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A METHODOLOGY TO ESTIMATE PASSENGER FLOW: RIVERSIDE LINE

MASSACHUSETTS BAY TRANSIT AUTHORITY BOSTON MA

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FINAL REPORT

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15. Supplementary Notes

Related reports are: Passenger Flow Analysis, 1978, Riverside Line, MBTA (UMTA-MA-06-0074-81-1) and MBTA Passenger Demand Analyses, 1977 (UMTA-MA-06-0074-81-2).

16. Abstract

The work documented in this report represents part of an endeavor by the Urban Mass Transportation Administration to develop improvements in management techniques to operate local transit systems more efficiently and economically. In particular, the ability to accurately ascertain route specific passenger flows or passenger demands has become essential for adequate resource allocation and scheduling of transit runs. This raises the requirement to develop an optimal survey procedure for the estimation of passenger profiles/distributions along the route. In the survey plan and methodology, to be adopted and utilized by the local transit properties, the procedure should aim for maximum precision and minimum cost.

This report presents the results and description of a methodology to collect boarding and deboarding passenger data on the Riverside Line of the Massachusetts Bay Transit Authority and to estimate for each station along the route an average passenger flow profile by half-hourly time periods. Such profiles can then be fed into a scheduling model which simulates and accommodates passenger congestion at various points in time. It is a culmination of several small-scale passenger surveys and a statistical model employing indicator variables and the survey data to estimate the station and time factors for the derivation of average flow rates per minute. Validation of the model was carried out, which strengthened previous findings, but indicated a need for modification when the model was applied toward routes that link heterogenous geographical areas. The results prove that relatively inexpensive sampling techniques can result in acceptable estimates of ridership by route.

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PREFACE

The Office of Transportation Management, Urban Mass Transportation Administration (UPM-40) has sponsored this work as part of its distinctive role in an overall program of research, development, and technical assistance to transit management. The particular problem broached is selection of a method of estimating passenger flow rates on routes that are heavily patronized. The resulting figures are needed for schedule planning and for reporting ridership to local, state and federal transportation agencies. These reports may affect funding levels. In congested urban areas, 100 percent counts, one way to secure such information, are expensive and impractical to manage, in addition to being fraught with human errors. Sampling reduces the task to manageable proportions.

The sampling in three successive years was managed by Pacific Consultants, Inc. (1979), H.H. Aerospace Inc. (1978), Boston firms, and Mary Roos of TSC (1977) who served as the project manager. Assistance in data analysis and computer programming was supplied by Wing Gor and Lawrence Jordan, TSC. Most of the work was done under the supervision of Donald Wright, TSC.

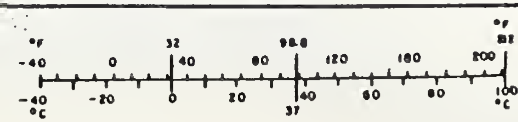
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

The work documented in this report represents part of an endeavor by the Urban Mass Transportation Administration to develop improvements in management techniques to operate local transit systems more efficiently and economically. In particular, the ability to accurately ascertain route specific passenger flows or passenger demands has become essential for adequate resource allocation and scheduling of transit runs. This in turn raises the requirement to develop an optimal survey procedure for the estimation of passenger profiles/distributions along the route. In the survey plan and methodology to be adopted and utilized by the local transit properties, the procedure should aim for maximum precision and minimum cost.

When the Light Rail Vehicles (LRVs) were introduced in January 1977 to Boston's Massachusetts Bay Transit Authority (MBTA) to replace the old PCCs on the Green Line extending from the Riverside Station to the Lechmere Station, it was deemed propitious to use this route as the experimental unit in the development of such a prototype passenger profile estimation scheme.

In May 1977, a transit trip survey was conducted along the surface segment of the route. About 67 inbound trips and 69 outbound trips were randomly selected from the daily schedule over a wide spectrum of time periods. The surveyors went aboard the vehicle in the beginning of the trip and obtained counts of boarding and deboarding passengers at each stop along the route. This method allows for the calibration of an average trip profile while at the same time the average trip time, average load, and station dwell time can be derived. A staff paper titled "MBTA Passenger Demand Analyses, 1977" summarizes the findings of the survey.

One year later, another survey was carried out. This time, the surveyors remained at the underground stations and at various selected time periods obtained counts of boarding and deboarding passengers when the LRVs arrived at the station. This new procedure, while it can not give directly a spatial distribution of passenger demands for the trip, makes possible the derivation of a station profile as it estimates the changing passenger flow rates (passenger counts divided by the headway in minutes) throughout the day. Such information is deemed more useful since rates are independent of the trip orginating time, and thus enhance the flexibility of a scheduling model, the calibration of which is precisely the objective of performing passenger surveys. Another staff paper, "Passenger Flow Analysis, 1978", resulted .

The current work marks the validation phase. For a similar time period in May 1979, two passenger surveys were simultaneously performed (one at the surface stations and the other at the underground stations) through the contracted assistance of the Pacific Consultants, Inc., Boston, Mass. The purpose is two-fold. First, due to the limitation of time and resources, and perhaps to an effort to maximize the economy of data collection, the 1978 underground station survey was designed to leave a number of data gaps to be "filled" by means of a statistical model. Table 1-1 should clarify the problem at hand. The estimates that filled these data gaps need to be validated in order to strengthen and justify the survey scheme. Second, for all practical purposes, one survey methodology should be applied to both the surface and underground segments which constitute the entire route. The 1979 work pursues the station count method as developed in 1978 and applies it to the surface stations.

TABLE 1-1. 1978 OBSERVED PASSENGER BOARDING RATES AT STATIONS: TRAINS GOING TO RIVERSIDE

Time	Kenmore	Auditorium	Copley	Arlington	Boylston	Park	Government Center	Haymarket	North Station	Science Park	Lechmere
700	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
730	0.00	0.00	0.73	0.00	0.00	3.22	0.00	2.24	0.00	0.00	0.00
800	1.00	0.00	0.82	3.11	0.00	8.53	1.35	4.87	11.68	0.04	0.00
830	0.19	0.00	1.14	2.39	0.00	13.41	5.75	2.06	13.19	0.06	0.00
900	0.53	0.00	0.00	0.84	0.00	6.33	2.81	5.22	3.90	0.20	0.00
930	0.10	0.00	0.00	0.78	0.00	4.18	4.73	0.00	4.80	0.13	0.00
1000	0.57	1.00	0.00	0.00	0.54	3.50	1.58	3.73	3.90	0.00	0.00
1030	0.36	0.38	0.00	1.15	0.60	4.57	1.71	2.22	0.00	0.00	0.00
1100	0.39	0.26	0.00	0.20	0.63	0.00	0.00	2.87	0.00	0.00	0.00
1130	0.48	0.52	0.00	0.47	1.11	0.00	0.00	0.00	0.00	0.00	0.00
1200	0.54	0.36	0.00	1.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1230	0.58	0.00	3.50	1.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1300	0.00	0.00	1.71	0.00	0.00	0.00	0.00	0.00	2.94	0.00	2.00
1330	1.05	0.00	1.57	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.19
1400	1.58	0.00	3.46	0.00	0.94	5.24	0.00	1.00	1.75	0.00	3.54
1430	0.69	0.00	2.00	0.00	0.77	4.55	0.00	1.93	2.77	0.00	1.87
1500	0.92	0.00	0.00	0.00	1.21	6.90	0.00	2.45	0.00	0.00	2.00
1530	0.83	0.00	0.00	0.00	0.00	12.33	0.00	1.69	0.00	0.00	1.64
1600	1.21	0.00	0.00	0.00	1.80	5.14	8.57	3.84	0.00	0.00	0.00
1630	1.06	0.00	0.00	0.00	1.28	7.11	6.25	1.65	0.00	0.00	0.00
1700	2.15	0.00	0.00	0.00	2.10	15.56	9.18	2.15	0.00	0.00	0.00
1730	2.96	0.00	0.00	0.00	1.52	15.23	12.87	0.00	0.00	0.00	0.00
1800	1.65	0.00	0.00	0.00	1.50	9.23	7.17	5.55	0.00	0.00	0.00
1830	0.81	0.00	0.00	0.00	0.00	10.80	5.63	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.00	0.00	4.36	0.00	0.00	0.00	0.00
1930	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2030	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

(Note: Zeroes indicate a data-gathering gap.)

2. 1979 SURVEY PLANS

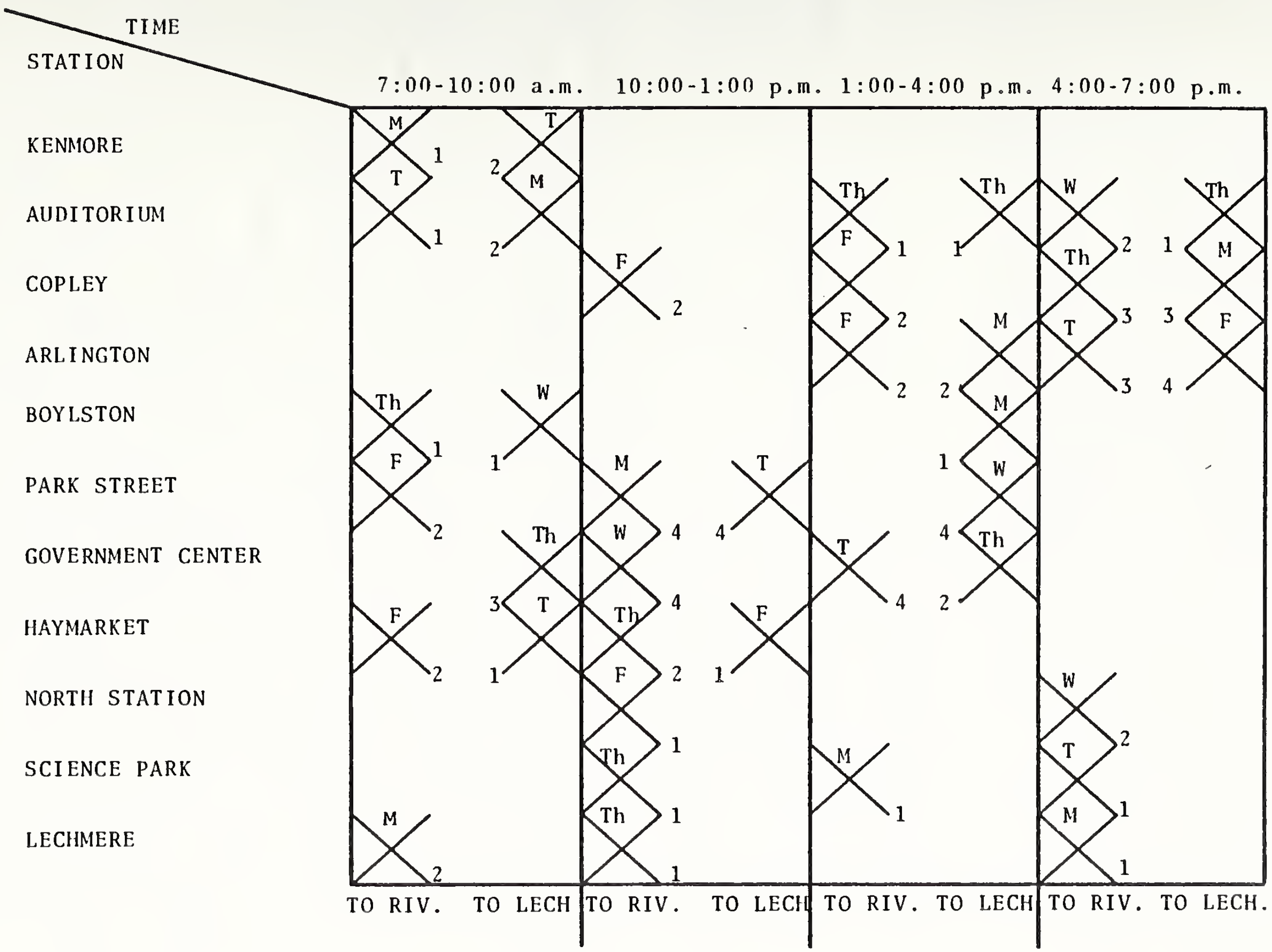
2.1 UNDERGROUND STATIONS

The 1979 underground station survey concentrates on those time-station slots left empty by the 1978 survey. Hence, randomness is with respect only to the day of the week and is sacrificed with respect to the choice of station and time periods. This is valid since the purpose is to compare the 1979 survey results with the 1978 estimated statistics. Provisions are also made to compare the 1979 survey results with some of the 1978 survey results. Any significant increase or change in ridership during the year may render the first comparison meaningless in terms of the level (vs. the pattern) of passenger flows. The second comparison is therefore necessary to assess such latent change due to population increase, change in travel behavior, etc. Figure 2-1 displays the 1979 survey plan.

2.2 SURFACE STATIONS

The 1979 surface station survey adheres to the sampling method developed in 1978 for the underground stations. That is, a 13 (hourly periods) x 13 (stations) matrix with 169 cells is set up to be the sampling frame. A sample of cells is then selected systematically with a random start to satisfy the following criteria:

- o that the marginal-column totals equal the number of cells selected (i.e., that each surface station is adequately represented in the sample)
- o that the peak periods, namely the morning and early afternoon shifts for inbound (Riverside to Lechmere) trains and the morning and late afternoon shifts for outbound (Lechmere to Riverside) trains are emphasized more than the others
- o that when a surveyor is assigned to a station-line slot, he/she is able to follow the direction of the train to go to the next station to collect passenger data for the next



KEY:

Letters denote days of the week.
Numbers denote number of surveyors assigned.

FIGURE 2-1. SURVEY PLAN FOR UNDERGROUND STATIONS time period. In this way, the surveyor's travel time is minimized and, hence, productivity maximized.

Table 2-1 shows the subsequent selection of 86 cells drawn from the inbound (Riverside to Lechmere) matrix, a 51 percent sample, while Table 2-2 shows the outbound (Lechmere to Riverside) counterpart, a sample of 63-cells constituting 46 percent of all the cells in the outbound matrix. Because of the relatively simple transit network along the surface segment of the route, this survey requires only four surveyors working eight hours per day for a 5-day week. An example of a surveyor's schedule appears on page 8.

2.3 SURVEY DATA DEFICIENCIES

Before proceeding to describe the survey results, a digression to discuss some grave data deficiencies is necessary. The 1979 survey employed a total of 12 surveyors, 8 for the underground stations and 4 for the surface stations. At the onset, the task was plagued with personnel problems, often resulting in re-arrangements of assignments. Not only was the specified survey schedule sometimes forsaken but also the number of surveyors taking counts was inadequate due to unexpected absences and tardiness. For example, at a busy transfer point such as Park Street Station four surveyors were assigned to the peak periods according to the survey plan; however, there was regretfully never a time when all four surveyors were present. Although the absentee always made up his time on another day, accuracy was sacrificed when only one or two surveyors manned the station. The problem was aggravated by a mechanical failure experienced by some LRV cars during the survey week. On May 9, 10, and 13 passengers of the Green Line witnessed extensive delays, sometimes total lack of service, crowded stations and frustrated, turned away patrons. The survey was therefore extended to include the next two weeks. Another extraneous factor which affected the late afternoon passenger counts was that a Red Sox home game was scheduled every night all through the survey period. Thousands of fans poured into Fenway Park and, of course, thronged the Riverside Line.

TABLE 2-1. 1979 SURFACE STATION SAMPLING PLAN (INBOUND)

Time	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beaconsfield	Brookline Hills	Brookline Village	Longwood	Fenway
6:30-7	F_4		F_3	M_1		W_1					W_2		
7-8	T_1	W_4			M_2	$T_{2,3}$	W_1		F_1	M_2	T_4		Th_2
8-9		T_1	W_4	Th_3	$F_{3,4}$	$M_{1,3}$	$T_{2,3}$	W_1		F_1		T_4	
9-10	F_2		T_1	W_4		F_3		T_2	W_2	Th_2	F_1		T_4
10-11					W_4	Th_3	F_3				Th_2	F_1	M_3
11-12	W_2	Th_1					Th_3	F_3				Th_2	F_1
12-1	T_3	W_2	Th_1	F_2	M_3			Th_3	F_3		T_2		
1-2		T_3			F_4	$M_{2,3}$		W_4				T_2	
2-3	F_1		T_3		Th_4	$F_{2,4}$	$M_{2,3}$		W_4		F_3		T_2
3-4	Th_3	F_1		T_3	W_2	Th_4	F_4	M_3		W_4			
4-5		Th_3	F_1					F_4	M_3		W_4	Th_1	
5-6	T_3						W_2			F_4			Th_1
6-7				Th_3		M_4		W_2					

Key:
M = Monday
T = Tuesday
W = Wednesday
Th = Thursday
F = Friday

Subscripts denote surveyor no.

TABLE 2-2. 1979 SURFACE STATION SAMPLING PLAN (OUTBOUND)

Time	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beaconsfield	Brookline Hills	Brookline Village	Longwood	Fenway
6:30-7							T_3	W_3	Th_1			T_4	
7-8			F_2		M_4			Th_1				W_2	Th_4
8-9				M_4			Th_1						
9-10					W_3	Th_1					Th_4		
10-11	F_2	M_4		W_3			M_2		W_1	Th_4		M_1	
11-12	M_4	T_1	W_3		F_4	M_2			Th_4			T_4	
12-1		W_3			M_2		W_1	Th_4		M_1	T_4		
1-2						W_1			M_1			Th_2	
2-3	Th_3			T_4				M_1	T_1	W_3			M_4
3-4					Th_2	F_2		T_1				M_4	
4-5	M_1		W_1		$F_{2,3}$		$T_{1,2}$				M_4		
5-6			Th_2	F_2		$T_{1,2}$				M_2	T_4	W_3	Th_4
6-7	W_1	Th_2							M_2		W_3		

Key:
M = Monday
T = Tuesday
W = Wednesday
Th = Thursday
F = Friday

Subscripts denote surveyor no.

SAMPLE OF SURVEYOR'S SCHEDULE

SCHEDULE A

OBSERVER 1

TIME	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
6:20-7AM	Eliot (in)		Newton Center (in)	Beaconsfield (out)	
7-8	Highland (in)	Riverside (in)	Chestnut Hill (in)	Reservoir (out)	Beaconsfield (in)
8-9	Newton Center (in)	Woodland (in)	Reservoir (in)	Chestnut Hill (out)	Brookline Hills (in)
9-10		Waban (in)		Newton Center (out)	Brookline Village (in)
10-11	Longwood (out)		Beaconsfield (out)		Longwood (in)
11-12		Woodland (out)		Woodland (in)	Fenway (in)
12-1 PM	Brookline Hills (out)		Chestnut Hill (out)	Waban (in)	
1-2	Beaconsfield (out)		Newton Center (out)		
2-3	Reservoir (out)	Beaconfield (out)			Riverside (in)
3-4		Reservoir (out)			Woodland (in)
4-5	Riverside (off)	Chestnut Hill (out)	Waban (out)	Longwood (in)	Waban (in)
5-6		Newton Center (out)		Fenway (in)	
6-7			Riverside (off)		

As much as the 1979 survey data may not reflect the usual circumstance that the scheduling model seeks to portray, they still went through a vigorous editing process. Obvious anomalies were screened out, door counts of passengers were extrapolated to represent the entire train, and headways were approximated. The editing procedure is described in an earlier staff paper, "Passenger Flow Analysis, 1978."

3. SURVEY AND VALIDATION RESULTS - SURFACE STATIONS

Tables 3-1 through 3-4 show the 1979 survey data for the surface stations in their final form. Each data point in the time-station matrices represents the observed rate of passenger flow (total number of passengers/total headway), R_{IJ}, within time period I at station J. When the R_{IJ} are shown to be zero, there is a data gap that needs to be estimated.

3.1 METHOD OF ESTIMATION OF AVERAGE PASSENGER FLOW RATE

The statistical model described below was applied to these data for the estimation of the average rate of passenger flow. The R_{IJ} are assumed to vary with the station and time factors such that

$$P(R_{IJ}) = P(R_I)P(R_J) \cdot$$

Further, R_{IJ} can be expressed as a sum of four components:

$$R_{IJ} = \mu+\alpha_I + \beta_J + \varepsilon_{IJ}$$

where μ is the grand average of flow rates across all time periods and all stations, α_I the time I effects, β_J the station J effects and ε_{IJ}, random terms with a zero mean and a variance σ^2. Using a generalized least square approach with indicator variables representing the time and station factors, and making a logarithmic transformation of the R_{IJ}, the final estimation model becomes:

$$\log_e R_{IJ} = \mu + \sum_i a_i T_i + \sum_j b_j S_j + \varepsilon_{IJ}$$

$$T_i = 1 \text{ if } i=I \text{ and } I\neq t$$

$$= 0 \text{ if } i\neq I \text{ and } I\neq t$$

$$= -1 \text{ for all } i \text{ if } I=t$$

$i = 1,2,3,\ldots t^{-1}$, t being the total number of time periods.

$$S_j = 1 \text{ if } j=J \text{ and } J\neq s$$

$$= 0 \text{ if } j\neq J \text{ and } J\neq s$$

$$= -1 \text{ for all } j \text{ if } J=s$$

j=1,2,3, S-1, s being the total number of stations.

TABLE 3-1. SURFACE STATIONS: BOARDING PASSENGERS PER MINUTE (RIVERSIDE TO LECHMERE)

Time	River-side	Wood-land	Waban	Eliot	High-land	Newton Center	Chest-nut Hill	Reser-voir	Beacons-field	Brook-line Hills	Brook-line Village	Long-wood	Fenway
700	1.68	2.43	1.00	0.33	1.14	0.97	0.00	0.00	0.00	0.00	0.63	0.00	0.00
730	4.00	2.63	0.00	0.00	2.86	2.22	1.71	0.00	0.67	1.16	1.22	0.00	1.67
800	3.44	3.39	0.00	0.00	2.65	3.36	2.45	0.00	0.38	2.29	1.68	0.00	2.65
830	0.00	2.13	1.45	0.49	2.28	3.54	2.50	1.70	0.00	2.10	0.00	2.53	0.00
900	0.00	1.17	1.21	1.76	3.03	2.67	2.61	1.32	0.00	1.16	0.00	2.74	0.00
930	1.65	0.00	0.94	0.66	0.00	1.91	0.00	0.68	0.48	1.25	1.63	0.00	1.42
1000	1.23	0.00	0.52	0.68	1.50	1.48	0.00	1.07	0.41	0.14	0.70	0.00	1.04
1030	0.00	0.00	0.00	0.00	1.00	1.03	0.97	0.00	0.00	0.68	1.65	0.66	1.13
1100	0.00	0.00	0.00	0.00	0.41	1.71	0.68	0.00	0.00	0.00	1.50	0.63	0.97
1130	0.53	0.44	0.00	0.00	0.00	0.00	0.52	0.62	0.00	0.00	0.80	0.88	1.50
1200	1.52	1.14	0.00	0.00	0.00	0.00	0.50	0.27	0.00	0.00	0.00	0.76	1.62
1230	0.90	0.80	0.13	0.00	0.06	0.00	0.00	0.50	0.24	0.00	1.13	0.00	0.00
1300	0.86	0.95	0.39	0.35	0.82	0.00	0.00	0.46	0.20	0.00	1.07	0.00	0.00
1330	0.00	0.90	0.00	0.00	0.85	1.08	0.00	0.26	0.00	0.00	1.10	0.57	0.00
1400	0.00	0.48	0.77	0.00	0.90	0.91	0.00	0.60	0.22	0.00	0.00	0.53	0.00
1430	1.00	0.00	0.43	0.00	1.00	1.76	1.21	0.00	0.57	0.00	1.36	0.00	2.82
1500	0.94	0.00	1.14	0.00	0.94	1.92	2.29	0.00	0.62	0.00	0.71	0.00	2.11
1530	1.15	1.40	0.00	0.54	0.00	1.89	1.45	1.20	0.00	1.03	0.00	0.00	0.00
1600	1.40	2.27	0.00	0.38	0.00	1.48	1.77	0.48	0.80	0.93	1.27	0.00	0.00
1630	0.00	0.53	0.49	0.00	0.00	0.00	0.00	0.21	0.29	0.00	2.00	2.20	0.00
1700	0.00	1.55	0.64	0.00	0.00	0.00	0.00	0.48	0.13	0.00	1.43	1.29	0.33
1730	3.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	0.00	0.00	1.34
1800	2.81	0.00	0.00	0.00	0.00	0.00	2.00	2.67	0.00	0.62	0.00	0.00	1.16
1830	0.00	0.00	0.00	0.45	0.00	1.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.50	0.00	0.67	0.00	0.61	0.00	0.00	0.00	0.00	0.00

TABLE 3-2. SURFACE STATIONS: DEBOARDING PASSENGERS PER MINUTE (RIVERSIDE TO LECHMERE)

Time	Wood-land	Waban	Eliot	High-land	Newton Center	Chest-nut Hill	Reser-voir	Beacons-field	Brook-line Hill	Brook-line Village	Long-wood	Fenway
700	0.00	0.14	0.01	0.00	0.12	0.00	0.00	0.00	0.00	0.18	0.00	0.00
730	0.01	0.00	0.00	0.01	0.11	0.04	0.00	0.96	0.01	0.91	0.00	0.67
800	0.01	0.00	0.00	0.12	0.18	0.07	0.00	1.34	1.64	1.32	0.00	0.56
830	0.03	0.03	0.01	0.03	0.36	0.13	0.37	0.00	0.97	0.00	4.22	0.00
900	0.04	0.08	0.05	0.16	0.33	0.58	0.15	0.00	0.88	0.00	2.26	1.14
930	0.00	0.03	0.01	0.00	0.21	0.00	0.32	0.01	0.25	0.50	0.00	1.13
1000	0.00	0.01	0.01	0.01	0.10	0.00	0.34	0.01	0.43	0.37	0.00	0.64
1030	0.00	0.00	0.00	0.01	0.14	0.09	0.00	0.00	0.11	0.31	0.34	0.25
1100	0.00	0.00	0.00	0.03	0.10	0.06	0.00	0.00	0.00	0.11	0.50	0.41
1130	0.01	0.00	0.00	0.00	0.00	0.21	0.24	0.00	0.00	0.27	0.43	0.35
1200	0.01	0.00	0.00	0.00	0.00	0.10	0.25	0.00	0.00	0.00	0.60	0.38
1230	0.02	0.03	0.00	0.02	0.00	0.00	0.19	0.04	0.00	0.26	0.00	0.00
1300	0.03	0.04	0.05	0.27	0.00	0.00	0.50	0.08	0.00	0.33	0.00	0.00
1330	0.01	0.00	0.00	0.01	0.13	0.00	0.26	0.00	0.00	0.30	0.24	0.00
1400	0.01	0.08	0.00	0.01	0.24	0.00	0.36	0.01	0.00	0.00	0.60	0.00
1430	0.00	0.01	0.00	0.00	0.21	0.16	0.00	0.01	0.00	0.60	0.00	0.59
1500	0.00	0.01	0.00	0.13	0.75	0.04	0.00	0.07	0.00	0.63	0.00	0.49
1530	0.03	0.00	0.03	0.00	1.64	0.41	1.20	0.00	0.12	0.00	0.00	0.00
1600	0.01	0.00	0.07	0.00	0.68	0.40	0.71	1.20	0.10	0.53	0.00	0.00
1630	0.06	0.03	0.00	0.00	0.00	0.00	0.89	0.29	0.00	0.88	0.33	0.00
1700	0.10	0.04	0.00	0.00	0.00	0.00	0.70	0.34	0.00	0.67	0.54	0.11
1730	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	1.06
1800	0.00	0.00	0.00	0.00	0.00	0.42	0.00	0.00	0.19	0.00	0.00	1.52
1830	0.00	0.00	0.17	0.00	0.19	0.00	0.90	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 3-3. SURFACE STATIONS: BOARDING PASSENGERS PER MINUTE (LECHMERE TO RIVERSIDE)

Time	Wood-land	Waban	Eliot	High-land	Newton Center	Chest-nut Hill	Reser-voir	Beacons-field	Brook-line Hill	Brook-line Village	Long-wood	Fenway
700	0.00	0.00	0.00	0.00	0.00	0.05	0.27	0.24	0.00	0.00	0.14	0.00
730	0.00	0.01	0.00	0.31	0.00	0.00	0.50	0.00	0.00	0.00	0.37	0.56
800	0.00	0.10	0.00	0.44	0.00	0.00	0.91	0.00	0.00	0.00	1.70	0.63
830	0.00	0.00	0.30	0.18	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.07	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00
930	0.00	0.00	0.00	0.33	0.26	0.00	0.00	0.00	0.00	0.55	0.00	0.00
1000	0.00	0.00	0.00	0.12	0.17	0.00	0.00	0.00	0.06	0.94	0.00	0.00
1030	0.01	0.00	0.01	0.00	0.00	0.06	0.00	0.00	0.07	0.00	0.07	0.00
1100	0.04	0.00	0.01	0.00	0.00	0.15	0.00	0.06	0.03	0.00	0.40	0.00
1130	0.01	0.03	0.00	0.17	0.94	0.00	0.00	0.05	0.00	0.00	0.00	0.00
1200	0.01	0.07	0.00	0.05	0.30	0.00	0.22	0.06	0.00	0.38	0.40	0.00
1230	0.01	0.00	0.00	0.10	0.00	0.03	0.41	0.00	0.09	0.13	0.00	0.00
1300	0.13	0.00	0.00	0.15	0.00	0.05	0.56	0.00	0.24	0.23	0.00	0.00
1330	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.46	0.00
1400	0.00	0.00	0.00	0.00	0.26	0.00	0.00	0.04	0.00	0.00	0.58	0.00
1430	0.00	0.00	0.05	0.00	0.00	0.00	0.19	0.01	0.00	0.00	0.00	0.89
1500	0.00	0.00	0.03	0.00	0.00	0.00	0.25	0.01	0.00	0.00	0.56	0.50
1530	0.00	0.00	0.00	0.17	0.52	0.00	0.29	0.00	0.00	0.00	0.00	0.00
1600	0.00	0.00	0.00	0.26	0.57	0.00	0.19	0.00	0.00	0.55	1.86	0.00
1630	0.00	0.01	0.00	0.06	0.00	0.52	0.00	0.00	0.00	0.75	0.00	0.00
1700	0.00	0.01	0.00	0.40	0.00	0.15	0.00	0.00	0.33	0.86	0.00	0.00
1730	0.00	0.04	0.03	0.24	0.31	0.00	0.00	0.00	1.16	1.31	1.70	1.40
1800	0.00	0.01	0.10	0.00	0.12	0.00	0.00	0.00	0.89	1.61	1.22	1.42
1830	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	2.31	0.00	0.00
1900	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.77	0.00	0.00

TABLE 3-4. SURFACE STATIONS: DEBOARDING PASSENGERS PER MINUTE (LECHMERE TO RIVERSIDE)

Time	River-side	Wood-land	Waban	Eliot	High-land	Newton Center	Chest-nut Hill	Reser-voir	Beacons-field	Brook-line Hill	Brook-line Village	Long wood	Fenway
700	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.30	0.00	0.00	0.00	0.41	0.00
730	0.00	0.00	0.27	0.00	1.00	0.00	0.00	0.50	0.00	0.00	0.00	1.52	0.83
800	0.00	0.00	0.43	0.00	1.19	0.00	0.00	0.00	0.00	0.00	0.00	1.94	0.75
830	0.00	0.00	0.00	0.23	1.24	0.00	4.24	0.00	0.00	0.00	0.00	0.00	0.00
900	0.00	0.00	0.00	0.07	0.00	0.00	1.78	0.00	0.00	0.00	0.00	0.00	0.00
930	0.00	0.00	0.00	0.00	0.61	0.85	0.00	0.00	0.00	0.00	0.80	0.00	0.00
1000	0.00	0.00	0.00	0.00	0.65	1.04	0.00	0.00	0.00	0.33	0.47	0.00	0.00
1030	1.06	0.83	0.00	0.25	0.00	0.00	0.61	0.00	0.00	0.63	0.00	0.64	0.00
1100	0.51	0.29	0.25	0.23	0.00	0.00	0.55	0.00	0.30	0.28	0.00	0.53	0.00
1130	0.65	0.72	0.10	0.00	1.17	0.97	0.00	0.00	0.14	0.00	0.00	0.00	0.00
1200	0.67	0.27	0.10	0.00	0.55	0.87	0.00	0.19	0.18	0.00	3.13	0.58	0.00
1230	0.00	0.75	0.00	0.00	0.41	0.00	0.47	0.93	0.00	0.16	0.96	0.00	0.00
1300	0.00	0.88	0.00	0.00	0.71	0.00	0.53	0.52	0.00	0.44	0.85	0.00	0.00
1330	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00	1.08	0.00
1400	0.00	0.00	0.00	0.00	0.00	0.84	0.00	0.00	0.88	0.00	0.00	0.91	0.00
1430	2.88	0.00	0.00	0.55	0.00	0.00	0.00	2.08	0.00	0.00	0.00	0.00	2.37
1500	0.76	0.00	0.00	0.59	0.00	0.00	0.00	2.83	0.70	0.00	0.00	1.56	2.53
1530	0.00	0.00	0.00	0.00	1.25	2.68	0.00	1.46	0.00	0.00	0.00	0.00	0.00
1600	0.00	0.00	0.00	0.00	0.74	1.70	0.00	3.22	0.00	0.00	1.27	0.98	0.00
1630	4.40	0.00	0.89	0.00	2.52	0.00	1.62	0.00	0.00	0.00	1.29	0.00	0.00
1700	1.83	0.00	1.14	0.00	3.00	0.00	1.15	0.00	0.00	1.89	0.41	0.00	0.00
1730	0.00	0.00	1.15	1.82	1.08	2.29	0.00	0.00	0.00	1.95	5.63	0.70	1.60
1800	0.00	0.00	1.22	2.17	0.00	1.65	0.00	0.00	0.00	2.70	3.32	3.10	2.03
1830	1.86	3.74	0.00	0.00	0.00	0.00	0.00	0.00	4.00	0.00	3.06	0.00	0.00
1900	2.36	2.20	0.00	0.00	0.00	0.00	0.00	0.00	1.39	0.00	1.64	0.00	0.00

The a_i and b_i are the coefficients associated with each T_i and S_j so that the following are true:

$$\mu = \mu$$

$$\alpha_I = a_I \text{ for all } I \neq t$$

$$\alpha_t = -\Sigma a_i \quad i = 1,2,\ldots,\ t-1$$

$$\beta_J = b_J \text{ for all } J \neq S$$

$$\beta_S = -\sum_j b_j \quad j = 1,2,\ldots,\ S-1$$

The results of the model when applied to the 1979 data are shown in Tables 3-5 through 3-8.

As the generalized least square method is applied to model (1) for the estimation of the coefficients a_i and b_j, the following observations help to conclude that the use of model (1) is appropriate.

- o All four regressions are significant with a significant F value.
- o The model consistently explains about 67-78 percent of the data variation in all of the four matrices. The fit is by no means superior when compared with those for the underground stations. This may be due to the data problems discussed earlier in this report. The regression results, however, are adequate for our purposes.
- o In all but one case the interaction test statistics are insignificant.
- o The plots of the predicted values $\hat{R}_{IJ}$ vs. the original data R_{IJ} do not reveal other than linear patterns around the line $\hat{R}_{IJ} = R_{IJ}$. Plotting the residuals vs. $\hat{R}_{IJ}$ also confirms the homogeneity of the variance, etc. Figure 3-1 is an example of such plots.

Incidentally, the magnitude of the B_J, the station effects, reflects the "market shares" of the stations, which are discussed in the 1977 survey. Only the B_J add up to zero instead of one, and, because of the presence of a grand average, μ, in the model (1),

TABLE 3-5. ANALYSIS OF VARIANCE FOR THE REGRESSION, AND ESTIMATION OF BOARDING RATE FOR ALL LECHMERE TRAINS

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DF	SUM OF SQUARE	MEAN SQUARE	F-VALUE
ATTRIBUTABLE TO REGRESSION	36.	66.5590	1.8489	7.9980
DEVIATION FROM REGRESSION	***	32.1321	0.2312	

INTERCEPT= -0.099
MULTIPLE CORR. COEFF. SQUARE=.67442
STANDARD ERROR OF ESTIMATE= 0.481

VARIABLE	REGR. COEFF.	STD.ERROR, OF COEFF.	COMPUTED T-VALUE
2	-0.0114	0.1820	-0.0628
3	0.5702	0.1607	3.5487
4	0.7586	0.1607	4.7212
5	0.7526	0.1609	4.6803
6	0.7841	0.1525	5.1421
7	0.2647	0.1605	1.6488
8	-0.1359	0.1523	-0.8922
9	-0.1171	0.1824	-0.6417
10	-0.3237	0.1968	-1.6451
11	-0.5007	0.1818	-2.7543
12	-0.3285	0.1965	-1.6720
13	-0.8871	0.1821	-4.8721
14	-0.3773	0.1705	-2.2127
15	-0.4325	0.1962	-2.2045
16	-0.4011	0.1824	-2.1994
17	0.0991	0.1704	0.5814
18	0.1891	0.1704	1.1097
19	0.2329	0.1819	1.2809
20	0.1828	0.1604	1.1396
21	-0.2552	0.1973	-1.2935
22	-0.3438	0.1824	-1.8844
23	0.4374	0.2788	1.5688
24	0.5041	0.2153	2.3408
25	-0.3838	0.2779	-1.3810
26	0.4437	0.1245	3.5634
27	0.3254	0.1235	2.6341
28	-0.3136	0.1377	-2.2777
29	-0.6228	0.1544	-4.0334
30	0.0839	0.1275	0.6582
31	0.4462	0.1171	3.8092
32	0.2060	0.1329	1.5505
33	-0.2831	0.1178	-2.4032
34	-0.8805	0.1377	-6.3963
35	-0.3755	0.1452	-2.5859
36	0.3443	0.1196	2.8801
37	0.2655	0.1526	1.7398

THE INTERACTION TEST STAT. , FSTAT: 1.4854

TABLE 3-5. (CONTINUED)

ESTIMATED BOARDING RATE - ALL LECHMERE TRAINS

TIME	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	1.40	1.24	0.65	0.48	0.97	1.40	1.10	0.67	0.37	0.62	1.26	1.17	1.28
730	2.50	2.22	1.17	0.86	1.74	2.50	1.97	1.21	0.66	1.10	2.26	2.09	2.30
800	3.02	2.68	1.41	1.04	2.10	3.02	2.38	1.46	0.80	1.33	2.73	2.52	2.77
830	3.00	2.66	1.41	1.03	2.09	3.01	2.36	1.45	0.80	1.32	2.71	2.51	2.76
900	3.09	2.75	1.45	1.06	2.16	3.10	2.44	1.50	0.82	1.36	2.80	2.59	2.85
930	1.84	1.63	0.86	0.63	1.28	1.84	1.45	0.89	0.49	0.81	1.67	1.54	1.69
1000	1.23	1.10	0.58	0.42	0.86	1.24	0.97	0.60	0.33	0.54	1.12	1.03	1.13
1030	1.26	1.12	0.59	0.43	0.88	1.26	0.99	0.61	0.33	0.55	1.14	1.05	1.16
1100	1.02	0.91	0.48	0.35	0.71	1.02	0.81	0.49	0.27	0.45	0.92	0.85	0.94
1130	0.86	0.76	0.40	0.29	0.60	0.86	0.67	0.41	0.23	0.38	0.77	0.72	0.79
1200	1.02	0.90	0.48	0.35	0.71	1.02	0.80	0.49	0.27	0.45	0.92	0.85	0.94
1230	0.58	0.52	0.27	0.20	0.41	0.58	0.46	0.28	0.15	0.26	0.53	0.49	0.54
1300	0.97	0.86	0.45	0.33	0.68	0.97	0.76	0.47	0.26	0.43	0.88	0.81	0.89
1330	0.92	0.81	0.43	0.32	0.64	0.92	0.72	0.44	0.24	0.40	0.83	0.77	0.84
1400	0.95	0.84	0.44	0.33	0.66	0.95	0.75	0.46	0.25	0.42	0.86	0.79	0.87
1430	1.56	1.39	0.73	0.54	1.09	1.56	1.23	0.75	0.41	0.69	1.41	1.30	1.43
1500	1.71	1.52	0.80	0.59	1.19	1.71	1.35	0.82	0.45	0.75	1.54	1.43	1.57
1530	1.78	1.58	0.84	0.61	1.24	1.79	1.41	0.86	0.47	0.79	1.61	1.49	1.64
1600	1.70	1.51	0.79	0.58	1.18	1.70	1.34	0.82	0.45	0.75	1.53	1.42	1.56
1630	1.09	0.97	0.51	0.38	0.76	1.10	0.86	0.53	0.29	0.48	0.99	0.92	1.01
1700	1.00	0.89	0.47	0.34	0.70	1.00	0.79	0.48	0.27	0.44	0.91	0.84	0.92
1730	2.19	1.94	1.03	0.75	1.53	2.19	1.72	1.06	0.58	0.96	1.98	1.83	2.01
1800	2.34	2.08	1.10	0.80	1.63	2.34	1.84	1.13	0.62	1.03	2.12	1.96	2.15
1830	0.96	0.85	0.45	0.33	0.67	0.96	0.76	0.47	0.26	0.42	0.87	0.80	0.89
1900	1.07	0.95	0.50	0.37	0.75	1.07	0.84	0.52	0.28	0.47	0.97	0.90	0.98

ESTIMATED STANDARD ERROR OF THE PRED.

TIME	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.74	0.65	0.35	0.26	0.51	0.74	0.59	0.36	0.20	0.33	0.67	0.63	0.69
730	1.30	1.16	0.62	0.46	0.91	1.30	1.03	0.63	0.35	0.58	1.18	1.11	1.20
800	1.57	1.40	0.75	0.55	1.10	1.57	1.24	0.76	0.42	0.70	1.42	1.35	1.45
830	1.57	1.39	0.74	0.55	1.09	1.56	1.24	0.75	0.42	0.70	1.42	1.32	1.45
900	1.62	1.43	0.76	0.56	1.12	1.60	1.27	0.77	0.43	0.71	1.46	1.36	1.48
930	0.96	0.86	0.45	0.33	0.68	0.96	0.77	0.46	0.26	0.43	0.87	0.82	0.88
1000	0.64	0.57	0.30	0.22	0.45	0.64	0.51	0.31	0.17	0.28	0.58	0.55	0.59
1030	0.67	0.59	0.32	0.23	0.46	0.66	0.52	0.32	0.18	0.29	0.60	0.56	0.61
1100	0.55	0.49	0.26	0.19	0.38	0.54	0.43	0.26	0.15	0.24	0.49	0.46	0.50
1130	0.45	0.40	0.22	0.16	0.32	0.46	0.36	0.22	0.12	0.20	0.41	0.38	0.42
1200	0.54	0.48	0.26	0.19	0.38	0.55	0.43	0.26	0.15	0.24	0.49	0.46	0.50
1230	0.31	0.27	0.14	0.11	0.21	0.31	0.25	0.15	0.08	0.14	0.28	0.26	0.29
1300	0.51	0.45	0.24	0.18	0.35	0.51	0.41	0.24	0.14	0.23	0.46	0.43	0.47
1330	0.49	0.43	0.23	0.17	0.34	0.49	0.39	0.24	0.13	0.22	0.44	0.41	0.45
1400	0.50	0.44	0.24	0.16	0.35	0.50	0.40	0.24	0.13	0.22	0.45	0.42	0.46
1430	0.82	0.73	0.39	0.29	0.57	0.82	0.65	0.40	0.22	0.37	0.74	0.70	0.75
1500	0.89	0.80	0.42	0.32	0.62	0.89	0.71	0.43	0.24	0.40	0.81	0.77	0.82
1530	0.94	0.84	0.45	0.33	0.66	0.94	0.74	0.45	0.25	0.42	0.86	0.81	0.88
1600	0.88	0.79	0.42	0.31	0.62	0.88	0.70	0.43	0.24	0.39	0.80	0.76	0.82
1630	0.59	0.52	0.27	0.21	0.41	0.59	0.47	0.28	0.16	0.26	0.53	0.49	0.54
1700	0.53	0.47	0.25	0.19	0.37	0.53	0.42	0.25	0.14	0.24	0.48	0.45	0.49
1730	1.24	1.12	0.59	0.44	0.88	1.26	1.00	0.61	0.34	0.55	1.14	1.07	1.14
1800	1.26	1.13	0.60	0.45	0.89	1.27	1.00	0.61	0.34	0.56	1.15	1.08	1.16
1830	0.55	0.49	0.26	0.19	0.39	0.54	0.44	0.26	0.15	0.25	0.50	0.47	0.51
1900	0.62	0.55	0.29	0.21	0.43	0.61	0.49	0.29	0.16	0.27	0.56	0.52	0.57

TABLE 3-6. ANALYSIS OF VARIANCE FOR THE REGRESSION, AND ESTIMATION OF DEBOARDING RATES FOR LECHMERE TRAINS

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DF	SUM OF SQUARE	MEAN SQUARE	F-VALUE
ATTRIBUTABLE TO REGRESSION	35.	275.2254	7.8636	8.8317
DEVIATION FROM REGRESSION	***	105.9552	0.8904	

INTERCEPT= -2.011
MULTIPLE CORR. COEFF. SQUARE=.72203
STANDARD ERROR OF ESTIMATE= 0.944

VARIABLE	REGR. COEFF.	STD.ERROR, OF COEFF.	COMPUTED T-VALUE
2	-0.2655	0.4753	-0.5586
3	-0.5275	0.3361	-1.5696
4	0.6179	0.3361	1.8385
5	0.5622	0.3185	1.7655
6	0.7847	0.3019	2.5995
7	-0.3274	0.3364	-0.9733
8	-0.6751	0.3178	-2.1246
9	-0.7603	0.3595	-2.1152
10	-0.7577	0.3876	-1.9548
11	-0.4285	0.3883	-1.1036
12	-0.4401	0.4256	-1.0340
13	-0.4871	0.3899	-1.2495
14	0.4545	0.3622	1.2548
15	-0.7753	0.3880	-1.9981
16	-0.5206	0.3609	-1.4426
17	-0.5986	0.3868	-1.5476
18	-0.0972	0.3591	-0.2706
19	0.7276	0.3881	1.8748
20	0.6286	0.3364	1.8687
21	0.4603	0.3904	1.1790
22	0.2820	0.3608	0.7816
23	0.6407	0.6728	0.9524
24	0.6024	0.5500	1.0952
25	0.9056	0.5484	1.6514
26	-2.0135	0.2511	-8.0193
27	-1.3948	0.2716	-5.1349
28	-1.8941	0.3171	-5.9728
29	-1.2451	0.2695	-4.6202
30	0.6301	0.2358	2.6725
31	0.2090	0.2631	0.7942
32	1.0419	0.2441	4.2679
33	-0.3155	0.2707	-1.1653
34	0.3786	0.2896	1.3075
35	1.3581	0.2356	5.7648
36	1.7168	0.2985	5.7507

THE INTERACTION TEST STAT. , FSTAT: 1.9839

TABLE 3-6. (CONTINUED)

ESTIMATED DEBOARDING RATE - ALL LECHMERE TRAINS

TIME	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.01	0.03	0.02	0.03	0.19	0.13	0.29	0.07	0.15	0.40	0.57	0.47
730	0.01	0.02	0.01	0.02	0.15	0.10	0.22	0.06	0.12	0.31	0.44	0.36
800	0.03	0.06	0.04	0.07	0.47	0.31	0.70	0.18	0.36	0.97	1.38	1.14
830	0.03	0.06	0.04	0.07	0.44	0.29	0.67	0.17	0.34	0.91	1.31	1.08
900	0.04	0.07	0.04	0.08	0.55	0.36	0.83	0.21	0.43	1.14	1.63	1.35
930	0.01	0.02	0.01	0.03	0.18	0.12	0.27	0.07	0.14	0.38	0.54	0.44
1000	0.01	0.02	0.01	0.02	0.13	0.08	0.19	0.05	0.10	0.27	0.38	0.31
1030	0.01	0.02	0.01	0.02	0.12	0.08	0.18	0.05	0.09	0.24	0.35	0.29
1100	0.01	0.02	0.01	0.02	0.12	0.08	0.18	0.05	0.09	0.24	0.35	0.29
1130	0.01	0.02	0.01	0.03	0.16	0.11	0.25	0.06	0.13	0.34	0.49	0.40
1200	0.01	0.02	0.01	0.02	0.16	0.11	0.24	0.06	0.13	0.34	0.48	0.40
1230	0.01	0.02	0.01	0.02	0.15	0.10	0.23	0.06	0.12	0.32	0.46	0.38
1300	0.03	0.05	0.03	0.06	0.40	0.26	0.60	0.15	0.31	0.82	1.17	0.97
1330	0.01	0.02	0.01	0.02	0.12	0.08	0.17	0.04	0.09	0.24	0.34	0.28
1400	0.01	0.02	0.01	0.02	0.15	0.10	0.23	0.06	0.12	0.31	0.44	0.37
1430	0.01	0.02	0.01	0.02	0.14	0.09	0.21	0.05	0.11	0.29	0.41	0.34
1500	0.02	0.03	0.02	0.03	0.23	0.15	0.34	0.09	0.18	0.47	0.68	0.56
1530	0.04	0.07	0.04	0.08	0.52	0.34	0.79	0.20	0.40	1.08	1.54	1.28
1600	0.03	0.06	0.04	0.07	0.47	0.31	0.71	0.18	0.37	0.98	1.40	1.16
1630	0.03	0.05	0.03	0.06	0.40	0.26	0.60	0.15	0.31	0.82	1.18	0.98
1700	0.02	0.04	0.03	0.05	0.33	0.22	0.50	0.13	0.26	0.69	0.99	0.82
1730	0.03	0.06	0.04	0.07	0.48	0.31	0.72	0.19	0.37	0.99	1.41	1.17
1800	0.03	0.06	0.04	0.07	0.46	0.30	0.69	0.18	0.36	0.95	1.36	1.13
1830	0.04	0.08	0.05	0.10	0.62	0.41	0.94	0.24	0.48	1.29	1.84	1.53
1900	0.02	0.03	0.02	0.04	0.25	0.16	0.38	0.10	0.19	0.52	0.74	0.61

ESTIMATED STANDARD ERROR OF THE PRED.

TIME	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.02	0.03	0.02	0.03	0.21	0.14	0.32	0.08	0.17	0.43	0.63	0.52
730	0.01	0.02	0.01	0.02	0.15	0.10	0.23	0.06	0.12	0.32	0.46	0.38
800	0.03	0.06	0.04	0.07	0.48	0.32	0.73	0.19	0.38	0.99	1.46	1.18
830	0.03	0.06	0.04	0.07	0.45	0.30	0.68	0.18	0.35	0.94	1.36	1.12
900	0.04	0.07	0.05	0.09	0.56	0.37	0.85	0.22	0.44	1.17	1.69	1.38
930	0.01	0.02	0.02	0.03	0.19	0.12	0.28	0.07	0.15	0.39	0.57	0.46
1000	0.01	0.02	0.01	0.02	0.13	0.09	0.20	0.05	0.10	0.27	0.40	0.32
1030	0.01	0.02	0.01	0.02	0.12	0.08	0.19	0.05	0.10	0.25	0.37	0.30
1100	0.01	0.02	0.01	0.02	0.12	0.08	0.19	0.05	0.10	0.25	0.37	0.30
1130	0.01	0.02	0.01	0.03	0.17	0.11	0.26	0.07	0.14	0.35	0.51	0.42
1200	0.01	0.02	0.01	0.03	0.17	0.11	0.26	0.07	0.14	0.36	0.51	0.42
1230	0.01	0.02	0.01	0.02	0.16	0.11	0.24	0.06	0.13	0.33	0.49	0.40
1300	0.03	0.05	0.03	0.06	0.41	0.27	0.62	0.16	0.33	0.85	1.25	1.02
1330	0.01	0.02	0.01	0.02	0.12	0.08	0.18	0.05	0.10	0.25	0.36	0.30
1400	0.01	0.02	0.01	0.02	0.15	0.10	0.23	0.06	0.12	0.32	0.46	0.39
1430	0.01	0.02	0.01	0.02	0.14	0.10	0.22	0.06	0.11	0.30	0.44	0.36
1500	0.02	0.03	0.02	0.04	0.24	0.16	0.36	0.09	0.19	0.49	0.72	0.58
1530	0.04	0.07	0.04	0.08	0.54	0.36	0.82	0.22	0.43	1.14	1.66	1.35
1600	0.03	0.06	0.04	0.08	0.48	0.32	0.73	0.19	0.38	1.00	1.47	1.20
1630	0.03	0.06	0.03	0.06	0.42	0.28	0.63	0.16	0.33	0.86	1.25	1.04
1700	0.02	0.05	0.03	0.05	0.35	0.23	0.52	0.13	0.27	0.71	1.04	0.85
1730	0.04	0.08	0.05	0.09	0.57	0.38	0.87	0.22	0.43	1.19	1.72	1.37
1800	0.04	0.07	0.04	0.08	0.52	0.34	0.79	0.20	0.40	1.07	1.56	1.25
1830	0.05	0.09	0.06	0.11	0.65	0.46	1.04	0.27	0.55	1.45	2.11	1.73
1900	0.02	0.05	0.03	0.05	0.33	0.23	0.52	0.13	0.27	0.71	1.03	0.85

TABLE 3-7. ANALYSIS OF VARIANCE FOR THE REGRESSION, AND ESTIMATION OF BOARDING RATES FOR RIVERSIDE TRAINS

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DF	SUM OF SQUARE	MEAN SQUARE	F-VALUE
ATTRIBUTABLE TO REGRESSION	35.	200.8418	5.7383	8.0361
DEVIATION FROM REGRESSION	78.	55.6977	0.7141	

INTERCEPT= -1.936
MULTIPLE CORR. COEFF. SQUARE=.78289
STANDARD ERROR OF ESTIMATE= 0.845

VARIABLE	REGR. COEFF.	STD.ERROR, OF COEFF.	COMPUTED T-VALUE
2	-0.2408	0.4296	-0.5605
3	-0.0052	0.3907	-0.0132
4	0.9737	0.3907	2.4922
5	1.0371	0.4993	2.0770
6	0.0211	0.6200	0.0340
7	0.1930	0.4966	0.3886
8	-0.3946	0.4329	-0.9113
9	-1.2354	0.3901	-3.1669
10	-0.4724	0.3550	-1.3307
11	0.2094	0.3865	0.5418
12	-0.2002	0.3049	-0.6566
13	-0.8256	0.3537	-2.3341
14	0.0651	0.3537	0.1842
15	0.3436	0.6079	0.5653
16	-0.0772	0.4974	-0.1552
17	-0.4753	0.4383	-1.0843
18	-0.5335	0.3913	-1.3633
19	0.1918	0.4972	0.3857
20	0.3489	0.3838	0.9091
21	0.0412	0.4315	0.0955
22	0.2807	0.3885	0.7225
23	0.6667	0.3081	2.1640
24	0.4773	0.3301	1.4460
25	-0.4114	0.4997	-0.8232
26	-1.8189	0.3128	-5.8154
27	-2.1327	0.3049	-6.9953
28	-1.1726	0.3171	-3.6981
29	0.0248	0.2381	0.1040
30	0.6413	0.2987	2.1469
31	-0.1821	0.3027	-0.6015
32	0.9036	0.2775	3.2566
33	-1.0213	0.2905	-3.5154
34	0.3797	0.3045	1.2469
35	1.5101	0.2567	5.8823
36	1.3096	0.2550	5.1372

THE INTERACTION TEST STAT. , FSTAT: · 0.7244

TABLE 3-7. (CONTINUED)

ESTIMATED BOARDING RATE - ALL RIVERSIDE TRAINS

TIME	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.02	0.01	0.04	0.12	0.22	0.09	0.28	0.04	0.17	0.51	0.42	0.54
730	0.02	0.02	0.04	0.15	0.27	0.12	0.35	0.05	0.21	0.65	0.53	0.68
800	0.06	0.05	0.12	0.39	0.73	0.32	0.94	0.14	0.56	1.73	1.42	1.81
830	0.07	0.05	0.13	0.42	0.77	0.34	1.00	0.15	0.59	1.84	1.51	1.93
900	0.02	0.02	0.05	0.15	0.28	0.12	0.36	0.05	0.22	0.67	0.55	0.70
930	0.03	0.02	0.05	0.18	0.33	0.15	0.43	0.06	0.26	0.79	0.65	0.83
1000	0.02	0.01	0.03	0.10	0.16	0.08	0.24	0.04	0.14	0.44	0.36	0.46
1030	0.01	0.00	0.01	0.04	0.08	0.03	0.10	0.02	0.06	0.19	0.16	0.20
1100	0.01	0.01	0.03	0.09	0.17	0.07	0.22	0.03	0.13	0.41	0.33	0.43
1130	0.03	0.02	0.06	0.18	0.34	0.15	0.44	0.06	0.26	0.81	0.66	0.84
1200	0.02	0.01	0.04	0.12	0.22	0.10	0.29	0.04	0.17	0.53	0.44	0.56
1230	0.01	0.01	0.02	0.06	0.12	0.05	0.16	0.02	0.09	0.29	0.23	0.30
1300	0.02	0.02	0.05	0.16	0.29	0.13	0.38	0.06	0.23	0.70	0.57	0.73
1330	0.03	0.02	0.06	0.21	0.39	0.17	0.50	0.07	0.30	0.92	0.75	0.97
1400	0.02	0.02	0.04	0.14	0.25	0.11	0.33	0.05	0.20	0.60	0.49	0.63
1430	0.01	0.01	0.03	0.09	0.17	0.07	0.22	0.03	0.13	0.41	0.33	0.43
1500	0.01	0.01	0.03	0.09	0.16	0.07	0.21	0.03	0.12	0.38	0.31	0.40
1530	0.03	0.02	0.05	0.18	0.33	0.15	0.43	0.06	0.26	0.79	0.65	0.83
1600	0.03	0.02	0.06	0.21	0.39	0.17	0.50	0.07	0.30	0.93	0.76	0.97
1630	0.02	0.02	0.05	0.15	0.29	0.13	0.37	0.05	0.22	0.68	0.56	0.71
1700	0.03	0.02	0.06	0.20	0.36	0.16	0.47	0.07	0.28	0.86	0.71	0.91
1730	0.05	0.03	0.09	0.29	0.53	0.23	0.69	0.10	0.41	1.27	1.04	1.33
1800	0.01	0.03	0.07	0.21	0.44	0.19	0.57	0.08	0.34	1.05	0.86	1.10
1830	0.02	0.01	0.03	0.10	0.18	0.08	0.24	0.03	0.14	0.43	0.35	0.45
1900	0.02	0.02	0.05	0.15	0.28	0.12	0.36	0.05	0.22	0.67	0.55	0.70

ESTIMATED STANDARD ERROR OF THE PRED.

TIME	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.02	0.01	0.04	0.11	0.22	0.09	0.27	0.04	0.17	0.51	0.41	0.55
730	0.02	0.02	0.04	0.14	0.27	0.12	0.34	0.05	0.21	0.63	0.51	0.67
800	0.06	0.04	0.12	0.37	0.71	0.32	0.91	0.14	0.55	1.68	1.35	1.77
830	0.07	0.05	0.13	0.42	0.80	0.34	1.04	0.15	0.62	1.89	1.55	2.05
900	0.03	0.02	0.05	0.16	0.31	0.13	0.40	0.06	0.24	0.73	0.60	0.79
930	0.03	0.02	0.06	0.18	0.33	0.15	0.45	0.07	0.27	0.79	0.67	0.88
1000	0.02	0.01	0.03	0.10	0.18	0.08	0.24	0.04	0.14	0.43	0.36	0.48
1030	0.01	0.00	0.01	0.04	0.08	0.03	0.10	0.01	0.06	0.18	0.15	0.20
1100	0.01	0.01	0.03	0.09	0.17	0.07	0.21	0.03	0.13	0.39	0.32	0.43
1130	0.03	0.02	0.05	0.17	0.33	0.15	0.43	0.06	0.26	0.78	0.64	0.85
1200	0.02	0.01	0.04	0.11	0.21	0.09	0.27	0.04	0.17	0.50	0.41	0.55
1230	0.01	0.01	0.02	0.06	0.12	0.05	0.15	0.02	0.09	0.27	0.22	0.30
1300	0.02	0.02	0.05	0.15	0.28	0.12	0.36	0.05	0.22	0.66	0.55	0.73
1330	0.04	0.03	0.07	0.23	0.42	0.19	0.55	0.08	0.33	1.00	0.79	1.08
1400	0.02	0.02	0.04	0.14	0.26	0.12	0.34	0.05	0.20	0.62	0.49	0.67
1430	0.01	0.01	0.03	0.09	0.17	0.08	0.22	0.03	0.13	0.41	0.33	0.42
1500	0.01	0.01	0.03	0.08	0.16	0.07	0.20	0.03	0.12	0.37	0.30	0.39
1530	0.03	0.02	0.06	0.19	0.33	0.15	0.43	0.07	0.27	0.81	0.66	0.88
1600	0.03	0.02	0.06	0.20	0.37	0.17	0.48	0.07	0.30	0.88	0.72	0.98
1630	0.02	0.02	0.05	0.15	0.29	0.12	0.37	0.05	0.22	0.66	0.55	0.74
1700	0.03	0.02	0.06	0.19	0.36	0.15	0.46	0.07	0.27	0.83	0.69	0.92
1730	0.04	0.03	0.08	0.27	0.50	0.22	0.66	0.10	0.39	1.18	0.97	1.28
1800	0.03	0.03	0.07	0.22	0.42	0.19	0.55	0.08	0.32	0.99	0.81	1.06
1830	0.02	0.01	0.04	0.10	0.19	0.08	0.24	0.03	0.15	0.43	0.36	0.48
1900	0.02	0.02	0.05	0.15	0.29	0.13	0.38	0.05	0.22	0.67	0.56	0.75

TABLE 3-8. ANALYSIS OF VARIANCE FOR THE REGRESSION, AND ESTIMATION OF DEBOARDING RATE FOR ALL RIVERSIDE TRAINS

ANALYSIS OF VARIANCE FOR THE REGRESSION

SOURCE OF VARIATION	DF	SUM OF SQUARE	MEAN SQUARE	F-VALUE
ATTRIBUTABLE TO REGRESSICN	36.	66.4766	1.8466	5.5121
DEVIATION FROM REGRESSION	85.	28.4752	0.3350	

INTERCEPT= -0.144
MULTIPLE CCRR. COEFF. SQUARE=.70011
STANDARD ERROR OF ESTIMATE= 0.579

VARIABLE	REGR. COEFF.	STD.ERROR, OF COEFF.	COMPUTED T-VALUE
2	-1.1486	0.3405	-3.3732
3	-0.1835	0.2666	-0.6884
4	0.1544	0.2978	0.5185
5	0.3259	0.3417	0.9538
6	-0.6184	0.4241	-1.4581
7	-0.4713	0.3400	-1.3862
8	-0.6196	0.2963	-2.0908
9	-0.3345	0.2435	-1.3736
10	-0.7605	0.2111	-3.6019
11	-0.6608	0.2427	-2.7221
12	-0.7651	0.1975	-3.8743
13	-0.6901	0.2425	-2.8457
14	-0.5005	0.2425	-2.0639
15	-0.1218	0.4196	-0.2902
16	-0.0606	0.3427	-0.1768
17	0.7445	0.3005	2.4780
18	0.4463	0.2442	1.8278
19	0.3944	0.3410	1.1565
20	0.1959	0.2630	0.7446
21	0.6771	0.2636	2.5690
22	0.3981	0.2421	1.6446
23	0.7429	0.2106	3.5268
24	1.0506	0.2257	4.6545
25	1.1492	0.2991	3.8422
26	0.2795	0.1884	1.4830
27	0.2113	0.2107	1.0031
28	-0.7940	0.1960	-4.0513
29	-0.8974	0.2165	-4.1449
30	0.2024	0.1633	1.2395
31	0.4301	0.2053	2.0952
32	0.3402	0.2074	1.6401
33	0.2046	0.2022	1.0121
34	-0.4004	0.2200	-1.8204
35	-0.1665	0.2081	-0.8001
36	0.3343	0.1742	1.9186
37	0.1885	0.1756	1.0731

THE INTERACTION TEST STAT. , FSTAT: 0.6283

TABLE 3-8. (CONTINUED)

ESTIMATED DEBOARDING RATE - ALL RIVERSIDE TRAINS

TIME	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.36	0.34	0.12	0.11	0.34	0.42	0.39	0.34	0.18	0.23	0.38	0.33	0.29
730	0.95	0.89	0.33	0.29	0.88	1.11	1.01	0.88	0.48	0.61	1.01	0.87	0.77
800	1.34	1.25	0.46	0.41	1.24	1.55	1.42	1.24	0.68	0.86	1.41	1.22	1.08
830	1.59	1.48	0.54	0.49	1.47	1.84	1.69	1.47	0.80	1.02	1.68	1.45	1.28
900	0.62	0.58	0.21	0.19	0.57	0.72	0.66	0.57	0.31	0.39	0.65	0.56	0.50
930	0.71	0.67	0.24	0.22	0.66	0.83	0.76	0.66	0.36	0.46	0.75	0.65	0.58
1000	0.62	0.58	0.21	0.19	0.57	0.72	0.65	0.57	0.31	0.39	0.65	0.56	0.50
1030	0.82	0.77	0.28	0.25	0.76	0.95	0.87	0.76	0.42	0.52	0.87	0.75	0.66
1100	0.54	0.50	0.18	0.16	0.50	0.62	0.57	0.50	0.27	0.34	0.57	0.49	0.43
1130	0.59	0.55	0.20	0.18	0.55	0.69	0.63	0.55	0.30	0.38	0.62	0.54	0.48
1200	0.53	0.50	0.18	0.16	0.49	0.62	0.57	0.49	0.27	0.34	0.56	0.49	0.43
1230	0.57	0.54	0.20	0.18	0.53	0.67	0.61	0.53	0.29	0.37	0.61	0.52	0.46
1300	0.69	0.65	0.24	0.21	0.64	0.81	0.74	0.64	0.35	0.44	0.73	0.63	0.56
1330	1.01	0.95	0.35	0.31	0.94	1.18	1.08	0.94	0.51	0.65	1.07	0.93	0.82
1400	1.08	1.01	0.37	0.33	1.00	1.25	1.14	1.00	0.55	0.69	1.14	0.98	0.87
1430	2.41	2.25	0.82	0.74	2.23	2.80	2.56	2.24	1.22	1.54	2.55	2.20	1.95
1500	1.79	1.67	0.61	0.55	1.66	2.08	1.90	1.66	0.91	1.15	1.89	1.63	1.45
1530	1.70	1.59	0.58	0.52	1.57	1.97	1.80	1.58	0.86	1.09	1.79	1.55	1.37
1600	1.39	1.30	0.48	0.43	1.29	1.62	1.48	1.29	0.71	0.89	1.47	1.27	1.13
1630	2.25	2.10	0.77	0.69	2.09	2.62	2.39	2.09	1.14	1.44	2.38	2.06	1.82
1700	1.70	1.59	0.58	0.53	1.58	1.98	1.81	1.58	0.86	1.09	1.80	1.56	1.38
1730	2.41	2.25	0.82	0.74	2.23	2.80	2.56	2.23	1.22	1.54	2.54	2.20	1.95
1800	3.27	3.06	1.12	1.01	3.03	3.81	3.48	3.04	1.66	2.10	3.46	2.99	2.65
1830	3.61	3.37	1.23	1.11	3.34	4.20	3.84	3.35	1.83	2.31	3.82	3.30	2.92
1900	2.21	2.06	0.75	0.68	2.04	2.56	2.34	2.05	1.12	1.41	2.33	2.01	1.78

ESTIMATED STANDARD ERROR OF THE PRED.

TIME	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacons-field	Brookline Hill	Brookline Village	Longwood	Fenway
700	0.26	0.24	0.09	0.08	0.23	0.30	0.27	0.23	0.13	0.17	0.27	0.23	0.21
730	0.64	0.61	0.21	0.20	0.58	0.75	0.69	0.58	0.33	0.41	0.67	0.57	0.52
800	0.92	0.87	0.31	0.29	0.82	1.07	0.98	0.85	0.47	0.59	0.96	0.81	0.73
830	1.12	1.06	0.38	0.34	1.01	1.31	1.16	1.05	0.58	0.72	1.18	1.02	0.93
900	0.46	0.44	0.16	0.14	0.43	0.55	0.47	0.43	0.24	0.30	0.49	0.42	0.39
930	0.51	0.48	0.17	0.16	0.45	0.57	0.54	0.47	0.26	0.33	0.52	0.46	0.42
1000	0.42	0.40	0.14	0.13	0.38	0.48	0.45	0.39	0.22	0.27	0.43	0.38	0.35
1030	0.53	0.50	0.19	0.17	0.50	0.64	0.57	0.51	0.28	0.34	0.57	0.45	0.45
1100	0.34	0.32	0.12	0.11	0.32	0.41	0.37	0.32	0.18	0.22	0.36	0.31	0.29
1130	0.38	0.36	0.13	0.12	0.35	0.45	0.42	0.37	0.20	0.25	0.41	0.35	0.33
1200	0.34	0.32	0.12	0.11	0.31	0.40	0.37	0.32	0.17	0.22	0.36	0.31	0.29
1230	0.38	0.35	0.13	0.12	0.34	0.44	0.40	0.35	0.20	0.24	0.39	0.34	0.32
1300	0.46	0.42	0.16	0.14	0.41	0.54	0.48	0.42	0.24	0.29	0.47	0.42	0.38
1330	0.76	0.72	0.26	0.24	0.70	0.89	0.82	0.71	0.37	0.49	0.80	0.67	0.63
1400	0.76	0.72	0.26	0.24	0.70	0.86	0.82	0.71	0.38	0.49	0.80	0.67	0.63
1430	1.62	1.56	0.57	0.50	1.51	1.94	1.77	1.51	0.85	1.07	1.74	1.50	1.33
1500	1.17	1.12	0.41	0.36	1.08	1.39	1.27	1.09	0.60	0.77	1.24	1.06	0.96
1530	1.20	1.13	0.41	0.38	1.07	1.36	1.29	1.09	0.62	0.78	1.26	1.09	1.00
1600	0.93	0.88	0.32	0.29	0.84	1.07	1.00	0.85	0.48	0.60	0.96	0.83	0.78
1630	1.48	1.42	0.51	0.47	1.36	1.77	1.58	1.41	0.78	0.97	1.56	1.37	1.26
1700	1.11	1.06	0.38	0.35	1.02	1.32	1.18	1.05	0.58	0.71	1.16	1.02	0.94
1730	1.56	1.48	0.53	0.48	1.41	1.80	1.68	1.46	0.81	1.00	1.62	1.40	1.28
1800	2.14	2.03	0.72	0.66	1.95	2.47	2.30	2.00	1.10	1.36	2.22	1.92	1.75
1830	2.41	2.27	0.85	0.77	2.27	2.90	2.65	2.31	1.23	1.60	2.55	2.25	2.07
1900	1.47	1.38	0.52	0.47	1.38	1.77	1.62	1.41	0.75	0.98	1.56	1.37	1.26

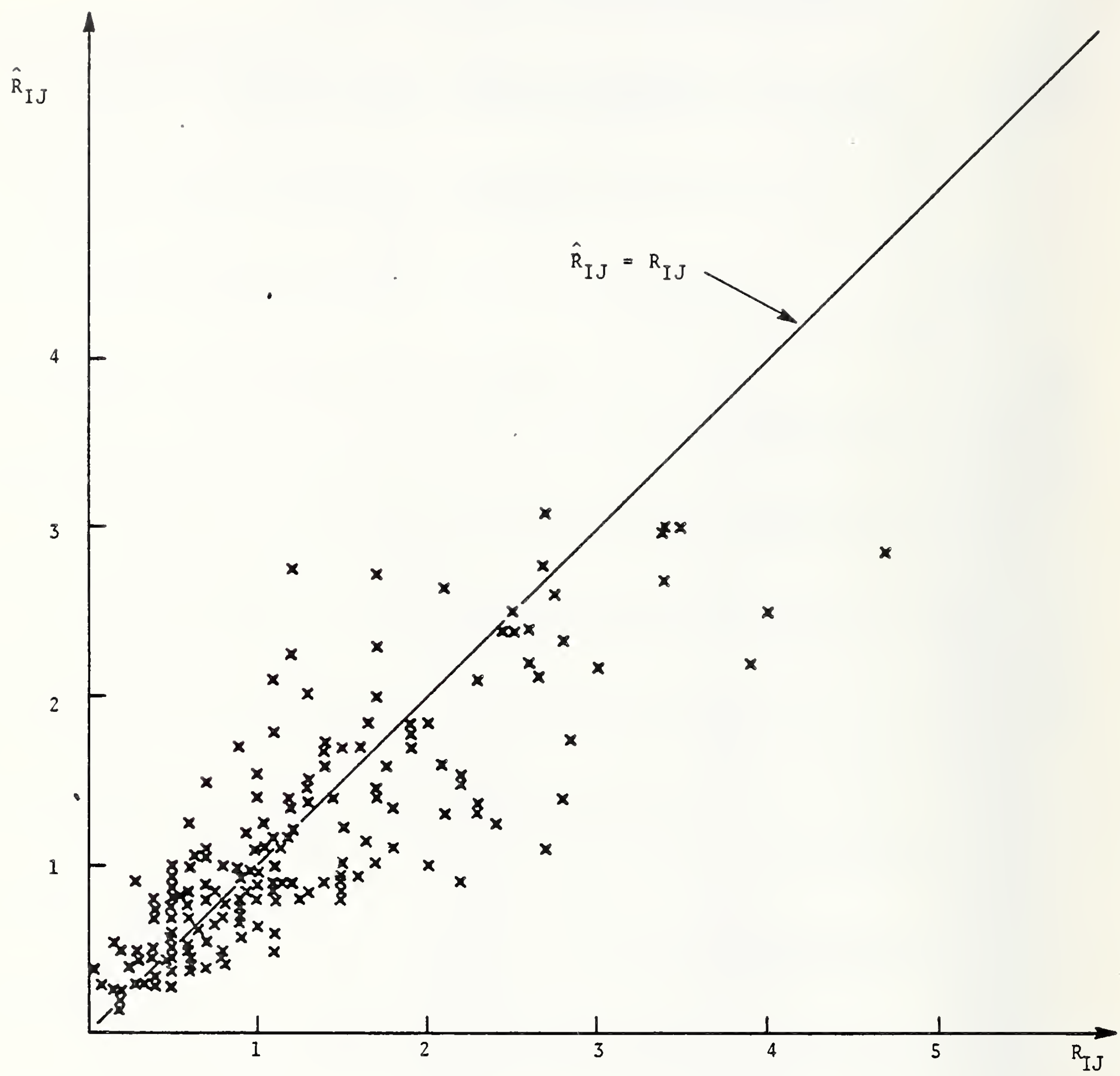


FIGURE 3-1. GRAPH OF RAW DATA, R_{IJ}, VS. ESTIMATED AVERAGES, $\hat{R}_{IJ}$: BOARDING PASSENGERS PER MINUTE (RIVERSIDE TO LECHMERE)

some betas are negative. To facilitate later comparisons between the β_J and the market shares, p_J, estimated from the 1977 survey, we further define a new set of variables, M_J.

$$M_J = \frac{1+\beta_J}{\sum_J (1+\beta_J)} \qquad J = 1,2,\ldots S$$

M_J, $J=1,2,\ldots S$, are always positive and add up to 1, and the variance of M_J, $Var(M_J)$, is $\frac{1}{S^2} Var(\beta_J)$, $J=1,2,\ldots S$.

3.2 CONSISTENCY OF PASSENGER VOLUME ESTIMATES-SURFACE STATIONS

Even though use of Model (1) has been determined appropriate, several additional questions need to be addressed.

- o The 1977 survey reveals a particular pattern of passenger flow into the Boston downtown (Riverside to Lechmere) area, showing the peak periods during the morning rush hours and the early afternoon (2:00-3:00 pm.). Does this pattern still persist in 1979?

o

- o The 1978 underground station passenger survey postulates an increase (approximately by 40 percent) in the use of the Riverside Line; can we substantiate that claim using the data from the 1979 survey?

- o Can we also validate the 1977 market shares estimate for the surface stations seeing that there is no reason for such changes in spite of the increase of the total passenger volume?

3.2.1 Consistency Of Temporal Dispersion - Surface Stations

In comparing the 1977 and 1979 passenger survey results, we have to note that the two passenger profiles are defined differently. One is an on-board trip count while the other is a station count. A profile derived from the former is a moving average of the number of loading passengers per trip while that derived from the latter denotes the average rate (per minute) of passengers (transit users) arriving at the station. One is dependent on the time the train leaves the trip originating station; the other describes passenger activity at times when the train arrives at the station. Because of the difference in definitions, a slight shift in pattern is not surprising when the two profiles are laid over one another. Figures 3-2 through 3-5 compare the inbound and outbound profiles of the 1979 passenger demand at Newton Center with the 1977 trip profiles of the entire surface segment of the Riverside Line. Immediately, a visual impression is that the points of inflection from both profiles correspond quite well. The extra peak portrayed by the 1979 inbound profile is the result of a 2-week long set of Red Sox Home Games which brought an unusual influx of people into Fenway Park.

3.2.2 Average Daily Volume Estimates - Surface Stations

For 1977 the average total daily inbound patronage of the Riverside Line surface segment was estimated at 8734 bounded by a 95 percent confidence interval of (7793, 9904). The total outbound volume was, however, estimated at 9893 bounded by a 95 percent confidence interval of (8799, 10987). According to the 1979 surface station survey, the two totals are 10,586 and 11,054 respectively, considerably higher than those for 1977. Because of the huge standard errors associated with the statistics, the increase in ridership cannot be substantiated by statistical testings. It is interesting, nevertheless, to note that, as in the previous 1977 analysis, the new survey shows that 70 percent of the inbound passengers at these stations go beyond Fenway into the underground towards Metropolitan Boston.

3.2.3 Comparison of Market Share Estimates

Comparing the two sets of market shares derived from two different surveys within different time frames and employing different methods of estimation certainly requires careful considerations. First, the data variations may reflect more than a random fluctuation, and it is difficult to attribute a significant difference to any one specific cause. Second, the problem is compounded by the 1979 survey data deficiencies mentioned earlier. That is, environmental changes may affect the market shares of the stations, and latent residual interaction between the station factor and time factor not counteracted by the logarithmic

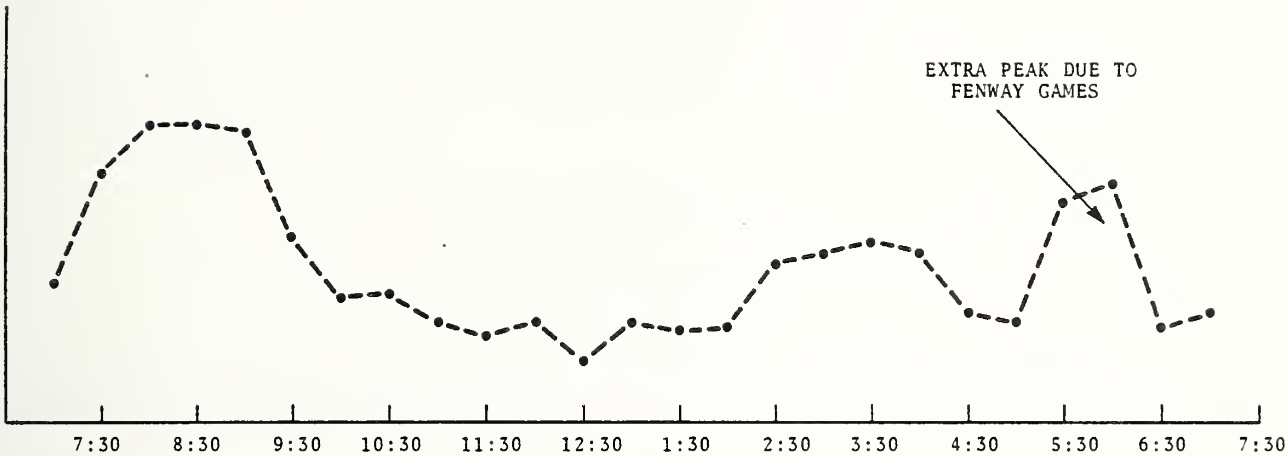


FIGURE 3-2. NEWTON CENTER: INBOUND BOARDING PROFILE

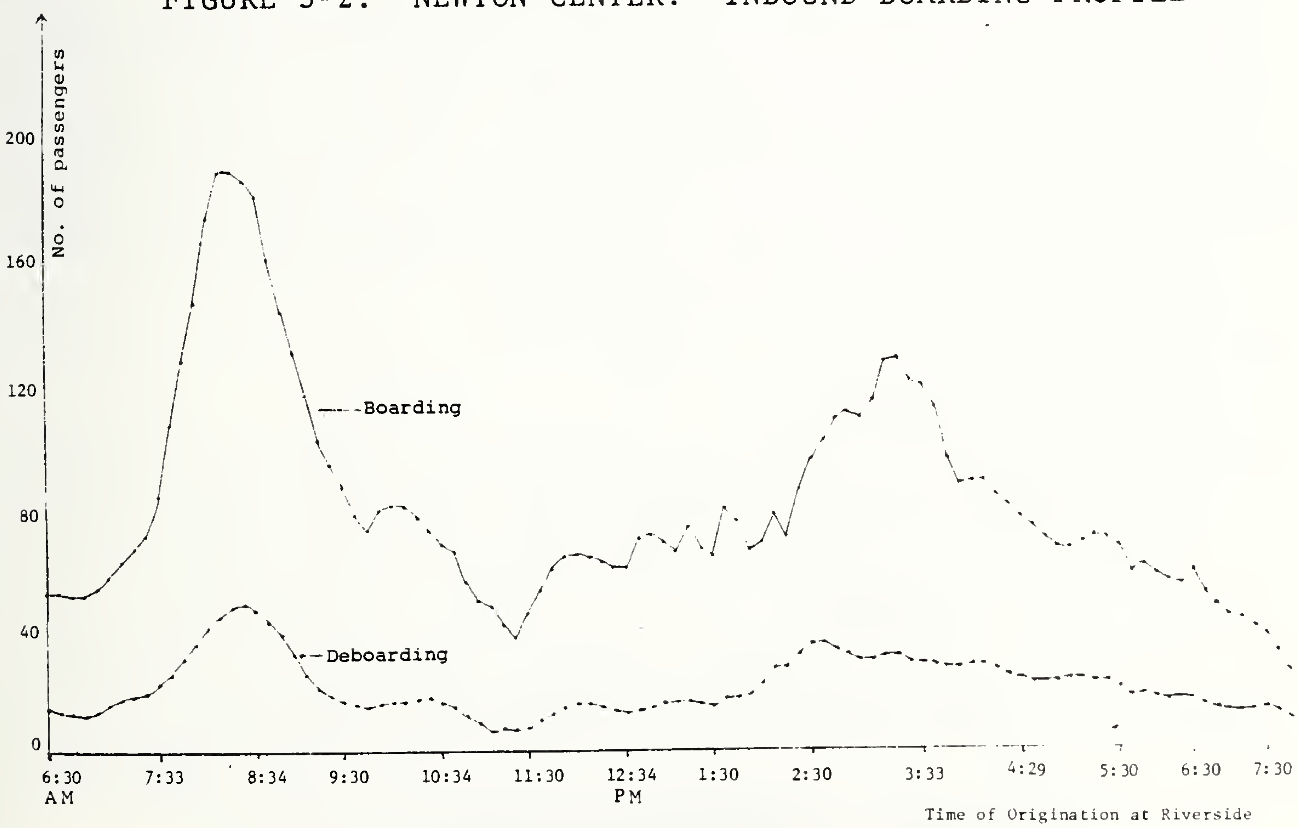


FIGURE 3-3. INBOUND SMOOTHED SERIES, 1977
(smoothed over a length of 5)

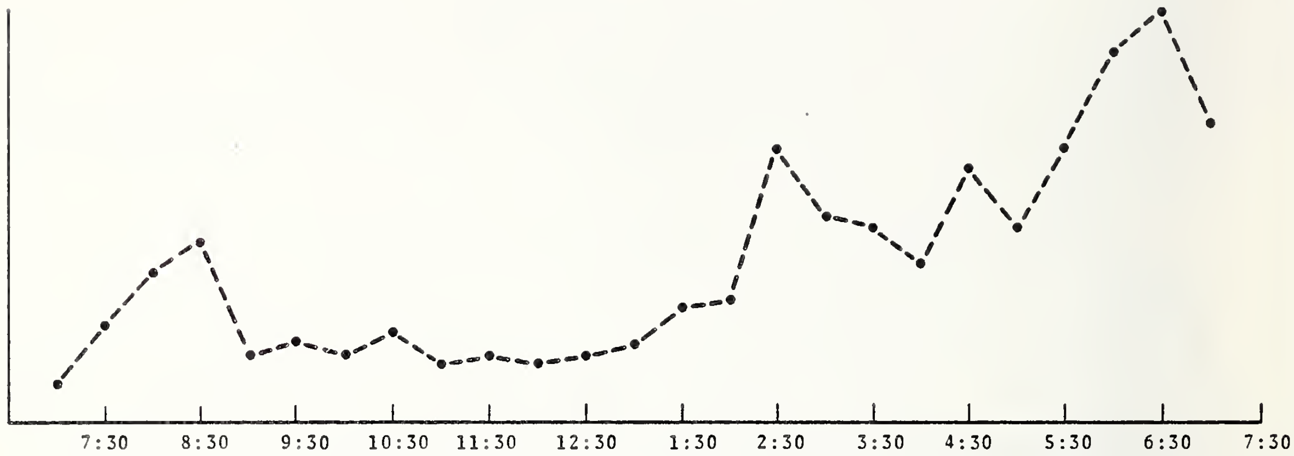


FIGURE 3-4. NEWTON CENTER: OUTBOUND DEBOARDING PROFILE, 1979

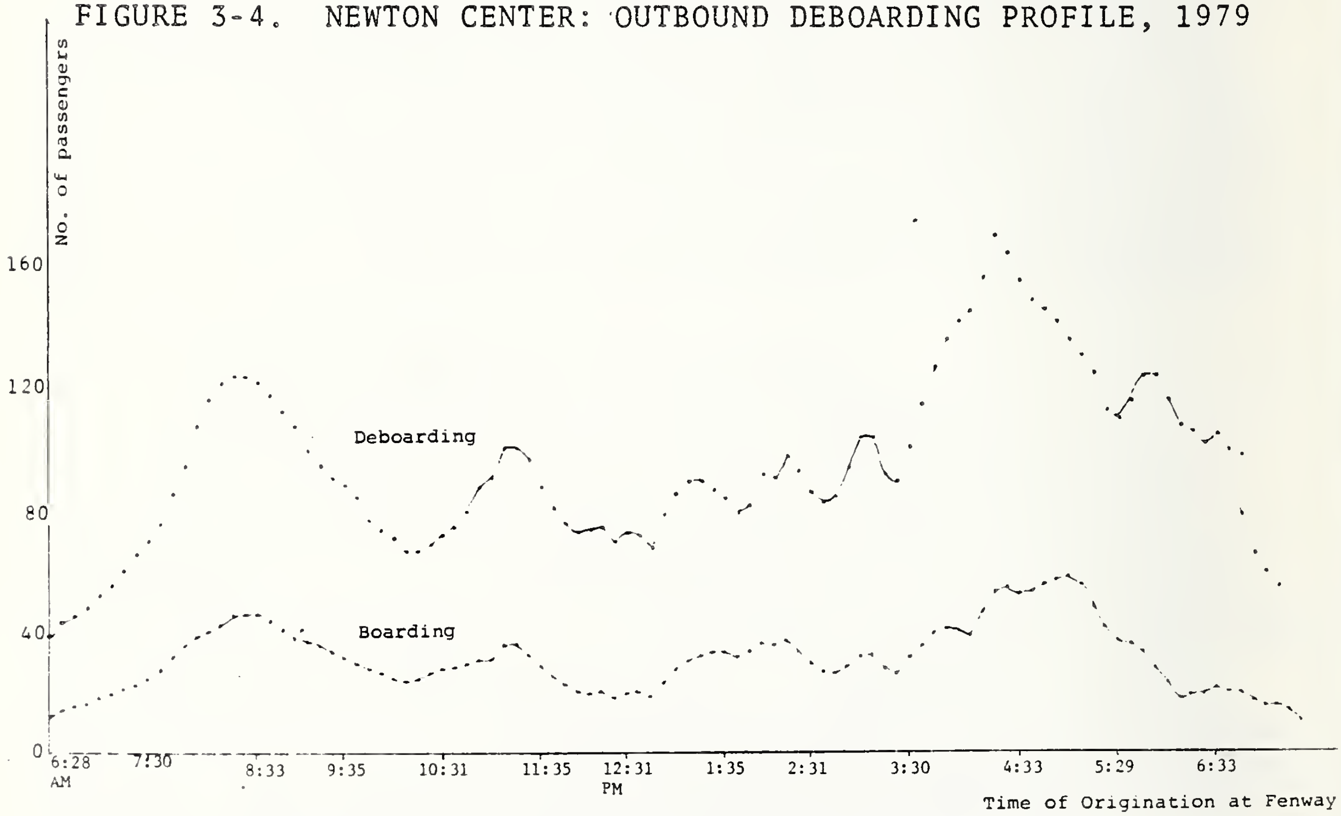


FIGURE 3-5. OUTBOUND SMOOTHED SERIES, 1977
(smoothed over a length of 11)

transformation of data may have caused some estimation bias. Figure 3-6 graphically compares the 1977 and 1979 surface station market shares for inbound trips. Tables 3-9 and 3-10 show the 1977 pooled estimates of market shares for the inbound and outbound trips at the 13 stations. Since the inbound boarding and outbound deboarding patterns are considered to be of more importance in the analysis of passenger activity at the surface stations, only these are portrayed here. Tables 3-11 and 3-12 compare the 1977 and 1979 market shares; they also record the test statistic t_J,

$$t_J = \frac{P_J - M_J}{\sqrt{SE(P_S)^2 + SE(M_J)^2}} \qquad J=1,2,3...13$$

which has a standard normal distribution. At a significant level of 0.5, the difference between P_J and M_J will be considered significant should $|t_J| > 1.96$.

In both tables, only Longwood is shown to have two significantly different estimates of market shares in the two surveys. We may place this single difference in proper perspective by considering the following. If all 13 purported differences are in fact zero, and each is tested at a 5 percent level of significance, then the average number of "false significances" should be

$$\leq (S) = \sum_{i=1}^{13} .05 = .65$$

Our null hypothesis is that the sets of M_J are no different from the sets of P_J, but our test results indicate one station out of 13 for which they <u>are</u> significantly different.

Can we assume that in fact it is very probable for this single significant case to have occured by chance? Under this assumption, the observed cases significant, S, is roughly Poisson. One can show that

$$\sqrt{4S+2} - \sqrt{4E(S)+1} \sim N(0,1).$$

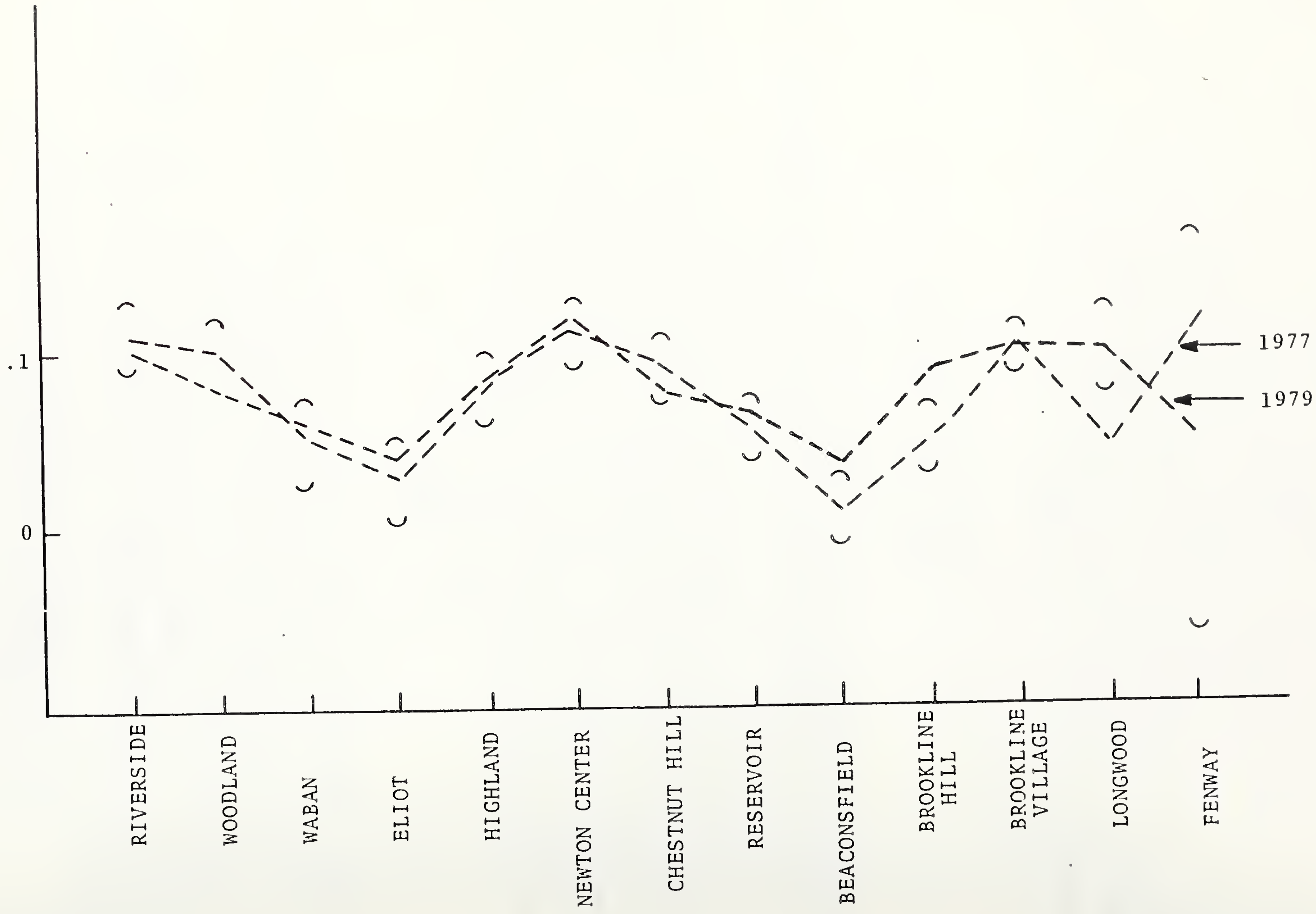


FIGURE 3-6. COMPARISON OF THE 1977 AND 1979 STATION MARKET SHARES (INBOUND TRIPS)

TABLE 3-9. 1977 MARKET SHARES OF INBOUND BOARDING PASSENGERS

STATION J	MORNING TRIPS	AFTERNOON TRIPS	P_J POOLED ESTIMATE	$SE(P_J)$* STANDARD ERRORS
Riverside	.119	.088	.1027	.0178
Woodland	.086	.070	.0778	.0156
Waban	.066	.052	.0590	.0137
Eliot	.052	.034	.0428	.0118
Highland	.104	.069	.0855	.0164
Newton Center	.115	.118	.1163	.0188
Chestnut Hill	.061	.088	.0753	.0154
Reservoir	.058	.067	.0624	.0142
Beaconsfield	.040	.029	.0342	.0106
Brookline Hill	.092	.080	.0855	.0164
Brookline Village	.104	.095	.0992	.0175
Longwood	.036	.052	.0445	.0121
Fenway	.066	.158	.1146	.0187
	1.000	1.000	1.000	
Number of passengers in sample	N_1=556	N_2=613	$N=N_1+N_2=1169$	

$$*SE(P_J) = \sqrt{P_J q_J \left(\frac{1}{N_1} + \frac{1}{N_2}\right)}$$

$$q_J = 1-P_J$$

TABLE 3-10. 1977 MARKET SHARES OF OUTBOUND DEBOARDING PASSENGERS

STATION J	MORNING TRIPS	AFTERNOON TRIPS	P_J POOLED ESTIMATE	$SE(P_J)$ STANDARD ERRORS
Riverside	.104	.106	.105	.0178
Woodland	.095	.093	.094	.0170
Waban	.054	.055	.055	.0133
Eliot	.026	.047	.040	.0114
Highland	.067	.095	.085	.0162
Newton Center	.139	.119	.116	.0186
Chestnut Hill	.082	.073	.077	.0155
Reservoir	.039	.076	.062	.0140
Beaconsfield	.019	.040	.033	.0104
Brookline Hill	.076	.069	.072	.0150
Brookline Village	.093	.099	.097	.0172
Longwood	.059	.040	.047	.0123
Fenway	.145	.088	.108	.0181
	1.000	1.000	1.000	
Number of passengers in sample	$N_1=461$	$N_2=821$	$N=N_1+N_2=1282$	

$$SE(P_J) = \sqrt{P_J q_J \left(\frac{1}{N_1}+\frac{1}{N_2}\right)}$$

$$q_J = 1-P_J$$

TABLE 3-11. COMPARISON OF MARKET SHARES OF INBOUND BOARDING PASSENGERS

STATION J	1977 P_S	$SE(P_J)$	1979 M_J	$SE(M_J)$	T Statistics
Riverside	.1027	.0178	.1110	.0095	- .411
Woodland	.0778	.0156	.1019	.0095	-1.319
Waban	.0590	.0137	.0528	.0106	.358
Eliot	.0428	.0118	.0291	.0119	.817
Highland	.0855	.0164	.0833	.0098	.115
Newton Center	.1163	.0188	.1113	.0090	.240
Chestnut Hill	.0753	.0154	.0928	.0102	- .947
Reservoir	.0624	.0142	.0551	.0091	.433
Beaconsfield	.0342	.0106	.0092	.0106	1.668
Brookline Hill	.0855	.0164	.0480	.0112	1.888
Brookline Village	.0992	.0175	.1034	.0092	- .212
Longwood	.0445	.0121	.0973	.0117	-3.137*
Fenway	.1146	.0187	.0492	.0573	1.085
	1.000				

$$T = \frac{|P_J - M_J|}{\sqrt{SE^2(P_J) + SE^2(M_J)}} \sim N(0,1)$$

*Indicates that the difference is significant at a 95% confidence level.

TABLE 3-12. COMPARISON OF MARKET SHARES OF OUTBOUND DEBOARDING PASSENGERS

STATION J	1977 P_J	EST. $SE(P_J)$	1979 M_J (1979 SURVEY)	EST. $SE(M_J)$	T STATISTICS
Riverside	.105	.0178	.098	.014	.309
Woodland	.094	.0170	.093	.016	.043
Waban	.055	.0133	.016	.015	1.95
Eliot	.040	.0114	.008	.017	1.85
Highland	.085	.0162	.093	.013	- .385
Newton Center	.116	.0186	.110	.016	.244
Chestnut Hill	.077	.0155	.103	.016	-1.167
Reservoir	.062	.0140	.093	.016	-1.458
Beaconsfield	.033	.0104	.046	.017	- .652
Brookline Hill	.072	.0150	.064	.016	.365
Brookline Village	.097	.0172	.103	.013	- .278
Longwood	.047	.0123	.091	.014	-2.36*
Fenway	.108	.0181	.072	.053	.643
	1.000		1.000		

$$T = \frac{|P_J - M_J|}{\sqrt{SE(P_J)^2 + SE(M_J)^2}} \sim N(0,1)$$

*Indicates that the difference is significant at a 95% confidence level.

Thus, in the current study,

$$\sqrt{4(1)+2} - \sqrt{4(.65)+1} = .55,$$

which is not significant for a standard normal deviate, indicating that the assumption cannot be rejected. Notwithstanding the lack of rigorous proof, we shall be content that the "multiple determination" technique has not detected a significant difference in the two sets of parameters (i.e. market shares).

3.3. CONCLUSION

So far, in the validation process of the 1977 surface station passenger flow estimates, the 1979 survey and analyses have not proved anything contradictory to previous results. The patterns of flow for the inbound and outbound passengers are compatible; the volume or the level of demand remain unchanged; and the estimates of market shares exhibit little deviation from the past. However, the "success" of the validation should not overshadow the need for a cautious approach in accepting the reliability of the 1979 survey data. The following have to be considered:

- o Tremendous data variation has prohibited the confirmation of an increase in level of passenger demand.
- o Regression results for the surface stations are, after all, not as favorable as those for the underground stations. We expected the contrary since the former are more homogeneous in nature (all servicing residential districts).

4. VALIDATION FOR UNDERGROUND STATIONS

The validation process for the underground station passenger flows proves to be somewhat dubious in its outcome. At the outset the trend at each station is often over shadowed by the tremendous fluctuations in the individual observed passenger count at any instantaneous moment. Tables 4-1 through 4-4 document the 1979 survey data for underground stations. When the 1978 estimated trends are compared with some of these individual observations taken in 1979, a wide margin of error has to be admitted. This margin of error includes not only the sampling error of the estimated trend, but also the intrinsic variability of one real life observation to another. In fact, the latter component has become so excessive that the acceptance range for a null hypothesis that the 1979 data are essentially similar in distribution to the 1978 estimated profile is deemed unmeaningful. At a 95 percent confidence level, the test does not show any significance.

Another popular test for the goodness of fit of the data is the chi-square goodness of fit test, which posits that if the chi-square statistic,

$$\chi^2 = \sum_{i=1}^{n} \frac{(f_i - e_i)^2}{e_i^{\;2}}$$

where f_i is the ith observed value and
e_1 is the corresponding expected value

is too large (when compared with a theoretical chi-square distribution), the comparability or goodness of fit of the data should be rejected. Again, since the power of this test is sensitive to sample size and scale of the data, a significant test result (meaning a large χ^2) does not preclude the possibility of a good correlation between the two sets of data. The study in consideration is a good example. The chi-square test rejects the fit, while the multiple t tests using confidence intervals as described in the paragraph above results in the opposite.

TABLE 4-1. UNDERGROUND STATIONS - 1979 SURVEY DATA: BOARDING PASSENGERS PER MINUTE (LECHMERE TO RIVERSIDE)

Time	Kenmore	Audito-rium	Copley	Arling-ton	Boylston	Park	Govern-ment Center	Hay-market	North Station	Science Park	Lechmere
730	0.55	1.40	0.00	0.88	0.00	5.68	0.00	0.00	0.00	0.00	6.50
800	1.27	2.63	0.00	2.71	0.40	11.50	0.00	4.31	0.00	0.00	6.25
830	0.76	0.83	0.00	2.74	0.19	6.56	0.00	3.34	0.00	0.00	6.19
900	1.33	0.87	0.00	1.61	0.14	7.73	0.00	5.57	0.00	0.00	3.71
930	0.26	0.83	0.00	0.65	0.28	2.09	0.00	0.88	0.00	0.00	2.58
1000	0.81	0.55	0.00	0.95	0.40	2.79	0.00	2.57	0.00	0.00	6.80
1030	0.00	0.00	0.63	0.00	0.00	4.80	4.58	0.00	1.55	0.20	3.66
1100	0.00	0.00	0.26	0.00	0.00	5.33	1.04	2.38	2.17	0.40	5.10
1130	0.00	0.00	1.35	0.00	0.00	4.87	4.16	0.32	1.13	0.11	1.93
1200	0.00	0.00	0.83	0.00	0.00	4.67	2.29	1.88	2.22	0.15	5.06
1230	0.00	0.00	2.56	0.00	0.00	5.88	3.67	1.58	1.31	0.27	2.91
1300	0.00	0.00	1.37	0.00	0.00	3.04	0.00	1.81	1.63	0.34	4.30
1330	0.00	0.40	2.13	3.67	0.00	0.00	1.82	0.00	0.00	0.83	0.00
1400	0.00	0.45	2.18	2.69	0.00	0.00	3.26	0.00	0.00	0.91	0.00
1430	0.00	0.93	3.10	2.73	0.00	0.00	4.00	0.00	0.00	0.24	0.00
1500	0.00	0.53	4.57	5.13	0.00	0.00	2.47	0.00	0.00	0.61	0.00
1530	0.00	1.40	3.64	2.00	0.00	0.00	6.79	0.00	0.00	0.03	0.00
1600	0.00	2.00	3.83	1.79	0.00	0.00	0.00	0.00	0.00	1.86	0.00
1630	0.00	1.17	2.88	8.92	0.00	0.00	0.00	0.00	4.44	0.21	1.70
1700	0.00	1.74	1.76	2.03	0.00	0.00	0.00	0.00	3.62	0.57	0.64
1730	0.00	3.23	1.21	3.00	0.00	0.00	0.00	0.00	3.36	1.20	3.21
1800	0.00	2.14	2.45	1.47	0.00	0.00	0.00	0.00	0.71	0.26	1.39
1830	0.00	1.36	1.56	4.45	0.00	0.00	0.00	0.00	1.89	0.60	4.79
1900	0.00	1.33	1.57	0.70	0.00	0.00	0.00	0.00	2.55	0.63	1.81
2000	0.00	0.00	0.00	0.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 4-2. UNDERGROUND STATIONS - 1979 SURVEY DATA: DEBOARDING PASSENGERS PER MINUTE (LECHMERE TO RIVERSIDE)

Time	Kenmore	Audito-rium	Copley	Arling-ton	Boylston	Park	Govern-ment Center	Hay-market	North Station	Science Park
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
730	3.14	0.84	0.00	4.48	0.00	2.21	0.00	0.00	0.00	0.00
800	0.80	2.25	0.00	9.65	0.85	3.05	0.00	1.07	0.00	0.00
830	4.55	2.03	0.00	8.74	0.51	2.00	0.00	0.00	0.00	0.00
900	4.54	1.61	0.00	7.86	1.39	4.33	0.00	0.00	0.00	0.00
930	1.81	0.96	0.00	5.43	0.78	0.65	0.00	0.00	0.00	0.00
1000	0.85	1.12	0.00	2.53	0.63	2.00	0.00	0.00	0.00	0.00
1030	0.00	0.00	3.83	0.00	0.00	4.96	0.29	0.00	0.00	2.00
1100	0.00	0.00	1.10	0.00	0.00	4.23	0.29	0.23	0.00	0.10
1130	0.00	0.00	2.13	0.00	0.00	1.90	0.29	0.05	0.00	0.00
1200	0.00	0.00	3.83	0.00	0.00	2.37	0.36	0.06	0.00	0.09
1230	0.00	0.00	1.83	0.00	0.00	3.48	0.41	0.04	0.00	0.00
1300	0.00	0.00	5.17	0.00	0.00	0.93	0.00	0.00	0.00	0.10
1330	0.00	1.10	3.63	3.00	0.00	0.00	0.43	0.00	0.00	0.53
1400	0.00	1.42	1.62	0.88	0.00	0.00	0.55	0.00	0.00	0.16
1430	0.00	1.43	1.57	0.00	0.00	0.00	0.30	0.00	0.00	0.04
1500	0.00	3.80	8.03	1.92	0.00	0.00	0.80	0.00	0.00	0.04
1530	0.00	1.23	4.28	1.37	0.00	0.00	0.63	0.00	0.00	0.00
1600	0.00	2.26	4.21	1.29	0.00	0.00	0.00	0.00	0.00	0.14
1630	0.00	0.63	1.94	4.67	0.00	0.00	0.00	0.00	0.44	0.00
1700	0.00	3.22	2.76	1.10	0.00	0.00	0.00	0.00	0.48	0.21
1730	0.00	2.92	1.36	1.20	0.00	0.00	0.00	0.00	0.51	0.08
1800	0.00	5.03	1.75	1.10	0.00	0.00	0.00	0.00	0.19	0.21
1830	0.00	1.79	2.33	0.83	0.00	0.00	0.00	0.00	0.09	0.80
1900	0.00	2.86	1.16	1.07	0.00	0.00	0.00	0.00	0.21	0.05

TABLE 4-3. UNDERGROUND STATIONS - 1979 SURVEY DATA: BOARDING PASSENGERS PER MINUTE (RIVERSIDE TO LECHMERE)

Time	Kenmore	Auditorium	Copley	Arlington	Boylston	Park	Government Center	Haymarket	North Station	Science Park
700	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
730	2.33	1.03	0.00	0.00	0.30	0.00	0.33	0.00	0.00	0.00
800	2.29	1.20	0.00	0.00	0.58	0.00	0.19	0.14	0.00	0.00
830	4.85	3.50	0.00	0.00	0.12	0.00	0.33	0.13	0.00	0.00
900	5.87	3.26	0.00	0.00	0.45	0.00	1.21	0.10	0.00	1.65
930	4.55	1.68	0.00	0.00	0.29	0.00	1.23	0.00	0.00	2.90
1000	1.34	1.46	0.00	0.00	0.23	0.00	0.20	0.24	0.00	0.00
1030	0.00	0.00	0.00	0.00	0.00	3.00	0.00	0.53	0.00	0.00
1100	0.00	0.00	0.00	0.00	0.00	5.55	0.00	0.12	0.00	0.00
1130	0.00	0.00	0.00	0.00	0.00	1.71	0.00	0.70	0.00	0.00
1200	0.00	0.00	0.00	0.00	0.00	4.77	0.00	0.55	0.00	0.00
1230	0.00	0.00	0.00	0.00	0.00	6.33	0.00	0.00	0.00	0.00
1300	0.00	0.00	0.00	0.00	0.00	10.84	0.00	0.04	0.00	0.00
1330	0.00	0.00	0.00	0.97	0.65	13.74	0.69	0.00	0.00	0.00
1400	0.00	0.00	0.00	2.00	1.09	4.09	1.17	0.00	0.00	0.00
1430	0.00	0.00	0.00	1.29	0.25	12.60	0.38	0.00	0.00	0.00
1500	0.00	0.00	0.00	1.32	0.30	4.54	0.20	0.00	0.00	0.00
1530	0.00	0.00	0.00	0.53	0.15	8.73	0.46	0.00	0.00	0.00
1600	0.00	0.00	0.00	1.77	0.46	8.24	0.44	0.00	0.00	0.00
1630	0.00	0.00	3.21	7.82	0.00	0.00	0.00	0.00	0.00	0.00
1700	0.00	0.94	12.57	4.10	0.00	0.00	0.00	0.00	0.00	0.00
1730	0.00	1.18	7.17	2.78	0.00	0.00	0.00	0.00	0.00	0.00
1800	0.00	2.53	3.10	8.00	0.00	0.00	0.00	0.00	0.00	0.00
1830	0.00	0.40	3.41	2.50	0.00	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.56	1.03	0.53	0.00	0.00	0.00	0.00	0.00	0.00

TABLE 4-4. UNDERGROUND STATIONS - 1979 SURVEY DATA: DEBOARDING PASSENGERS PER MINUTE (RIVERSIDE TO LECHMERE)

Time	Kenmore	Auditorium	Copley	Arlington	Boylston	Park	Government Center	Haymarket	North Station
700	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00
730	0.33	0.80	0.00	0.00	0.96	0.00	8.67	0.33	0.00
800	0.57	1.67	0.00	0.00	2.05	0.00	2.03	1.18	0.00
830	0.88	2.05	0.00	0.00	1.91	0.00	9.47	1.42	0.00
900	1.23	2.19	0.00	0.00	2.26	0.00	8.71	1.40	0.00
930	1.05	1.30	0.00	0.00	2.68	0.00	11.71	1.11	0.00
1000	0.45	1.15	0.00	0.00	1.23	0.00	7.72	1.43	0.00
1030	0.00	0.00	0.00	0.00	0.00	8.29	0.00	6.80	1.00
1100	0.00	0.00	0.00	0.00	0.00	10.03	0.00	1.12	0.59
1130	0.00	0.00	0.00	0.00	0.00	9.00	0.00	2.90	2.22
1200	0.00	0.00	0.00	0.00	0.00	12.05	0.00	4.13	1.06
1230	0.00	0.00	0.00	0.00	0.00	16.38	0.00	3.90	1.59
1300	0.00	0.00	0.00	0.00	0.00	3.78	0.00	2.15	2.06
1330	0.00	0.00	0.00	0.47	1.12	14.26	7.59	0.00	0.00
1400	0.00	0.00	0.00	1.00	0.40	6.91	8.04	0.00	0.00
1430	0.00	0.00	0.00	0.83	0.30	9.60	3.24	0.00	0.00
1500	0.00	0.00	0.00	1.74	1.60	6.75	1.63	0.00	0.00
1530	0.00	0.00	0.00	0.77	0.52	20.73	4.62	0.00	0.00
1600	0.00	0.00	0.00	0.66	0.43	13.06	9.32	0.00	0.00
1630	0.00	0.00	2.03	9.73	0.00	0.00	0.00	0.00	0.00
1700	0.00	0.35	3.07	2.05	0.00	0.00	0.00	0.00	0.00
1730	0.00	1.04	3.07	1.03	0.00	0.00	0.00	0.00	0.00
1800	0.00	0.65	2.53	6.05	0.00	0.00	0.00	0.00	0.00
1830	0.00	0.70	1.55	1.32	0.00	0.00	0.00	0.00	0.00
1900	0.00	0.36	0.90	0.63	0.00	0.00	0.00	0.00	0.00

Our last resort, therefore, is not to compare the trend with the 1979 observed data, but rather to compare the 1978 data series (from which the trend was derived) with the 1979 data series after the trend is taken out from both. The comparisons will be with respect to:

- o the normality of the two series of residuals,
- o the similarity of locations and variances if the assumption of normality is verified.

Figure 4-1 presents four histograms of the distribution of the detrended inbound-outbound boarding-deboarding passenger flow rates. Our first step is to test the normality of the eight distributions. A cursory glace at these histograms may or may not convince us of the strength of our hypothesis. Normality probability plots are made so that normality is accepted if the plot shows an approximately straight line and rejected if it curves substantially. Still, if visual examination does not give enough credence to the conclusions, formal tests based on these plots follow.

Verifying the similarity of locations and variances is straight forward once the two samples are accepted as independent coming from a normal population. Table 4-5 depicts the relevant statistics for each sample.

Two conclusions can be gathered from the test results above. First, the residuals are normally distributed and the variances of the residual distribution have proved to be similar for the two years. That is, the amount and pattern of fluctuation of the passenger flow for 1979 is no different from that of the year before. Second, the testing of the equality of the residual averages reveals a significant difference in the levels for boarding flows in both directions. For these two flows, the 1979 distributions of $(R_{79}-\hat{R}_{78})$ have a positive expectation (see Figure 4-1) depicting a definite increase in the level of passenger demand in 1979 over 1978. That the increase has not become obvious for the deboarding flow may be due to the tendency of the surveyors to concentrate on boarding rather than deboarding counts. The magnitude of increase, as seen from the new mean of $(R_{79}-\hat{R}_{78})$, is at least 25 percent.

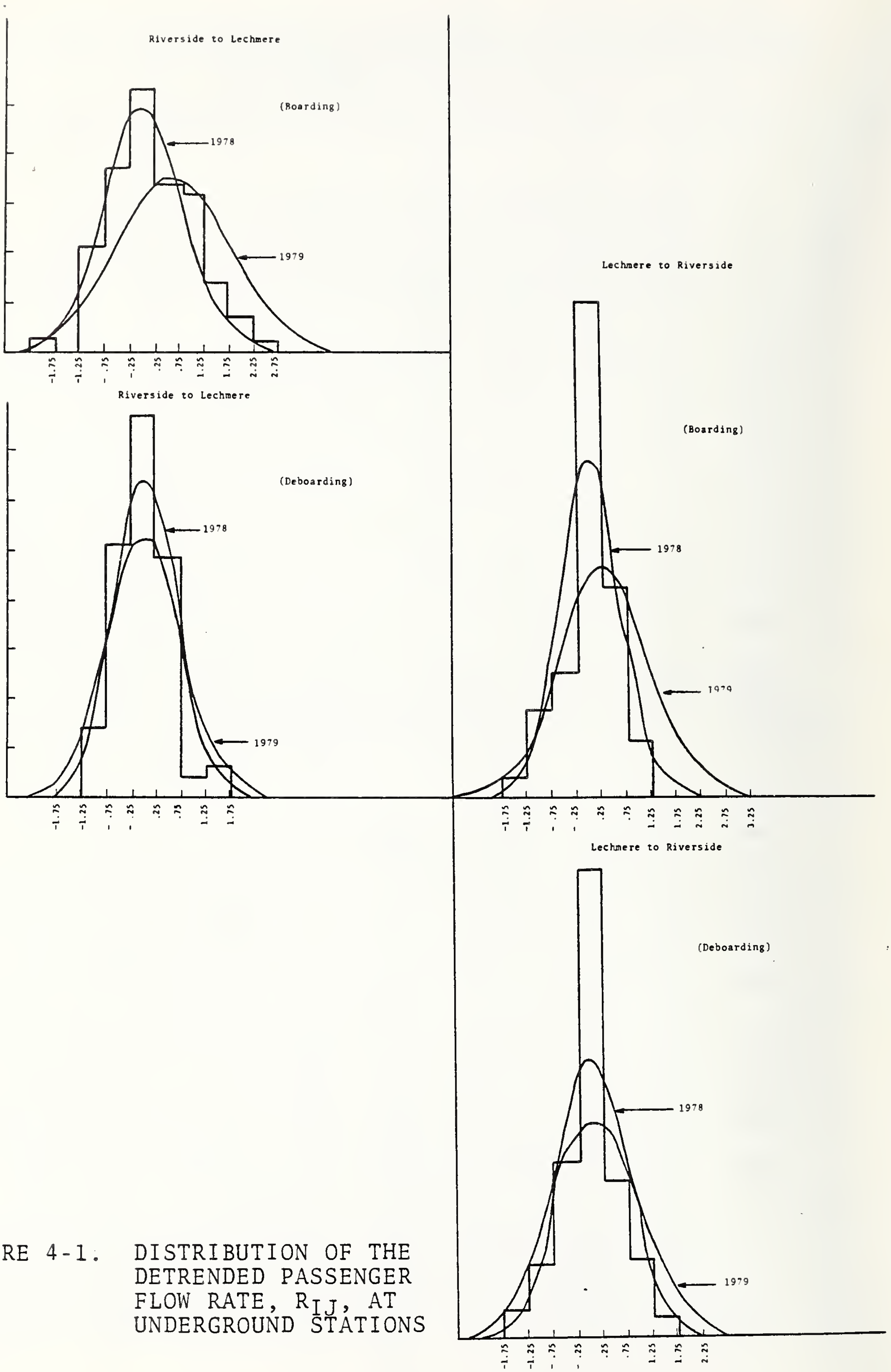


FIGURE 4-1. DISTRIBUTION OF THE DETRENDED PASSENGER FLOW RATE, R_{IJ}, AT UNDERGROUND STATIONS

TABLE 4-5. RESIDUALS DEFINED AS $R-\hat{R}$ = (OBSERVED - ESTIMATED)

	RIVERSIDE TO LECHMERE				LECHMERE TO RIVERSIDE			
	BOARDING		DEBOARDING		BOARDING		DEBOARDING	
	1978	1979	1978	1979	1978	1979	1978	1979
Mean of residuals	.00	.25	.00	-.05	.00	.60	.00	.03
Variance of Residuals	.34	.72	.47	.79	.63	1.28	.38	.55
Degrees of freedom	85	137	65	91	66	73	76	86
1 At a 5% significant level, test for equality of variances								
Calculated F Statistics	.34/.72 = .47		.47/.79 = .59		.63/1.28 = .49		.38/.55 = .69	
Compared with	F(.975,85,137) >1.22		F(.975,65,91) >1.35		F(.975,66,73) >1.47		F(.975,76,86) >1.35	
Conclusion:	Accept		Accept		Accept		Accept	
Pooled variance	.57		.66		.97		.47	
2 At a 5% significant level, test for equality of means.								
Calculated t Statistics:	5.0		.71		7.50		.60	
Compared with	1.96		1.96		1.96		1.96	
Conclusion:	Reject		Accept		Reject		Accept	

A plot of the 1979 observed rates and the 1978 predicted rates shows a significant correlation between the two. The interest lies in the proportion of variations in the former that the latter group is able to explain. A consistent R^2 of 50-55 percent prevails over all regressions for each direction - boarding or deboarding combination. That is, although $\hat{R}_{78}$, as derived from the statistical model using data from '78, correlates in general with R_{79}, using $\hat{R}_{78}$ to predict passengers flow in '79 is not the most statistically propitious in that the average level of demands differs from year to year and the random fluctuation of the demand over the time periods of the day makes one-to-one comparison difficult. The extensive variability in human behavior (with respect to choice of mode, choice of travel time and choice of route) and the environmental conditions make a moment to momemt prediction of passenger flow rate difficult.

4.1 STATION BY STATION VALIDATION

After a rather cursory overview on the comparability of the 1978 and 1979 predicted and observed data for the underground stations system as a whole, we now turn to the individual stations, examine their market shares and verify that the model (1) gives reasonable estimates for these segments that comprise the entire underground line. A few findings can be summarized as follows:

- Model (1) gives reasonable estimates for stations whose levels of passenger traffic are quite consistent throughout the day (e.g., Park Street, Kenmore, Auditorium, etc.). A particular anomaly is the Arlington Station (business district) which receives an extremely high influx of deboarding passengers during the morning rush hours and of boarding passengers during the afternoon rush hours but maintains a relatively low profile for the rest of the day.
- For those stations which exhibit different traffic patterns from the rest of the system, model (1)'s estimates are less effective than desired. A case in point is the Copley Station whose peak traffic hours occur around noon time or in the early afternoon.

Figures 4-2 through 4-5 represent graphically a sample of the individual station profiles. The correspondence between the 1978 and 1979 passenger flow trends ranges from excellent (Auditorium, Park St.) to poor (Copley, Arlington). This reflects an internal weakness of the model over and above errors incurred either during the data collection phase or at random. The weakness lies in the original assumption that the underground stations are homogeneous in character. Interactions between the station and time period (the two factors in the model) are, therefore, treated as negligible. Even when a modified logarithmic model is employed, the residual effect of the interaction is still significant enough for some stations that ignoring it induces bias in the model estimates. This is serious enough to warrant an a priori warning in the application of this unreplicated, unbalanced linear model to the passenger flow estimation problem: This model should be used only when no significant aberrations in passenger traffic pattern (not level) are suspected among the stations for which an estimated profile is required. The Green Line Riverside Surface Stations are a good example of homogeneity in that all the surface stations are in residential areas, and, with the exception of Fenway, are consistent in their market shares of the level passenger demands.

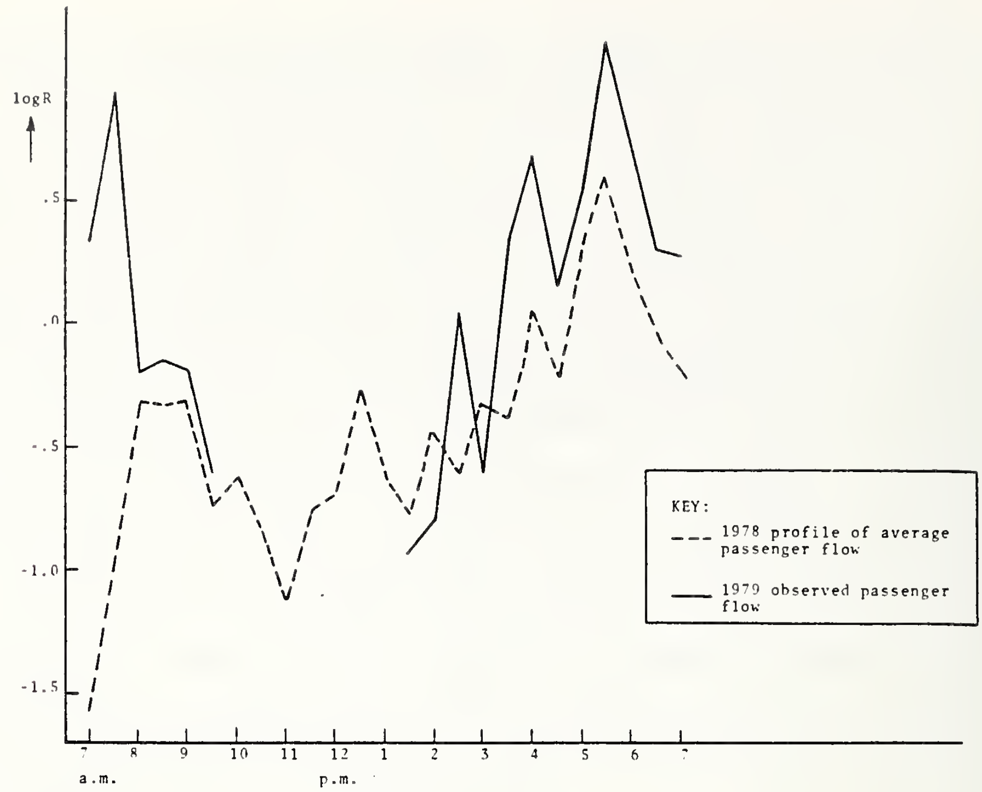


FIGURE 4-2. AUDITORIUM BOARDING PROFILE (TO RIVERSIDE)

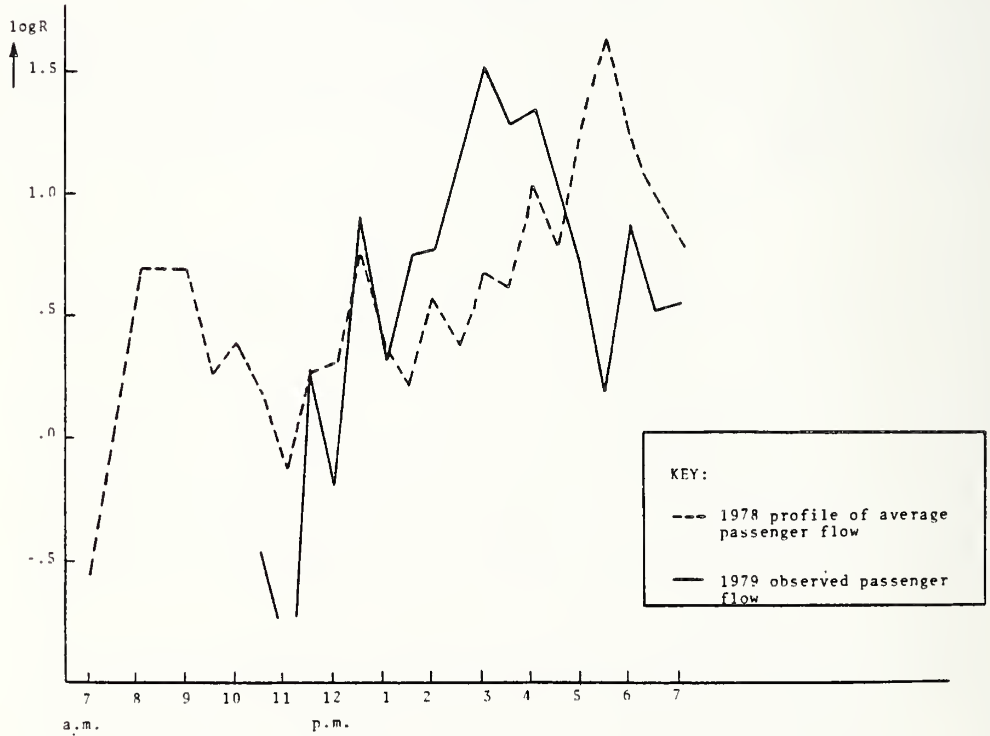


FIGURE 4-3. COPLEY BOARDING PROFILE (TO RIVERSIDE)

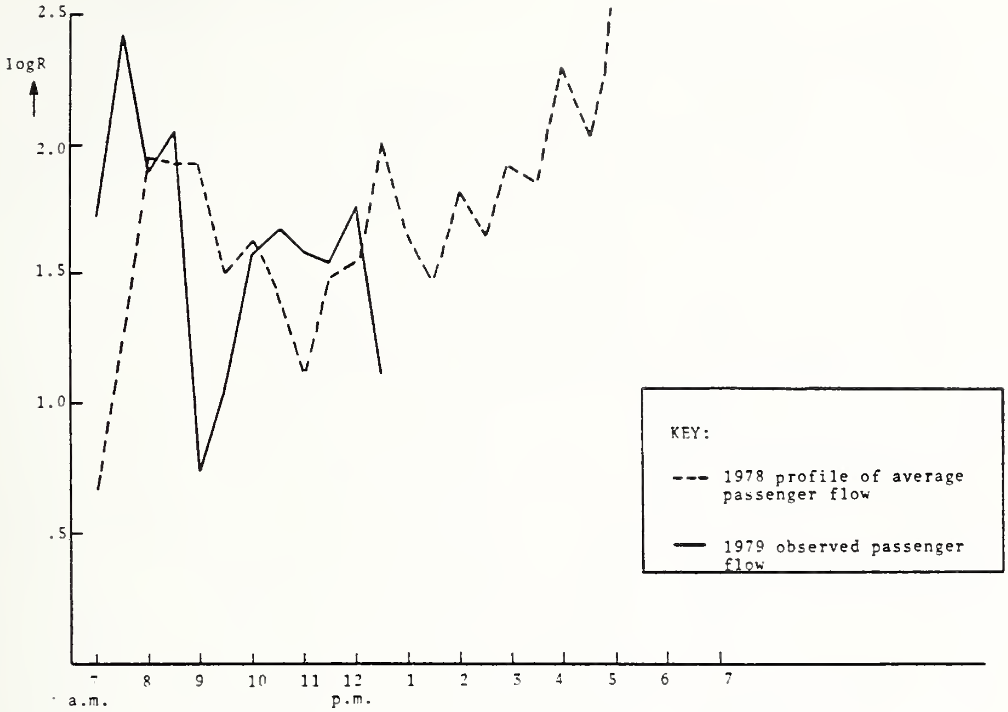


FIGURE 4-4. PARK ST. BOARDING PROFILE (TO RIVERSIDE)

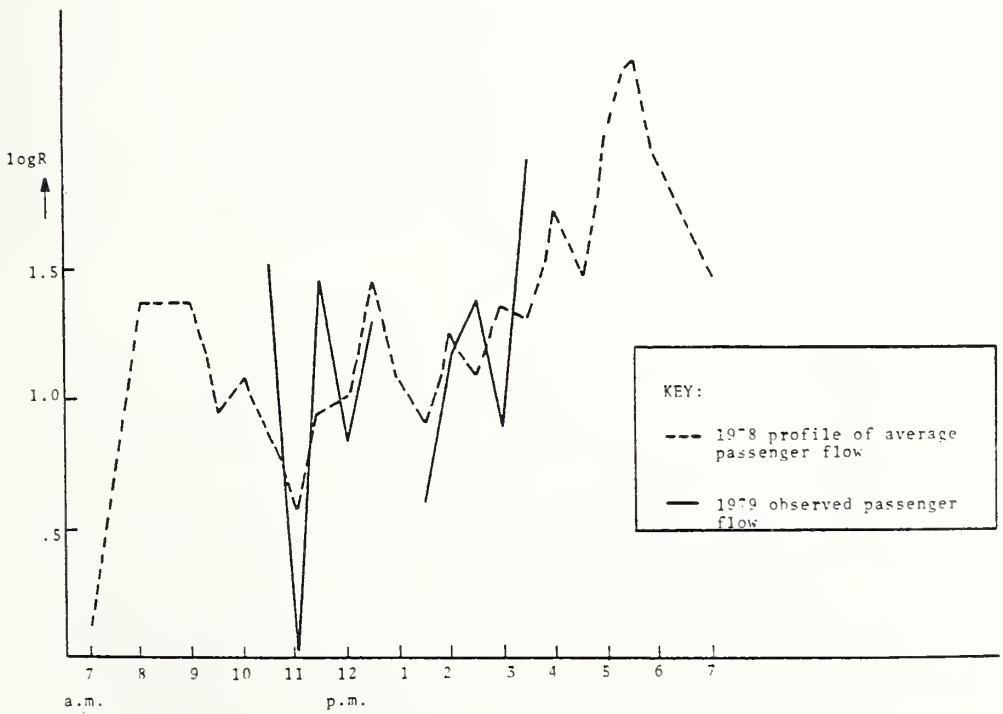


FIGURE 4-5. GOVERNMENT CENTER INBOUND BOARDING PROFILE (TO RIVERSIDE)

5. SUMMARY OF SUFFICIENCY OF METHOD

5.1 UNDERGROUND STATIONS

A major handicap of any ridership survey is the huge intrinsic fluctuation in passenger arrivals, particularly at transfer points where passengers generally arrive in large clusters. Furthermore, in this particular survey, the use of an additive statistical model applied to the heterogeneous underground stations has failed to capture some station specific characteristics or travel patterns. An example is the Copley or Arlington Station where particularly high peaks are exhibited in the early afternoons and late afternoons respectively. The 1978 survey did not consider such anomalies as inherent in the underground station structure, and therefore, missed these time periods for these stations when random selection of schedules was performed. Consequently, the statistical procedure, having utilized the average demand level for Arlington, for instance, and the average demand level for the late afternoon periods to estimate the missing data, underestimates the presence of the statistical interaction between the two effects on demand levels. In spite of the caveats, the 1978 and 1979 passenger profiles compare fairly well with respect to the shape of the distribution over time. An increase of about 25 percent in level is detected, although not substantiated by formal statistical testing.

5.2 SURFACE STATIONS

For the surface stations along the Riverside Line, data deficiencies again have affected the general fitness of the statistical model. Still, the viability of the model with respect to the estimation of passenger flows is attested by comparing 1979 results with those of the 1977 trip survey. The market shares of the stations remain unchanged, as does the daily pattern of passenger activity. Although the estimated total passenger volume indicates an increase in patronage, the exact percentage increase is difficult to ascertain due to the wide margin of error associated with both the 1977 and 1979 estimates.

5.3 GENERAL SUMMARY

The 1979 passenger survey of the MBTA Riverside Line has accomplished two purposes: 1) to validate the estimates derived in 1978 using the statistical modelling approach for the underground stations; 2) to apply similar survey and modelling procedures to the surface stations and to compare results with those of the 1977 trip survey.

Recommendation of the survey scheme and the application of the statistical model is made with caution. It is believed, however, that when applied properly, the methodology is an economical and reliable approach to obtain passenger flow statistics at the stations along a specific route. It relies heavily on a priori knowledge of the route as a whole: where and when passenger traffic is more concentrated and what extraneous factors may distinguish one station from the others at certain times. The selection or sampling of cells in the time period-station matrix is then randomly made according to the weights assigned to each cell based on such knowledge. Special emphasis should be made, during the execution phase of the survey, on the adherence to the survey schedule and counting method (e.g., systematically rotating the selection of doors when counting the entire car is infeasible). When the survey data are ready for analysis, it may be appropriate to incorporate a $time_I$ x $station_J$ variable to account for the interaction between time period I and station J. The ideal situation is one when time and resources allow for the selection of all the cells at least twice. Then a regular two-way replicated model of the Analysis of Variance can be set up to estimate 1) the $time_I$ effect, 2) the $station_J$ effect, and 3) $time_I$ x $station_J$ interaction effect, if any. This, in our present case, for the 13 underground stations and 25 time periods, requires a sample of 650 cells. The sample size for our 1978 underground stations was about 1/6 of the requirement of the "ideal model." In terms of the scope of the present effort, namely, the inbound and outbound, boarding and deboarding daily passenger profiles for each of the stations on the route, and in light of the intrinsic variable nature of passengers' travelling behavior, this study has accomplished what it has set out to do. It develops a survey technique and estimation methodology to estimate route, station and time specific passenger flow profiles within the constraints of the precision and economic requirements.

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