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MODELING WALKING ACCESSIBILITY TO PUBLIC TRANSPORT TERMINALS: CASE STUDY OF SINGAPORE MASS RAPID TRANSIT

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Abstract: Walking accessibility is defined as how easy it is to access public transport terminals by walking. Walking effort instead of walking distance or walking time is used to represent the utility of walking as access mode to public transport terminals (Mass Rapid Transit (MRT) stations). This effort is expressed by an equivalent walking distance, which consists of actual walking distance and generalized walking effort. The main objective of this research is to develop walking accessibility measure using equivalent walking distance. The probability of walking is introduced to show the acceptable walking distance to public transport terminal. This concept assumes that for every distance to the terminal, there is a probability of walking to access. Eventually, all components of walking route would be converted to equivalent distance. Each type of walking routes to access public transport (i.e. walkways, sidewalks and road crossings) has some elements that influence the effort of walking.

Keywords: Walking accessibility, Equivalent walking distance, Walking effort.

1. INTRODUCTION

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; and Polzin et al., 2000). 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 meters 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 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. So, 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. Thus, the walking share model could be developed to capture characteristics of the access mode choice to reach public transport terminal.

The characteristics of walking routes influence the walking effort and hence the qualities of public transport accessibility. They could not be derived from examining only walking distance or walking time. Equivalent walking distance will be introduced to express walking effort to access public transport terminal based on walking route characteristics. It would be derived from the walking share model and could be applied to assess public transport accessibility measure. The main objective of this paper is to model 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.

2. WALKING AS ACCESS MODE

In many public transport studies, walking is the important mode to access public transport terminals. As an example, the role of this mode to access rail stations, i.e. rapid transit system and conventional rail system, can be shown in Figure 1. The proportion of walking to access the main public transport in those cities is more than 20%. Since most of the rail stations are located in city centre, there is a higher proportion of walking in egress trip from station to the final destinations.

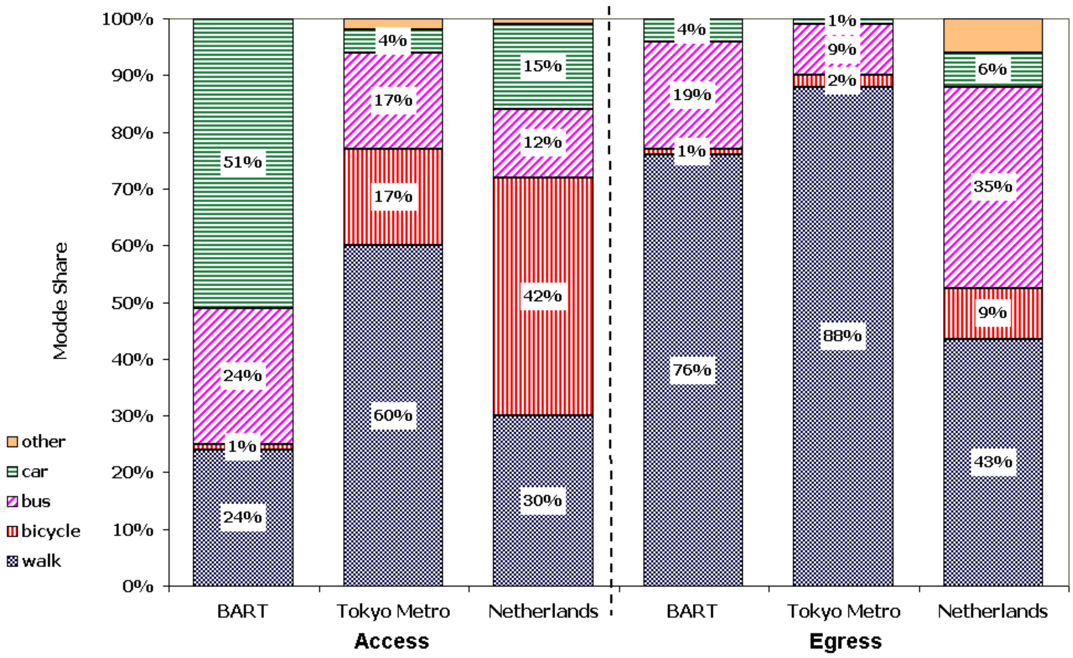


Figure 1 Access and Egress Mode Share
BART = Bay Area Rapid Transit, San Francisco

Walking distance to reach public transport terminals is the most important factor to indicate public transport accessibility. Most of public transport studies assumed that walking as an access mode occurred up to 400 to 800 meters of walking distance or 10 to 15 minutes of walking time (see Mitchell and Stokes, 1982; Stringham, 1982; O'Sullivan and Morrall, 1996; Halden et al. (2000), and Pikora et al., 2001 for detail). However, since walking accessibility is defined as the effort to reach public transport terminal, the characteristics of walking route may take into account to walking accessibility assessment (Wibowo, 2005).

3. WALKING ACCESS MODEL

3.1 Characteristics of Study Areas

To obtain a wide spread of localities and features relevant to walking accessibility, four study areas were selected for data collection. These areas are based on location of MRT stations. They are Clementi and Bedok (East-West MRT Line) and Bukit Batok and Choa Chu Kang (North-South MRT Line). The detailed analysis of walking share model and walking accessibility assessment were carried out for these four stations.

Each 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 only in Bukit Batok station). Thus, it was presumed that the stations could be reached by all possible access modes, such as walking, bus, taxi, car, bicycle and motorcycle. In Choa Chu Kang station, there is a Light Rapid Transit (LRT) operates as feeder mode.

On-site interviews and walking route assessments were carried out in the study areas. In the 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). 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.

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. Then, walking access model was 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.

3.2 Model Specifications

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 one chooses a walking as an access mode, he or she 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 walking 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.

The walking access model was developed for the catchment area that defined by 2000 meters 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 (origin point) and MRT station (MRT entrance point). The illustration of walking access model can be shown in Figure 2.

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 walking, bus, and LRT were 299 (46.3%), 316 (48.9%), and 31 (4.8%), respectively.

Binary logit model is utilised to develop walking access model. 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), or, can be expressed as,

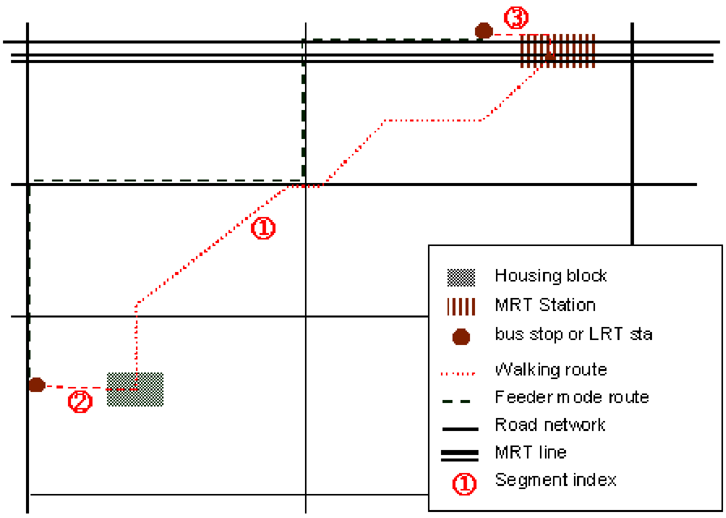
$$P_W = \frac{1}{1+e^{-(V_w - V_{nw})}} = \frac{1}{1+e^{-z}}; z = V_w - V_{nw}$$

where $V_w - V_{nw} = \boldsymbol{\beta}'\mathbf{x_i} = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_K x_K.$

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.



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 2 An Illustration for Walking Access Model

The descriptive statistics of the explanatory variables are shown in Table 1. Signalised and unsignalised (midblock and intersection) crossings are counted together as number of road crossings (RXING). Zebra crossings and other unmarked crossings are also counted in, whereas 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 (TCONF).

Table 1 Variables in Walking Access Model

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

3.3 Coefficient Estimation

Based on available data, ten variables were included in the model, as shown in Table 2. They 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 2 Data Input for Walking Access Model

Coeff.	Walking Mode	Feeder Mode	Input Variable	Remark
β_1	1	0	**MODE**	
β2	WDIST1	WDIST2+WDIST3	**DDIST** = WDIST1-(WDIST2+WDIST3)	Generic
β3	0	NWTIME	**-NWTIME**	Alt. specific feeder
β4	RXING1	RXING2+RXING3	**DRXING** = RXING1-(RXING2+RXING3)	Generic
β5	ASTEP1	ASTEP2+ASTEP3	**DASTEP** = ASTEP1-(ASTEP2+ASTEP3)	Generic
β6	TCONF1	TCONF2+TCONF3	**DTCONF** = TCONF1-(TCONF2+TCONF3)	Generic
β7	1: male 0: female		**SEX**	Alt. spec. socio
β8	1: 21-50 years old 0: otherwise		**AGEGP**	Alt. spec. socio
β9	1: feeder mode = LRT; 0: otherwise		**LRT**	Alt. specific feeder
β10	1: feeder mode = trunk bus; 0: otherwise		**TBUS**	Alt. specific feeder

LIMDEP version 7.0 (1998) was used to estimate the coefficients of walking access model. 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. As the result, the most satisfactory model was achieved and shown in Table 3.

Table 3 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		

The likelihood ratio test was carried out to test the null hypotheses of $\beta_i = 0$ 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 β_i could not be zero.

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:

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

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:

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

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

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

The effort to cross a car park or access road is equal to 36.31 meters of walking approximately.

4. EQUIVALENT WALKING DISTANCE

Walking accessibility to public transport is examined 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.

One possibility of the concept of equivalent walking effort is Equivalent Walking Distance (EWD). 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:

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

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. WDIST could be obtained from the survey directly. The characteristics of walking route can be derived from the Walking Access Model. Then, the EWD equation can be expressed as follows:

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

which based on Table 2, the complete equation becomes:

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

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

It is shown that EWD is the actual walking distance with the equivalent distance of the number of road crossing, ascending steps, and traffic conflicts. Unit of distance, i.e. metre, is used as the common unit.

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 airline distance (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 4 shows the average values of EWD, WDIST, ADIST and the ratios as well.

Table 4 Ratio of Average EWD, WDIST and ADIST

Location (MRT station name)	**$EWD_{ave.}$**	**$WDIST_{ave.}$**	**$ADIST_{ave.}$**	$\frac{EWD_{ave.}}{WDIST_{ave.}}$	$\frac{WDIST_{ave.}}{ADIST_{ave}}$	$\frac{EWD_{ave.}}{ADIST_{ave}}$
Clementi	1063.8	852.0	648.2	1.25	1.31	1.64
Bukit Batok	1161.3	877.9	673.6	1.32	1.30	1.72
Choa Chu Kang	1338.2	964.4	786.8	1.39	1.23	1.70
Bedok	1681.0	1404.8	979.0	1.20	1.44	1.72
All	**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. Choa Chu Kang station and Clementi have the longest and the shortest detour in average. There are need 'additional walking distance' such as number of road crossing, ascending steps, and number of traffic conflict, of 31% and 25%, respectively.

Walking facilities improvements can be examined using EWD 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. As an example, an additional pedestrian bridge will increase number of ascending steps but reduce number of road crossings. To find out the best scenario of improvement, EDW concept can be employed.

5. CONCLUSION

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.

Since 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.

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

Some future research can be carried out following this study. Some improvements on walking accessibility measure are needed, such as to use the GIS software for map calculation and presentation, extended for 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.

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