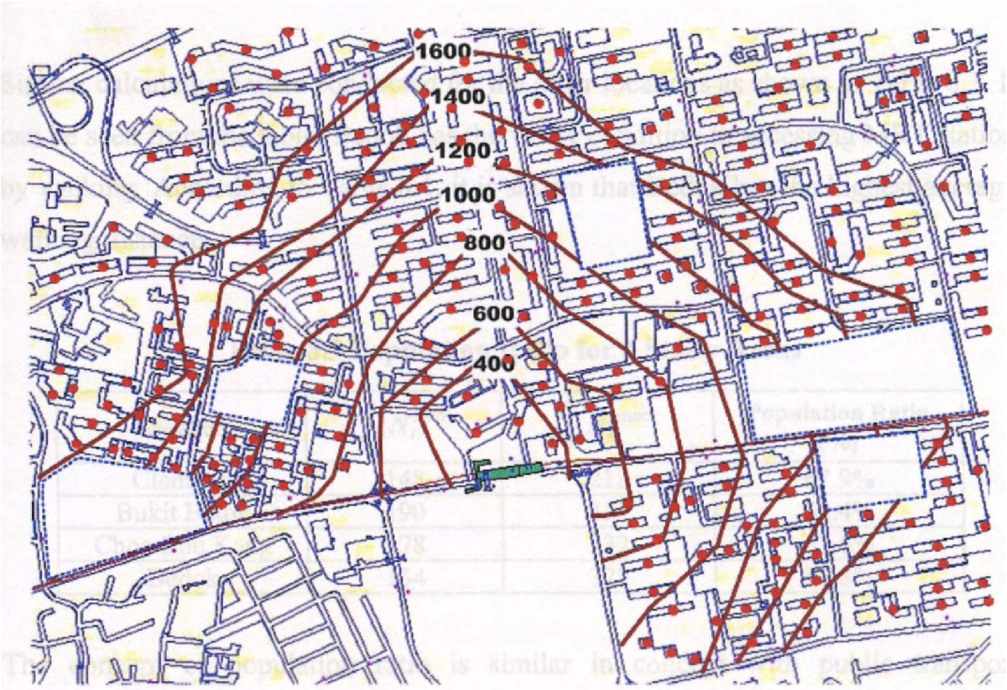
According to Stringham (1982), the distance of 1200 metres can be applied as maximum acceptable distance. Based on Table 8.1, the walking distance of 1200 metres is equal to 1200 x 1.28 = 1526 metres of EWD. Thus, the distance of 1600 metres was used as the limit. Catchment area on airline distance basis was drawn at the same location and for the maximum airline distance of 1600 metres. Figure 8.3 shows an example of the EWD and ADIST contour for the Bedok area.

Number of housing blocks can be calculated for every contour band such as between 0 to 400 metres, 400 to 600 metres, and so on. As the result, the total numbers of housing blocks covered by EWD and ADIST 1600 metres contour are 154 and 322 blocks, respectively.

It was assumed that in ADIST contour an individual could access to MRT station without any resistance of walking. The walking route is a straight line, no road crossings, no steps, and so on. The ratio between the total number of housing blocks covered by EWD and ADIST contours can be calculated as the population ratio. This ratio indicates how good an area in the term of accessibility to reach MRT station by walking. However, this ratio is useful for comparing similar locations and its value depends on the distribution of population within the catchment area. This concept was already used in the preliminary analysis.

For example, the population ratio for Bedok can be calculated as follows:

$$\text{Population Ratio (\%)} = \frac{\sum_{i}^{n} N_i^{EWD}}{\sum_{i}^{n} N_i^{ADIST}} \times 100\% = \frac{154}{322} = 47.8\% \qquad (8.7)$$



(a) EWD Contour for Bedok

(b) ADIST Catchment Area for Bedok

Figure 8.3 EWD and ADIST Contour for Bedok Area

Similar calculations were conducted for the other locations as shown in Table 8.3. It can be seen from the table, Bedok has the worse condition in accessing MRT station by walking. According to Table 8.1, it is shown that Bedok has the highest average walking distance.

Table 8.3 Population Ratio for 4 Study Areas

Location	$\sum_i^n N_i^{EWD}$	$\sum_i^n N_i^{ADIST}$	Population Ratio (%)
Clementi	**148**	**218**	**67.9%**
Bukit Batok	**190**	**320**	**59.4%**
Choa Chu Kang	**178**	**332**	**53.6%**
Bedok	**154**	**322**	**47.8%**

The concept of population ratio is similar in concept with public transport accessibility analysis using GIS approach (e.g. Hsiau et al, 1997 and Hilman, 1997). However, this concept is more precise because it uses EWD instead of walking distance.

8.2.3 Walking Accessibility Index (WAI)

From the results of on-site interview survey, it was found that some respondents chose feeder mode to access MRT station although their origin point was located within a reasonable walking distance. On the other hand, others did walk for longer distances than a 'reasonable one' while there were bus services provided. Thus, it is assumed that for every distance to the station, there is a probability of walking.

Walking Accessibility Index (WAI) was developed to incorporate walking probability into the public transport accessibility measure. This is a new concept of assessment, which combines population ratio and walking probability. The general expression of WAI is,

$$\mathrm{WAI} = \frac{\sum_i^n N_i^{EWD} P_{wi}}{\sum_i^n N_i^{ADIST} P_{wi}} \tag{8.8}$$

where: WAI = public transport accessibility index
Pw_i = walking probability for distance interval i
N_i^{EWD} = number of housing blocks covered by EWD contour interval i
N_i^{ADIST} = number of housing blocks covered by Airline Distance contour interval i

For. four study areas (Clementi, Bukit Batok, Choa Chu Kang, and Bedok), a distance of 2000 metres is applied as the maximum catchment area. Figure 8.4 shows the walking probability that was drawn based on equation (8.6) for 200-metre intervals. As can be seen from the figure, up to 400 metres of EWD from the station, all individuals walk to access the terminal. Then, the walking probability (share) decreases with EWD until it is only 5% for the interval 1800-2000 metres.

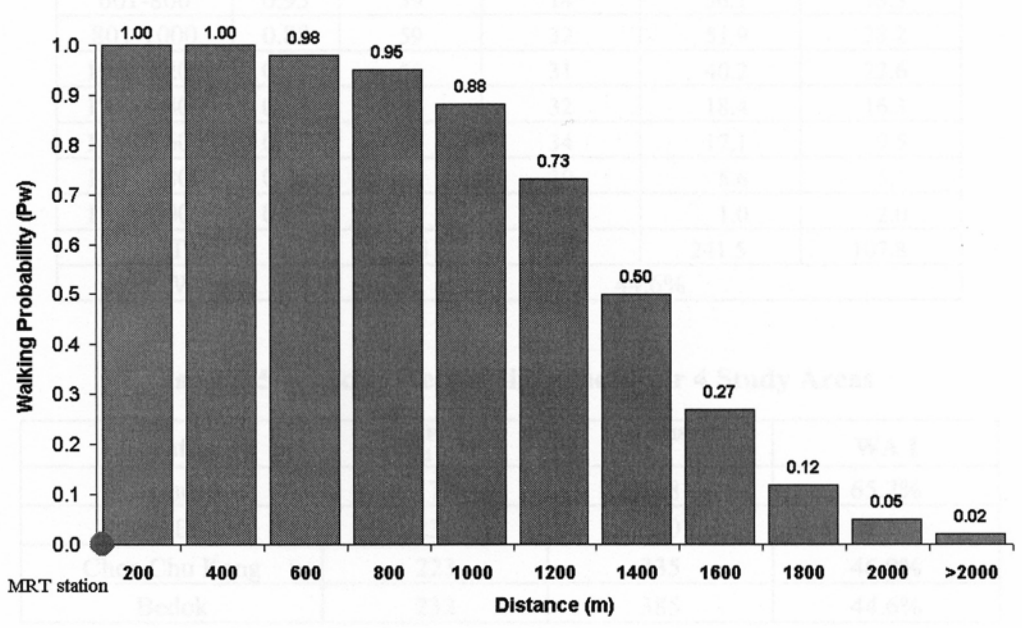


Figure 8.4 Walking Probability for 200-metre Intervals

Using equation (8.8), an example of WAI calculation for the Bedok area is shown in Table 8.4. Similar calculations were carried out for the other three locations and the results are shown in Table 8.5. A higher value of WAI indicates that the given location has better walking accessibility. As shown in Table 8.5, comparing to the other locations, Bedok has the worst index. It can be explained as follows:

According to Table 8.1, Bedok has the lowest of 'additional' walking distance due to the characteristics of walking route. It indicates there is the less of the additional effort of walking. However, Bedok has the longest of average walking distance and detour of walking route to access MRT station. Since the walking probability decreases with increasing walking distance, the lower WAI could be caused by the small value of walking probability. Table 6.3 also shows that the modal split between walking and bus for Bedok is 40:60.

Table 8.4 WAI Calculation for Bedok Area

Interval Contour (m)	P_w	N_i^{EWD}	N_i^{ADIST}	$N_i^{EWD} * P_{wi}$	$N_i^{ADIST} * P_{wi}$
0-400	1.00	19	3	19.0	3.0
401-600	0.98	33	8	32.3	7.8
601-800	0.95	59	14	56.1	13.3
801-1000	0.88	59	32	51.9	28.2
1001-1200	0.73	55	31	40.2	22.6
1201-1400	0.51	36	32	18.4	16.3
1401-1600	0.28	61	34	17.1	9.5
1601-1800	0.13	43	39	5.6	5.1
1801-2000	0.05	20	39	1.0	2.0
Total		385	232	241.5	107.8
WAI		44.6%			

Location	N_i^{EWD}	N_i^{ADIST}	WA I
Clementi	179	218	65.2%
Bukit Batok	232	320	51.9%
Choa Chu Kang	223	335	46.9%
Bedok	232	385	44.6%

8.3 Evaluation of Walking Facility Improvement

One of the advantages of WAI concept is that an improvement of walking facilities to access **MRT** station can be examined more easily. This section discusses an example of the effect of walking facilities improvement on WAI.

For example, let us suppose that a new entrance point is built to reduce access delay due to road crossing in Bedok area. Figure 8.5 shows the new access underpass to the station.

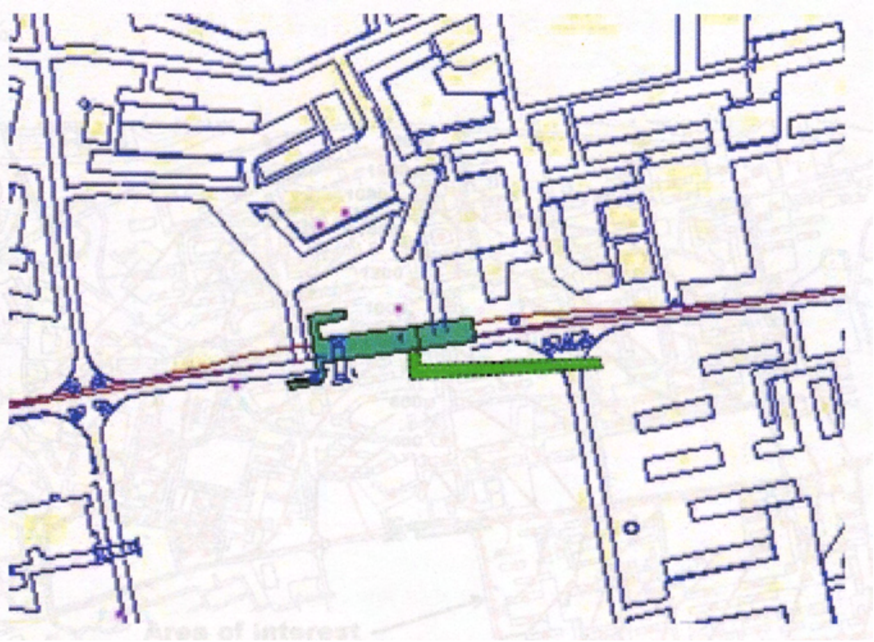


Figure 8.5 New Entrance Point for Bedok

Analysis was carried out on a specific area (area of interest). It was assumed that the new entrance point did not change the walking pattern outside the specific area. The boundaries of the area are as follows:

- North side: New Upper Changi Road
- South side: Bedok South Road
- West side: Bedok South Avenue 1
- East side: Bedok South Avenue 3

Based on new entrance point, EWD of each origin point was recalculated, especially for the area of interest. Then, EWD contour was redrawn, as shown in Figure 8.6.

The result of WAI calculation for the area of interest is shown in Table 8.6. Existing condition is the condition without the new entrance point. It can be seen from the table, the number of housing blocks within 2000 metres EWD contour increases from 48 to 55. The value of WAI also increases from 45.49% to 58.20%, or by 12.71%.

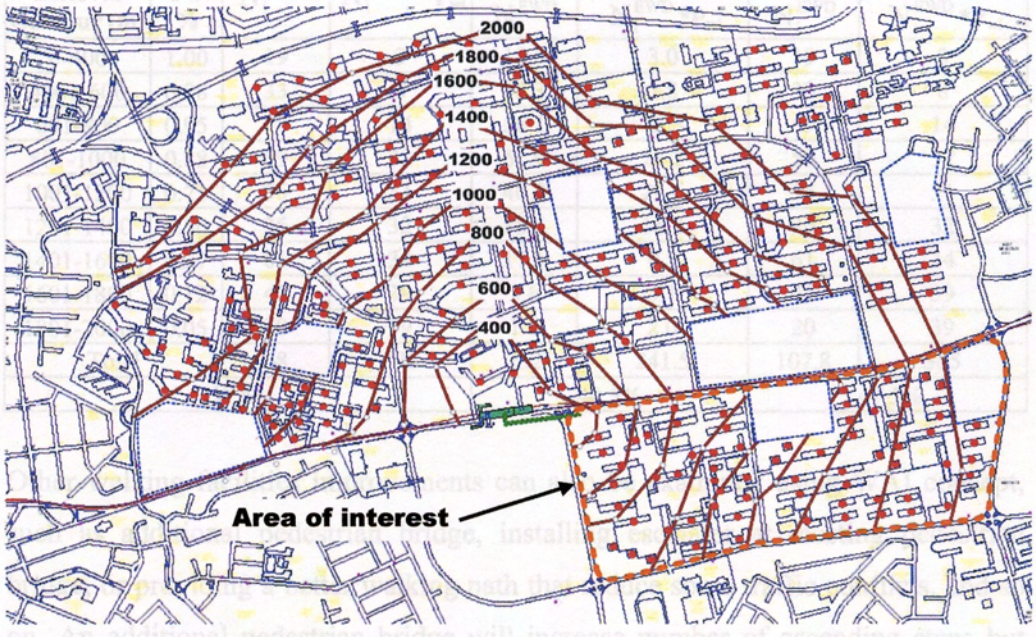


Figure 8.6 EWD Contour as result of New Entrance Point

Table 8.6 WAI Calculation for Area of Interest

Interval Contour (m)	Pw %	N_i^{ADIST}	$N_i^{ADIST}*P_{wi}$	Before		After	
				N_i^{EWD}	$N_i^{EWD}*P_{wi}$	N_i^{EWD}	$N_i^{EWD}*P_{wi}$
0-400	1.00	3	3.0	0	0.0	0	0.0
4001-600	0.98	10	9.8	1	1.0	4	3.9
601-800	0.95	15	14.3	3	2.9	5	4.8
801-1000	0.88	8	7.0	7	6.2	10	8.8
1001-1200	0.73	10	7.3	8	5.8	7	5.1
1201-1400	0.50	16	8.0	8	4.0	8	4.0
1401-1600	0.27	6	1.6	7	1.9	6	1.6
1601-1800	0.12	0	0.0	6	0.7	11	1.3
1801-2000	0.05	0	0.0	9	0.5	13	0.7
Total		68	51.0	49	22.9	64	30.2
WAI				44.9%		59.1%	

However, for the whole area of Bedok, the value of WAI increases by only 2.67%, as shown in Table 8.7.

Table 8.7 WAI Calculation for Whole Area

Interval Contour (m)	**Pw %**	N_i^{ADIST}	$N_i^{ADIST} *P_{wi}$	**Before**		**After**	
				N_i^{EWD}	$N_i^{EWD} *P_{wi}$	N_i^{EWD}	$N_i^{EWD} *P_{wi}$
0-400	1.00	19	3	19.0	3.0	19	3
4001-600	0.98	33	8	32.3	7.8	33	8
601-800	0.95	59	14	56.1	13.3	59	14
801-1000	0.88	59	32	51.9	28.2	59	32
1001-1200	0.73	55	31	40.2	22.6	55	31
1201-1400	0.50	36	32	18.4	16.3	36	32
1401-1600	0.27	61	34	17.1	9.5	61	34
1601-1800	0.12	43	39	5.6	5.1	43	39
1801-2000	0.05	20	39	1.0	2.0	20	39
Total		68	385	232	241.5	107.8	385
WAI				44.5%		47.5%	

Other walking facilities improvements can also be examined using WAI concept, such as additional pedestrian bridge, installing escalator at existing pedestrian bridge, or providing a better walking path that reduce some traffic conflicts, and so on. An additional pedestrian bridge will increase number of ascending steps but reduce number of road crossings. The WAI concept can be employed to find out the best scenario of improvement.

Chapter 9 Summary and Conclusions

9.1 Summary of Findings

In this research walking accessibility is defined as how easy it is to access main public transport terminal (i.e. MRT station) by walking. Walking effort is applied in the mode share model instead of walking distance or walking time. This effort is expressed by an equivalent walking distance, which incorporates generalised model of walking route characteristics, such as number of road crossing, ascending step, and conflict point. These characteristics are generalised in the term of walking distance.

Walking access model was developed to capture the walking mode share to access public transport terminals. Due to data available, the model considers only two access modes, i.e. walking and feeder mode or non-walking mode (i.e. bus and LRT). Unlike other cities in Canada and USA, Singapore operates LRT as a feeder mode to the main public transport system, i.e. MRT.

Most of data was obtained from on-site interview survey and walking route assessment. The on-site interview survey was carried out in terminal building of MRT stations. Respondents of this survey were passengers who took MRT as the main mode to reach their destination. Walking route assessment, which was carried out later, was done to obtain the exact characteristics of walking routes.

Nine study areas were selected centred on MRT stations. They are: Clementi and Bedok MRT station (East-West Line); Bukit Batok and Choa Chu Kang MRT Station (North-South Line); and Sengkang, Hougang, Kovan, Serangoon, Boon Keng (North-East Line). However, only five areas were used for more detailed analysis, i.e. Clementi, Bedok, Bukit Batok, Choa Chu Kang and one area from the pilot survey, i.e. Tampines.

Some important findings of the surveys are as follows:

- Access Modal Split

  Walking and taking bus or LRT are the most frequent access modes to reach MRT station. Observations from 10 stations (including one station from pilot survey) show that the average proportion of walking and bus or LRT is 59.6% and 37.2%, respectively. It indicates how important walking is in public transport service.

  The proportion of walking could be examined related to respondent characteristics, such as trip purpose, income and age. There is a higher proportion of walking to access MRT station for compulsory trips, i.e. working and educational trips. Higher proportion of walking occurred for respondents with age between 16 and 50 years. However, there is no strong evidence to show that choice of walking was influenced by income of respondents.

- Walking Distance and Speed

  The average walking distance to access five MRT stations is about 630 metres. This number is similar to the one found in some cities in Canada, USA, and UK. Since the result showed that more than 50% of respondents were willing to walk for a distance up to 1000 metres, the maximum acceptable walking distance of 1200 metres can be applied. This number is similar with the one in Stringham (1982).

  Walking speed was derived from measured walking distance divided by walking time. As research did not measure directly the walking time, the time was obtained from what respondents reported in the interview. Based on this method, the average walking speed of 70.5 m/min was obtained.

- Factors Affecting Walking Choice

  Examination of factors affecting the walking choice to access MRT station (9 stations, 1300 respondents) shows that walking distance was not the only main factor. The characteristics of walking route have a role. The two top factors rated *very important* are weather protection and walking distance.

  However, these factors were obtained from respondent perception and based on options given in the survey form. It would be of interest to consider correlation between these factors. As an example, the effort of walking for 100 metres is equal approximately to walking of 115 metres on route with weather protection or 80 metres on route without. It could be said that an individual will walk longer along a protected walking path.

- Walking Access Model

  The development of walking access model showed that probability of choosing walking (walking probability) to access MRT station is influenced by walking distance, number of road crossings, ascending steps and traffic conflicts. Within a sub set data, weather protection becomes another significant factor in the model.

  Some trade-offs between walking distance and components of walking route are, as follows:

  - The effort of crossing one road (signalised or unsignalised crossing) is equal to 55.40 metres of walking.
  - The effort to climb one step is equal to 2.81 metres of level walking. Climbing a pedestrian bridge with 32 ascending steps is equal to 90 metres of walking.
  - The effort to cross a car park or access road is equal to 36.31 metres of walking.

  - The average effort of walking for 100 metres is equal approximately to walking of 115 metres on route with weather protection or 80 metres on route without.

- Equivalent Walking Distance (EWD)

  EWD was developed from five MRT stations, i.e. Clementi, Bukit Batok, Choa Chu Kang, Bedok and Tampines. The general equation of EWD that is applied in public transport accessibility measurement is:

$$\text{EWD} = \text{WDIST} + 55.40\ \text{RXING} + 2.81\ \text{ASTEP} + 36.31\ \text{TCONF}$$

  On average, EWD value is 1.275 times higher than measured walking distance. It might be said that the effort of walking related to some component of walking route is comparable with additional 27.5% walking distance.

  According to data, all respondents walked to MRT stations for EWD less and equal to 400 metres. About 50% of respondents walked for EWD between 1000 – 1200 metres. However, only 2% of respondents did walk for EWD more than 2000 metres.

- Walking Accessibility Assessment

  There were two types of catchment areas that were used in walking accessibility measure: based on ADIST and EWD. Number of housing blocks was used to represent population covered in the catchment areas. The ratio between the total number of housing blocks that covered by EWD and ADIST contour can be calculated as the population ratio. This ratio indicates how good an area in the term of accessibility to reach MRT station by walking. Comparing with the concept of public transport accessibility analysis using GIS approach (e.g. Hsiau et al, 1997 and Hilman, 1997), the population ratio is better because the effort of walking to access is adapted well.

  Results from on-site interview survey showed that some respondents chose feeder mode to access MRT station although their origin point was located within a reasonable walking distance and others did walk for longer distances while there were bus services provided. Thus, it is assumed that for every distance to the station, there is a probability of walking. Walking Accessibility Index (WAI) was developed to incorporate walking probability into the public transport accessibility measure. WAI is a new concept of walking accessibility assessment, which combines population ratio and walking probability. The WAI values for the four stations are 65.23%, 51.92%, 46.99%, and 44.66% for Clementi, Bukit Batok, Choa Chu Kang, and Bedok, respectively.

A higher value of WAI indicates that the given location has a better walking accessibility. Since Bedok has the lowest index, it could be said that comparing with the other three locations, Bedok has worse walking accessibility. To be noted here, the assessment is more meaningful in comparing similar areas rather examining an area with its value of WAI.

9.2 Conclusions

This research has shown that the characteristics of walking route could be incorporated into public transport accessibility measurement. The advantage is that the measurement becomes more precise and comprehensive instead of using only the value of walking distance or time.

In this research, walking accessibility is defined as how easy it is to access public transport terminal by walking. The effort of walking to access MRT station was affected not only by walking distance but also by characteristics of walking route, such as number of road crossings, ascending steps and conflict points. The joint effect of these components is expressed by equivalent walking distance. The parameters of equivalent walking distance function were derived from the walking access model.

Walking access model was developed to capture the relationship between walking as an access mode and other feeder mode to access main public transport terminal.

Binary logit model was applied and estimation result showed that walking distance and characteristics of walking route influenced walking probability. Walking was more preferable than other feeder modes, i.e. bus and LRT.

Equivalent walking distance can be applied in walking accessibility measurement. This is a new method that can measure public transport accessibility more precisely and comprehensibly. Some advantages of this method are, firstly, the effort of walking is incorporated in the measure. Secondly, walking environment quality can be captured. Lastly, improvement in walking facilities to access MRT can be evaluated.

To be noted here, as the scope of this study is limited, the detailed analysis is done for five station areas (including one area from pilot survey). Further research is needed to analyse the other five areas in detail. Therefore, the integrated result from all ten areas would produce a better walking accessibility assessment.

Some future research can be carried out following this study. Improvements on walking accessibility measurement are needed, such as using the GIS software for map calculation and presentation. The study could be extended to egress trips (trips from public transport terminal to final destination), extended for commercial and industrial areas as the origin point of respondents, and so on. Since walking is an important access mode to reach public transport terminals, the walking accessibility assessment can be developed as a tool to examine public transport performance. Accordingly, the research to investigate the effect of public transport accessibility on travel behaviour, especially for commuter behaviour, for example, can be conducted using this accessibility measure.

References

Allan, A. **(2001),** "Walking as a Local Transport Modal Choice in Adelaide", Australia: Walking the **21st** Century, Proceeding, **20 - 22** February, Perth, West Australia, pp. **122-134.**

Ben-Akiva, M. and Lerman, S.R. **(1985),** Discrete Choice Analysis: Theory and Application to Travel Demand, The MIT Press, Cambridge, Massachusetts.

Beimbom, E.A., Greenwald, M.J., and Jin, **X. (2003),** "Transit Accessibility and Connectivity Impacts on Transit Choice and Captivity", Proceeding, TRB **2003** Annual Meeting, National Research Council, Washington DC.

Bradshaw, C. **(1993),** "Creating and Using a Rating System for Neighbourhood Walkability", Ottawalk Bulletin, Ottawa.

Cervero, R. **(2001),** "Walk-and-Ride: Factors Influencing Pedestrian Access to Transit", Journal of Public Transport, **Vol.7** Issue **3,** January, pp. **1-23.**

Clark, D.E. **(1997),** "Estimating Future Bicycle and Pedestrian Trips from a Travel Demand Forecasting Model", Compendium of Technical Papers, Institute of Transportation Engineers, pp. **407-414.**

Dejeammes, M. (2000), "Boarding Aid Devices for Disabled Passengers on Heavy Rail Evaluation of Accessibility", Transportation Research Record, No. 17**13,** Transportation Research Board, National Research Council, Washington **DC,** pp. **48-55.**

Dixon, L. **(1996),** "Bicycle and Pedestrian Level-of-Service Performance Measures and Standards for Congestion Management Systems," Transportation Research Record No **1538,** Transportation Research Board, National Research Council, Washington DC, pp. **1-9.**

Eash, R. **(1999),** "Destination and Mode Choice Models for Non-motorised Travel," Transportation Research Record No. **1674,** Transportation Research Board, National Research Council, Washington DC, pp. **1-8.**

Evans **IV,** J.E., Perincherry, V., Douglas III, G.B. **(1997),** "Transit Friendliness Factor, Approach to Quantifying Transit Access Environment in a Transportation Planning Model", Transuortation Research Record, No. **1604,** Transportation Research Board, National Research Council, Washington DC, pp. **32-39.**

FDOT (2001), Transit Level of Service (TLOS) Software, User's Guide, Version **3.1 ,** Florida Department of Transportation.

FHWA **(1999),** Guidebook on Methods to Estimate Non-Motorised Travel: Overview Method, Federal Highway Administration, US Department of Transportation.

Fock, W.T. (2003), "Measuring Walking Accessibility to Public Transport", Final Year Project, Nanyang Technological University, Singapore.

Fruin, J.J. (1971), Pedestrian Planning and Design, Metropolitan Association of Urban Designers and Environmental Planners, Inc., New York.

Gallin, N. **(2001),** "Quantifying Pedestrian Friendliness – Guidelines for Assessing Pedestrian Level of Service", Australia: Walking the **21st** Centurv, Proceeding, **20** - **22** February, Perth, West Australia, pp. **119-127.**

Greenwald, M.J. and Boarnet, M.G. **(2001),** "Built Environment as Determinant of Walking Behavior: Analyzing Nonwork Pedestrian Travel in Portland, Oregon", Transuortation Research Record No **1780,** Transportation Research Board, National Research Council, Washington DC, pp. **33-42.**

Gujarati, D.N. (2002), Basic Econometrics, Fourth Edition, McGraw-Hill.

Guyano, J.A. (1988), "A Study on Pedestrian Characteristics in Bangkok", Master Thesis, Asian Institute of Technology, Bangkok.

Halden, D., McGuigan, D., Nisbet, A., and McKinnon, A. (2000), Accessibility: Review of Measuring Techniques and Their Application, Scottish Executive Central Research Unit.

Handy, S.L. and Niemeier, D.A. (1997), "Measuring Accessibility: An Exploration of Issue and Alternatives", Environment and Planning A, Vol. 29, pp. 1175-1194.

Hansen, W.G. (1959), "How Accessibility Shapes Land Use", Journal of American Institute of Planners, No. 25, pp. 73-76.

Hass-Klau, C. (2001), "Walking and the Relationship to Public Transport", Australia: Walking the 21st Century, Proceeding, 20 - 22 February, Perth, West Australia, pp. 83-89.

Henk, R.H. and Hubbard, S.M. (1996), "Developing an Index of Transit Service Availability", Transportation Research Record No 1521, Transportation Research Board, National Research Council, Washington DC, pp. 12-19.

Hilman, R. (1997), "GIs-based Innovations for Modelling Public Transport Accessibility", Association for Geographic Information 1997 Conference, Proceeding, Birmingham, England.

Hsiao, **S.,** Lu, **J.,** Sterling, J., and Weatherford, M. (1997), "Use of Geographical Information System for Analysis of Transit Pedestrian Access", Transportation Research Record No 1604, Transportation Research Board, National Research Council, Washington DC, pp. 50-59.

Ingram, D.R. (1971), "The Concept of Accessibility: A Search for an Operational Form", Regional Studies, Vol.5, pp.101-107.

Jones, S.R. (1981), Accessibility Measures: A Literature Review, TRRL Laboratory Report 967, Department of Transport, Department of the Environmental, Transport and Road Research Laboratory.

Kean, A. and Tyler, N. (1999), Accessibility and Community-Centred Public Transport, Final Report, Centre for Transport Studies, University of London, London.

Ker, I. and Ginn, **S.** (2003) "Myths and Realities in Walkable Catchments: The Case **of** Walking and Transit", 21st AARB and 11th **REAA** Conference, 18-23 May 2003, Cairns, Queensland, Australia.

Knoblauch, R.L., Pietrucha, M.T., and Nitzburg, M. (1996), "Field Studies of Pedestrian Walking Speed and Start-up Time", Transportation Research Record No 1538, Transportation Research Board, National Research Council, Washington DC, pp. 27-38.

Loutzenheiser, D.R. (1997), "Pedestrian Access to Transit, Model of Walk Trip and their Design and Urban Form Determinants Around Bay Area Rapid Transit Stations", Transportation Research Record No 1604, Transportation Research Board, National Research Council, Washington DC, pp. 40-49.

Limdep version 7.0 (1998), User's Manual and Reference Guide, Econometric Software, Bellport, New York.

Makri, M.B. (2001), "Accessibility Indices. A Tool for Comprehensive Land-Use Planning", The 5th TLEnet (The Nordic Research Network on Modelling Transport, Land Use and The Environment) Workshop, 28 – 30 September, Nynashamn, Sweden.

Makri, M.C. and Folkesson, C. (1999), "Accessibility Measures for Analyses of Land Use and Travelling with Geographical Information Systems", http://www.trg.dk/td/papers/papers99/papers/paper/bpot/makri/makri.pdf (date of access: October 2002).

Manski, C.F. and McFadden, D. (1981), Structural Analysis of Discrete Data with Econometric Applications, The MIT Press, Cambridge, Massachusetts.

Meyer, M.D. and Miller, E.J. (2001), Urban Transportation Planning, Second Edition, McGraw-Hill International Edition, Singapore.

Milazzo 11, **J.S.,** Rouphail, N.M., Hummer, J.E., and Allen, D.P. (1999), "Quality of Service for Uninterrupted-Flow Pedestrian Facilities in Highway Capacity Manual 2000", Transportation Research Record, No. 1678, Transportation Research Board, National Research Council, Washington DC, pp. 18-24.

Miller, H.J. and Wu, YH **(2000),** "GIS Software for Measuring Space-Time Accessibility in Transportation Planning and Analysis", GeoInformatica, Vol. **4,** pp. **141-159.**

Mitchell, C.G.B. and Stokes, R.G.F. **(1982),** Walking as a Mode Transport, TRRL Laboratory Report **1064,** Transport and Road Research Laboratory, Department of the Environmental, Department of Transport.

Moudon, A.V. **(2001),** "Targeting Pedestrian Infrastructure Improvements: A Methodology to Assist Providers in Identifying Suburban Locations with Potential Increases in Pedestrian Travel", Research Report No. WA-RD 5**19.1,** Washington State Transportation Commission and **U.S.** Department of Transportation.

Olszewski, P. and Tan, C.S. **(1999),** "Walking lessons: Pedestrian travel in Singapore", Traffic Engineering and Control, Vol. **40,** No. 10, pp. **480-483.**

Ortuzar, J. D. and Willumsen, L.G. (2001), Modelling Transport, third edition, John Wiley and Sons, Ltd, Chichester.

O'Sullivan, S. and Morrall, J. **(1996),** "Walking Distances to and from Light-Rail Transit Stations", Transportation Research Record, No. **1538,** Transportation Research Board, National Research Council, Washington DC, **pp. 19-26.**

Parking Today **(2000),** "How Far Should Patrons Have to Walk After They Park?" Parking Today Bulletin, May **2000,** pp. **34-36.**

Pikora, T.J., Giles-Corti, B., and Donovan, R. **(2001),** "How Far will People Walk to Facilities in Their Local Neighbourhoods", Australia: Walking the 21st Centurv, Proceeding, 20 **- 22** February, Perth, West Australia, pp. **26-31.**

Polzin, S.E., Chu, **X.,** and Rey, J.R. **(2000),** "Density and Captivity in Public Transit Success, Observation from the **1995** Nationwide Personal Transportation Study", Transportation Research Record No **1735,** Transportation Research Board, National Research Council, Washington DC, pp. **10-18.**

Porter, C., Suhrbier, J., and Schwartz, W. **(1999),** "Forecasting Bicycle and Pedestrian Travel," Transportation Research Record **1674,** Transportation Research Board, National Research Council, Washington DC, pp. **94-101.**

Pushkarev, B. and Zupan, J.M. (1975), Urban Space for Pedestrian, The MIT Press, Cambridge, Massachusetts.

Rudnicki, A. (1999), "Equivalent Travel Time of Passengers as a Synthetic Performance Measure in Urban Public Transport", Urban Transport System, Proceeding of 2nd KFB Research Conference, 7-8 June, Lund, Sweden.

Seneviratne, P. and Fraser, P. (1987), "Issues Related to Planning for Pedestrian Needs in Central Business Districts, Pedestrian and Bicycle Planning with Safety Considerations", Transportation Research Record, No. 1141, Transportation Research Board, National Research Council, Washington DC, pp. 7-14.

Shriver, K. (1996), "Influence of Environmental Design on Pedestrian Travel Behaviour in Four Austin Neighbourhood", Transportation Research Record, No. 1578, Transportation Research Board, National Research Council, Washington DC, pp. 64-75.

Spear, B.D. and Weil, E.W. (1999), "Access to Intercity Public Transport Services form Small Communities: Geospatial Analysis", Transportation Research Record No 1666, Transportation Research Board, National Research Council, Washington DC, pp. 65-73.

Stringham, M. (1982), "Travel Behaviour Associated with Land Uses Adjacent to Rapid Transit Stations, ITE Journal, Vol. 52, No.4, pp.16-18.

Tanaboriboon, Y. and Guyano, J.A. (1989), "Level-Of-Service Standard for Pedestrian Facilities in Bangkok: A Case Study", ITE Journal, Vol. 59, No. 11, pp 39-41.

Tanaboriboon, **Y.** and Jing, Q. (1994)," Chinese Pedestrians and Their Walking Characteristic: Cace Study in Beijing", Transportation Research Record, No. 1441, Transportation Research Board, National Research Council, Washington D.C., pp. 16-26.

Tanaboriboon, **Y.**, Sim, S.H., and Chin, H.C. (1986), "Pedestrian Characteristics Study in Singapore", Journal of Transportation, Vol.112, No. **3**, pp.229-235.

TRB **(2000),** Highway Capacitv Manual **2000,** Transportation Research Board, National Research Council, Washington D.C.

Tyler, N. **(1999),** Measuring Accessibility To Public Transport: Concepts, Working Paper, Centre for Transport Studies, University College of London, London.

UIPT **(1981),** Dictionary of Public Transport, Union Internationale des Transports Publics, Brussels.

VTPI **(2003),** "Nonmotorized Transportation Planning: Identifying Ways to Improve Pedestrian and Bicycle Transport", Online TDM Encyclopedia, Victoria Transport Policy Institute, **http://www.vtpi.org/tdm/tdm25.htm** (last update: **10** December **2003),** data of access: **18** May **2004.**

Wapole, R.E., Meyers, R.H., Meyers, **S.L.,** and Ye, K. (2002), Probabilitv and Statistics for Engineers and Scientists, Seventh Edition, International Edition, Prentice Hall, New Jersey.

Yip, Y.B. **(2003),** "Measuring Walking Accessibility to Public Transport", Final Year Project, Nanyang Technological University, Singapore.

Zaworski, K.H, and Hron, M. L. (1999), **"Bus** Accessibility for People with Cognitive Disabilities", Transportation Research Record, No. **1671,** pp. **34-39.**