Transportation 10 (1981) 149–164
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SUBJECTIVE VALUE OF TIME IN BUS TRANSIT TRAVEL

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ABSTRACT

A psychological scaling technique, magnitude estimation, is used to rate time spent on various elements of bus transit trips. Relative values of time are found for in-vehicle portions of trips, walking, waiting and transferring. Because magnitude estimation produces a ratio scale, results can be directly incorporated into modal choice analyses, route planning and evaluation procedures where monetary values of time are not necessarily required.

Introduction

In contrast to competing modes, a relatively small percentage of the effort expended in bus transit travel actually results in physical progress toward a destination. Transit users spend substantial amounts of time planning their trips, coping with unfamiliar areas, dealing with crowds, contending with the weather, walking, waiting, transferring or otherwise satisfying the basic constraints of the bus mode. Transit users recognize these differences in travel conditions when they evaluate time spent in bus transit travel. This paper illustrates the relative values travelers attach to the time spent in separate elements of their bus transit trips and will demonstrate that techniques of psychological scaling can be used to quantify values of time in a manner consistent with the requirements of demand estimation and system evaluation.

Monetary values of time in travel have been routinely computed for some elements of transit travel. By observing tradeoffs between time and money that travelers make while considering alternative modes, it is possible to infer monetary values of time from travel behavior. It has become widely accepted that an interval of out-of-vehicle time is valued higher than a similar interval of in-vehicle time (Wachs, 1976). But time valuation can be complex. For example, Algers, Hansen and Tegner (1975) demonstrated that the value of bus travel time can vary according to how the time is spent: waiting, trans-

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ferring, walking, riding while seated and riding while standing. A similar argument has been advanced by DeSerpa (1973), who states that a traveler may gain additional utility from a portion of a trip because the time can be used in a particularly pleasing or productive manner. The value of time on that portion of the trip would be affected accordingly.

Determining values of time for elements of transit trips by observing behavior is not a simple procedure even when available data is of high quality. The multitude of variables that influence choice of mode are not easily measured. Statistical estimation equations must be specified accurately (Stopher, 1976). Seemingly innocuous changes in variables included in the analysis can cause large changes in the values of time for different trip elements (e.g., Algers, Hansen and Tegner, 1975; Train, 1976).

One method suggested to circumvent specification error is to determine relationships between values of time for different trip elements, using methods of psychological scaling (Stopher, 1976; Watson, 1974). Then an appropriately weighted, composite travel-time index for each trip can be calculated prior to modal choice model calibrations. The advantages of this approach are an elimination of specification error and a possible reduction in the amount of behavioral data required. The principal disadvantage is the additional need for an independent scale of time valuation which produces results that are consistent with behavioral analyses.

In an earlier study (Horowitz, 1978), 84 Chicago residents were asked to rate the time spent on a selection of common urban trips. Among these trips were several transit trips that varied in time length, number of transfers, transfer time, wait time, need to wait and seat availability. The ratings of these trips were performed using magnitude estimation. In this magnitude estimation experiment, respondents were asked to rate a series of "comparative" trips against a single "standard" trip for which a numerical value had previously been established. Since respondents were instructed to rate worse trips higher on the numerical scale, the results were a representation of the disutility of the time spent in travel. An example question follows:

> Time spent on a work trip of 20 minutes by automobile has a rating of 10;
>
> what is your rating of a 30 minute trip to work by bus?

The first part of the question describes the standard trip while the second part of the question describes the comparative trip.

Magnitude estimation, as applied here, produces a ratio psychological-scale of trips. The scale inherently encompasses evaluations of each trip's comfort, convenience and reliability. Through such a scale, transit trips that are identical in all but one element can be compared and the subjective value associated with that element can be isolated.

The use of psychological scaling in transit planning is extensive (Dobson, 1979), particularly with regard to attitude measurement. However, only a few studies have attempted to generate a ratio scale of trips or portions of trips (Shinn, 1972; Pulliam et al., 1976). Ratio scales, with clearly defined zero points and equal intervals, are potentially important for transportation planning because they could be directly incorporated into modal choice models and evaluation procedures. For example, with a ratio scale of the value of time, the ratio of values of walking time to riding time could be computed without any additional information. With similar relationships for other elements of trips, a disutility measure for whole transit trips can be synthesized.

The following sections detail the experimental procedure, the construction of the psychological scales and the implications of the results for transit planning.

Experimental Design

The psychological scaling experiment was performed in a laboratory under the guidance of an experimental psychologist. The primary instrument was a loose-leaf booklet that contained instructions, a description of the standard trip and a random series of comparative trips positioned one to a page. Respondents were briefed on the purpose of magnitude estimation, the requirement to rate worse trips higher, the concept that time in travel can vary in quality as well as quantity, and the important baseline conditions to be assumed for the various modes. Once instructions had been given, the respondents were told to progress through the comparative trips at their own pace. In order to promote independence of ratings, respondents were instructed to rate each comparative trip only with reference to the standard trip and not to previously rated comparative trips.

Respondents were selected from the Chicago area using random digit dialing. The sample of respondents was balanced to Chicago SMSA statistics for age, sex, income and employment status. Persons without high school education or who were over 65 years of age were removed from the sample. Thus, the resulting sample approximated a cross-section of Chicago travelers, not just transit users.

In order to prevent any respondent from having to rate one hypothetical trip against another hypothetical trip, the standard trip was preselected as an everyday trip for that respondent. Across all respondents eleven different standard trips were used. Standard trips selected were work trips for those respondents who were employed outside the home and shopping trips for the remaining respondents.

Of the 115 comparative trips rated by the respondents, 60 of them either represented bus transit trips or provided a meaningful contrast to bus transit trips. These 60 comparative trips were organized into three two-way experimental designs and two one-way experimental designs. The three two-way experimental designs were:

(a) Mode (bus, automobile, walk) by time length (5 to 60 minutes by 5-minute increments) for work trips.
(b) Total bus trip length (30, 45 minutes) by waiting time (0, 5, 10, 15 minutes) for work trips.
(c) Bus in-vehicle time (20, 30, 40 minutes) by transfer time (0, 5, 10 minutes) for work trips.

The one-way experimental designs were:

(d) Number of 5-minute transfers (0, 1, 2) on a bus trip to work of 30 minute riding time.
(e) Environmental conditions of various 30 minute trips.

Experimental designs (a) and (e) have been previously analyzed (Horowitz, 1978), but have been included in this discussion for the sake of completeness.

While initially testing the experiment it became evident that subjects would become fatigued if administered all of the comparative trips. Consequently, each respondent was given only one-half of those trips in experimental design (a). This caused imbalances in experimental designs (b) and (c) which used some of these same trips. The statistical procedures adopted for this study have been based upon generalized least squares analysis, which is unaffected by this imbalance (Searle, 1971).

Analysis of Trip Ratings

Two properties of magnitude-estimated scales impact the statistical methods used to analyze the trip ratings. The first property is Ekman's Law of Psychophysics which states "variability [psychological error] in subjective units, tends to grow as a linear function of subjective magnitude" (Stevens, 1966). The second property states that a change in standard trip (or "standard stimulus", more generally) will cause a constant multiplicative change in all ratings (Krantz, 1972). Both standard trips and psychological error have multiplicative effects on ratings. The simplest linear statistical model of one-way experimental designs that incorporates these multiplicative effects is,

$$\log R_{ijl} = S_i + A_j + SA_{ij} + \epsilon_{ij(l)} \qquad (1)$$

where R_{ijl} is the respondent's rating, S_i is the ith standard trip, A_j is the jth trip description, SA_{ij} is an interaction term and $\epsilon_{ij(l)}$ is the error term. The subscript, l, indicates replication across respondents, but since the design is unbalanced, the number of replications differ for each cell (i,j) in the design. The inclusion of the standard trip as a factor in the model of the one-way experimental design requires a two-way analysis of variance model. For the two-way experimental designs, a three-way analysis of variance model is required:

$$\log R_{ijkl} = S_i + A_j + B_k + SA_{ij} + SB_{ik} + AB_{jk} + \epsilon_{ijk(l)} \qquad (2)$$

where A_j and B_k are the two factors in each trip description (e.g., transfer time and riding time) and SA_{ij}, SB_{ik} and AB_{jk} are interaction terms. The statistical analysis of the ratings consist of, first, determining the significance of the factors using analysis of variance and, second, computing the coefficients of the model using dummy variable regression.

MODE BY TIME LENGTH

The subjective value of travel time varies according to mode, even if the time lengths of trips are the same. A comparison of three modes (automobile, bus, and walking) is shown in Fig. 1. The curve for each mode was found by estimating the coefficients of:

$$R_{ij} = s_i \, m_j \, t^{\alpha_j} \qquad (3)$$

from experimental design (a). In this equation R_{ij} is the rating, s_i is a coeffi-

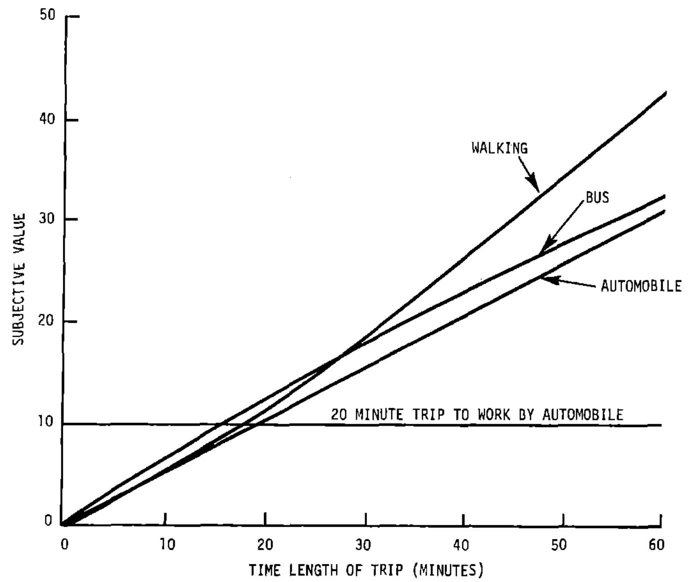

Fig. 1. Subjective value of time spent in travel to work by trip length and mode.

cient for standard trip i, m_j and α_j are coefficients for mode j and t is the time length of the trip. Equation 3 is a special case of Steven's Law of Psychophysics. A complete description of this statistical analysis may be found in Horowitz (1978).

All respondents, and therefore all standard trips, are included in the analysis. However, in order to improve interpretability of the results, the curves shown in Fig. 1 are based upon a single standard trip of "20 minutes to work by automobile." This standard trip has an assigned subjective value of 10. Thus, a trip that is considered twice as bad as this standard trip has a subjective value of 20; a trip half as bad has a subjective value of 5. The subjective values of time presented in this and remaining analyses are simply the ratings that would have been expected to result if all respondents had been given this one standard trip. The subjective value scale is arbitrary, and it can vary as a constant multiple with any change in either the standard trip or its assigned subjective value.

Respondents were told, unless otherwise stated, that their bus was full but it had seat availability and that no wait was required. They were also told, unless otherwise stated, that automobile trips were in moderate traffic and that walking would be in fair weather. From Fig. 1 it can be seen that for trips of similar length respondents rated bus travel nearly identical to automobile travel. Subjective values of bus and automobile trips differ by at most five subjective units at about 35 minutes. Under normal loading conditions and when waiting was not required, respondents were essentially indifferent between equal time length trips for automobiles and buses. Both bus and automobile trips were considered better than walking trips at the same time length greater than 24 minutes. As will be seen, the similarities between subjective values of time on these modes are dependent upon the lack of adverse travel conditions normally associated with bus transit.

There is no evidence in Fig. 1 that respondents were exaggerating negative aspects of particularly long trips or biasing responses toward automobiles, the dominant mode of travel to work in Chicago. These results support intuition by demonstrating that each minute of travel time is valued essentially the same, regardless of when that minute occurs on a trip and regardless of mode, as long as the traveler is progressing comfortably toward a destination.

WAITING TIME

Within experimental design (b), two factors were varied: the total length of bus trips and the amount of waiting time. Respondents were told that the waits were at uncovered stops during fair weather. Analysis of variance of logarithmically transformed ratings for this experimental design is show in Table 1. All of the main effects, standard trip, wait time and time length,

TABLE I

Analysis of Variance for Bus Wait Time by Time Length

Source of variation	Sum of squares	Degrees of freedom	Mean square	F
Main effects				
Standard	111.6	10	11.2	14.7[1]
Wait time	18.0	3	6.0	7.9[1]
Time length	9.2	1	9.2	12.1[1]
Interactions				
Standard-wait time	6.4	29	0.2	0.3
Standard-time length	3.5	9	0.4	0.5
Time length-wait time	3.0	3	1.0	1.3
Explained	151.7	55	2.8	3.6[1]
Residual	240.8	318	0.8	
Total	392.5	373	1.1	

[1] Significant with $p < 0.001$.

were highly significant with $p < 0.001$. However, none of the interaction terms were even weakly significant with $p < 0.05$. Thus, equation 2 without interactions holds for this experimental design.

Eliminating the logarithmic transformation, the error term and ten of the eleven standard trips produces a subjective value of time model of the form,

$$R_{ij} = s_{20} a_i b_j \tag{4}$$

TABLE II

Coefficients in the Subjective Value of Time Equation for Wait Time

Factor	Level	Coefficient
Wait time	0 minutes	0.74
	5 minutes	1.06
	10 minutes	1.15
	15 minutes	1.28
Total time length	30 minutes	0.87
	45 minutes	1.20
Standard trip (s_{20})		28.2

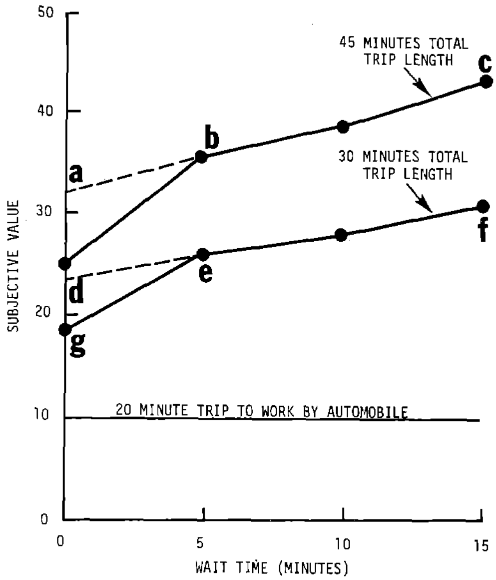

Fig. 2. Subjective value of bus waiting time.

In this equation a_i is a coefficient for waiting time, b_i is a coefficient for trip length, and s_{20} is a constant dependent upon a standard trip of 20 minutes to work by automobile. The estimated values of the coefficients for equation 3 are shown in Table II; the eight subjective values for the trips in experimental design (b) are shown in Fig. 2.

Figure 2 illustrates that the first five minutes of a wait are valued much more highly than either the second or third five minutes. Based upon the consistent ratings of intervals of time from experimental design (a), there is no a priori reason to expect that time valuation would change markedly in the course of a wait. Wait time alone did not produce this large increase in subjective value between trips with zero and five-minute waits. Rather, the respondents appear to be reacting negatively to the requirement for a wait of any length of time at all. Once the fact of a wait is established, the subjective value of time that is added to trips for the second and third five-minute increments is relatively small. The subjective value of this requirement for a wait can be computed by first estimating the subjective value of bus trips with zero time waits. This can be accomplished by extrapolating through points (c) and (b) and through points (f) and (e) to the subjective value axis (points (a) and (d), respectively). The subjective value of an additional requirement for a wait is seen to be 5.1 subjective units (difference between (d) and (g) in Fig. 2) for a 30 minute trip and 7.2 subjective units for a 45 minute trip. In more physical terms, the requirement for a wait represents a subjective value equivalent to 13.0 minutes of riding added on to a 45 minute trip and 8.4 minutes of riding added on to a 30 minute trip.

TABLE III

Bus In-Vehicle Time Equivalents of Waits and Waiting Time

Bus in-vehicle time	Amount of in-vehicle time equivalent to a requirement to wait	Amount of in-vehicle time equivalent to 10 minutes of additional waiting time
30	8.4	18.9[1]
45	13.0	23.2[1]

[1] The equivalent additional time on a trip because ten minutes is spent waiting instead of riding plus ten minutes.

The positive slope of both curves in Fig. 2 is due to respondents valuing wait time greater than riding time. The 10 minutes of additional waiting time between points (b) and (c) represents an increase in subjective value of 7.4 subjective units, while the 10 minutes of additional waiting time between points (e) and (f) adds 5.4 subjective units. Again in physical terms, waiting ten minutes, as opposed to riding for that same 10 minutes, adds the equivalent of 13.2 minutes to a 45 minute trip and adds the equivalent of 8.9 minutes to a 30 minute trip. These results are summarized in Table III.

TRANSFER TIME

Experimental design (c) varied in-vehicle time and transfer time for work trips with at most one transfer. In-vehicle time, not total trip time, was selected as the factor because it permitted trip descriptions to be conveniently phrased with the transfer in the middle of the trip. Trips with in-vehicle times of 20, 30 and 40 minutes were split into two segments of 10, 15 and 20 minutes, respectively. Bus trips with transfers of 5 or 10 minutes were compared to bus trips without transfers.

The analysis of variance of logarithmically transformed ratings is shown in Table IV. As in the previous experimental design all main effects are shown to be highly significant and all interactions are shown to be insignificant. Equation 4 can again be used to model subjective value. In this instance, a_i's are the coefficients for in-vehicle time and b_j's are the coefficients for transfer time. These coefficients are shown in Table V, and the computed subjective values are shown in Fig. 3.

From Fig. 3 it is readily apparent that large increases in subjective value occur when a transfer is required. The addition of a single, five-minute transfer more than doubles the subjective value of the trip. However, increasing the length of a transfer to 10 minutes has comparatively little additional effect on subjective value.

TABLE IV

Analysis of Variance for Bus In-Vehicle Time by Bus Transfer Time

Source of variation	Sum of squares	Degrees of freedom	Mean square	F
Main effects				
Standard	89.8	10	9.0	13.4[1]
Time length in bus	11.7	2	5.9	8.7[1]
Transfer time	76.0	2	38.0	56.6[1]
Interactions				
Standard-time length	3.3	20	0.2	0.2
Standard-transfer time	6.8	19	0.4	0.5
Time length-transfer time	3.2	4	0.8	1.2
Explained	190.8	57	3.3	4.9[1]
Residual	238.4	355	0.7	
Total	429.2	412	1.0	

[1] Significant with $p < 0.001$.

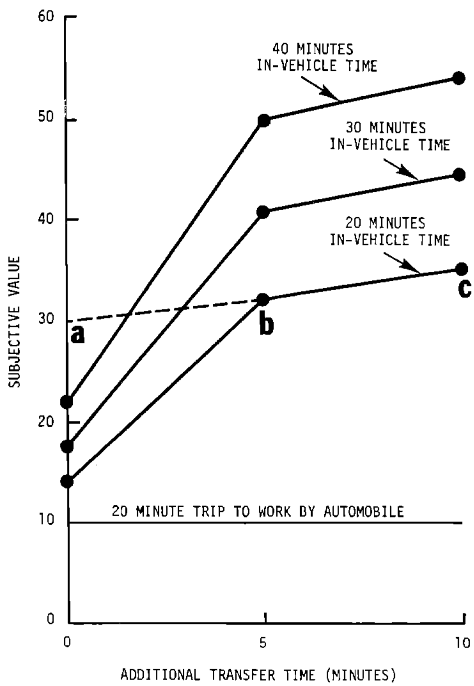

Fig. 3. Subjective value of bus in-vehicle time and bus transfer time.

TABLE V

Coefficients in the Subjective Value of Time Equation for Transfer Time

Factor	Level	Coefficient
Riding time	20 minutes	0.80
	30 minutes	1.01
	40 minutes	1.23
Transfer time	0 minutes	0.58
	5 minutes	1.36
	10 minutes	1.48
Standard trip (s_{20})		30.0

TABLE VI

Bus In-Vehicle Time Equivalents of Transfers and Transfer Time

Bus in-vehicle time	Amount of in-vehicle time equivalent to a requirement to transfer	Amount of in-vehicle time equivalent to 5 minutes of additional transfer time
20	22.8	8.2
30	40.7	6.2
40	45.6	4.1

TABLE VII

Analysis of Variance for Number of Transfers on Bus Trips

Source of variation	Sum of squares	Degrees of freedom	Mean square	F
Main effects				
Standard	57.4	10	5.7	6.8[1]
Number of transfers	68.1	2	34.1	40.2[1]
Interaction	9.1	18	0.5	0.6
Explained	134.6	30	4.5	5.2[1]
Residual	149.3	176	0.8	
Total	283.9	206	1.4	

[1] Significant with $p < 0.001$.

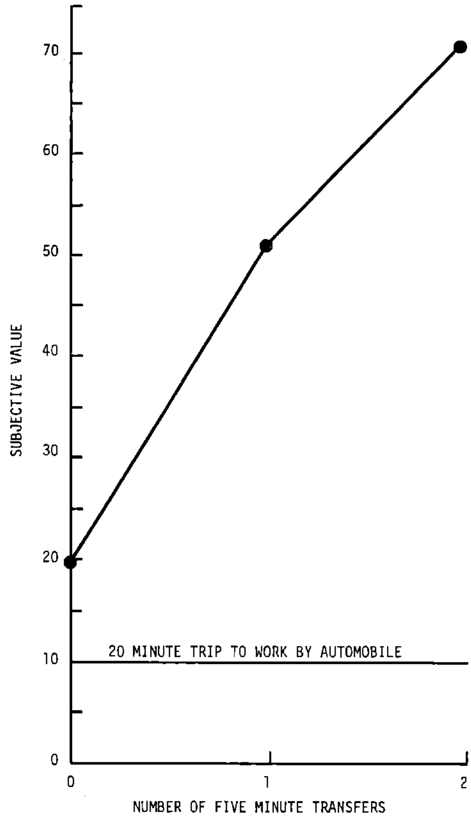

Fig. 4. Subjective value of number of transfers on bus trips with 30 minutes of in-vehicle time.

The subjective value associated with a zero time transfer requirement (i.e., a transfer with no waiting time) can be calculated in the same manner as the subjective value of a wait requirement. Extrapolating from point (c) to (b) to the subjective value axis shows that a 20 minute bus trip with a zero time transfer has a value of 29.8 subjective units (point a). The requirement to transfer adds 15.8 subjective units or an equivalent of 22.8 minutes of in-vehicle time onto the trip. Repeating this calculation for the other trips results in transfer requirements being equivalent to 40.7 minutes added onto a 30 minute trip and 45.8 minutes added onto a 40 minute trip.

The subjective value of time spent transferring can be computed from the slope of these curves between five and ten minutes. Five minutes of transfer time is equivalent to 8.2 minutes of in-vehicle time on a 20 minute trip, 6.2 minutes of in-vehicle time on a 30 minute trip, and 4.1 minutes of in-vehicle time on a 40 minute trip. Thus, transfer time is not necessarily valued greater than in-vehicle time. These results are summarized on Table VI.

NUMBER OF TRANSFERS

One comparative trip had two five minute transfers with three in-vehicle segments of ten minutes each. This trip was included in experimental design (d) along with a trip of 30 minutes of in-vehicle time and one five minute transfer as well as a trip of 30 minutes of in-vehicle time and no transfer. A two-way analysis of variance was used to determine the significance of number of transfers in explaining variance in logarithmically transformed ratings (Table VII). As in previous experimental designs, main effects were highly significant and the single interaction was insignificant. The model of subjective value, based upon equation 2, is:

$$R_{ij} = s_{20}\, a_i$$

with the a_i's representing the coefficients for number of transfers.

The estimated coefficients of equation 2 are shown in Table VIII and the subjective values of these three trips are shown in Fig. 4. The effect of a second transfer on a 30 minute trip is almost as large as the first. A 40 minute bus trip that includes two transfers has a subjective value three times that of a 40 minute bus trip without transfers. This analysis illustrates that each successive transfer adds considerably to negative evaluations of bus trips.

ENVIRONMENTAL CONDITIONS

The experimental design concerned with environmental conditions has

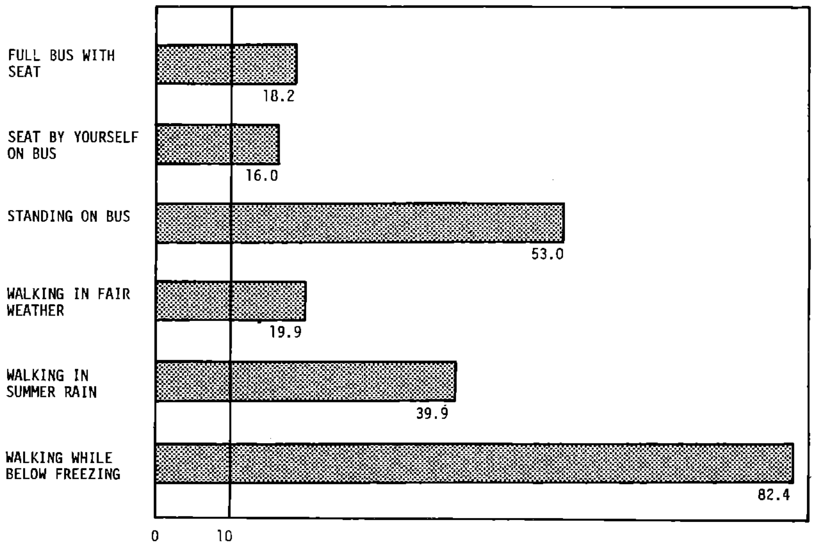

Fig. 5. Subjective values of time for environmental conditions on 30 minute trips to work.

TABLE VIII

Coefficients in the Subjective Value of Time Equation for Number of Transfers

Factor	Level	Coefficient
Number of transfers	0	0.50
	1	1.27
	2	1.77
Standard trip (s_{20})		40.0

been previously analyzed (Horowitz, 1978), and the results are summarized in Fig. 5. The trips of interest are those that vary the conditions of in-vehicle time and walking time, which are two important elements of bus transit travel. These are all 30 minute trips.

The number of passengers on a bus does not greatly affect subjective value of time, as long as a seat is assured. The difference between being on a bus that is full and being on an uncrowded bus with a seat by one's self is only 2.2 subjective units. However, respondents rated a 30 minute trip while standing as three times worse (or higher in subjective units) than a 30 minute trip while sitting.

One activity that is almost always associated with bus transit travel is walking, and the subjective value of walking time is strongly influenced by weather. Walking 30 minutes in the rain is considered twice as bad as walking 30 minutes in fair weather. Walking in below-freezing weather is considered four times worse than walking in fair weather. One would also expect weather to be a similarly strong influence on waiting and transferring at outdoor stops; however, this hypothesis was not specifically tested in the experiment.

The subjective values of time presented in this paper were based on a sample of Chicago adults who were under 65 years of age. Consequently, planners should exercise normal care when applying these results to other locales or other groups of potential transit riders. Chicago was originally selected as the study site because both its transit system and its population were judged to be representative of major cities in the United States. Throughout the experiment and subsequent analysis, there were no indications that the chosen sample was unrepresentative in any important respect. While the 84 respondents differed widely in their socioeconomic and personal characteristics, their responses were consistent. Particularly, it was not possible to significantly improve any of the estimates by including socioeconomic variables in the regression equation. In contrast to the present study, a lack of significance of socioeconomic variables would be considered unusual in behavioral value of time studies.

Conclusions

Transfer and seat assurance emerge, respectively, as the most important negative and positive influences when measuring subjective value of time. Due to the strength of these effects, transfers and seat assurance should be routinely and quantitatively considered in route planning, benefit-cost analyses and travel demand studies. Studies should take into account the fact that it is not only the duration of the transfer time which impacts negatively on evaluations of trips, but the requirement to transfer at all.

Bus transit at its best is not considered an inferior mode of travel by the respondents in this study. However, the conditions necessary for bus transit to be evaluated equal to automobile travel are not often observed. Assuming that bus transit speeds are comparable to those of automobiles, there must be guaranteed seats, little or no waiting, no transfers, and protection from weather. One system that approaches these favorable conditions is the express bus on an exclusive freeway lane (Wachs, 1976). With such a system, the requirement to wait can be offset by potential travel time advantages.

Magnitude estimation of value of time can be a valuable tool in transit planning. A large amount of statistically significant information can be obtained from relatively small samples. Time necessary to administer the questions is short (less than one hour in this study) and results can be represented by linear models. Importantly, eliciting evaluations in a controlled psychological scaling experiment can lead to relationships for time valuation that could not be obtained in any other manner. The results can be used, without additional information, in travel demand estimation and studies of transit system effectiveness where dollar values of time are not necessarily required.

Acknowledgement

The data set used in the study was collected by the Transportation and Traffic Science Department of the General Motors Research Laboratories; the opportunity to use these data is gratefully acknowledged.

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