IMPACT OF WALKING DISTANCE ON ATTRACTIVENESS OF TRANSIT USE

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ABSTRACT

Stated preference data are used to investigate the impact of walking distance on the attractiveness of transit use. These data were obtained in experiments of mode choice comparing transit and other options under ranges of values for walking distances and other relevant attributes. A total of approximately 800 observations were collected in November and December of 2008. These were used to estimate the parameter values for a range of different utility functions in logit models. The results show that the 'per block' sensitivity to walking distance is significantly greater when the total walking distance is less than 2 blocks rather than more than 2 blocks, and that person age and vehicle ownership also have significant impacts. Some of these findings are novel while others are consistent with work done previously, and these findings have some implications for both theory and practice.

Keywords: Transit Attractiveness; Mode Choice; Walking Distance; Walking Time; Transit Service; Stated Preference; Logit Modelling

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1. INTRODUCTION

Walking has been identified as the most natural and significant method of access to transit (*Cervero 2001; Loutzenheiser 1997)*. Walking accessibility is often considered in the assessment of the performance and quality of transit services.

In many cases, transit service guidelines define a catchment area for transit use based on walking distances out from stations and/or stops. A range of upper limits for what riders are willing to walk of 400 to 800 meters distance or 10 to 15 minutes time are indicated (*TRB 2003*). For example, the maximum walking distance identified for the Miami Tri-Rail System is 2,000 feet *(Shaw 1991)*; and it is 2,000 meters for the Singapore rail system *(Wibowo and Olszewski 2005)*. But such maximum values on their own fail to represent how increased walking effort acts to reduce the attractiveness of transit along a continuum. That is, an increase in the required walking distance for a specific journey by transit from 50 to 350 meters, while still below the upper limit, nevertheless has a negative impact on the attractiveness and therefore on the likely use of transit and on the consumer surplus enjoyed by the user.

That transit use decreases as transit walking distance increases along a continuum is well known; egs: (*Ozbil et al., 2009; Untermann, 1984).* This is often expressed as a 'willingness to walk' profile, for example, where 'most people were willing to walk 500 ft, 40% would walk 1000 ft, but only 10% would walk a half mile'. Specifically, what is happening is that the attractiveness of transit is reducing as the walking requirement is increasing. This needs to be taken into account in the evaluation of services along with the other factors influencing the attractiveness of the service.

In transport demand modelling, the standard approach when representing the attractiveness (or 'utility') of transit alternatives is to include the impact of the required walking components by adding a total walking time factored by a constant sensitivity rate per unit time. Typically, this constant sensitivity is about two times the constant sensitivity for the ride time components, drawing on wide-ranging empirical results (*Wardman 2004; Wardman 2001; Gleave 1997; McKnight 1982)*. But, for any walking, the essential cost is related to the distance that is being traversed. The time it takes to cover the distance is endogenous – the result of the walking person's decision about how fast to cover the distance. A given distance is the same for all walkers, but the speed with which it is covered varies from person to person. On this basis, it is more appropriate to represent the impact of the required walking component using distance. The use of a constant sensitivity also seems constraining. Yet there appears to be little in the literature describing investigations of a non-linear representation.

This paper describes an investigation of a non-linear treatment of the impact of walking distance on the attractiveness of transit. The approach is to consider alternative utility functions for the transit option with different representations of the walking component, including piecewise-linear and separated forms for the sensitivity parameter, considering variations in sensitivities with distance, age, gender, income, car ownership and journey component (origin end vs destination end).

2. REVIEW OF PREVIOUS WORK

Various studies have considered the factors that affect walking accessibility to rail transit stations, including both light and heavy rail services (*Cervero 2001; Cervero and Kockelman 1997; Loutzenheiser 1997; Ozbil, et al., 2009; Wibowo and Olszewski 2005; Kim et al., 2007; Chalermpong and Wibowo 2007; Kuby et al 2004; Debrezion et al 2009; Park and Kang 2008; Jumsan et al., 2005*). The factors identified by these kinds of studies can be classified into three types:

1. Distance to transit station or stop
2. Socio-economic characteristics of the travellers
3. Characteristics of the built environment around the station or stop

In the strictest sense, these kinds of studies are considering impacts on walking accessibility to transit – specifically on the factors that influence the attractiveness of walking as a mode of access to transit – and not the impacts of walking distance on transit attractiveness per se. But they do provide some insight into the factors related to walking that can be expected to impact the attractiveness of transit.

Walking distance emerges as the single most important factor impacting the walking accessibility – underlying its important role in influencing the attractiveness of transit overall. A range of different relationships between physical walking distance and transit accessibility and resulting transit use have been observed, as demonstrated in Figures 1 and 2. Socio-economic characteristics, including age and gender, are also found to have impacts on walking accessibility *(Loutzenheiser 1997; Kim, et al., 2007)*. This suggests walking distance impacts transit attractiveness, but without a clear indication of the nature of that influence beyond increasing distances make transit less attractiveness. It also suggests there is some maximum distance that people are willing to walk that varies depending on circumstances. There is little to suggest whether the impact of walking distance is linear or non-linear, marginally increasing with distance or marginally decreasing with distance, etc. Various mathematical functions are fit to the distributions of walking distances directly – negative exponential a common choice – but this merely indicates the resulting draw of people to transit, and the resulting walking distances they will accept, not the impact of walking distance on the attractiveness of transit. It is also noted there is a strong focus on the origin end as opposed to the destination end of the walking component of transit use.

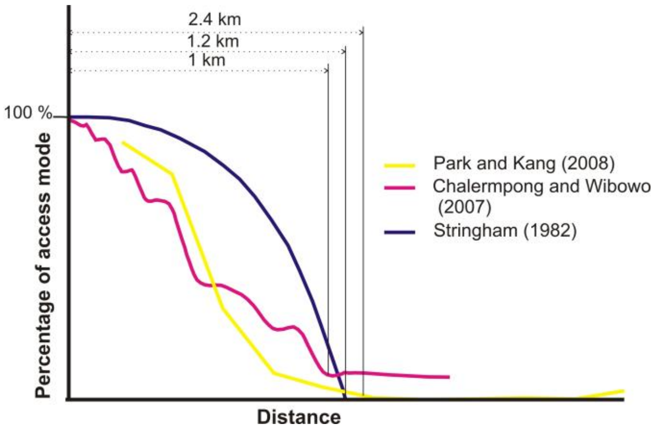

Figure 1: Walk mode share by distance (Compiled, modified and generalized from the study of Park and Kang (2008), Chalermpong and Wibowo (2007) and Stringham (1982*)*

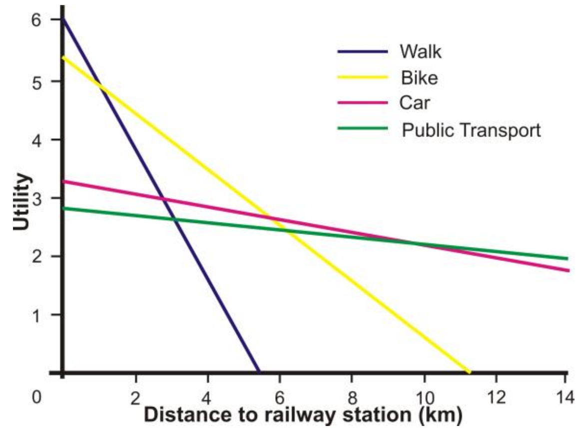

Figure 2: The Utilities of various access modes. Modified from Debrezion, Ples, and Rietveld (2009)

A few studies have considered walking accessibility (or related distributions of walking distance) to bus separate from rail. *Jumsan et al. (2005)* found that walking times to bus stops in particular varied across the population of bus users according to an exponential distribution, with gender, income and car ownership displaying significant influences. *O'Sullivan and Morrall (1996)* found that people tend to walk further to reach LRT than to reach bus. This again suggests that other aspects of transit attractiveness may compensate for the impact of walking distance – in this case the more appealing LRT service compensating for the more unappealing longer walk.

3. METHOD

3.1 Analysis Approach

The approach used in this work is to investigate the influences of various factors on transit attractiveness, with a focus on the influence of walking distance in particular. Relevant logit choice models are estimated using stated preference (SP) observations of the bus mode-related choices people make. SP observations in this case indicate the choices respondents make regarding hypothetical situations and options. The resulting coefficient estimates and associated statistics form the basis for inferences about the strength and statistical significance of the influences of specific factors on the attractiveness of alternatives.

The logit choice model has the following form for the choice situation concerning two hypothetical bus use alternatives considered here:

$$P_{B1} = \frac{\exp(U_{B1})}{\exp(U_{B1}) + \exp(U_{B2})}$$

Where,
P_{B1} = Probability that bus alternative 1 is preferred
U_{B1} = Utility value associated with bus alternative 1
U_{B2} = Utility value associated with bus alternative 2

The utility function that ascribes utility values to bus use alternatives has the following general linear form:

$U_{Bi} = \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_n X_{ni} + \ldots$

Where,

n = index representing attributes
X_{ni} = value of attribute n for alternative *i*
β_n = utility function coefficient associated with attribute n.

The logit model and the estimation of the coefficients in the utility function using empirical data are well-known. See *Ben-Akiva and Lerman (1985)* for a review of the relevant methods, issues and interpretation of results as used here. Computer programs that estimate the coefficients using maximum likelihood are readily available and ALOGIT *(Daly, 1992)* is used in this work

When the values for the utility function coefficients have been estimated, the relative influences of factors or the marginal rate of substitution can be determined by taking ratios among the resulting coefficient values *(Ben-Akiva and Lerman, 1985).* The significance of differences among the estimates can be considered using standard t-statistics and t-ratios, with the t-ratio for a given parameter estimate being the t-statistic for the estimate's difference from 0. A difference is 'significant' when the corresponding t-statistic or t-ratio has an absolute value greater than 1.96, indicating there is a less than 5% chance that the associated difference is due to random effects only *(Ang and Tang, 1975).* The overall model goodness of fit is considered using the $\rho^2(0)$ adjusted likelihood index, which is analogous to the R^2 statistic for linear regression and takes into account the number of parameters used in the model, favouring those specifications with fewer parameters *(Ben-Akiva and Lerman, 1985).*

3.2 Bus Attributes Considered

Many factors impact the attractiveness of transit use. Those more related to the design and operation of the system are of interest here, such as fare, service frequency, comfort, travel time, schedule, and stop spacing. Since a significant number of respondents find the task too difficult and do not try to be accurate if too many attributes are presented in the stated preference experiments *(Bates, 1988),* consideration was limited to those attributes and factors identified to be of specific interest in light of the literature review. The attributes are as follows:

- Walking distance from origin to boarding stop: 1, 2, 5 and 7 block were used
- Ride time: 15, 25, 30, and 45 minutes of ride time were used
- Bus fare (One way): C$1, C$2.5 and C$3 were used (here C$ denotes Canadian dollar)
- Walking distance from alighting stop to destination: 1, 2, and 7 block were used
- Schedule miss-match due to early or late arrival: 5, 10, 25 and 45 minutes were used.

Descriptions of the hypothetical alternatives were developed by selecting one out of a set of possible values for each of these attributes and combining these selected values into a bundle representing a complete alternative. With 4 possible values of three attributes and 3 possible values of two attributes, there were a total of 576 distinct hypothetical bus alternatives. Examples of two randomly generated hypothetical bus alternatives are presented in Table 1, together with some of the notes included to prompt interviewers through the interviews.

3.3 Survey Instrument

Each of the distinct hypothetical bus alternatives was printed on a separate 3"x5" (7.5cm x 12.5cm) card. An 11"X8.5" sheet of paper with socio-economic questions and survey instruction was used to conduct the survey and record the responses, one sheet for each respondent.

In each interview, the respondent was asked to participate in three SP trials where both an outbound and a return journey were considered, resulting in six separate SP 'games' in total. In all six games, a set of two bus alternatives and a set of three other alternatives were selected randomly from two full set of available combinations of conditions[1]. The respondent was then left to consider and physically move around the cards as part of the determination of the order of preference among the five alternatives.

When the respondent finally settled on an order of preference, he or she was then asked to rate each hypothetical alternative on a whole number scale from 0 to 10, where 0 represents 'terrible'

[1] The original survey conducted used five alternative hypothetical scenarios, two bus alternatives and three other alternatives from a set including taxi, car passenger with relation already driving, car passenger with relation not already driving, car passenger with friend already driving and car passenger with friend not already driving. The work described here considered only the bus alternatives and the relative preferences and scores among them.

Table 1: Examples of two randomly generated hypothetical bus alternatives

Bus alternative 1		**Bus alternative 2**	
Walk distance to stop	7 blocks	Walk distance to stop	1 block
Ride time stop to stop	45 mins	Ride time stop to stop	25 mins
Bus fare (one way)	$ 3.00	Bus fare (one way)	$ 1.00
Walk distance from stop	2 blocks	Walk distance from stop	2 blocks
Arrive before or Leave after meeting	10 mins	Arrive before or leave after meeting meeting	25 mins

- Consider journey where you are travelling from home to an all-day meeting and back home again; weather is good
- You do not have a car available for you to use as a driver
- You do not have any transit pass for this journey and must pay the full fares indicated here in all cases
- Consider alternative journey possibilities:
  - Different modes and arrangements, some involving friends or relations driving you
  - Relation is someone in your immediate family living in your household
  - Some involve arriving at meeting place early before meeting starts (with a wait time before meeting) or leaving from meeting place later after meeting ends (with a wait time after meeting); always waiting inside
- With different times and costs possible
- Described on cards
- Randomly select 2 cards from blue deck (the bus alternatives) and 3 cards from white deck (the non-bus alternatives) and put in order of preference and also rate on 0-10 scale; 3 runs, considering outbound and return in order – for a total of 6 trials

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5 represents 'neutral' and 10 represents 'excellent'.

This acted to confirm the indicated order of preference: if any inconsistency arose between the indicated order of preference and the 0 to 10 scores, where an alternative with a higher ranking got a lower score, then the order of preference and the scoring were revisited until the inconsistency was eliminated.

As part of the interview, the respondent was also asked to provide the following socioeconomic information:

- gender;
- age;
- household size;

- yearly income before tax;
- number of licensed drivers in the household; and
- number of private vehicles.

3.4 Data Collection

Calgary is the major city in the southern portion of the Province of Alberta in Canada. According to the Canadian Federal Census, the population of the City of Calgary was 988,193 in 2006.

In November and December 2008, a total of 16 students split into eight groups of 2 students each conducted interviews at market places and malls, transit stations and door-to-door. A total of approximately around 800 completed interviews were obtained, and this data set was used to estimate the coefficients in different utility functions. Orme (1998) has indicated this is a large enough sample to reveal the main effects and all two-way interactions.

4. RESULTS

4.1 Sample Characteristics

In the sample, the mean age of respondents was just above 31 years, with a minimum age of 14 years and a maximum age of 78 years. 11.2 percent of the respondents lived in households with no private vehicle. The average vehicle ownership overall was 1.58 per household, with a maximum ownership of 9 vehicles. The average number of licensed drivers per household was just above 2. 58.9 percent of the respondents were male. The average annual before-tax household income of those responding to the income question was C$87,956.

4.2 Model Output

Various alternate utility functions were considered using different combinations of variables. The estimation results for a selection of some of these utility functions are displayed in Table 2 and Table 3, with the parameter definitions provided in Table 4. These results are discussed below.

4.2.1 Function 1 - Baseline

Function 1 is the simplest and most direct representation of the preferences of the sample. For each attribute there is one coefficient that represents the overall average sensitivity for the entire sample. All the coefficient estimates are statistically significant and have signs consistent with expectations. For example, the coefficient for BWalk is negative, consistent with the notion that an increase in walking distance would make the bus use less attractive. The value for ρ^2 (0) is 0.3664, which is reasonably good for this form of model.

The ratio of the parameter estimate for BRide over the parameter estimate for BFare is C$0.08 per minute. This implies that the value of bus ride time in bus is about C$4.84 per hour (1 Canadian dollar = 0.97 USD approx.), which is a bit low compared to some previous results obtained in Calgary and elsewhere *(Iseki and Taylor, 2009)* but still in line with some other results *(Wardman, 1997)*. There may be some small amount of over-representation of low income persons and households in the sample, leading to a slightly low implied value of time generally.

The ratio of the parameter estimate for BWalk over the parameter estimate for BFare is 0.45. This implies that the value of walking is C$0.45 per block; or about C$3.00 per km based on about 150m for the length of a typical city block in Calgary. Assuming an average pedestrian speed of 4.50 km/h, the walking time value is found to be C$13.5. This is about 2.78 times the value of ride time, which is in the range of similar ratio values obtained work done previously *(Davies and Rogers, 1973; Gleave, 1997; and McKnight, 1982)*, which adds further credence to the result obtained here.

The ratio of the parameter estimate for BSchedMis over the parameter estimate BFare is 0.115, implying that the value of schedule mismatch due to early arrival or late departure caused by obligatory bus headway is C$0.115 per minute or C$6.90 per hour. This indicates that the respondents valued schedule mismatch waiting time more than in-vehicle travel time value.

Table 2: Estimation results for selection of utility functions considered, showing coefficient estimates, values of t-ratios and goodness-of-fit statistics

Parameter	Function 1		Function 2		Function 3		Function 4	
	Coeff.	*t-ratio*	*Coeff.*	*t-ratio*	*Coeff.*	*t-ratio*	*Coeff.*	*t-ratio*
BWalk	-0.2829	-27.1						
BRide	-0.0527	-17.7	-0.0527	-17.7	-0.0528	-17.7	-0.0528	-17.7
BFare	-0.6542	-17.9	-0.6546	-17.9	-0.6542	-17.8	-0.6553	-17.9
BSchedMis	-0.0753	-22.0	-0.0753	-22.0	-0.0755	-22.0	-0.0755	-22.0
BWalkOrig			-0.2931	-20.4				
BWalkDest			-0.2862	-22.7				
BWalkA					-0.4142	-8.1		
BWalkB					-0.3150	-21.0		
BWalkOrigA							-0.3688	-4.9
BWalkOrigB							-0.3107	-14.3
BWalkDestA							-0.4625	-6.8
BWalkDestB							-0.3204	-17.6
$\rho^2(0)$	0.3664		0.3665		0.3675		0.3678	

Table 3: Estimation results for selection of utility functions considering socio-economic attributes, showing coefficient estimates, values of t-ratios and goodness-of-fit statistics

Parameter	Function 5		Function 6		Function 7		Function 8		Function 9	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
BRide	-0.0527	-17.7	-0.0540	-17.8	-0.0537	-17.7	-0.0529	-17.6	-0.0529	-17.7
BFare	-0.6553	-17.9	-0.6584	-17.7	-0.6554	-17.6	-0.6490	-17.6	-0.6557	-17.9
BSchedMis	-0.0754	-22.0	-0.0749	-21.5	-0.0742	-21.5	-0.0752	-21.9	-0.0754	-22.0
BWalkM	-0.2877	-21.6								
BWalkF	-0.2913	-18.6								
BWalkAge1			-0.3552	-3.5						
BWalkAge2			-0.2634	-19.2						
BWalkAge3			-0.3200	-19.7						
BWalkAge4			-0.4416	-7.0						
BWalkIncm1					-0.2859	-18.2				
BWalkIncm2					-0.3566	-12.6				
BWalkIncm3					-0.3012	-11.9				
BWalkIncm4					-0.2673	-14.4				
BWalkNVeh							-0.2454	-9.0		
BWalkVeh							-0.2956	-25.9		
BWalkVD1									-0.2498	-10.0
BWalkVD2									-0.2853	-16.0
BWalkVD3									-0.3017	-21.7
$\rho^2(0)$	0.3666		0.3708		0.3695		0.3664		0.3670	

Table 4: Definitions of variables

Parameter	Definition
BWalk	Walking distance related to bus use
BRide	Bus ride time
BFare	Bus fare
BSchedMis	Schedule mismatch due to bus use
BWalkOrig	Walking distance from origin to boarding stop
BWalkDest	Walking distance from alighting stop to destination
BWalkA	Walking distance when walking distance from origin to boarding stop is less than or equal to 2 blocks, 0 otherwise
BWalkB	Walking distance when walking distance from origin to boarding stop is less than or equal to 2 blocks, 0 otherwise
BWalkOrigA	Walking distance when walking distance from origin to boarding stop is less than or equal to 2 blocks, 0 otherwise
BWalkOrigB	Walking distance when walking distance from origin to boarding stop is greater than 2 blocks, 0 otherwise
BWalkDestA	Walking distance when walking distance from alighting stop to destination is less than or equal to 2 blocks, 0 otherwise
BWalkDestB	Walking distance from alighting stop to destination is greater than 2 blocks, 0 otherwise
BWalkM	Walking distance when the respondent is male, 0 otherwise
BWalkF	Walking distance when the respondent is female, 0 otherwise
BWalkAge1	Walking distance when age of the respondent is less than 18 years, 0 otherwise
BWalkAge2	Walking distance when age of the respondent is between 18 and 30 years, 0 otherwise
BWalkAge3	Walking distance when age of the respondent is between 30 and 55 years, 0 otherwise
BWalkAge4	Walking distance when age of the respondent is between 55 and 78 years, 0 otherwise
BWalkIncm1	Walking distance when household income of the respondent is less than $40000, 0 otherwise
BWalkIncm2	Walking distance when household income of the respondent is between $40000 and $65000, 0 otherwise
BWalkIncm3	Walking distance when household income of the respondent is between $65000 and $95000, 0 otherwise
BWalkIncm4	Walking distance when household income of the respondent is more than $95000, 0 otherwise

Table 4: Definitions of Variables - continued

Parameter	**Definition**
BWalkNVeh	Walking distance when the household of the respondent doesn't own any vehicle, 0 otherwise
BWalkVeh	Walking distance when the household of the respondent owns one or more vehicle, 0 otherwise
BWalkVD1	Walking distance when vehicle over driving license ratio of the respondents household is less than 0.34, 0 otherwise
BWalkVD2	Walking distance when vehicle over driving license ratio of the respondents household is between 0.34 and 0.67, 0 otherwise
BWalkVD3	Walking distance when vehicle over driving license ratio of the respondents household is more than 0.67, 0 otherwise

This is consistent with findings elsewhere: that transit riders are very sensitive to out-of-vehicle time, particularly waiting time *(Cervero, 1990)*. A common rule of thumb is that waiting time is considered twice as onerous as in-vehicle time, and was supported by several studies reviewed by *Wardman (2001).* However, those studies considered waiting time at transit stops, where waiting time disutility might be exaggerated by waiting in unpleasant or threatening environments, such as cold, hot or rainy weather, in an unsafe and unsecured location. This study found that time spent waiting for transit or spent waiting because of transit – the schedule mis-match time, is more onerous than riding time, even in a pleasant environment and secured location. This is consistent with the notion of 'time-drag' – which is time spent inactive or unfulfilled that is judged unproductive and/or burdensome *(Dziekan and Kottenhoff, 2007)* and thus felt more keenly, and even perceived to be longer in duration that in reality (*Dziekan and Vermeulen, 2006*).

4.2.2 Function 2 - Differences in sensitivities for origin and destination walk distances

Function 2 is designed to test the hypothesis that the sensitivity to walking distance varies between origin end and destination end of travel.

The estimated coefficients for the walking distances at the origin and destination end are marginally different, indicating travelers are slightly more sensitive to walking at origin end, with 1 block at the origin end equivalent to 1.025 blocks at the destination end. This difference is not statistically significant, with a t-statistics of only -0.42. This contradicts the findings of previous work by *Hunt (1990)*, who found a statistically significant difference in the sensitivity to walking distance at origin end and destination ends using revealed preference (RP) rather than stated preference data. Different combinations of levels were used for the origin walking distances (1, 2, 5 and 7 blocks) and destination walking distances (1, 2 and 7 blocks) in order to keep the number of alternatives to a manageable size, and it was hypothesized that this may have had some impact on the results obtained here. As a test, the observations with 5 blocks at the origin end were removed from the sample and the estimation re-run, and it was found that results were essentially the same. Of course, the results found elsewhere for a different location and a different situation may be different because the actual behavior was different, such that both sets of results are valid. Or the results found using the RP behavior may have been affected by the strategy used to identify the un-chosen alternatives. But it may be that walking distances are perceived differently in the real world, and that those distances at the start are more onerous than those at the end of a journey, because they are encountered in that sequence, which can be measured with RP data, but cannot be measured with SP data where both the origin and destination end distances are presented simultaneously. This does raise some concerns about the use of SP in this context.

4.2.3. Function 3 and Function 4 - Non-linear sensitivity to walk distances

Function 3 and Function 4 are designed to test the hypothesis that the sensitivity to walking distance is a non-linear function of distance. The breakpoint distance considered is 2 blocks. That is, one sensitivity coefficient showing the sensitivity per block is considered for distances up to and including 2 blocks and another sensitivity coefficient showing the sensitivity per block is considered for distances greater than 2 blocks. Function 3 tests the non-linearity in sensitivity for all walking distances; whereas Function 4 tests the non-linearity in sensitivity for origin end and destination end walking separately.

It is found that the coefficient for walking distances up to and including 2 blocks are significantly more negative than that for walking distances greater than 2 blocks, with a t-ratio of 2.50 on the difference. This indicates that walking distances are more onerous per block for short distances (up to 2 blocks) and then less onerous per block beyond that.

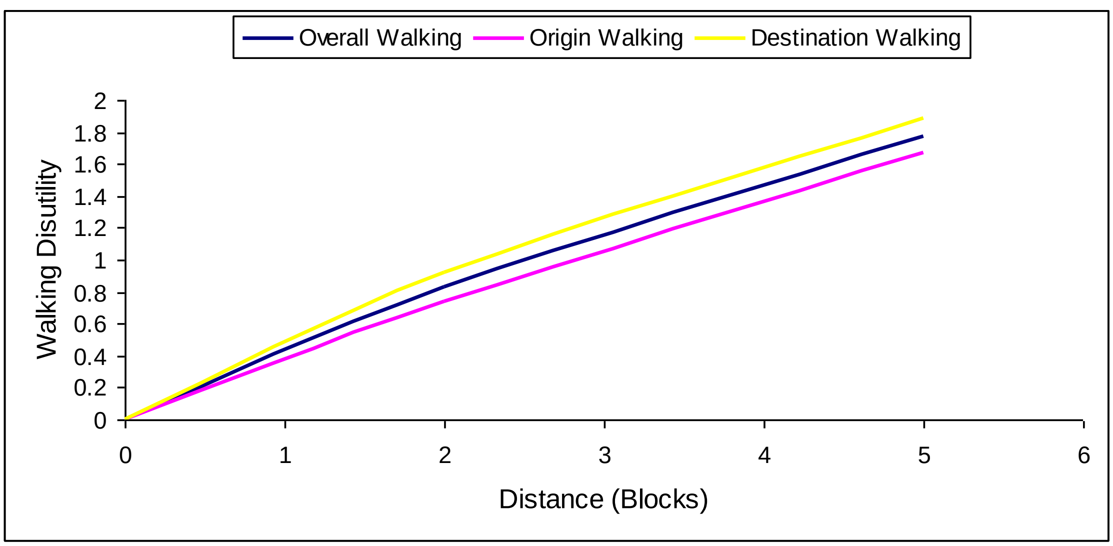

Figure 3: Walking Disutility as a Function of Walking Distance

The coefficients estimates for BWalkA and BWalkB together imply that each additional block after the first 2 is only 0.76 as each of the first two. This is consistent with the concept of diminishing marginal utility (or disutility) where the per unit impact of attributes decreases as the number of units increases. It is also counter to the common practice in transport modelling of representing walking disutility as a linear function of distance, although the relationship is still close to linear, as can be seen in Figure 3.

Horowitz (1981) found evidence that the subjective value of walking time increases at about the same rate as the corresponding values for bus and auto for trip lengths less than 24 minutes, but increases at a much greater rate for trip lengths more than 24 minutes. This suggests an increasing rate of disutility for longer walking distances, contrary to the findings here. The same study found indications that for bus waiting times, the second and third sets of five minutes are not as onerous as the first set of five minutes, so the concept of diminishing marginal utility was supported for some attributes, but not for walking. It may be that walking for long distances is perceived differently, or that ex post justification dominates for longer distances where walking is most unlikely. It could also be that the non-linear nature of the influence of walking distances changes for substantially longer distances. The work here considered walking distances up to a maximum of 7 blocks, equivalent to about 1km based on about 150m for the length of a typical city block in Calgary. Some greater distances should be considered in further work in order to further elucidate this issue.

The parameter estimates for Function 4 are broadly consistent with the parameter estimates for Function 3. The coefficients estimates for BWalkOrigA and BWalkOrigB together imply that each block of walking up to 2 blocks at origin end is 1.18 times as onerous as each block of walking beyond 2 blocks, though the t-statistic for the difference is only -1.01. For the destination end, the coefficient estimates for BWalkDestA and BWalkDestB together imply that each block of walking up to 2 blocks is 1.44 times as onerous as each block of walking beyond 2 blocks, with a t-statistic of -2.63. Considering the sensitivity to each block of walking up to and including 2 blocks at the two ends, the coefficient estimates for BWalkOrigA and BWalkDestA together indicate that walking at the destination end is 1.25 times as onerous as walking at the origin end, but with a t-statistic of only 0.95 on the difference. For beyond 2 blocks at each end, the coefficient estimates for BWalkOrigB and BWalkDestB are not significantly different statistically, with a t-ratio of only 0.37. Thus the results for Function 4 are broadly consistent with those for Functions 2 and 3: that sensitivities to each additional block of walking distance are greater for short distances (up to 2 blocks) and not significantly different at the origin rather than the destination end.

The values of the coefficient estimates for the walking sensitivities in both Function 3 and Function 4, including in particular BWalkA and BWalkB in Function 3 and BWalkOrigA, BWalkOrigB, BWalkDestA and BWalkDestB in Function 4, are somewhat surprising, relative to the values for the walking sensitivities in Functions 1 and 2, including in particular BWalk in

Function 1 and BWalkOrig and BWalkDest in Function 2. The values in Function 2 (-0.2931 and -0.2862) are both similar to the single value in Function 1 (-0.2829) as would be expected. But the values in Function 3 (-0.4142 and -0.3150) are both substantially larger in absolute magnitude than those in Functions 1 and 2. Those in Function 4 (-0.3688, -0.3107, -0.4625 and -0.3204) are also substantially larger than those in Functions 1 and 2. The values for the estimated coefficients for the other attributes included in the utility functions remain quite stable across these four functions. It was expected that the walking sensitivities would change across these functions, indeed, the variations in these was the subject under investigation. But it was also expected that the set of results with multiple split sensitivities (in Functions 2, 3 and 4) would 'bracket' the single sensitivity (in Function 1). This has been the experience of the authors in previous such work. However, it did not occur in any of Functions 2, 3 or 4; rather, the multiple split values were always greater in absolute magnitude. The differences were very minor in Function 2, and substantially larger in Function 3 and 4. Concern about the validity of these results gave rise to a substantial amount of rechecking of the function specifications and the analysis results. All appear to be valid. These results and discussion are included here without a clear understanding of why they have been obtained and what they signify.

4.2.4 Function 5 to Function 9 - Sensitivity across socio-economic groups.

Functions 5 through 9 are designed to examine the sensitivity to walking distance across various socio-economic categorizations.

Function 5 concerns the variation in sensitivity across gender. It indicates that females are marginally more sensitive to walking distances, but with a t-statistic of only 0.20 for the difference. This is consistent with the findings of previous work by *Chalermpong and Wibowo (2007)*, but it contradicts those of other work by *O'Sullivan and Morrall (1996); Loutzenheiser (1997); and Kim et al. (2007.*

Function 6 concerns the variation in sensitivity across age groups. The sensitivities to walking distances are plotted for different age groups in Figure 4. The results are as expected: older people and very young people are relatively more sensitive to walking distances compared to people in the age groups from 18 to 55 years. Those in the 18 to 30 years age group are the least sensitive to walking distance. The parameter estimates for the middle two age groups, BWalkAge2 and BWalkAge3, are significantly different statistically, with a t-statistic of 2.80; whereas those for the older two age groups, BWalkAge3 and BWalkAge4, are not so much so, with a t-statistic of 1.87. Variations in the sensitivity to transit walking distances across age have been noted in previous work by others, including *Neilson and Fowler (1972); Loutzenheiser (1997); and Jumsan et al. (2005)*.

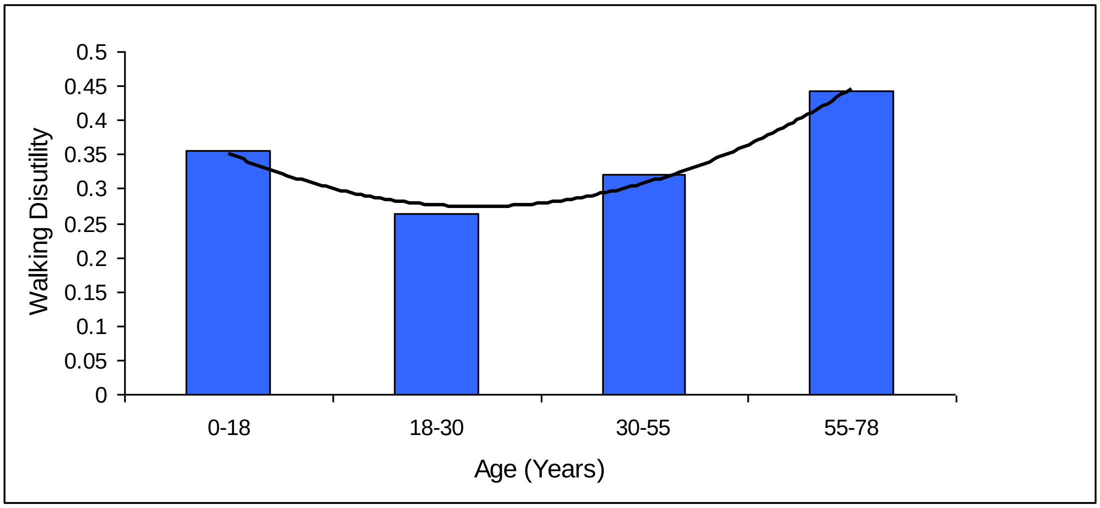

Figure 4: Sensitivity to Walking Distance by Age Group

Function 7 concerns the variation in walking sensitivity across income groups. There was some expectation that those with higher incomes would display greater sensitivities to walking distances, analogous to the higher values of time displayed. Previous work has also obtained such indications *(Jumsan et al. 2005; and Loutzenheiser 1997).* The results obtained for the coefficient estimates for BWalkIncm1 through BWalkIncm4 do not display a consistent pattern of increasing sensitivity, but with some of the t-statistics for the differences greater than 2.00 in absolute magnitude. This could be in part due to difficulties in getting reliable indications of incomes in the survey.

Function 8 concerns the variation in walking sensitivity across vehicle ownership status. It indicates that those from households with private vehicles are more sensitive to walking distances, with a t-statistic of 1.73 for the difference.

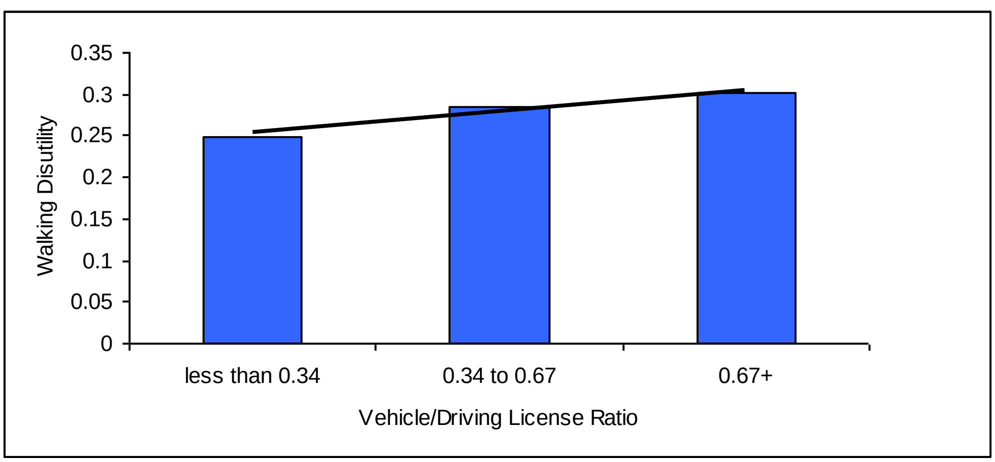

Figure 5: Sensitivity to Walking Distance by Vehicle Availability

Function 9 concerns the variation in walking sensitivity across vehicle availability, as measured by the ratio of the number of vehicles over the number of licensed drivers in the household. The results for the walking sensitivity parameters, BWalkVD1, BWalkVD2 and BWalkVD3, are shown graphically in Figure 5. As expected, and consistent with the results for Function 8 and the expected contributing effects, sensitivity to walking distance increases as vehicle availability increases.

5. CONCLUSION AND POLICY IMPLICATIONS

This study analyzed the impact of walking distances on the attractiveness of transit use. Stated preference data describing preferences among public transport service attributes were obtained and used to establish indications of sensitivities to these attributes and how these sensitivities vary across conditions and various socioeconomic factors.

Walking distances to and from bus stops are shown to have important and significant influences of the attractiveness of bus use, along with fares, ride times and schedule mis-match times. All these influences are shown to be negative in that the attractiveness of transit is reduced as these values increase. The implied value of ride time is C$4.84, which is perhaps a bit low but still broadly consistent with results from other work.

Differences in sensitivities to walking distance were identified across gender, age, and vehicle ownership and availability consistent with expectations. Differences across income groups could not be established consistent with expectations. Statistically significant differences in sensitivities to walking distance at different distances were found, amounting to indication of a non-linear influence of distance where the marginal impact is decreasing as distance increases. Origin and destination end walking distances were shown to have much the same rates of impact, which is contrary to findings of some other works, for reasons that are not clear.

Some of the results obtained in the consideration of variations in the sensitivity to walking distance are curious. When the single sensitivity for all contexts is split into two, one for distances up to 2 blocks and another for distances beyond two blocks, then the resulting two values do not bracket the original single sensitivity. This is different from previous experience, for reasons that are not clear.

The results obtained here have some important implications for the theory and modelling of transit use and the factors influencing this use. The representation of the sensitivity to walking distance should allow for non-linearity, consistent with the notion of diminishing marginal impacts. It should also be permitted to vary across the population, with different values for different age groups and different levels of automobile ownership and availability. The sensitivity to walking distance for the origin component of the journey (to the bus stop) may not be significantly different from the corresponding sensitivity for the destination component (from the bus stop) – contrary to the results of some previous work. The implication is that the origin and destination components of walking distance can be summed into a single total value to be used in utility functions of transit use. But there is enough uncertainty about this finding that more investigation into the relative sensitivities at origins and destinations is warranted.

The results obtained here also have some important implications for transit design and analysis. In general, the sensitivities to walking distance and other attributes of transit service in the results can be used to guide the tradeoffs to be made among these attributes in the design of routes and networks. For example, there may be two options for service configuration under consideration. One option has a more even distribution of services with each route running along its own path less frequently in order to minimize walking distances at the expense of schedule mis-match. The other option has an uneven distribution of services with groups of routes running along shared paths more frequently in order to minimize schedule mis-match at the expense of walking distances. The relative sensitivities established in this work can be used to evaluate which option has more utility for passengers – perhaps in the form of utility equations and corresponding changes in consumer surplus. This potential practical use of these sensitivity indications has been identified previously; see, for example, the TRAM model *(Hunt and Cooper, 1992).* The finding that increases in walking distance are more onerous for short distances has the implication that all other things being equal there should be more focus on reducing walking distances to transit in higher density areas where distances are already short. Variations in route patterns and walking distances in different locations should also be considered, such as in areas with lower car ownership or a greater proportion of people aged 18-55 years for example, where the route pattern design need not focus as much on reduced walking distances. Conversely, as older people are comparatively more sensitive to walking distances, more emphasis should be placed on minimizing walking distances for senior housing and recreation centres.

This study was limited to the investigation of sensitivities to certain attributes using stated preference data. The focus was on the impacts of walking distances, with these distances expressed in units of blocks. Other more precise and transferrable representations of distances should be considered in further work, such as meters and feet, along with a greater range of more values, beyond just 1, 2, 5 and 7 blocks. The influence of LRT, as opposed to bus, on the sensitivity to walking distance should also be considered – to see if people are willing to walk greater distances to LRT because of (a) the better service provided by LRT compensating for longer walking or (b) the sensitivity to walking distance itself reducing with LRT. Finally, the 0 to 10 scores collected in the survey are in effect measures of the direct utility the respondents associated with the options. These could be used as the dependent variables in more standard regression analysis, and in truncated forms of such analysis, in order to further investigate the influences of the attributes.

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