cost allocation model. The increased sensitivity and complexity of the other procedures do not appear to increase relative model accuracy for minute bus service modifications. This may be attributable to the numerous intermediate solutions (e.g., number of trippers and drivers) possible. For more substantial service changes, the proposed and modified Adelaide models may be preferred. In cases in which the cost impacts are expected to be relatively high, use of a more rigorous, and potentially more accurate, evaluation tool may be warranted.

Another issue related to the selection of an incremental costing procedure is the intended use of the resulting cost estimates. For a preliminary investigation of a wide range of bus service options, the simplistic techniques may be appropriate. In this case, the resources required to apply the technique would not unduly constrain the number of service changes that could be investigated. If a relatively limited number of changes were considered for implementation, a more accurate, but more time-consuming, model might be appropriate. Such an approach is consistent with other transportation analyses in which sketch-planning techniques are applied initially to screen a large field of options and then followed by more rigorous and detailed procedures for the most promising scenarios.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Estimating Bus Ridership

HERBERT S. LEVINSON and ORIKAYE BROWN-WEST

ABSTRACT

A route-based approach to estimating bus ridership is described. Bus riders on a typical Hartford, Connecticut, route were classed by walking distance and car ownership status, and compared to the number of dwelling units in each status. A series of "ridership penetration curves" shows how the number of bus riders per dwelling unit relates to car ownership and walking distance. For each level of car ownership, these curves decline with increasing walking distance. They show a drop of about 5 rides per 100 dwelling units for every 100-ft increase in walking distance, and a decrease of about 10 rides per 100 dwelling units when the first car is acquired and again when the second car is acquired. The data appear consistent with patterns derived from origin-destination surveys.

Public transportation planning and operation in today's urban environment increasingly concentrate on adjustments to existing services. They emphasize ways to increase transit service efficiency and to reduce operating deficits, instead of trying to assess impacts of large-scale investments. This involves adapting service to changing ridership patterns and cutting or restructuring service to bring costs and revenues into better balance. It calls for route-sensitive ridership estimation techniques that are keyed to fine-tuned service changes.

Much work, of course, has been done on estimating transit ridership. There is an extensive literature on network-based modal split models keyed to the relative disutilities of car and bus travel (i.e., logit modal split models). At the other end of the spectrum there is a growing body of elasticity factors that are keyed to service frequencies, fares, and travel times. Neither of these techniques properly addresses the question: If a new route is extended into a residential suburb, how many riders will it attract? Conversely, if a route is cut back, what will be the net loss in patronage?

Most of the current ridership estimation techniques are either too complex or too general to provide timely and meaningful responses to these fine-grained service changes. For these reasons, simplified and reliable estimating techniques that can be applied at the route level remain an important research need (1).

RESEARCH APPROACH

The results of a ridership research study conducted during 1981 and 1982 for the Connecticut Department of Transportation are discussed. The research objective was to develop a method for quickly estimating the ridership impacts of bus service changes in Connecticut cities (2).

Pilot surveys were conducted on six Hartford bus lines in June 1981 to identify parameters and refine the research approach. This was followed by a resurvey of riders on Line U-3 in June 1982. The ridership data for U-3 were compared with 1980 census data to obtain "penetration ratios" (ridership rates) by car ownership and walking distance strata. Finally, comparisons, applications, and extensions of the research were developed.

The research approach is shown in Figure 1. Detailed steps were as follows:

1. June 1981 on-board surveys obtained the travel patterns of 1,224 inbound riders out of a total of 21,130 weekday (two-direction) riders. The

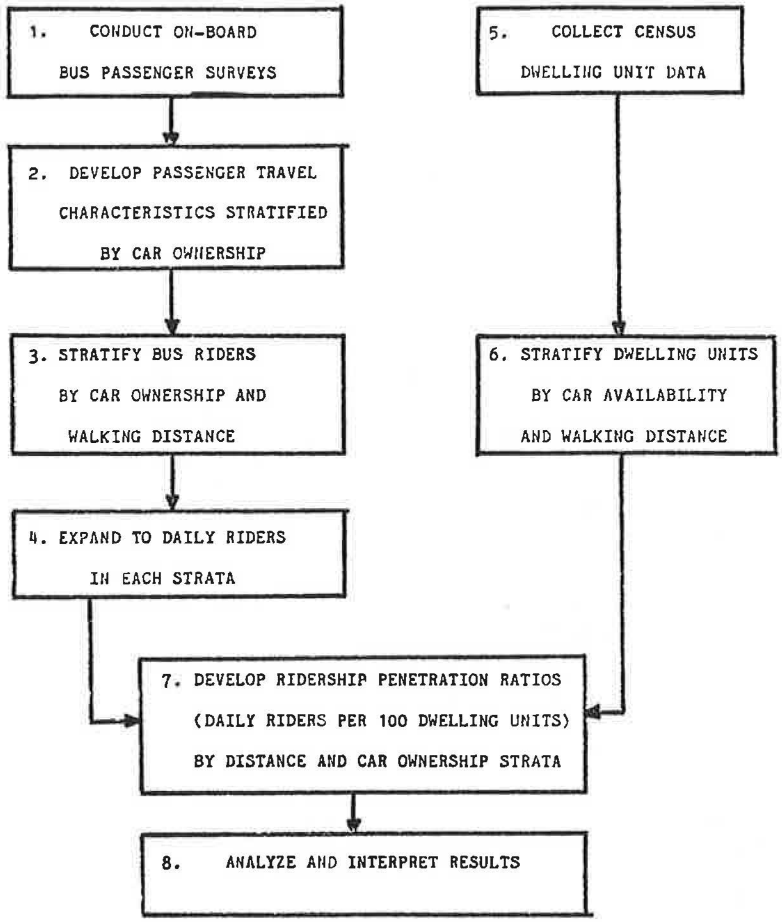

FIGURE 1 Research approach.

June 1982 survey obtained information on 515 riders out of a total of 2,213 daily weekday riders.

2. Passenger travel characteristics were summarized and stratified by car ownership.

3. Bus riders were further stratified by car ownership status and walking distance to bus stop.

4. Sample data were expanded to represent the average daily two-way ridership.

5. Dwelling unit data were obtained on a block and tract basis from the 1980 Census.

6. The number of dwelling units within various walking distances of bus lines by car availability status were estimated. In general, where two or more bus lines shared a census tract corridor, the tract data were distributed equally. However, where natural barriers (e.g., rivers) or man-made barriers (e.g., railroad yard or track) formed a barrier or restricted access to a specific bus line within a tract, most of the tract was allocated to the bus line that had easy access.

7. Ridership penetration ratios were obtained by dividing the bus riders in any stratum into the number of dwelling units (DUs) in that stratum, for both individual lines and all lines. That is,

$$\text{Penetration ratio} = \text{Riders}_{ij}/\text{DU}_{ij}$$

where i is walking distance stratum and j is DU stratum.

8. The resulting relationships were compared with available information for other cities, as well as with information from the initial surveys. Finally, applications and extensions of the research were developed.

RIDERSHIP SURVEYS

The U-3 bus route runs outbound from downtown Hartford to the Wethersfield Shopping Center (6.20 miles) and inbound from the shopping center to downtown (6.86 miles). It forms the southern continuation of Line U-1 from Bishop's Corner in West Hartford and Line U-2 (inbound from Bloomfield and part of West Hartford). It serves part of Southeast Hartford, Wethersfield, and the northern fringes of Rocky Hill. Its passenger generating area overlaps that of other bus routes in some sections, and it shares the same corridor in other places.

The ridership surveys were conducted between June 2 and June 10, 1982, between 5 a.m. and 7 p.m. The surveys obtained 515 responses of which 359 (70 percent) represented home-based trips, 80 (16 percent) involved transfers, and 76 (14 percent) were incomplete (see Figure 2). The 359 usable home-based responses accounted for 16 percent of the daily ridership (both directions) of 2,213 persons. This produced an expansion factor of 6.16 that was subsequently applied to the survey data (Table 1).

BUS RIDERSHIP PENETRATION

The general distribution of bus riders by car ownership status and walking distance is given in Table 2.

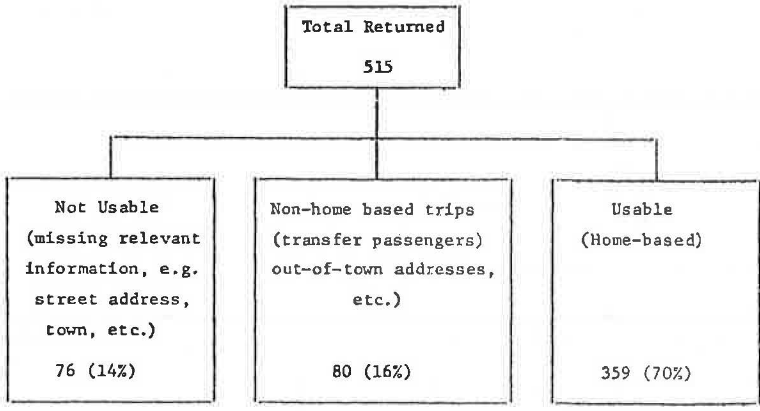

FIGURE 2 Hartford bus ridership survey, 1982: questionnaire returns.

TABLE 1 Hartford Bus Ridership Survey, June 1982: Comparison of Sample Responses with Actual Bus Riders (Line U-3)

Daily Weekday ConnTransit Riders (two-way)	No. of Questionnaires Returned (inbound riders)	Usable Questionnaires Returned	Ratio of Usable Questionnaires Returned to Weekday Riders	Expansion Factor[a]
2,213	515	359	0.1622[b]	6.16

[a] To represent two-way ridership.
[b] 0.3248 for inbound riders.

TABLE 2 Hartford Bus Ridership Survey, 1982: Expanded Two-Way Daily Ridership by Car Ownership Status and Walking Distance (Line U-3)

Approximate Walking Distance (ft)	No. of Respondents (x 6.16)	Percentage	No. of Cars Owned				
			0	1	2	3+	2+
200	1,140	51.5	407	493	234	6	240
400	671	30.4	234	308	123	6	129
600	240	10.9	86	105	37	12	49
800	117	5.3	31	37	37	12	49
1,000	42	1.9	12	12	6	12	18
Total	2,211	100.0	770	955	437	49	486
Percentage	100		34.8	43.2	19.8	2.2	22.0

Data are summarized for six walking distance strata as follows:

Stratum (ft)	Approximate Average or Midpoint (ft)
0-300	200
300-500	400
500-700	600
700-900	800
More than 900	1,000

Walking Distance

Approximately 52 percent of all riders lived within 200 ft of Line U-3, 82 percent within 400 ft, and more than 90 percent within 600 ft.

Car Ownership

Approximately 35 percent of all riders came from zero-car households, 43 percent from one-car households, and 22 percent from multicar households.

Detailed Penetration Curves

Ridership penetration curves were developed by relating the bus ridership data given in Table 2 to the 1980 dwelling unit statistics given in Table 3. The resulting ridership penetration curves and values for Line U-3 are given in Table 4 and shown in Figure 3. Ridership penetration ratios by walking distance stratum decrease from the 58 daily rides per 100 DUs for dwellings within 200 ft of a bus stop to 48 for those within 400 ft, 39 for those within 600 ft, and about 20 for those beyond 600 ft.

The patterns vary, however, for each level of car ownership.

- Daily ridership per 100 DUs for zero-car households drops from 65 at 200 ft to 22 at 1,000 ft. It averages 56 overall.
- Daily ridership per 100 DUs for one-car households drops from 55 at 200 ft to 15 at 1,000 ft. It averages 48 overall.
- Daily ridership per 100 DUs for multicar households drops from 50 at 200 ft to 20 at 800 ft. It averages 38 overall. (Because of small responses for 3+ car households it was necessary to group all multicar households into a single category.)

TABLE 3 1980 Car Availability per Dwelling Unit (census tract and block statistics) Stratified by Average Walking Distance from Nearest Bus Stop (Line U-3)

Approximate Walking Distance (ft)	No. of Dwelling Units	Percentage	No. of Cars Owned 0	1	2	3+	2+
200	1,979	42.3	599	896	468	16	484
400	1,398	29.9	442	629	308	19	327
600	610	13.0	191	263	109	47	156
800	475	10.2	97	132	175	71	246
1,000	216	4.6	55	80	50	31	81
Total	4,678	100.0	1,384	2,000	1,110	184	1,294
Percentage	100.0		29.6	42.8	23.7	3.9	27.6

TABLE 4 Hartford Bus Ridership Survey, 1982: Ridership Penetration for Line U-3 (daily rides per 100 DUs)

Walking Distance (ft)	No. of Cars Owned per Dwelling Unit 0	1	2	3+	2+	All Ownership
200	67.95	55.02	50.00	37.50	49.59	57.60
400	52.94	48.97	39.94	31.58	39.45	48.00
600	45.02	39.92	33.94	25.53	31.41	39.34
800	31.96	28.03	21.14	16.90	19.92	24.63
1,000	21.82	15.00	12.00	38.71[a]	22.22[a]	19.44
All distances	55.63	47.75	39.37	26.63	37.56	47.26

[a] Data are questionable because of small sample size.

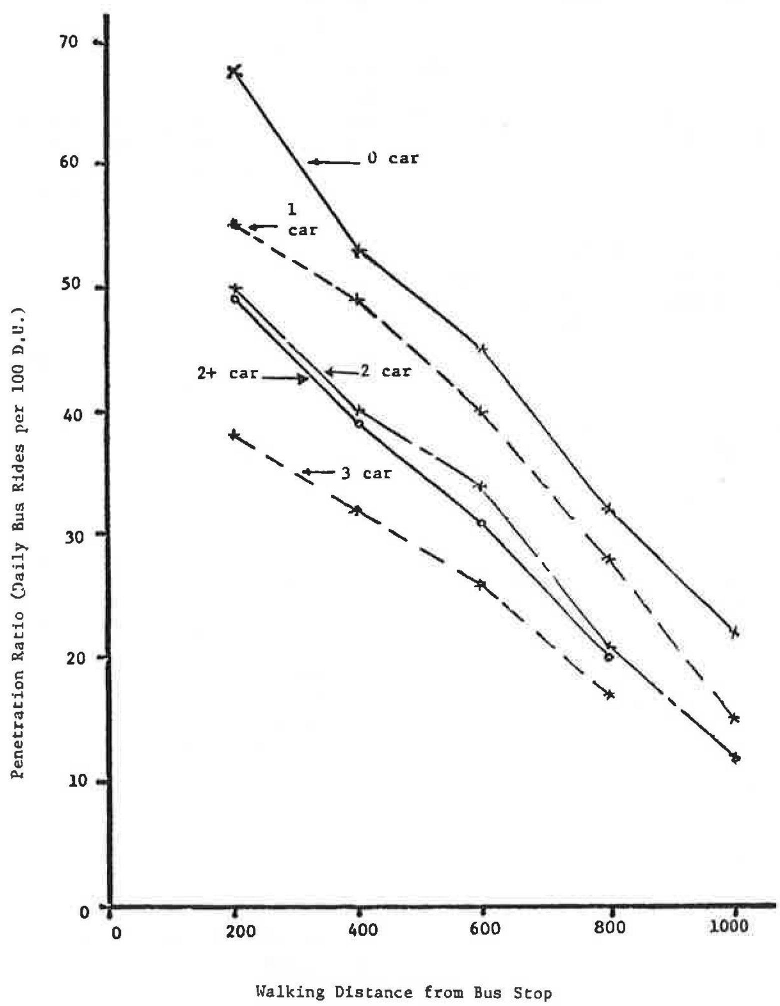

FIGURE 3 Ridership penetration curves for Line U-3 (1982 data).

The ridership penetration curves for zero-car, one-car, and multicar households follow expected patterns. Ridership decreases as distance from the bus stop increases and as car ownership increases. The decreases appear to be linear for each level of car ownership and suggest the following relationships:

$$R_0 = 77.91 - .05652X \quad (1)$$

$$R_1 = 67.68 - .05049X \quad (2)$$

$$R_2 = 59.84 - .04740X \quad (3)$$

$$R_{2+} = 59.36 - .048525X \quad (4)$$

where

X = distance from bus stop (ft);
R_0 = daily rides per 100 DUs, zero-car households;
R_1 = daily rides per 100 DUs, two-car households; and
R_{2+} = daily rides per DUs, 2+ car households.

The average values, from which these formulas were derived, had correlations generally exceeding 0.9. An inspection of these curves shows a drop of about 5 rides per 100 DUs for every 100-ft increase in walking distance. There is also a decrease of about 10 rides per 100 DUs when the first and, again, second cars are acquired. This suggests the following general formula for approximating bus ridership:

$$R_i = 80 - 10c_i - .05X_i \quad (5)$$

where c_i is cars/DU in stratum i at distance X_i and R_i is rides per 100 DUs per day in stratum i.

Comparison of Results

The penetration ratios compared with those obtained from origin-destination surveys are given in Tables 5 and 6. The data appear consistent with those for typical "small" cities; more precisely, they are correct in scale or order of magnitude.

TABLE 5 Estimated Transit Rides per Person per Day in U.S. Cities (1960-1970s) (3)

	Cars per DU		
City Size	0	1	2+
Large	0.70	0.30	0.20
Medium	0.40	0.20	0.10
Small	0.30	0.15	0.10

TABLE 6 Estimated Transit Rides per DU per Day in U.S. Cities (1960-1970s) (3)

	Cars per DU		
City Size	0	1	2+
Large	1.30	0.95	0.76
Medium	0.79	0.63	0.38
Small	0.59	0.48	0.38
Hartford Line U-3 service area only	0.56	0.48	0.39

IMPLICATIONS AND EXTENSION

The penetration curves are based on a bus service frequency of approximately 20 min and a fare of $0.60. They can be applied in the following manner to obtain an initial estimate of route ridership:

1. Delineate the target area of the bus route or route change.
2. Identify the population within the "tributary area" in appropriate distance bands, discounting for competing lines. Stratify this population in distance bands or car ownership or availability, or both.
3. Apply the penetration curves or the formula $R_i = 80 - 10c_i - .05X_i$.
4. If there are regional generators along the line (outside the central area), their ridership potential should be added to the estimates obtained in Step 3.
5. Estimates should be made of the desired service frequency and fare structure.
6. Apply appropriate headway and fare elasticity data, assuming a 20-min headway and a $0.60 fare as a base.

The approach provides a much-needed refinement to the "riding habit" approach used by many transit agencies. The logical next steps should involve a small-scale test of the ridership penetration curves to access their real-world application and possible adjustments in scale or amplitude.

Additional surveys in Hartford would provide a basis for assessing the effects of route type on these relationships. Similar analyses in other cities would be useful in identifying the impacts of city type or central business district character. In addition, further research is also needed to better pinpoint the effects of competing line transfer passengers and non-home-based trips.

ACKNOWLEDGMENT

The assistance and insight of Charles Dougan, Director of Research, Connecticut Department of Transportation, is appreciated. Work was performed through the Joint University Research Advisory Council.

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Publication of this paper sponsored by Committee on Bus Transit Systems.