Assessment of Transfer Penalty to Bus Riders in Taipei: A Disaggregate Demand Modeling Approach

ANTHONY FU-WHA HAN

A transfer penalty to bus riders has long been recognized as an important factor characterizing the service performance of a transit system. Nevertheless, the way the transfer penalty is treated in current transit network design and improvement planning processes is rather subjective. The transfer penalty is usually treated by use of either subjective values assigned by transit planners or time-value proxies inferred from activities irrelevant to transfers in transit travel. In this paper, the transfer penalty is assessed in terms of monetary and time units with a disaggregate demand modeling approach. The models developed take a binary logit format with two alternative path choices, one that requires a transfer en route and another that does not. Data collected from 1,850 randomly sampled transit users in Taipei are used for model calibration. The penalty of one bus-to-bus transfer is approximately equivalent to the cost of 4.5 N.T. dollars (14 U.S. cents), 30 min of in-bus travel, or 10 min of waiting at a bus stop. The assessment results suggest that in current practice transit planners may underestimate the transfer penalty to bus riders. Some characteristics of transit travel in Taipei are also explored and discussed.

Transfer penalty or transfer inconvenience to transit users has long been recognized as one important factor characterizing the service performance of a transit system *(1, 2)*. Nevertheless, in the past, few studies have been concerned with the assessment of transfer penalties to transit users. Recently, some studies *(3, 4)* have attempted to derive subjective values of transfer penalties by using market research methods for scaling attitude measures of user perceptions of transfers into numerical values. Results of these studies can help promote better understanding of the demand of transit travel and predict responses of transit users to service-oriented actions. However, subjective values of transfer penalties have limited use for transit network optimization and evaluation purposes. As a result, the way the factor of transfer penalty is treated in current transit network design or optimization models *(5, 6)* is arbitrary. Specifically, transfer penalty is usually treated through the use of either subjective values assigned by transit planners or proxies inferred from time value analyses that are irrelevant to transfer activities.

In this study, results more useful than subjective values of transfer penalties are derived. A behavior-based choice-modeling approach is applied to determine the values of transfer penalty and other related service attributes such as in-vehicle travel time, wait time, and walk time in transit travel. These values, when assessed in monetary or equivalent time units, can be used for quantifying economic benefits of service-oriented transit projects, enhancing current transit planning to achieve better service performance.

Analysis procedure of this study consists of three steps. First, disaggregate binary logit choice models were specified for describing the behavior of bus riders choosing between two alternative paths, of which one requires a transfer en route and the other does not. Second, the utility functions underlying the choice model were calibrated with data of 327 sampled bus riders in Taipei, Taiwan. Finally, values of transfer penalty and related attributes were assessed from the estimates of coefficients associated with various attributes in the calibrated utility functions.

Before describing the analysis works of this study, a brief introduction of the Taipei transit system is given at the outset of this paper.

TAIPEI TRANSIT SYSTEM

Taipei is the capital city of Taiwan, the Republic of China. The city is hilly in the southeast, mountainous in the northeast, and flat in the west. The central part of the city is surrounded by three natural boundaries—the Tamsui, Hsintein, and Keelung Rivers. The southwest portion, from where the city originated, is now the city's central business district (CBD) area. Currently, the city of Taipei has an area of 272 km^2 within its administrative boundaries, and a population of about 2.5 million *(7)*.

As population and travel activity increased rapidly in the last 20 years, the city expanded and developed along its six radiating transportation corridors from the old city district into its surrounding areas to form a metropolitan area about 20 km in diameter. With a land area of 538 km^2, the Taipei metropolitan area currently has an estimated population of about 4.5 million. Following this growth trend, the population in the metropolitan area is expected to reach about 6.1 million by the year 2001 *(8)*.

At present, all travelers in Taipei depend almost entirely on a road-based transportation system. Bus transit is the most important transportation mode. It carries more than 40 percent of the total daily passenger trips generated in the metropolitan area. The remaining trips rely on paratransit as well as private transportation modes such as taxis, automobiles, motorcycles, and bicycles (Table 1).

Department of Transportation Engineering and Management, National Chiao Tung University, Hsinchu, Taiwan, Republic of China.

TABLE 1 DAILY PASSENGER TRIP VOLUME IN TAIPEI

MODE	1981		2001 PREDICTION	
	TRIP/DAY (10^3)	MODE SHARE	TRIP/DAY (10^3)	MODE SHARE
PUBLIC TRANSPORTATION	2,508	41.6%	4,479	39%
PRIVATE TRANSPORTATION	2,647	43.9%	5,616	48.9%
TAXI	606	10.5%	978	8.5%
OTHERS	270	4.0%	414	3.6%
TOTAL	6,031	100.0%	11,487	100.0%

Scheduled transit services in the Taipei area are currently provided by 17 bus companies of which 10 major companies have joined to form the Unified Operating System (UOS). In 1985, the UOS operated 205 routes with 3,158 buses, carrying approximately 2.6 million passenger trips per day *(7)*. All UOS companies use the same tickets for providing convenient transfers between UOS routes. Students, policeman, the military, and the elderly are privileged to use discount bus tickets of which the price is half that of the regular tickets. It was estimated in 1985 that approximately 48.9 percent of UOS bus riders were discount ticket users (data provided by UOS).

A significant portion of passenger trips in Taipei transit travel involves transfers. Major bus transfer locations in the Taipei area are shown in Figure 1. On the average about 60 percent of passenger trips originating from bus stops at these locations are transfer trips. It is roughly estimated that in the Taipei area more than 1 million passenger trips per day are made through bus transfers.

CHOICE MODELING ANALYSIS

Binary Choice Set

Disaggregate binary choice models are developed in this study to assess transfer penalties in transit travel. The choice set of each individual is defined by two alternative paths connecting a fixed pair of origin and destination points. As shown in Figure 2, Path 1 is the no-transfer choice alternative; Path 2 is the one-transfer alternative, which requires a bus transfer en route. Because the Taipei area is well covered by more than 200 bus routes, most of the bus riders in the Taipei area can complete their trips with no more than one transfer. Therefore, for simplicity, the path choices involving more than one transfer en route are not considered in this study.

Note that, due to the overlapping route structure of the Taipei transit network, the actual situation in Taipei is slightly different from that depicted in Figure 2. Specifically, in most cases in Taipei, the boarding stops A and A' as well as transfer stops B and B' coincide with each other. When the two alternative paths start with the same boarding bus stop, a bus rider's choice may be influenced by which bus arrives at the stop first. The factor of first-arrival bus is thus considered in the analysis and will be discussed later.

As mentioned earlier, the transit network in Taipei is characterized by its overlapping route structure; almost all bus routes overlap in part with other bus routes. Although many transit systems outside North America are characterized by networks with extensively overlapping routes *(9)*, the competition among the 17 bus companies makes this phenomenon even more significant in Taipei. At major transfer locations in Taipei as shown earlier in Figure 1, there are generally more than 25 bus routes passing the same streets. Therefore, the no-transfer path alternative is actually an abstract presentation of a set of overlapping bus routes connecting A and C (Figure 2). Similarly, the one-transfer alternative represents the combination of two sets of overlapping routes connecting A' and B, and B' and C, respectively. Consequently, the service attributes (travel time, walk time, wait time, fare, etc.) associated with the two choice alternatives are measures of the overall performance of a set of overlapping routes rather than those performance measures of a specific route.

Model Specification

The choice models developed in this study take the format of binary logit models. The two choice alternatives are as defined in the previous section: Alternative 1 is the no transfer alternative, and Alternative 2 the one-transfer alternative. Notation used for specifying the utilities functions of these two alternatives is defined as follows:

V_i = measured utility of Alternative i ($i = 1, 2$);
WK_i = walk time in minutes of Alternative i ($i = 1, 2$);
WT_i = wait time in minutes of Alternative i ($i = 1, 2$);

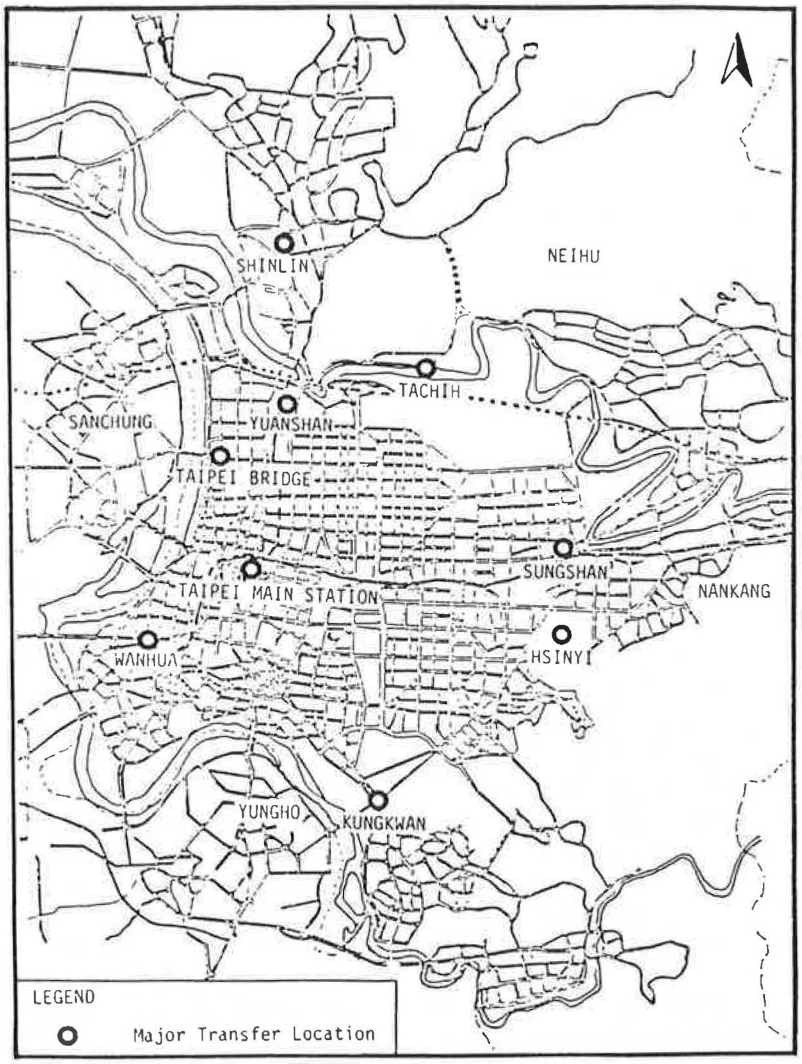

FIGURE 1 Major transfer locations in Taipei metropolitan area.

IV_i = in-vehicle travel time in minutes of Alternative i (i = 1, 2);
FR_i = bus fare in N.T. dollars of Alternative i (i = 1, 2);
OV_i = out-of-vehicle time of Alternative i, $OV_i = WK_i + WT_i$ (i = 1, 2);
δ_i = 1 if the first available bus belongs to Alternative i, 0 otherwise (i = 1, 2); and
β_j = coefficients to be estimated (j = 1, 2, . . .)

Although most of these attributes are well-defined, a few points need to be clarified. The wait time associated with the one-transfer alternative WT_2 includes wait times both for the first and second bus en route. WK_2 includes walk times both from the trip origin to the first boarding stop and from the first alighting stop to the second boarding stop. Similarly, both IV_2 and FR_2 consist of two components each of which is associated with the first and second bus journey, respectively. Therefore, in this study the transfer penalty means the inconvenience of the bus-to-bus transfer activity per se, and does not include that of the additional in- or out-of-vehicle travel times of the second bus journey. The dummy variable δ_i needs to be explained as well. The variable denotes the first available bus instead of the first arrival bus because in Taipei, particularly during peak hours, the buses are usually operated close to or at their capacities. As a result, in Taipei the first arrival bus at a bus stop may not be the first available bus for an individual to get on board. Therefore, for this study the factor of the first available bus is considered more appropriate than that of the first arrival bus.

Three model specifications are given in Table 2. All three of these models have generic service attributes of *WK*, *WT*, *IV*, and *FR* to form linear utility functions, and use the constant term β_1 to measure the revealed utility (or disutility) of one bus-to-bus transfer to the rider. Yet these models are somewhat different from each other. Model 1 (as defined in Table 2) includes only the aforementioned four service attributes and is the simplest one among the three. Both Models 2 and 3 take the dummy variable δ_i for the first available bus into consideration. Model 3 combines *WK* and *WT* into a single attribute *OV*, and is just a simplified version of Model 2. The model yielding the best results will be applied to determine the values of transfer penalties and other related service attributes.

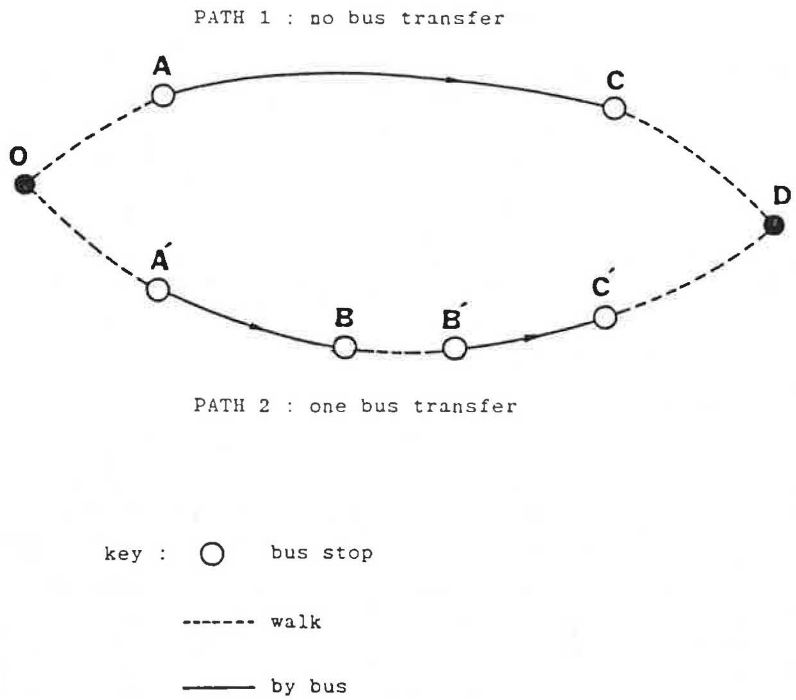

FIGURE 2 Two path choices.

TABLE 2 MODEL SPECIFICATION

Model 1	$V_1 = \beta_1 + \beta_2(WK)_1 + \beta_3(WT)_1 + \beta_4(IV)_1 + \beta_5(FR)_1$ $V_2 = \beta_2(WK)_2 + \beta_3(WT)_2 + \beta_4(IV)_2 + \beta_5(FR)_2$
Model 2	$V_1 = \beta_1 + \beta_2(WK)_1 + \beta_3(WT)_1 + \beta_4(IV)_1 + \beta_5(FR)_1 + \beta_6(\delta_1)$ $V_2 = \beta_2(WK)_2 + \beta_3(WT)_2 + \beta_4(IV)_2 + \beta_5(FR)_2 + \beta_6(\delta_2)$
Model 3	$V_1 = \beta_1 + \beta_2(OV)_1 + \beta_3(IV)_1 + \beta_4(FR)_1 + \beta_5(\delta_1)$ $V_2 = \beta_2(OV)_2 + \beta_3(IV)_2 + \beta_4(FR)_2 + \beta_5(\delta_2)$

Data Sampling

The three models are calibrated with a data set containing disaggregate information associated with 327 bus riders in Taipei. The data collection was done during the period from December 1985 through January 1986. There were 1,850 bus riders randomly selected and interviewed at the major transfer locations in Taipei, as shown in Figure 1. Each interviewee was asked to provide detailed data associated with the interviewee's previous bus trips. The data items included estimates of service attributes (walk time, wait time, bus fare, and in-vehicle travel time) as well as the path choice made during the last bus trip. Among those 1,850 interviewed, 327 riders provided complete information on their experienced path choices, forming the basis of the data set used for model calibration.

Some characteristics of the 327 sampled bus riders are as follows:

1. Age is approximately normally distributed; the majority (63.6 percent) is in the range of 20 to 30 years of age.
2. In occupation 54.4 percent of the sampled riders are students; 20.4 percent work for private business or industries, and 12.9 percent for government agencies; the other 12.3 percent are not employed.
3. Most trips are school trips (53.8 percent) and work trips (34.3 percent); the other 11.9 percent of trips are social and shopping trips.
4. Sampled riders using discount tickets amount to 56.3 percent.

No statistical tests have been conducted to show the lack of bias of the sample of 327 bus riders. Yet the aforementioned characteristics of the sample show a reasonable profile of transit travel in Taipei; the sample is thus deemed appropriate for representing the target population of riders who regularly face the binary path choices defined by our models.

Model Calibration

The TROMP computer package developed by Sparmann and Daganzo *(10)* was applied to calibrate the three binary logit

TABLE 3 CALIBRATION RESULTS

(Sample Size : N = 327)

Attribute	Model 1 $\hat{\beta}$	Model 1 t*	Model 2 $\hat{\beta}$	Model 2 t	Model 3 $\hat{\beta}$	Model 3 t
Constant Term, β_1	0.328	1.695	0.600	2.815	0.446	2.168
Walk Time, WK	-0.133	-5.143	-0.121	-4.430	NA**	NA
Wait Time, WT	-0.078	-4.089	-0.059	-2.870	NA	NA
Out-of-Vehicle Time, OV	NA	NA	NA	NA	-0.081	-4.776
In-Vehicle Time, IV	-0.028	-2.194	-0.020	-1.421	-0.023	-1.589
Bus Fare, FR	-0.123	-2.502	-0.134	-2.508	-0.124	-2.387
Dummy Variable, δ	NA	NA	0.875	5.382	0.858	5.474
$LL(\hat{\beta})$	-178.668		-160.307		-162.674	
LL(0)	-226.659		-226.659		-226.659	
$\rho^2 = 1 - \frac{LL(\hat{\beta})}{LL(0)}$	0.212		0.293		0.282	

* Asymtotic t value

** Not Applicable

models specified in Table 2. Calibration results of each model included the estimates of coefficients $\hat{\beta}$, the asymptotic t values of the estimates, and the value of the likelihood ratio index ρ^2. These results are presented in Table 3.

As shown in Table 3, all three models yield estimates of reasonable signs, explaining logical travel behavior underlying the specified utility functions. Nevertheless, Model 1 does not yield a statistically significant estimate of β_1, which is essential for the assessment of the transfer penalty, and thus cannot be accepted for further analysis. Models 2 and 3 yield similar results; both yield a ρ^2 value greater than 0.28 and statistically significant estimates of all parameters except for that of in-vehicle travel time IV (of which the absolute asymptotic t value is less than 2). Yet Model 2 explores significantly different values of walk time WK and wait time WT; thus, calibration results of Model 2 will be used for determining the values of transfer penalties and other related service attributes.

The choice behavior of bus riders using regular tickets is not much different from that of bus riders using discount tickets. As shown in Table 4, Model 2 yields statistically indifferent results when calibrated with two subsamples of regular and discount ticket users. The formal statistical test procedure given in the appendix shows no significantly different taste variations between the two subgroups of transit users in Taipei. Therefore, the assessment of transfer penalties will be made for all transit users in Taipei as a whole; detailed assessment for different subgroups of bus riders seems unnecessary.

TABLE 4 RESULTS OF TWO SUBSAMPLES

Attribute	Regular Ticket Users (N=143) $\hat{\beta}$	Regular Ticket Users (N=143) t	Discount Ticket Users (N=184) $\hat{\beta}$	Discount Ticket Users (N=184) t
Constant Term, β_1	0.605	1.748	0.665	2.522
Walk Time, WK	-0.112	-2.844	-0.131	-3.164
Wait Time, WT	-0.068	-2.509	-0.045	-1.546
In-Vehicle Time, IV	-0.019	-0.951	-0.023	-1.385
Bus Fare, FR	-0.140	-2.006	-0.111	-1.334
Dummy Varialbe, δ	0.956	3.641	0.857	4.420
$LL(\hat{\beta})$	-65.233		-94.626	
LL(0)	-99.120		-127.539	
$\rho^2 = 1 - \frac{LL(\hat{\beta})}{LL(0)}$	0.342		0.258	

ASSESSMENT RESULTS AND DISCUSSION

The values of transfer penalty and other related attributes can now be determined on the basis of the calibration results of Model 2. Specifically, the estimate of a coefficient in the utility functions represents the value in utility units per unit of its corresponding attribute. The negative of the estimated constant β_1 represents the disutility or penalty of one transfer. Time or money equivalents of the values of each attribute can be obtained from the ratios between appropriate pairs of the estimates. The assessment results are given in Table 5.

As presented in Table 5, the disutility of one bus transfer perceived by an average transit user in Taipei is approximately equivalent to 4.5 N.T. dollars (about 14 U.S. cents, assuming an

TABLE 5 ASSESSMENT RESULTS

Value \ Attribute	In-Vehicle Time (minute)	Wait Time (minute)	Walk Time (minute)	Bus Fare (N.T. Dollar)	Transfer Penalty* (utility unit)
Estimate of Coefficient (utility unit)	-0.020	-0.059	-0.121	-0.134	-0.600
Money Equivalency (N.T. Dollar)	0.15	0.44	0.90	1.00	4.48
In-Bus Travel Time Equivalency (minute)	1.00	2.95	6.05	6.70	30.00
Wait Time Equivalency (minute)	0.34	1.00	2.05	2.27	10.17
Walk Time Equivalency (minute)	0.16	0.49	1.00	1.11	4.96

*The disutility of one bus transfer.

exchange rate of 1 U.S. dollar to 32 N.T. dollars), 5 min of walk time, 10 min of wait time, or 30 min of in-bus travel time. These values suggest that in current practice transit planners may underestimate the transfer penalty to bus riders. Consequently, a truly optimal transit network structure might be more connective than what transit planners originally thought.

The estimated values of walk time, wait time, and in-bus travel time associated with transit travel in Taipei are also given in Table 5. The value of in-bus travel time is approximately 9 N.T. dollars (28 U.S. cents) per hour, which is about 10.5 percent of the hourly wages of an average worker in Taipei. The value of wait time is about 26.4 N.T. dollars (82.5 U.S. cents) per hour, and the value of walk time is about 54 N.T. dollars (1.68 U.S. dollars).

The values of walk time and wait time are six and three times of the value of in-bus travel time, respectively. The apparently overestimated value of walk time implies that pedestrians in Taipei are experiencing significant inconvenience or unpleasantness when they walk on the streets because the design of traffic signs and signals in Taipei tends to ignore the pedestrian traffic. Pedestrians in Taipei also lack adequate walking space. Many sidewalks are blocked with parked motorcycles, and most covered walkways are constantly crowded with stalls of illegal peddlers. All this makes it difficult for pedestrians to move about in Taipei.

The first available bus has a tremendous influence on the transit behavior of bus riders in Taipei. As shown in the calibrated utility function of Model 2 (Table 3), the preference for the first available bus is even greater than that for avoiding a bus transfer: $\beta_6 = 0.875$, which is greater than $\beta_1 = 0.60$. This difference means that a bus rider in Taipei is likely to get on board the first available bus, even if it requires a transfer en route. Specifically, all other factors being equal, a first available bus requiring one transfer en route would be preferred with a probability of 0.56. This preference implies that when the capacity of a transit system is not sufficient to carry its demand, bus riders might be more concerned about getting on a bus than about avoiding bus transfers.

The assessment results and implications reported in this paper may not apply to those transit systems in North America that have relatively low demand volumes as compared to their capacities. To what degree the assessment results of transfer penalty to bus riders in Taipei can be transferred or applied to transit systems in other geographic areas appears to be an interesting question and needs to be further studied.

ACKNOWLEDGMENTS

The data collection part of this research was supported by Chia-Juch Chang, Director of the Institute of Traffic and Transportation, National Chiao Tung University, Taipei, Taiwan. His support is greatly appreciated. The author is also grateful to Kuo-Shan Lin for his assistance in the data analysis.

REFERENCES

1. C. H. Alter. Evaluation of Public Transit Services: The Level-of-Service Concept. In *Transportation Research Record 606*, TRB, National Research Council, Washington, D.C., 1976, pp. 37–40.
2. W. G. Allen and F. DiCesare. Transit Service Evaluation: Preliminary Identification of Variables Characterizing Level of Service. In *Transportation Research Record 606*, TRB, National Research Council, Washington, D.C., 1976, pp. 41–47.
3. A. J. Horowitz and D. J. Zlosel. Transfer Penalties: Another Look at Transit Rider's Reluctance to Transfer. *Transportation*, Vol. 10, 1981, pp. 279–282.
4. A. J. Horowitz. Subjective Value of Time in Bus Transit Travel. *Transportation*, Vol. 10, 1981, pp. 149–164.
5. H. R. Matthias et al. Transfer Optimization in an Interactive Graphic System for Transit Planning. In *Transportation Research Record 619*, TRB, National Research Council, Washington, D.C., 1976, pp. 27–33.
6. M. Kyte, K. Stanley, and E. Gleason. Planning, Implementing and Evaluating a Timed-Transfer System in Portland, Oregon. In *Transportation Research Record 877*, TRB, National Research Council, Washington, D.C., 1982, pp. 23–29.
7. *The Statistical Abstract of Taipei Municipality.* Taipei Municipal Government, Taipei, Taiwan, 1986.
8. C. J. Chang. Urban Traffic in Taipei. Paper presented at International Workshop on Urban Transportation Management, Taipei, Taiwan, Nov. 15, 1985.

9. A. F. Han and N. Wilson. The Allocation of Buses in Heavily Utilized Networks with Overlapping Routes. *Transportation Research*, Vol. 16B, 1982, pp. 221–132.
10. J. M. Sparmann and C. F. Daganzo. *TROMP User's Manual*. ITS Research Report, UCB–ITS–RR82–4, Institute of Transportation Studies, University of California, Berkeley, 1982.

APPENDIX: TEST OF TASTE VARIATIONS BETWEEN TWO GROUPS OF TRANSIT USERS IN TAIPEI

The transit users in Taipei can be divided into two groups: one that uses regular tickets; the other, discount tickets. Let two market segments, $g = 1$ and 2, which represent regular and discount ticket user groups, respectively, be defined. To test if there are significant taste variations between these two groups of transit users in Taipei, the following hypothesis testing is performed.

The null hypothesis is that there are no taste variations between the two groups of users or market segments, that is,

$$H_0: \quad \beta^1 = \beta^2$$

where β^g is the vector of coefficients of market segment g ($g = 1, 2$). The test statistic is given by

$$-2\left[L_N(\hat{\beta}) - \sum_{g=1}^{2} L_{N_g}(\hat{\beta}^g)\right]$$

where

$L_N(\hat{\beta})$ = the maximum log likelihood of the restricted model that is estimated on the pooled data set with N observations, and

$L_{N_g}(\hat{\beta}^g)$ = the maximum log likelihood of the model estimated on the gth subset of the data with N_g observations ($g = 1, 2$).

From Tables 3 and 4, using the results of Model 2,

$N = 327$,
$N_1 = 143$,
$N_2 = 184$,
$L_N(\hat{\beta}) = -160.307$,
$L_{N_1}(\hat{\beta}^1) = -65.233$, and
$L_{N_2}(\hat{\beta}^2) = -94.626$.

The value of the test statistic is thus 0.448.

The test statistic as just defined is χ^2 distributed with six degrees of freedom. At $\alpha = 0.05$, the critical value is $\chi^2_{0.05,6} = 12.592$, which is larger than the calculated test statistic, 0.448. Therefore, H_0 cannot be rejected. This result implies that there are no significant taste variations between the two groups of transit users in Taipei.

Publication of this paper sponsored by Committee on Passenger Travel Demand Forecasting.