Modeling Travelers' Perceptions of Travel Time

JAMES E. CLARK

In order to better understand and model the way urban travelers make decisions, the relation between travel times as actually measured and travel times as reported by travelers themselves is examined. Stevens' Law, the psychological theory that the perception of a stimulus is related to the actual stimulus by an exponential function, is used to analyze the relation between a set of travel times reported by travelers and the corresponding travel times actually measured. A comparison of the measured and reported times suggests that Stevens' Law does apply to the perception of travel time and that travel times for different modes of travel are perceived in different ways. The effects of these differences between reported and measured travel times for planning models are then examined, and a suggestion is made as to how Stevens' Law can be used to overcome these differences and improve the accuracy of transportation planning models.

It has long been recognized that there are problems in choosing what values to use to represent variables such as travel times and costs in transportation planning models (1). The growing use of behavioral model forms (such as logit analysis) that are explicitly based on economic and psychological theories of how individuals make choices has brought these problems into clearer focus. In all theories of choice behavior, an individual's choices of such items as travel mode and destination are based on the individual's perception of the characteristics of various modes and destinations.

Unfortunately for transportation planners, information on travelers' perceived values of travel times, travel costs, and other such variables is not directly available. The two available methods of representing the perceived values of such variables are by the use of the actual, measured values and by the use of values reported by travelers in surveys. Both of these methods, however, have at least potential inaccuracies in comparison with the perceived values. In addition, it has recently been shown that there frequently are large differences between measured and reported values for travel times and costs (2).

As will be discussed later, the use of measured values in estimating models of the sort usually used in transportation planning requires the implicit or explicit assumption that the measured values of variables are a linear function of the perceived values or at worst that the perceived values are randomly distributed around the actual measured values. However, the psychological theory of perception, discussed in more detail below, suggests that the perceived values are likely to be nonlinear functions of the measured values. Although this would suggest that using reported values would be preferable to using measured values in transportation planning models (at least where reported values are available), it must be acknowledged that reported values may also not accurately reflect perceived values. In some cases, travelers may never have considered the value of some variables (for example, the travel time by bus for a trip the traveler always makes by car), so the reported values may well be largely guesses rather than perceptions. In addition, travelers may consciously or subconsciously distort their perceptions so that their reported values for travel times, costs, etc., make their own choices seem better or more logical than they really are. In the marketing literature, this phenomenon is known as "postpurchase bias", and it is commonly found that buyers of a particular product report more favorable perceptions of the product after the purchase is made than they did before the purchase. Although this paper recognizes the possibility that reported values may well differ from perceived values, reported values of travel times are used here as proxies for the unavailable perceived values.

The remainder of this paper is an exploration of the differences between reported and measured travel times and of the effects of these differences on the estimation of an urban transportation planning model. The first section outlines the general theory of perception that has been developed by psychologists. Next, the data set used is described. This is followed by a comparison of measured and reported travel times as a test of the applicability of the psychological theory of perception to travel behavior. The effects of the differences between measured and reported times on the estimation of a modal-split model of the logit type are then examined. Finally, the conclusions that can be drawn from the exploration are presented.

PSYCHOLOGY OF PERCEPTION

The basic concept of psychology regarding the relation of perceived values of a phenomenon to their actual values is summarized in Stevens' Law (3), which states that the perceived values are a power function of the actual values, or

$$PV = a \cdot (AV)^b \tag{1}$$

where

PV = perceived value,
AV = actual value, and
a and b = coefficients related to characteristics of the particular phenomenon involved.

In experiments by psychologists, Stevens' Law has been found to describe accurately the relation between the perceived magnitudes of various stimuli (as reported by those exposed to the stimuli) and their actual magnitudes (4). In the psychological literature and in the geography literature referred to below, reported values have been assumed to be equal to perceived values.

During the 1970s, geographers have used Stevens' Law to explore the relations between perceived physical distance ("cognized distance", in their terminology), as reported by groups of experimental subjects, and actual distance. In general, Stevens' Law has been found to apply to the reported perceptions of actual physical distances. For a sample of persons in Kingston, Ontario, Ericksen (5) estimated the following relation between perceived distance and actual distance: a = 1.51, b = 0.91, and R^2 = 0.45. For a sample from Columbus, Ohio, Briggs (6) estimated the following: a = 1.55, b = 0.57, and R^2 = 0.76. Other similar studies (7-9) have had similar results.

These efforts led to a study by Burnett (10) that related reported perceptions of travel times ("cognized time") to actual measured travel times for driving trips to various locations in the Dallas-Fort Worth, Texas, metropolitan area from the then new Dallas-Fort Worth Regional Airport. Information on drivers' reported travel times to their destinations was gathered by interview from drivers leaving the airport and was matched with measured driving times to the destinations. The data set consisted of 200 pairs of reported and measured travel times to various destinations.

Power functions in the form of Stevens' Law were then estimated by Burnett for the various subsets (different directions, destination types, and age and income groups) of the sample. Except for one subset, the estimated values of a fell between 1.31 and 3.65 and the estimated values of b fell between 0.60 and 0.89; R^2 values were between 0.52 and 0.84. Comparisons of the results for different subsets showed that, although the direction of travel (toward or away from the city center) has a statistically significant effect on the estimated coefficients, age and destination differences have no significant effects. Large differences in income also produce significant differences in estimated coefficients.

The research described in this paper can be regarded as both an extension and an expansion of Burnett's pioneering efforts. Whereas Burnett's data covered a relatively low-density geographic area, the data used here are from a much more densely populated area. In addition, the data cover not only automobile drivers but also automobile passengers and users of bus and rapid transit services. Finally, the variety of modes available allows the estimation and comparison of modal-choice models by using reported and measured travel times.

DATA DESCRIPTION

The data on reported travel times and other trip and traveler characteristics used in this study were collected from a sample of people who traveled to Evanston, Illinois, to shop. Evanston, a predominately residential suburb located on Lake Michigan immediately north of Chicago, had a population of 80 000 at the time the data were collected. The downtown area is typical of older North American cities and suburbs, with shop-lined streets rather than shopping malls. There are two large department stores and numerous specialty shops along with many restaurants and office buildings. Convenient and reasonably inexpensive parking, both on the street and in off-street parking lots and ramps, makes driving practical. The shopping area is served by several bus routes that connect the downtown shopping area with other parts of Evanston, other suburbs, and the northern parts of Chicago. A north-south elevated rapid transit line (the "L") provides service to the downtown area from a large part of Evanston and Wilmette (immediately north of Evanston) and connects with the Howard Street rapid transit line that serves northern Chicago. Although Evanston is also served by the Chicago and North Western commuter railroad and by taxi services, these are not included below due to insufficient data; walking and bicycling were also used by some of those surveyed to travel to the shopping area.

Data on travel times (both in-vehicle and out-of-vehicle), travel costs, trip origins, and other trip characteristics, both of the mode actually chosen by the traveler and of the mode the traveler gave as the alternative he or she would use if the chosen mode were not available, were obtained from self-administered questionnaires distributed to persons shopping in downtown Evanston on days with pleasant weather conditions in June 1975. The survey also obtained socioeconomic data on the travelers themselves.

Data on measured in-vehicle travel times by automobile were obtained by actually driving the reported trips and measuring the time required, by way of the fastest route available, for each trip. Each trip was driven twice in each direction at the same time of day as the reported trip; the measured time was obtained by discarding the fastest and slowest times and then using the mean of the two remaining times. Using the mean of all four trips noticeably changed the measured times of a few trips due to atypically high or low measured times on one of the four runs and resulted in a somewhat worse fit when the times were compared with the reported travel times.

A problem with developing the measured driving times arose from the manner in which the trip origin was obtained from questionnaire respondents. To preserve the respondents' anonymity, only the approximate address was requested on the questionnaire. During the coding of the returned questionnaires, the location of each trip origin was assigned to one of the 0.5-mile² zones into which the study area was divided. The actual driving times were measured from the most centrally located major intersection in each zone to the center of the downtown shopping area. To allow for the driving time from the actual trip origin to the zone center intersection, 2 min was added to each of the measured driving times. The figure of 2 min was obtained from trials in which runs were made from several randomly chosen locations in five zones to the downtown center. Using times of 1 or 3 min did not significantly change the results presented below.

Measured in-vehicle travel times for bus and L-riders were obtained from the timetables in effect at the time of the survey. Sample measurements of actual travel times show that these schedules are consistently met. The number of observations for which both a reported and a measured time are available is given below:

Mode	Chosen	Alternative
Automobile		
Driver	213	134
Passenger	59	72
Bus	82	147
L	32	79
Total	386	432

The totals for chosen or alternative mode do not agree due to the use by some respondents of taxi, train, walking, or bicycle as either their chosen or alternative mode.

Although this study does not focus on differences between reported and actual travel costs, due to the difficulty of accurately estimating a specific individual's driving costs for a particular trip, the data available do permit a few comparisons of reported and actual transit fares. Among those who actually used transit to travel to Evanston on the survey date, 98 percent of bus riders and 81 percent of L-riders correctly reported the fare paid; many of those reporting incorrectly were apparently confused between one-way fares (as requested in the questionnaire) and round-trip fares. However, of those who gave transit as their alternative mode, only 84 percent of the potential bus riders and 68 percent of the potential L-riders correctly reported the fares they would have paid if they had used transit. Most of the incorrectly reported fares--91 percent for bus and 96 percent for L--were higher than the actual fares.

COMPARISON OF REPORTED AND MEASURED TRAVEL TIMES

Initial comparison of reported and measured in-vehicle travel times was made by regressing the log of reported time on the log of measured time plus a constant term. This functional form is the equivalent of Stevens' Law [$PV = a \cdot (AV)^b$, where PV is represented by the reported time and AV by the measured time]. The resulting estimates of a and b are given in Table 1, along with goodness-of-fit measures, for the sample as a whole and for subsamples broken down by mode and by whether the observation is of the traveler's chosen or alternative mode.

In these regression estimations, all those with "yes" in the b < 1? column (all but regressions 7 and 15) have b coefficients that are less than 1 at the 1 percent level of significance. A b coefficient that is significantly different from 1 implies that there is the sort of nonlinear relation between perceived times (as represented by reported times) and measured times that Stevens' Law predicts, whereas a b coefficient of 1 would imply that reported travel times are merely proportional to actual travel times. There may be problems with using the usual methods of modeling and forecasting travel choices and behavior if there is a nonlinear relation between perceived and measured travel times. This is discussed in the next section of this paper.

The extremely low R^2 for regression 1 containing all the data, especially when compared with the R^2 values in the various subsets, seems to imply that different groups within the sample may perceive (or at least report) travel times in different ways or on different scales. This might come about because travel time is perceived differently for different modes or because those travelers who actually used a particular mode perceived (or reported) their travel time differently from those who did not use that mode.

As described by Williams (11), it is possible to construct a statistic based on the differences between the regression error sums of squares for a data set as a whole and for the various subsets; this statistic has an F-distribution. A significant F-statistic implies that the regressions performed on the various subsets have different coefficients, and an insignificant F-statistic would imply that the regression coefficients are not in fact very different. For each mode except automobile driver, there is no significant difference in the perception of travel time between those who actually chose the mode and those who gave that mode as their alternative; the difference between those who chose to drive a car and those for whom driving was their alternative is significant at the 1 percent level. There is also no significant difference between automobile drivers and automobile passengers.

However, there is a significant difference (at the 1 percent level) among the different modes in how the travel time by those modes is perceived. A comparison of regressions 8, 11, and 14 shows that the scale factor a is higher for both bus and L than for automobile, which suggests that, at least initially, a minute spent in an automobile seems shorter than a minute spent on a bus or on the L. The exponent b, however, is lower for bus and L travel than for automobile travel; the time spent traveling seems to increase at a slower rate on public transit than in driving or riding in a car.

APPLICATION TO TRANSPORTATION PLANNING MODELS

The analysis above strongly suggests that travel time is perceived by travelers in a manner different from actual measured travel time and that perceived time is related to measured time by Stevens' Law. This relation has at least the potential for creating inaccuracies in the types of transportation planning models commonly used.

As an example, consider the logit model, probably at this time the most frequently used model form for transportation research; logit analysis is also being applied more and more frequently in actual transportation planning and forecasting models. Where an individual is choosing between options i and j, the logit model has the following form:

$$P_i = e^{G(X_{j,i})}/[1 - e^{G(X_{j,i})}] \quad (2)$$

where P_i is the probability of choosing option i and $G(X_{j,i})$ is a function of the relative characteristics of choices i and j. The function G is usually assumed to be linear in the differences between the characteristics of the two choices. For example, if a person were to choose between bus (b) and car (c) for a trip and the travel times and costs of the two modes were used as the choice criteria, the function G would take the following form:

$$G = a_1(T_b - T_c) + a_2(C_b - C_c) \quad (3)$$

where

T_b and T_c = travel times by bus and car, respectively;
C_b and C_c = travel costs; and
a_1 and a_2 = coefficients to be estimated.

If it is thought that some inherent characteristics

Table 1. Regression estimations: reported and measured times.

Mode	Regression No.	Chosen or Alternative Mode	a	b	b < 1	R^2	No. of Observations
All	1	Both	5.37	0.101	Yes	0.016	818
Automobile driver	2	Both	2.03	0.721	Yes	0.278	347
	3	Chosen	2.61	0.604	Yes	0.224	213
	4	Alternative	2.01	0.645	Yes	0.191	134
Automobile passenger	5	Both	1.91	0.711	Yes	0.309	131
	6	Chosen	2.56	0.541	Yes	0.192	59
	7	Alternative	1.47	0.862	No	0.431	72
All automobile	8	Both	2.01	0.713	Yes	0.283	478
	9	Chosen	2.54	0.602	Yes	0.224	272
	10	Alternative	1.83	0.717	Yes	0.271	206
Bus	11	Both	3.09	0.481	Yes	0.254	229
	12	Chosen	3.70	0.355	Yes	0.146	82
	13	Alternative	2.88	0.536	Yes	0.305	147
L	14	Both	2.30	0.624	Yes	0.282	111
	15	Chosen	2.13	0.724	No	0.265	32
	16	Alternative	2.47	0.539	Yes	0.268	79
All transit	17	Both	2.51	0.588	Yes	0.379	340
	18	Chosen	2.79	0.516	Yes	0.245	114
	19	Alternative	2.42	0.619	Yes	0.440	226

of buses or cars affect the person's choice, a dummy variable in the form of $a_3(D)$ can be added to the function G.

Although the linear form for G both is intuitively appealing and has the weight of consumer choice theory (12) behind it, problems arise when this form, using measured values, is confronted with Stevens' Law. Other things being equal, the usual form of the logit model, estimated from actual travel times, would imply that a relative change in travel time of, say, 10 min will have the same effect on the choice probability between car and bus regardless of the length of the trip involved. Stevens' Law, however, with b coefficients estimated above as less than 1, implies that a change of 10 min will be perceived as becoming smaller the longer the trip.

Some of the effects of these differences between measured travel times and those reported by travelers can be seen by estimating logit models of modal choice by using first the measured travel times from above and then reported travel times. The results of such a comparison are given in models 1 and 2 in Table 2. The coefficients presented are the estimated a_i from Equations 1 and 2.

Table 2 gives the estimated coefficients for logit models based on the hypothesis that a traveler's choice of mode depends on relative travel costs, travel times, and specific characteristics of the modes available. Both models used a data set with 256 observations; these consist of those individuals surveyed as described above whose chosen and alternative modes were among the driver, passenger, bus, and L modes. The data are the same for both models except that travel time in model 1 is obtained by adding the measured in-vehicle travel times to the travelers' reported out-of-vehicle travel times whereas model 2 uses the sum of the in-vehicle and out-of-vehicle travel times reported by the travelers.

Travel time and travel cost would a priori be expected to have negative coefficients; the higher the cost or time of a mode, the lower the probability of choosing that mode would be expected to be. The insignificant coefficient on travel cost is not surprising for a data set based on relatively infrequent shopping trips; similar results have been found by others in similar situations (13). The negative signs on the coefficients for specific modes refer to their unattractiveness in comparison with automobile driver, the base mode for these equations.

As can be seen in Table 2, the results of the two models are somewhat dissimilar. In particular, model 1, using measured times, implies that travel time is not a significant factor in the modal-choice decision of those travelers surveyed (the t-statistic is not significant even at the 10 percent level). Model 2, using reported times, implies, on the other hand, that travel time is a highly significant determinant of modal choice (the t-statistic is significant at the 1 percent level). The other coefficients are also quite different. Although both are significant at the 1 percent level, the higher F-statistic for model 2 implies that model 2 fits the data better than model 1.

The foregoing analysis suggests that using reported rather than measured data on travel times to estimate demand models is to be preferred. But reported data are frequently not available. In particular, reported data will not be available for forecasting the future effects of changes in the transportation system. One possible way to counteract this problem is to modify the actual travel-time data according to travelers' perceptions of those times. Model 3 in Table 2 presents the results of a logit model run on the data discussed above for measured travel times, where the measured times are transformed according to Stevens' Law by using the a and b regression coefficients for each mode as estimated in the previous section. As can be seen, the estimates in model 3 agree quite closely with those in model 2 based on reported travel times.

CONCLUSIONS

In order to better understand and model the way urban travelers make decisions, this paper has examined the relation between travel times as actually measured and travel times as reported by travelers themselves by using reported times as proxies for perceived times. Stevens' Law, the psychological theory that the perception of a stimulus is related to the actual stimulus by an exponential function, was used to analyze the relation between a set of travel times and trips reported by travelers and the corresponding travel times actually measured. A comparison of the measured and reported times implied that Stevens' Law does apply to the perception of travel time and that travel times for different modes are seemingly perceived in different ways. The effects of these differences between reported and measured travel times on transportation planning and forecasting models were then examined.

Several useful conclusions can be drawn from this study. The first is that the way in which travelers perceive the characteristics of transportation systems is not described with complete accuracy by the engineering characteristics of the systems. Transportation planners and forecasters must be aware of how perceptions differ from reality; Stevens' Law seems to describe at least a major part of the connection between perception and reality. Second, if a planner knows or can estimate the a and b coefficients in the Stevens' Law equation that relate perception to reality, the accuracy of planning models can be improved by transforming the actual values of system characteristics, such as travel times, to reflect travelers' perceptions of these characteristics more closely.

These conclusions suggest several recommendations for future research on modeling travelers' perceptions. The testing of the applicability of Stevens' Law to other modal characteristics, such as travel cost and access and egress times, would be straight-

Table 2. Logit estimations.

Model No.	Travel Cost		Travel Time		Passenger		Bus		L		F-Statistic	Correctly Predicted (%)
	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic	Coefficient	t-Statistic		
1	0.001 87	0.78	-0.0116	-0.90	-0.783	-3.08	-1.129	-3.71	-1.272	-3.86	66.8	73.0
2	0.002 29	0.94	-0.0526	-2.99	-0.756	-2.94	-0.408	-1.14	-0.703	-1.91	76.1	73.4
3	0.002 25	0.94	-0.0523	-2.98	-0.799	-3.10	-0.527	-1.60	-0.734	-2.02	75.9	73.4

forward as would testing the transferability of the coefficients of Stevens' Law among localities in different geographic areas and with different characteristics. Preliminary psychological research (4) suggests that it may be possible to develop a single equation that captures the relations between reality and perception for all types of travel characteristics.

Another potentially fruitful area for further research would be an integration of the Stevens' Law concept with the concept of cognitive dissonance. The usefulness for transportation choice modeling of the theory of cognitive dissonance, with its implications regarding the interrelation of attitudes and behavior, has been explored by Golob, Horowitz, and Wachs (14), Dumas and Dobson (15), and others. Further application of the insights into human behavior that are available in the literature on psychology and marketing should prove beneficial in improving both knowledge of travel behavior and the ability to forecast future behavior.

ACKNOWLEDGMENT

The collection of the data on reported travel times and costs was supported by a grant to Northwestern University from the U.S. Department of Transportation. I would like to thank E. Hauer of the University of Toronto and several anonymous referees for helpful comments.

REFERENCES

1. P.L. Watson. Problems Associated with Time and Cost Data Used in Travel Choice Modeling and Valuation of Time. HRB, Highway Research Record 369, 1971, pp. 148-158.
2. A.H. Meyburg and W. Brög. Validity Problems in Empirical Analyses of Non-Home-Activity Patterns. TRB, Transportation Research Record 807, 1981, pp. 46-50.
3. S.S. Stevens. On the Psychophysical Law. Psychological Review, Vol. 64, 1957, pp. 153-181.
4. R. Teghtsoonian. On the Exponents in Stevens' Law and the Constant in Ekman's Law. Psychological Review, Vol. 78, 1971, pp. 71-80.
5. R.H. Erikson. The Effects of Perceived Place Attributes on the Cognition of Distance. Department of Geography, Univ. of Iowa, Iowa City, Discussion Paper 23, 1975.
6. R. Briggs. Urban Cognitive Distance. In Image and Environment: Cognitive Mapping and Spatial Behavior (R.M. Downs and D. Shea, eds.), Aldine Publishing Co., Chicago, 1973.
7. O. Bratfish. A Further Study of the Relation Between Subjective Distance and Emotional Involvement. Acta Psychologica, Vol. 29, 1969, pp. 244-255.
8. D. Cantor and S.K. Tagg. Distance Estimation in Cities. Environment and Behavior, Vol. 7, 1975, pp. 59-80.
9. R.A. Lowrey. Distance Concepts of Urban Residents. Environment and Behavior, Vol. 2, 1970, pp. 52-73.
10. P. Burnett. Time Cognition and Urban Travel Behavior. Presented at Geographical Perspectives on the American City Conference, Philadelphia, 1976.
11. E.J. Williams. Regression Analysis. Wiley, New York, 1959, pp. 129-137.
12. T.A. Domencich and D. McFadden. Urban Travel Demand. North-Holland, Amsterdam, Netherlands, 1975.
13. T.J. Adler and M. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. TRB, Transportation Research Record 569, 1976, pp. 136-150.
14. T.H. Golob, A.D. Horowitz, and M. Wachs. Attitude-Behaviour Relationships in Travel-Demand Modelling. In Behavioural Travel Modelling (D.A. Hensher and P.R. Stopher, eds.), Croom Helm, London, 1979.
15. J. Dumas and R. Dobson. Traveler Attitude: Behavior Implications for the Operation and Promotion of Transport Systems. TRB, Transportation Research Record 723, 1979, pp. 64-71.

Publication of this paper sponsored by Committee on Traveler Behavior and Values.

Design and Analysis of Simulated Choice or Allocation Experiments in Travel Choice Modeling

JORDAN J. LOUVIERE AND DAVID A. HENSHER

A new approach for modeling traveler trade-offs and choices is proposed, described, and illustrated. Based on research in psychology, marketing, and economics, a method for developing discrete choice models from controlled laboratory simulation experiments is developed and presented. The method borrows statistical theory from discrete choice theory in econometrics and from the design of statistical experiments to marry work in trade-off analysis with choice analysis. The method is illustrated by means of several travel-choice-related examples that involve choice of mode and destination. Recent evidence of validity in forecasting the actual behavior of real markets is reviewed in support of the approach.

Since the early 1970s, the study of revealed-choice behavior based on the random utility derivations of discrete choice theory in econometrics (1-6) has gained a following in the analysis and forecasting of travel behavior. If real choice data satisfy the conditions assumed in the statistical choice models, it is possible to derive aggregate-level trade-offs and to simultaneously forecast choice behavior. Hence, methods based on revealed choice have high external validity and practical applicability to strategic policy problems.

Other approaches have recently gained attention--notably, laboratory simulation methods such as variations of conjoint measurement or trade-off analysis (7-9) and functional measurement (10-15), which are the primary methods of approach for developing quantitative descriptions of multiattribute individual