Transportation **24**: 377–396, 1997
© 1997 *Kluwer Academic Publishers. Printed in the Netherlands.*

Accessibility: an evaluation using consumer welfare

DEBBIE A. NIEMEIER
Department of Civil and Environmental Engineering, University of California, Davis, CA 95616, USA

Accepted 24 January 1997

Key words: accessibility, journey to work, transit

Abstract. This study explores the worth consumers place on mode-destination accessibility for the AM journey to work trip. To accomplish this, a multinomial mode-destination choice model is estimated and the denominator of the specified logit model is used as an estimate of mode-destination accessibility. To improve the interpretability of this measure, compensating variation is then applied to convert the mode-destination accessibility to units of dollars per AM journey to work trip. The model is estimated using travel survey data from the Puget Sound Region in Washington state. It is reasonable to assume, for example, that the worth placed on mode-destination accessibility varies by mode, by destination, and by market segment (e.g., low income, high income). Less intuitive, however, are the magnitude and direction of these variations. This paper presents a methodological approach, followed by an empirical evaluation, for examining the worth of journey to work mode-destination accessibility. The results have important policy implications and also provide a mechanism for incorporating a monetary value for accessibility in future cost-benefit analyses.

Introduction

Although there is constant outcry suggesting the need for improving mode and destination accessibility, there is really little to no information on how an individual might actually value changes in accessibility. Consequently, it is difficult to assess if the cost of improving mode or destination accessibility would outweigh the consumer's willingness or ability to pay. It is reasonable to assume, for example, that the worth placed on mode-destination accessibility varies by mode, by destination, and by market segment (e.g., low income, high income). Less intuitive, however, are the magnitude and direction of these variations. This paper presents a methodological approach, followed by an empirical evaluation, for examining the worth of journey to work mode-destination accessibility. The results have important policy implications and also provide a mechanism for incorporating a monetary value for accessibility in future cost-benefit analyses.

The discussion begins with a brief overview of common measures of accessibility, including single index measures such as the gravity type and cumulative opportunities indicators. The second section presents a methodological approach using random utility theory and compensating variation. The presentation continues with a description of the empirical analysis and results. Finally, the paper concludes with a discussion of policy implications and future research needs.

Accessibility: a review

Accessibility typically refers to the "ease" with which desired destinations may be reached and is frequently measured as a function of the available opportunities moderated by some measure of impedance. Opportunities may be expressed as employment levels and retail or non-retail square footage depending upon the application; impedance is usually denoted by travel time. Early techniques, such as that used by Cohen and Basner (1972), applied graphical curve construction techniques relating travel time to opportunity to reflect accessibility by mode, by period of day, by income, ethnicity, employment, shopping, recreation, etc. (1972). Curves were then compared to averages for local or regional travel trends.

Black and Conroy (1977), building on the graphical techniques, represented opportunities as a cumulative distribution in which accessibility is measured as a function of the proportion of activities passed and their distribution over time. The drawbacks associated with these measures include the arbitrary selection of a cut-off time and the practicality of examining every curve for every analysis area or socio-economic construct. These drawbacks lead naturally to accessibility measures that can be aggregated over the one to many exchanges, providing a single accessibility value for a given analysis area.

Early single value studies (Wachs & Kumagal 1973; Wickstrom 1971) modeled accessibility as cumulative functions of opportunities that could be reached within a predefined time. The drawbacks to using this measure of accessibility include an arbitrary time specification and the lack of efficiency when examination by socio-economic variables is desired. As others have noted (Vickerman 1974), this measure also implies that all jobs are equally desirable, regardless of the time spent in travel or the type of job opportunity. To partially address these criticisms, other accessibility measures have been proposed specifying a functional form allowing accessibility to decrease as the travel time to destinations becomes longer.

Perhaps the most generally used measure of accessibility having this type of functional form is the denominator of the gravity model. A number of transportation agencies, including the Erie Transportation Study and the Puget

Sound Transportation Study (Basmaciyan & Schmidt 1964) have used the denominator of the gravity model to evaluate accessibility. In the Puget Sound Study, accessibility was stratified by income groups in each zone and ratios of transit to highway accessibility's were integrated in the mode choice estimation. Handy (1992) also recently applied a modified disaggregate form of the denominator of the gravity model in an evaluation of differences between local and regional accessibility in the San Francisco Bay Area.

As with previously discussed accessibility measures, there are difficulties associated with using either the denominator of the gravity model or summations of opportunities to reflect accessibility. Although Handy's (1992) recent work suggests that with careful application the gravity model will provide important insights, the most obvious problem with these methods is the lack of a direct relationship between individual choice and accessibility; for a specified area (zone) all individuals will receive the same value of accessibility regardless of their travel choices (Ben-Akiva & Lerman 1979). There are also methodological issues associated with determining the appropriate level of aggregation, constructing a friction factor to reflect spatial separation and general travel patterns and deciding on the appropriate measure of attractiveness (Hanson & Schwab 1987).

The multiplicity of these assumptions, particularly that associated with travel by the individual, have motivated researchers to develop accessibility measures that link individual choice with mode and opportunity. Burns (1979) proposed an alternative framework for conceptualizing accessibility in which accessibility is associated with the "freedom of individuals to decide whether or not to participate in different activities". Constraints that limit individual freedom, or accessibility, are organized into three components: transportation, temporal, and spatial.

Burns study provides an important conceptual extension to previous measures of accessibility. The benefit of transportation improvements are viewed in terms of how well individual freedom is enhanced. Both temporal and spatial dimensions are incorporated and finally, accessibility is "*value-weighted*"; accessibility benefits are subjective and based on the value of opportunities assigned by individuals. Random choice utility models provide a formal modeling mechanism for incorporating several important aspects of Burns' framework.

Accessibility: an econometric framework

Regarding accessibility as the realization on a set of transportation choices, *TC*, leads to construction of an accessibility measure based on random utility models. If it is assumed that each alternative *k* in choice set *TC* has total utility,

U_k, and further, that each individual will select the alternative that maximizes their total utility, then a simple definition for accessibility is (Ben-Akiva & Lerman 1979):

$$E\,(\max_{\forall k \in TC} U_k) \tag{1}$$

where E denotes the expected value.

It is well known that this value, associated with the deterministic portion of the total utility, V, may be derived under a multinomial logit formulation as (McFadden 1981):

$$A_n = \ln\,(\sum_{\forall k \in TC} e^{V_{nk}}) \tag{2}$$

where,

A_n = accessibility for person n

V_{nk} = observable transportation, temporal, and spatial components of indirect utility of choice k for person n

However, in order to utilize the expected maximum utility, or logsum, as a measure of accessibility, it is important to first return to Burns' compositional framework of accessibility.

If, as Burns (1979) hypothesizes, accessibility has transportation, temporal, and spatial components then the choice set for measuring accessibility must reflect each of these dimensions. Thus, this methodological approach begins by defining an indirect utility function describing a mode-destination choice set structure with transportation, temporal, and spatial components. Dropping the individual subscript n and separating the combined mode-destination alternative k into components i for mode and j for destination to improve clarity, an indirect utility function for the mode-destination choice may be specified as:

$$V_{ij} = f(TP_{ij}, T_{ij}, S_j, \varepsilon_{ij}) \tag{3}$$

where,

V_{ij} = Indirect utility of mode choice i and destination choice j

TP_{ij} = Vector of modal char. associated with mode choice i and destination choice j

T_{ij} = Vector of temporal char. associated with mode choice i and destination choice j

S_j = Vector of spatial char. associated with destination choice j

ε_{ij} = Unobserved random portion of utility

By assuming ε_{ij} random and generalized extreme value distributed (McFadden 1981), the model specified in (Eq. 3) may be estimated using a multinomial logit (MNL) random utility model. Under the joint MNL mode-destination choice construct, the logsum, or natural log of the denominator reflects the journey to work accessibility of the joint temporal, mode and destination choice.

As Williams (1979) notes, the MNL form of accessibility is also linked to consumer welfare: the model specification can be viewed as the demand curve for a particular mode-destination alternative *k*. The difference in consumer surplus can be calculated for two scenarios based on the change in systematic utilities, i.e., the difference in expected maximum between a base condition, V^1, and a scenario reflecting a policy change, V^2:

$$\ln \sum_{k \in TC^1} e^{V_k^2} - \ln \sum_{k \in TC^1} e^{V_k^1} \tag{4}$$

There is one serious drawback to accessibility in this form; different model specifications can not be compared (Ben-Akiva & Lerman 1985). However, utilizing theoretical research in the econometric literature, accessibility may be converted to monetary, and thus comparable, real units using compensating variation (CV). Compensating variation may be interpreted as the dollar amount an individual would have to be compensated to be as well off as before a policy change (Freeman 1993; Zerbe & Dively 1994). The benefits of this transformation include the ability to compute an average "worth" for the journey to work temporal-spatial-transportation choice as well as facilitating comparisons of similar accessibility worths computed by different model specifications.

Small and Rosen (1981) have shown that an estimate of consumer welfare, using compensating variation, can be derived in discrete choice situations for the MNL model as:

$$\Delta CV = -\left(\frac{1}{\lambda}\right)\left[\ln \sum_{k=1}^{l} e^{V_k}\right]_{V^1}^{V^2} \tag{5}$$

where,

ΔCV = Compensating Variation (in units of dollars)
λ = Marginal utility of income
V = Mean indirect utility
k = a combined mode-destination choice
V^1 = Mean indirect utility for scenario 1
V^2 = Mean indirect utility for scenario 2

The term in brackets reflects the expected maximum utility before and after a change (e.g., pricing policy). This difference is multiplied by the inverse of the marginal utility of income to derive the compensating variation (in units of dollars for the same time period reflected in the choice set). Thus accessibility, in monetary units, may be derived for different individuals or sub-populations.

Compensating variation (CV) has been used to estimate the change in consumer welfare in many recent applications. Mannering and Winston (1987) used CV to estimate the change in consumer welfare before and after the voluntary export restrictions negotiated with the Japanese government in 1981. Their research showed that the deadweight loss to society from the restrictions approached $5 billion. Mannering (1994) also used the technique to estimate the change in consumer welfare before and after a proposed audio home copying ban. The results indicated that, on average, a consumer would have to be compensated $10.25 if a ban on audio home copying were established.

Recent transportation applications using the Small and Rosen formation of CV include an benefit cost assessment for automotive safety restraints based on changes in expected collision costs (Winston & Mannering 1984), the effects on consumer welfare of queue formation and dissipation (Mannering et al. 1990), and finally, CV was used as a measure of effectiveness for HOV lanes (Mannering & Hamed 1990). The measure has not been previously applied to evaluate accessibility worth.

Empirical analysis

The empirical evaluation begins with the construction of a model under the accessibility framework described in the previous section (i.e., using temporal, transportation and spatial components). However, (Eq. 3) must first be modified to reflect the limitations in travel behavior theory and the availability of data associated with the temporal component of accessibility. Constraints, and how the relaxation of those constraints affect individual time allocation, and thus activity participation, is only recently beginning to be understood (e.g., Kitamura & Kermanshah 1983; Kitamura & Kermanshah 1984, and Kitamura 1994).

To capture temporal constraints, the empirical application is limited to a model of the AM journey to work mode-destination choice (i.e. T_{ij}) and thus, accessibility. The remaining two dimensions of accessibility may be formally specified in the model by defining a combined mode-destination choice set reflecting transportation and spatial characteristics. Thus, the indirect utility function (with prices and income) may now be formulated as:

$$V_k = f\left(\frac{c_k}{\text{inc}}, TP_k, S_k, \varepsilon_k\right) \tag{6}$$

where,

V_k = The indirect utility of mode-destination choice k
c_k = Cost of travel for mode-destination choice k
inc = Household income (used as a socio-economic indicator)
TP_k = Vector of modal attributes
S_k = Vector of spatial characteristics
ε_k = Unobserved random portion of utility

The limitations to this model specification for accessibility include selection of the AM period for analysis, the absence of residential location choice from the model, possible correlation in attraction variables and the advantages and disadvantages of a joint mode-destination choice model structure. Beginning with selection of the AM period of analysis, while there are several compelling reasons for selecting this period (e.g., it provides the clearest indicator of journey to work mode-destination accessibility, there are limited competing choices and results directly reflect a fundamental travel need), it clearly limits the generality of the results. Although the proposed model specification is clearly relevant for policy decisions, it does not address the role non-work trips play in the mode-destination choice. Thus, if an individual were to choose an AM journey to work mode-destination choice on the basis of non-work opportunities, the model results would likely underestimate the utility, and consequently the worth of the accessibility, of the mode-destination choice.

The model specification also implicitly assumes a stable residential location. Thus, the selection of residential location is not part of the journey to work mode-destination choice model. It seems reasonably intuitive that the predictive capabilities of the proposed model would be greatly enhanced by including residential choice in the choice set. However, the data precluded defining residential location.

The third limitation is associated with possible correlation in specified attraction variables. As will be seen in the next section, the model utilizes several variables representing the proportion of different job types in the destination zone. It has been shown that in order for proportionality to be maintained between the choice probability and the size variable, thus independent of the geographic borders of the analysis region, the size variable must be specified in log form with associated size coefficients (Ortuzar & Willumsen 1994). It is important to note that the model specified in this study is dependent on the underlying zonal structure.

Finally, mode and destination are jointly specified in the model. The implication is that the fluidity of the choice set is similar, i.e., that mode and destination may be varied with equal ease. There are two perspectives from which to examine this assumption. First, assume that job mobility is high, e.g. a lower waged individual may be more likely to frequently vary jobs. Under this scenario, the joint selection of both mode and destination seems highly probable. Alternatively, assume that job mobility is low, e.g., a higher waged, older individual. Then the selected mode is likely chosen, given the journey to work destination; this suggests that the mode choice may be likely to vary without varying the destination choice.

Given the limitations of this analysis, attention may now be focused on the empirical estimation of the worth of the AM journey to work mode-destination accessibility. The empirical evaluation uses three primary sources of data: the Puget Sound Regional Transportation Panel (PSRTP), the Puget Sound Transportation Model (PSTM), and the 1990 census data (CD). The PSRTP is composed of four waves as of 1994 (see Murakami & Watterson 1990; Goulias & Ma 1995). Only those individuals completing both Waves 1 and 2, conducted in 1989 and 1990, respectively, were selected for analysis. These respondents were chosen for two reasons. First, the data coincide with 1990 CD (to ensure consistency at the block level) and 1990 PSTM and second, including only those appearing in both waves also implies a certain degree of household stability with respect to employment and residential location, thus emphasizing the inferential properties of the results.

A wide range of household and personal travel characteristics as well as a two day travel diary may be found in the data. The travel diaries provide information for every trip taken including the type of trip, mode used, activity undertaken, number of individuals in the vehicle, time of day. The household and personal data include many standard socio-economic variables such as age, income, number of children, number of vehicles. The model was estimated using only those respondents making an AM peak period journey to work trip to a destination zone within King County. The empirical analysis was restricted to King County first, because it encompasses the major employment areas for Puget Sound and second, because Metro, the transit service within King County, is well established with a large, rich, and accessible database. Table 1 presents the basic summary statistics for the King County subset. A comparison of the sample statistics to the CD was also conducted and indicated that the subset was representative data for analysis.

Results

Given the specification presented in (Eq. 6), the mode-environment choice utility function can be readily computed with two estimation caveats. First, the

Table 1. AM peak period journey to work summary statistics.[1]

No. observations	761
Mode split	
% auto	90.6
% transit	9.4
Sex	
% male	55.5
% female	45.5
	Means (Std. deviations)
Age (yrs.)	41.8 (11.60)
HH income ($)	45,937 (16,530.70)
HH size	2.66 (1.16)
No. child 6–17	0.42 (0.74)
No. HH vehicles	2.38 (1.14)
No. days work	4.94 (0.98)

[1] Adjusted to reflect choice based sampling.

PSTP data was gathered using choice based sampling (Pendyala 1993), requiring the use of a weighted exogenous sample maximum likelihood (WESML) function. Second, the mode-destination choice set is composed of a possible 662 choices (331 destination and two modes). With very large choice sets, it has been shown that estimation may be conducted on a choice variable subset without loss of consistency (Ben-Akiva & Lerman 1985). The estimation of performed as if the respondent faced only the choices in the subset; these choices must be randomly selected from the full choice set (this study used 100 random choices). The resulting likelihood function is statistically consistent (Train 1990).

Model estimation

Table 2 presents the variables entering the final model and their estimated parameters using the WESML procedures. The first variable, *Cstinc*, represents the ratio of the cost of travel by the selected mode to the household income. The sign indicates, as expected, that the probability of selecting a particular mode-destination choice decreases as the ratio of the mode cost to household income gets larger.

The second variable, *Wbus*, is equal to one if the respondent is a female and the mode choice is transit. The sign indicates the probability of mode-destination choice decreases if the individual is female and the mode is transit. This result is consistent with previous research on women's travel patterns (e.g., Erikson 1977; Hanson & Johnston 1985; Rosenbloom 1994). *Eldcbd*, also an indicator variable, is equal to one if the respondent is over age 60 and

Table 2. Multinomial logit model of mode-destination choice.

Explanatory variable	Est. coef.	Std. error	*t*-stat
Costinc: Cost of trip ($)/HH income (1,000 $)	–15257.5	61794.65	–8.50**
Wbus: Mode Sex Indicator *1 if female, 0 otherwise, defined for Transit Alt.*	–0.50	0.32	–1.59
Eldcbd: Elderly CBD destination indicator *1 if over age 60, 0 otherwise, defined for CBD Destination Alt.*	–2.35	0.90	–2.61**
Whcbd: White collar CBD destination indicator *1 if white collar, 0 otherwise, defined for CBD Destination Alt.*	0.84	0.25	3.39**
Whest: White collar eastside destination indicator *1 if white collar, 0 otherwise, defined for Eastside Destination Alt.*	0.55	0.29	1.89*
Btime: Travel time (minutes) *defined for Transit Alt.*	–0.04	0.002	–13.92**
Serv: Proportion of King County service jobs *defined for Destination Alt.*	26.56	7.64	3.48**
Manu: Proportion of King County manufacturing jobs *defined for Destination Alt.*	23.82	3.40	7.01**
Oretail: Proportion of King County retail jobs *HH income < $35,000, defined for Destination Alt.*	31.31	11.05	3.53**
Uretail: Proportion of King County retail jobs *HH income > $35,000, defined for Destination Alt.*	65.92	18.66	2.83**
Uwctu: Proportion of King County wholesale, commercial, transportation, utility jobs *HH income < $35,000, defined for Destination Alt.*	8.17	9.51	0.86
Owctu: Proportion of King County wholesale, commercial, transportation, utility jobs *HH income > $35,000, defined for Destination Alt.*	17.14	4.62	3.71**
No. of observations	710		
Log-likelihood at zero	–1150.40		
Log-likehood at convergence	–526.43		
ρ^2	0.45		

** Significant at the 0.05 level (two tailed).

the individual is traveling to the Seattle CBD. As expected, there is a decreasing probability of selecting the Seattle CBD, regardless of mode, for those respondents over age 60. This result is also consistent with much of the recent research which indicates the number of suburban elderly has exploded (e.g., Rosenbloom 1988) concurrent with an overall decline in trip rates to urban areas (Gordon et al. 1988).

The fourth and fifth variables, *Whcbd and Wheast*, represent indicators for white collar respondents to the CBD or the Eastside subareas, respectively. The sign of these variables indicates an increasing probability of these destinations for white collar workers for both modes. The sixth variable, *Btime*, is the travel time by transit to the selected destination. As expected, there is a declining probability of selecting a bus alternative, regardless of the destination choice, as bus travel time increases.

The variables, *Serv* and *Manu* represent the proportion of King County service and manufacturing jobs contained within the destination traffic analysis zone. As can be seen the probability of any mode-destination choice is increased when the proportion of service or manufacturing job opportunities grow. In addition to these variables, several combinations of destination subarea and job type were also tested, all were non-significant.

Finally, the coefficients for *Oretail*, *Uretail*, *Owctu*, and *Uwctu*, reflect the different values placed on retail and the wholesale, commercial, transportation and utility sector employment by the over and under $35,000 income segments. All of the coefficients are of expected sign and the *Uwctu* coefficient is not statistically significant in the model specification, suggesting that less value is placed on the *Wctu* sector employment by those with household incomes under $35,000.

The marginal rate of substitution (MRS) for various coefficients are presented in Table 3. These rates represent how much of one good a consumer is willing to give up for a given increase in another good. The MRS are computed in the standard manner as the ratio of the respective estimated model coefficients. The pooled data indicates that respondents are willing to pay an average of $0.13 per one minute decrease in AM journey to work bus travel time. However, closer inspection by market segment indicates great disparity, with individuals with household incomes less than $35,000 willing to pay less than one half of those with household incomes over $35,000.[1] Reviewing MRS's for job opportunities, it can be seen that, regardless of the income segment, individuals would be willing to spend approximately $110 to $115 for a one percent increase in retail job opportunities. For both service and manufacturing job opportunities, individuals with household incomes less than $35,000 are willing to pay only about one-half those with household incomes greater than $35,000. For *Wctu* job opportunities, individuals with an income greater than $35,000 are willing to pay far more for a one percent increase in job opportunities than those with household incomes less than $35,000.

Welfare computations

Compensating variation (CV), as noted in (Eq. 5), may be thought of as a measure of change in an individual's welfare following, for example, a change

Table 3. Marginal rates of substitution.

MRS		Based on avg. income for pooled data	Based on avg. income for HH inc < $35,000	Based on avg. income for HH inc > 35,000
Bus travel time	($/min)	0.13	0.07	0.14
Prop. retail employment (over $35,000)	($/%)	N/A	N/A	114.25
Prop. retail employment (under $35,000)	($/%)	N/A	111.28	N/A
Prop. service employment	($/%)	86.26	44.83	69.92
Prop. manu. employment	($/%)	77.37	42.01	86.92
Prop. WCTU employment (over $35,000)	($/%)	N/A	N/A	62.55
Prop. WCTU employment (under $35,000)	($/%)	N/A	13.79	N/A

in prices. For a scenario in which an individual gains something, e.g., improvement in travel time, the compensating variation represents the maximum amount of income that can be exchanged for this gain without leaving the individual worse off than before the change. Alternatively, if the result is a loss, e.g. increased travel costs, compensating variation represents the amount an individual must be compensated to be as well off as before the change. By constructing a series of hypothetical policy scenarios changes in consumer welfare associated with mode-destination, accessibility worth may be examined. Finally, it should also be noted that these results represent a lower bound of CV for the constructed scenario's. It is assumed that no changes occur in the remaining choices when one is removed, e.g. auto travel times do not change when bus is removed as a mode-destination alternative.

The average AM journey to work mode-destination accessibility worth can be computed by constructing first, a policy change in which the journey to work auto-destination alternative is eliminated from the choice set and second, a policy change in which the journey to work transit-destination alternative is removed. This is equivalent to computing (Mannering 1994):

$$CV = \left[-\frac{1}{\lambda}\right][\ln(1 - P_k^l)] \tag{7}$$

where P_k^1 is the probability that choice k in the base scenario is selected. The marginal utility of income, λ, is equal in magnitude to the mode cost parameter. In this model, the marginal utility of income, λ, equals the purchase price/income coefficient (*Costinc*), divided by the household income. The estimates of CV were obtained by enumerating through the sample, for all choices contained within the choice set. The CV's reported in the remainder of the paper refer to the AM journey to work mode-destination accessibility only. The reader is reminded of this sporadically throughout the paper, but generally this terminology is dropped to improve readability.

Using the standard interpretation of compensating variation, it can be seen from Table 4(a) that an individual, on average, would require a minimum compensation of $5.30, if the morning journey to work auto-destination accessibility were eliminated, to be as well off as before the policy change. Likewise, eliminating transit results in an average consumer welfare loss in transit-destination accessibility of $0.89 per morning journey to work trip. Thus, the compensation required to make an individual indifferent to the reduced mode-destination accessibility (i.e., either the auto-destination or the transit-destination alternative is removed from the choice set) is about six times higher for auto than for transit.

The change in consumer welfare may also be computed for restricted destination choices. In this policy scenario, the CV represents the minimum compensation required to make an individual, on average, indifferent to the loss of mode-destination accessibility to sub-area destinations having greater than average job opportunities. Three sub-areas within King County were identified as having a greater than average number of job opportunities: the Seattle Central Business District (CBD), the south end of King County (which includes Boeing aircraft industries) and the eastside (downtown Bellevue and outlying area).[2]

Turning to Table 4(b), an individual, on average, would require a minimum compensation of $2.23 to retain the same level of accessibility worth after eliminating the journey to work mode-CBD alternative. The AM journey to work mode-CBD accessibility is worth, on average, at least 4.2 times more

Table 4. CV for policy scenarios.

Policy scenario	CV ($)
(a) Mode eliminated	
Auto	5.30
Transit	0.89
(b) Subarea destination eliminated	
CBD	2.23
South	0.53
Eastside	0.20
(c) Mode to CBD eliminated	
Auto	1.23
Transit	0.67

than the journey to work mode-south accessibility and 11.2 times more than the mode-eastside accessibility. Examining the CBD subarea more closely reveals that differences in the minimum compensations for auto- and transit-destination journey to work accessibility are much smaller for the CBD than for King County overall. From Table 4(c), the compensating variation for auto is $1.23 while for transit is $0.67, i.e., the minimum CBD journey to work auto-destination accessibility compensation is only two times the amount required for transit. This ratio is considerably smaller than the six times noted for King County as a whole. Intuitively, this is reasonable and reflects, in part, the higher quality, mostly radial, transit service, greater job density and the higher cost of parking in the CBD.

Disaggregating the analysis by market segment, Table 5(a) indicates that eliminating journey to work transit-destination accessibility for individuals with household incomes under $35,000 requires a compensation of $1.26 for the individual to be as well off as before the change. The comparable figure for individuals with household incomes over $35,000 is $0.77. Thus, individuals with household incomes below $35,000 would require slightly more than 1.5 times the compensation for loss of transit-destination accessibility than those with incomes greater than $35,000.

Turning to auto-destination accessibility, it can be seen that individuals in the higher income market segment would require about 5 times the compensation ($6.33) of individuals in the lower market segment ($1.29) to compensate for a loss in journey to work auto-destination accessibility to be as well off as before the change. It is also notable that removal of either the auto or transit from the journey to work mode-destination choice requires approximately the *same* amount of compensation for individuals with household incomes under $35,000. This speaks to the importance of transit-destination accessibility in the journey to work mode-destination choice for the lower income market segment.

Table 5(b) presents the compensating variation for income segments by destination. The results suggest that eliminating journey to work mode-CBD accessibility requires a compensation of $1.88 and $2.32 for households under $35,000 and over $35,000, respectively, to maintain the same level of welfare as before the change. This is approximately 20 percent more compensation for individuals with household incomes over $35,000 than for individuals with household incomes below $35,000 and suggests that the journey to work mode-CBD accessibility is comparably valued by both market segments. A slightly different result is found when comparing CV's to the eastside or south subareas. On average, individuals having household incomes greater than $35,000 would require roughly three times the compensation of individuals with household incomes below $35,000, by any mode, if journey to work accessibility to either the east or south subareas was eliminated.

Table 5. CV by market segment.

Policy scenario	CV ($)	
	< $35,000	> 35,000
(a) Mode eliminated		
Auto	1.29	6.33
Transit	1.26	0.77
(b) Subarea destination eliminated		
CBD	1.88	2.32
South	0.26	0.60
Eastside	0.08	0.23
(c) Mode to CBD eliminated		
Auto	0.35	1.45
Transit	1.11	0.55
(d) Mode to south eliminated		
Auto	0.23	0.54
Transit	0.03	0.05
(e) Mode to eastside elminated		
Auto	0.07	0.21
Transit	0.01	0.02

Limited analysis can also be made for each mode within each subarea. Tables 5(c–e) presents modal breakdowns by subarea. As might be expected from previous analysis, eliminating the mode-CBD accessibility requires greater compensation than removing either of the other two subareas alternatives from the choice set. More important, there is a clear pattern of higher worth placed on transit accessibility for the CBD subarea journey to work trip. The compensating value of CBD journey to work transit-destination accessibility for individuals with household incomes under $35,000 is three times higher than that of auto, reflecting a generally greater reliance and value placed on this mode.

The two remaining subareas require substantially less compensation for loss of accessibility than found in the CBD subarea. The compensating variation suggests that loss of transit to either the east or south subareas is roughly comparable between individuals in the income segments. Loss of journey to work auto-destination accessibility would require roughly 11 times greater compensation that of transit, to either subarea, for individuals with household incomes greater than $35,000 and approximately 7 times for those with household incomes below $35.000.

The compensating variation may also be calculated for each market segment under incremental policy changes. Consider two scenarios: 1) the auto operating cost is increased, and 2) the transit travel time is decreased. Referring to Figure 1(a), the effects of reducing bus travel time on the compensating variation can be seen by the two lines representing the compensating variation for individuals with household incomes over $35,000, point estimates shown by an “o”, and individuals with household incomes under $35,000 with point estimates shown as a “u”. In this case both market segments are clear gainers, i.e., the decrease in travel time benefits both to some extent. Also from the figure, it can be seen that the amount of income that can be taken from either market segment is roughly equivalent, with the under $35,000 segment only slightly higher, for travel time reductions less than roughly 48 percent. This suggests that both market segments benefit comparably when travel time is cut by half.

When travel time is reduced by more than one half, the benefits clearly favor the over $35,000 market. Interestingly, the dollar amount that can be taken, based on the benefits from reduced transit time, and leaving the individual no worse off than before, also accrue more quickly. This suggests that reducing transit travel time by more than 50 percent of the current journey to work time predominantly favors, in terms of added accessibility, those with household incomes greater than $35,000. As a side note, it is interesting to point out that a 50 percent reduction in bus travel time is roughly equivalent to the current journey to work auto commute time in King County.

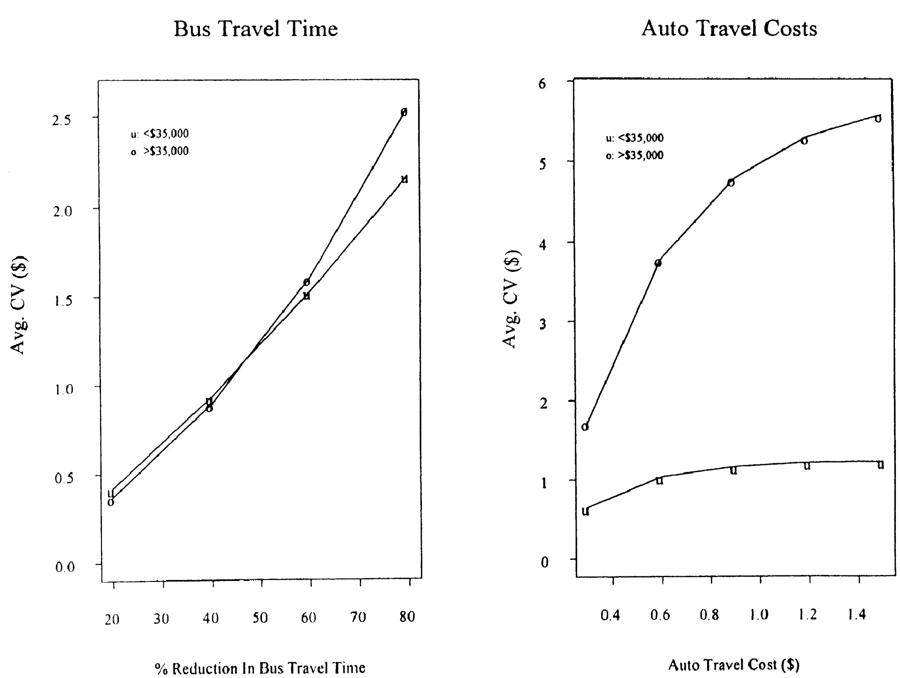

Fig. 1. Change in avg. CV when bus travel times and auto travel costs are varied.

Consider scenario 2, an increase in auto travel cost. Referring to Figure 1(b), it is important to first note that the compensating variation levels off for both market segments. For the under $35,000 group, the CV begins to flatten out at approximately $1.21; for the over $35,000 group, the CV levels off at roughly $5.50. To understand the significance of Figures 1(a) and 1(b) consider the following joint scenario. Assuming no other changes, bus travel time is reduced by 50 percent with auto travel operating and maintenance costs increasing to an arbitrarily set value of $1.40 per mile. Computations indicate that, on average, individuals will still require compensation of as much as $3.00 per morning journey to work commute to retain the same level of mode-destination accessibility "worth" as before the changes. Thus, in this very simple scenario, transit travel time reductions of as much as 50 percent do not fully offset the mode-destination accessibility worth lost after increasing auto travel costs.

Policy discussion

These results establish the benchmark monetary estimates of the worth of the AM journey to work mode-destination accessibility for King County, WA. and consequently, give rise to many important practice and policy implications. Beginning with the practical issue of using the values of mode-destination accessibility worth, it is useful to note that these values provide a mechanism for introducing a monetary value of accessibility into the traditional cost-benefit analysis. If alternative policy or infrastructure scenarios are constructed and modeled, the change in accessibility can be included s benefit or disbenefit in the cost-benefit computations. Most travel demand models now compute the log-sum value as part of the mode choice modeling process. By utilizing the log-sum and the requisite demographic data, a monetary value of accessibility can be derived and incorporated directly into the cost-benefit analysis.

The results also provide insight on job densities as well as pricing and transit capital infrastructure that must be in place in order to achieve optimal mode-destination accessibility. For example, the value attached to the peak period transit mode-destination accessibility in this study was much greater in the subareas with higher job densities, such as the CBD. This value declined with increases in both commute distance as well as job density.

The results also suggest that, absent bus travel time reductions on the order of 50 percent, there is still likely to be a substantial loss in consumer welfare if the auto-destination alternative is removed from the choice structure for individuals with household incomes over $35,000. Conversely, the results indicate a strong transit-destination market, with a comparable choice structure, for those with household incomes less than $35,000. In short, and as might be expected, these individuals may not gain appreciably from express bus strategies.

Last, the issue of market equity must be considered. This research has indicated that the worth of the auto-destination and transit-destination accessibility for individuals with household incomes less than $35,000 is roughly comparable, while individuals with household incomes greater than $35,000 benefit from roughly five times the auto-destination accessibility. Further, when subarea destinations are considered, it is clear that modal improvements to south and CBD better serve the lower income market segment than journey to work modal improvements to the eastside. These findings suggest that a beneficial capital and marketing direction, serving the predominantly captive lower income market, would be investments in service to the CBD and south Seattle.

Conclusions and future research

This research has presented a methodology for measuring the worth of the AM journey to work mode-destination accessibility. This methodology was demonstrated using econometric extensions to a MNL model specified with travel data collected in King County, Washington. The major findings include the minimum compensation for loss of AM journey to work auto-destination ($5.30) and transit-destination ($0.89) accessibility for an individual to be as well off as before the mode alternatives were removed. It was also shown that loss of the journey to work mode-CBD accessibility requires a compensation of approximately four times that of the south King County major employment subarea ($0.53) and 11 times that of the major employment area on the eastside of Lake Washington ($0.20).

The research has also shown that mode-destination accessibility is substantially different when market segments are considered. Findings suggest that lower income individuals would require almost twice the compensation ($1.29) as higher income individuals ($0.77) when journey to work transit-destination accessibility is eliminated. The results also show that lower income households require little compensation, relative to the CBD, for reduced mode-destination accessibility to either the southern King County major employment area or the eastside major employment area.

Additional research needs include exploration of an accessibility specification which more directly incorporates temporal constraints and is conducted for alternative periods of analysis (e.g., the PM peak period). This of course, implies greater insight into the dimensions of non-work accessibility. Conducting a dynamic analysis to incorporate network impacts when pricing and modal service alternatives are modified or eliminated would also be very insightful. Finally, performing similar analysis for other regions would be useful for comparative purposes and provide insight on relative levels of accessibility.

Acknowledgment

The author wishes to acknowledge Drs. Small and Mannering for their insightful review and helpful comments. In addition, comments from the anonymous reviewers greatly enhanced the overall presentation of this paper.

Notes

1. Market segments were determined based on data size constraints and evaluation of the state median household income ($31,181), Puget Sound median household income ($35,161) and King County median ($36,179).
2. The Seattle CBD is the main urban core of the Puget Sound region; the south end of King County abuts the CBD and includes primarily industrial land uses, such as Boeing manufacturing and the municipal airport, and finally, the eastside abuts the eastern shore of Lake Washington and includes Bellevue, with primarily service oriented land uses, and the outlying suburbs.

References

Basmaciyan H & Schmidt J (1964) *Development and Application of a Modal Split Model for the Puget Sound Region*, PSRTS Staff Report, No. 12, Seattle, Washington, 5–28.

Ben-Akiva M & Lerman S (1979) Disaggregate travel and mobility choice models and measures of accessibility. In: Hensher D & Stopher P (eds) *Behavioral Travel Modeling* (pp 654–679). London: Croom Helm.

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

Black J & Conroy M (1977) Accessibility measures and the social evaluation of urban structure. *Environment and Planning A* (9): 1012–1031.

Burns L (1979) *Transportation, Temporal and Spatial Components of Accessibility*. Lexington, Ma: Heath and Company.

Cohen D & Basner D (1972) *Accessibility – Its Use as an Evaluation Criteria in Testing and Evaluating Alternative Transportation Systems*. Washington, DC: US Department of Transportation, FHWA.

Freeman A (1993) *The Measurement of Environmental and Resource Values: Theory and Methods*. Washington, DC: Resources for the Future.

Goulias K & Ma J (1995) *Analysis of Longitudinal Data from the Puget Sound Transportation Panel*. FHWA, BAT-94-016, Washington, DC.

Handy S (1992) *Regional versus Local Accessibility: Variations in Suburban Form and the Effects on Non-work Travel*. PhD dissertation, Berkeley, California: University of California.

Hanson S & Schwab M (1987) Accessibility and intraurban travel. *Environment and Planning A* (19): 735–748.

Hanson S & Johnston I (1987) Gender differences in work trip lengths. *Urban Geography* 6: 735–748.

Erikson J (1988) An analysis of the journey to work for women. *Social Problems* 24.

Gordon P, Kumar A & Richardson H (1988) Beyond the journey to work. *Transportation Research A* (22A): 419–426.

Kitamura R & Kermanshah M (1983) Identifying time and history dependencies of activity choices. *Transportation Research Record* 944: 22–30.

Kitamura R & Kermanshah M (1984) Sequential model of the interdependent activity and destination choices. *Transportation Research Record* 987: 81–89.

Kitamura R (1994) Time of day characteristics of travel. *1990 NPTS Report Series: Special Reports on Trip and Vehicle Attributes*. U.S. Department of Transportation.

Mannering F & Winston C (1987) Economic effects of voluntary export restrictions. In: *Blind Intersection: Policy and the Automobile Industry*. Washington D.C.: Brookings Institute.

Mannering F & Hamed M (1990) Commuter welfare approach to high occupancy vehicle lane evaluation: an exploratory analysis. *Transportation Research A*, 24A(5): 371–379.

Mannering F (1994) Assessing the impacts of audio home copying restrictions. *Quarterly Journal of Business and Economics* 33(1): 31–45.

Mannering F, Abu-Eisheh S & Arnadottir A (1990) Dynamic traffic equilibrium with discrete/continuous econometric models. *Transportation Science* 24(2): 105–116.

McFadden D (19??) Econometric models of probabilistic choice. In: Manski & McFadden (eds) *Structural Analysis of Discrete Data with Econometric Applications*. Cambridge, MA: MIT Press.

Murakami E & Watterson T (1991) Developing a household travel panel survey for the Puget Sound Region. *Preprint*, 73rd Annual Meeting, Washington, DC: Transportation Research Board.

Ortuzar J & Willumson L (1994) *Modelling Transport*. New York, NY: Wiley.

Pendyala RM, Goulias KG, Kitamura R & Murakami E (1993) Development of weights for a choice-based panel survey sample with attribution. *Transportation Research* Part A, 27(6): 477–492.

Rosenbloom S (1988) The mobility needs of the elderly. In: Malfetti (ed) *Transportation in an Aging Society* (pp 21–71). Transportation Research Board, National Research Council.

Rosenbloom S (1994) Travel by women. In: Pisarski (ed) *NPTS: Demographic Special Reports* (pp 75–164). FHWA, USDOT.

Small K & Rosen H (1981) Applied welfare economics with discrete choice models. *Econometrica* 49: 105–130.

Train K (1990) *Qualitative Choice Analysis: Theory, Econometrics, and Application to Automobile Demand*. Cambridge, Ma: MIT Press.

Vickerman R (1974) Accessibility, attraction, potential: a review of some concepts and their use in determining mobility. *Environment and Planning A* 6.

Wachs M & Kumagal T (1973) Physical accessibility as a social indicator. *Socio-Economic Planning Sciences* 7.

Wickstrom G (1971) Defining Balanced Transportation – a question of opportunity. *Traffic Quarterly* 25.

Williams H (1976) Travel demand models, duality relationships and user benefit analysis. *Journal of Regional Science* 16: 147–166.

Winston C & Mannering F (1984) Consumer demand for automobile safety. *American Economic Review* 74(2): 13–21.

Zerbe R & Dively D (1994) *Benefit-Cost Analysis: In Theory and Practice*. New York, NY: Harper Collins.