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MBTA PASSENGER DEMAND ANALYSES, 1977

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16. Abstract

A survey was made of the number of passengers using the Highland Branch of the MBTA Green Line. All the old PCC streetcars on that line were to be replaced by new light rail vehicles within the year. Therefore, this count was intended to represent the "before" segment of a before-and-after survey to estimate increase in demand due to the new vehicles. Analysis of the data confirmed a "market share" theory for the stations and suggested that fairly sparse sampling could yield estimates of total passenger movement acceptable at the 90 percent confidence level.

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PREFACE

The present study is performed under Project Plan Agreement UM-37, sponsored by the U.S. Department of Transportation, Urban Mass Transportation Administration, Office of Planning Management and Demonstrations, Office of Transportation Management, UPM-40. It is undertaken for the calibration and the analyses of MBTA passenger data to be used as an input to the main operational performance simulation model being developed under the same PPA. Acknowledgement is given to Mary Roos and George H. Wang of TSC Code 20 for their direction and helpful advice in the study.

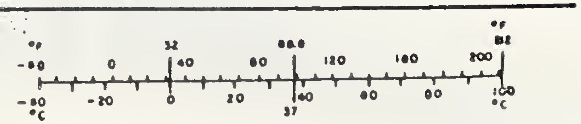
METRIC CONVERSION FACTORS

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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I. INTRODUCTION

This report summarizes findings resulting from a special transit study which included 67 inbound trips (Riverside-Fenway) and 69 outbound trips (Fenway-Riverside) of patronage data collected between May 23 and June 1, 1977. This was about 15% of the trips for that period. The parameters measured during each trip for each of the 13 stations are: the time of arrival, the total boarding passengers, total alighting passengers, and the dwell time with comments on extraneous delay. Subsequently, statistics such as the total movement (= total on + total off), the load of vehicle upon immediate departure from the station, and the total trip time can also be calculated. The 15% sample was collected from over a wide spectrum of time periods and days of the week so that an average profile of ridership and transit operation can be delineated. Also, the reliability of the data thus collected is assessed and discussed with respect to the requirement of the MBTA Green Line operational simulation model being developed under Project Plan Agreement UM-37.

It is assumed throughout the course of analysis that the number of passengers boarding an inbound train (or the number of passengers alighting an outbound train) at a station truly reflects the passenger demand of the system at that station during the period, and is independent of the number of cars associated with that trip. It is of course conceivable that during rush hours, this assumption may be invalid because the volume of patrons boarding a train depends upon the load already carried by the train. However, data on the load factors show that this measure rarely goes beyond "medium" even during rush hours. Hence train capacity (number of cars) is not considered.

A few trips are deleted from the inbound data because they reflected the effects of unusual conditions (scheduled baseball games) which resulted in a large influx of people into Fenway or Kenmore stations. These trips were on 5/31/77 at 4:58pm, 5:42pm, 6:32pm and 6:42pm.

The sample is distributed over time as outlined in Table 1.

TABLE 1. TRIP DISTRIBUTION SAMPLE

Date			Trips Observed	Trips Generated by MBTA over the same period	Sampling Fractions
5/23 Mon	6am-1pm	Inbound	9	57	.16
		Outbound	10	53	.19
5/24 Tues	1pm-8pm	Inbound	10	52	.19
	"	Outbound	9	53	.17
5/25 Wed	6am-1pm	Inbound	8	59	.14
	"	Outbound	8	53	.15
5/26 Thurs	1pm-8pm	Inbound	11	52	.21
	"	Outbound	10	53	.19
5/27 Fri	6am-1pm	Inbound	10	57	.18
	"	Outbound	10	53	.19
5/31 Tues	1pm-8pm	Inbound	11(-4)	52	.21
	"	Outbound	13	53	.25
6/1 Wed	6am-8pm	Inbound	10	107	.09
	"	Outbound	8	106	.08

II. ANALYSIS OF PASSENGER FLOW BY TEMPORAL DIVISION

A. Estimated daily volume of patronage (from the 13 stations)

It was discovered in the early stages of the study by ranking the trips according to their passenger volume, and testing the distribution of the ranks within each day, that the average daily passenger demand does not vary significantly from day to day. Hence all trip data thus collected are treated as if they have come from a single population rather than from five (Mon-Fri) different ones. The matrices in Tables 2.a and 2.b show the results of stratifying the trips by the hours.

Estimated daily inbound volume is:

$$Y = \frac{N \sum N_h \bar{y}_h}{\sum N_h} = 107 \times 81.62 = 8734$$

where N is the total number of inbound trips in one day, (=107) and $\bar{y}_h$ is the average number of trips per day in stratum (hour) h.

The variance of Y is:

$$V(Y) = \frac{N^2 \sum N_h^2 (1 - f_h) \sigma^2_{\bar{y}_h}}{(\sum N_h)^2} = 245{,}380.84$$

standard error = $\sqrt{V(Y)}$ = 495 or 5.7%,

Hence a 95% confidence interval for the actual total inbound volume is $(Y \pm 1.96 * \sqrt{V(Y)})$, which is (7793,9704).

Similarly, from the outbound matrix, estimated daily outbound volume, X, is :

$$X = \frac{N \sum N_h \bar{x}_h}{\sum N_h} = 106 \times 93.33 = 9893$$

where N is the total number of outbound trips from 6:00am to 8:00 pm. In this case, N = 106.

$$V(X) = \frac{N^2 \sum N_h^2 (1 - f_h) \sigma^2_{\bar{x}_h}}{(\sum N_h)^2}$$

Standard error = $\sqrt{V(X)}$ = 558 or 5.8%.

Hence a 95% confidence interval for the actual total outbound volume is $(X \pm 1.96 * \sqrt{V(X)})$, which is (8799,10987).

TABLE 2. AVERAGE PASSENGERS PER TRIP

a. Inbound Boarding

	6-7 am.	7-8	8-9	9-10	10-11	11-12	12-1pm	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Approx. # of trips, N_h, generated during sampling period	32	36	32	28	36	28	32	28	36	32	36	24	24	24
# of trips in sample, n_h	5	3	5	5	5	4	4	5	5	5	3	3	4	8
sampling fraction, n_h/N_h	.16	.08	.16	.18	.14	.14	.13	.18	.14	.16	.08	.13	.17	.33
Avg. total loading passengers per trip, $\bar{y}_h$	44	109	170	84	72	49	74	83	88	107	73	63	61	40
sample variance, σ_{y_h}	13	64	55	19	19	22	23	51	48	46	12	24	21	9
standard error of $\bar{y}_h$, $\sigma_{\bar{y}_h}$	6	37	25	9	9	11	11	23	22	21	7	14	11	3

b. Outbound Deboarding

Time of Day	6-7 am	7-8	8-9	9-10	10-11	11-12	12-1pm	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Approx. # of trips, N_h, generated during sampling period	24	32	36	28	32	28	32	28	32	32	36	32	28	24
# trips in sample, n_h	7	3	4	4	6	3	5	5	4	5	4	5	6	4
sampling fraction, n_h/N_h	.29	.09	.11	.14	.19	.11	.16	.13	.13	.16	.11	.16	.21	.17
Avg. total deboarding passengers per trip, $\bar{x}_h$	42	45	126	106	54	89	72	84	104	117	166	110	87	77
Standard error of $\bar{x}_h$, $\sigma_{\bar{x}_h}$	5	7	17	22	16	27	10	24	35	28	15	24	25	21

B. Time distribution of passenger demand by time of day

Comparing the inbound demand (dominated by boarding passengers) with the outbound demand (dominated by disembarking passengers) shows that one time series is almost the mirror image of the other, except that the latter is more erratic and the demand remains relatively high in the evening hours. This latter fact could explain the difference in the total passenger volume estimated earlier. The 95% confidence intervals around the total inbound and total outbound passenger volume estimates overlap, which indicates that the difference as supported by the data is not necessarily significant. Note also that the afternoon peak for outbound trains (4-5:00pm) occurs one and a half hours later than for inbound trains (2-3:00pm).

Another interesting observation from Tables 2.a and 2.b is the reliability of the estimates for the passenger demand for an average trip. Even though an average demand statistic is obtained for each time period, the variation, σ_{y_h} (or σ_{x_h}) of the individual trip demand around the mean is quite high. In fact, the average variability for any trip, regardless of which time period it falls into, is, for inbound trips,

$$\sigma_y = \sqrt{\frac{\sum(n_h - 1)\,\sigma^2_{y_h}}{(\sum n_h) - 13}} \approx 34$$

and for outbound trips,

$$\sigma_x = \sqrt{\frac{\sum(n_h - 1)\,\sigma^2_{x_h}}{(\sum n_h) - 13}} \approx 44$$

If an estimate is required of a flow rate at a particular time, then a sampling window of 60 minutes or more permits considerable shifting of the mean. The high variability alludes to not only the fluctuating nature of passenger demand, but also the effect which any departure from the train schedule may have on the load factor.

III. SPATIAL DISTRIBUTION OF PASSENGER DEMAND

As reported earlier, marked differences exist in the level of inbound passenger demand among the thirteen surface stations with Newton Center, Riverside, Brookline Village, Fenway, Woodland being the busier stations. This section attempts to quantify the spatial distribution of demand across these stations. The first question is whether such a spatial distribution is similar from hour to hour, so that an overall cross-sectional profile can be obtained for all time periods.

Define $n_j^{(k)}$ = the average number of loading passengers from station j when the trip originates during time period k.

$n^{(k)}$ = total loading passengers from all stations when the trip originates during time period k

$p_j^{(k)} = n_j^{(k)}/n^{(k)}$, station j's share of the trip demand for the time period k.

Our hypothesis is:

$$H_o: p_j^{(1)} = p_j^{(2)} = \ldots\ldots = p_j^{(K)} = p_j \text{ for all } j$$

The χ^2 test of homogeneity is employed, for which the test statistic,

$$D = \Sigma\ \Sigma\ \frac{n^{(k)}[p_j^{(k)} - p_j]^2}{p_j},$$

is calculated for both the morning and afternoon shifts.

Under the hypothesis H_o, D will be distributed as a χ^2 statistic with (13-1)*(K-1) degrees of freedom, where K is the number of hourly periods. Since over 20% of the expected values in the subsequent contingency table (see Appendix 1A) is less than 5, a modified test is used. The details are shown in Appendixes 1, A-E, with the results of the test clearly indicating the acceptance of our hypothesis. Hence, for any inbound or outbound trip, the distribution of demand across the stations is depicted by Figure 1.

A note of interest is that while 77% of the total passengers on an inbound trip go beyond the Fenway Station and into the underground, only an estimated 69% of those on the outbound train originate from the underground stations. Although this difference seems significant, percentages can be misleading since 77% of the inbound passengers is approximately 8734 x .77 = 6725, and 69% of the outbound passengers is 9893 x .69 = 6826. Thus it is reasonable to presume that people using the line to get in town generally get back by the same means.

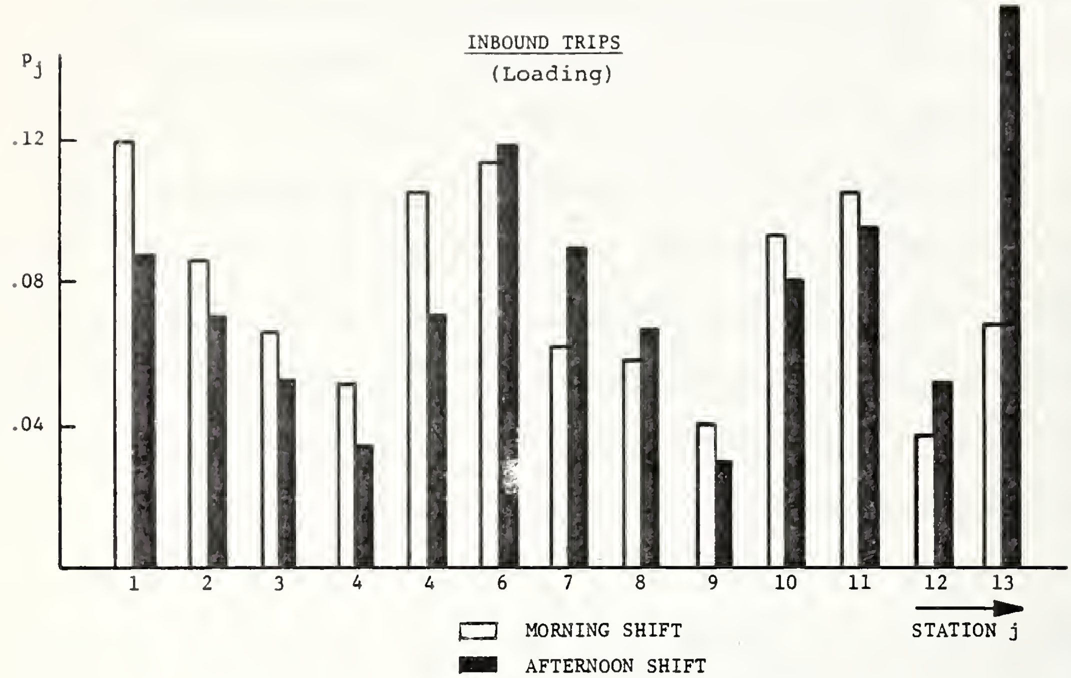


Fig.3.b.

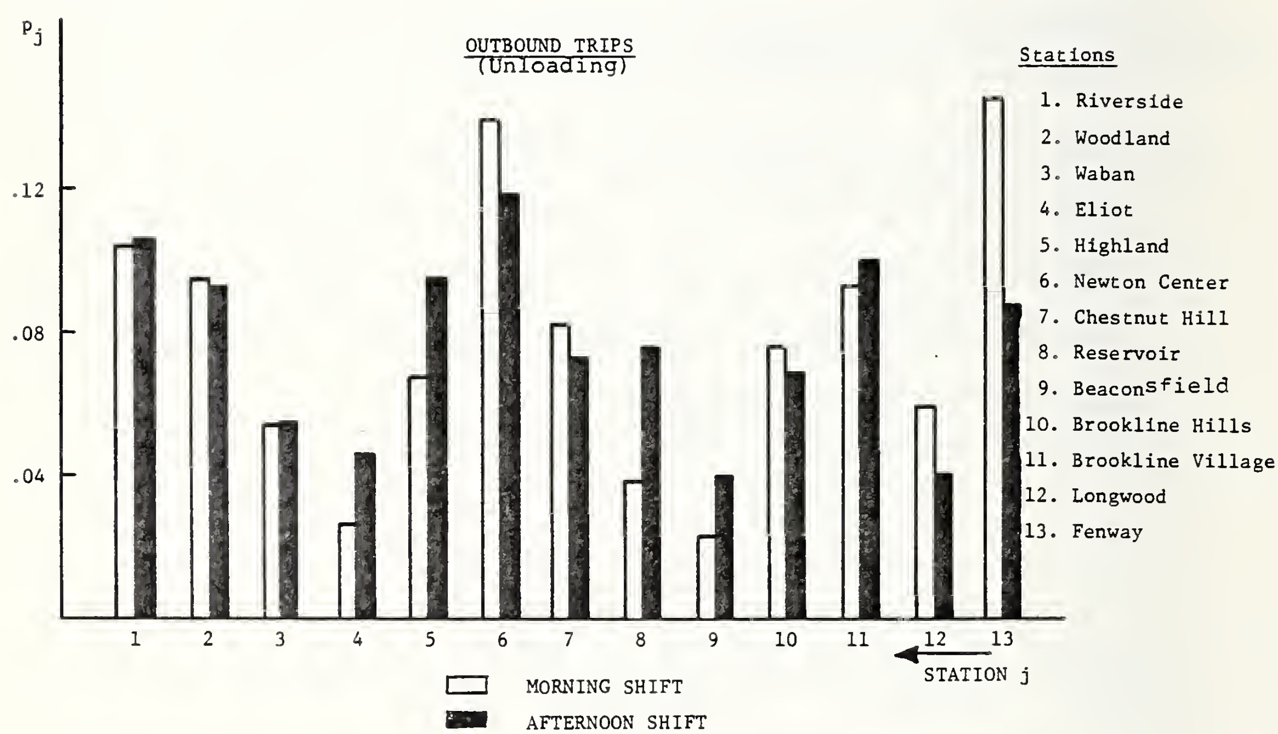


FIGURE 1. DEMAND DISTRIBUTION

IV. GENERATION OF PASSENGER DEMAND

To derive probability distribution functions, $f_{jt}(x)$, for the generation of the number of passengers getting on or off at station j and time t, previous conclusions on constant market shares for the thirteen stations prove to be useful. Suppose a train leaving the originating station at time t has its expected total trip passengers represented by X_t, then the expected number of people getting on this trip from station j is $p_j X_t$. If the probability distribution which generates the total trip demand is a Poisson distribution with paramenter $\lambda_t h$, where h is the arbitrary headway, then $f_{jt}(x)$ is a Poisson distribution with paramenter $p_j \lambda_t h$. The choice of the Poisson distribution follows from the hypothesis that the batch size of passengers arriving at a station within the time interval h has a probability expressed by the Poisson function.[1] $p_j \lambda_t$, then, becomes the rate of arrival at station j when the train leaves the originating station at time t.

It remains to determine the set of values λ_t's. However, the estimation of such paramenters requires repeated sampling at time t, which is not available at present. The next preferable solution is to regard our data series as one analogous to a discrete time series, u_t, t=1,2...,(interpolating

[1]Feller, William, "An Introduction to Probability Theory and Its Applications," p.156-164.

if necessary to estimate the missing u_t's) and fitting a time trend to the series by a simple moving average of certain length, say 2L+1. Then,

$$\hat{u}_t = 1/(2L+1)[u_{t-L}+\ldots+u_{t-1}+u_t+u_{t-1}+\ldots+u_{t+L}]$$

For example, for a length of 5,

$$\hat{u}_t = 1/5[u_{t-2}+u_{t-1}+u_t+u_{t+1}+u_{t+2}]$$

Figures 2 through 5 show the inbound and outbound raw series and the extracted time trends using simple moving averages of length 5 and 11 and data from Tables 3.a and 3.b. It is worthy to note that these smoothed series are by no means a differentiable function of time, so that they cannot be modeled by any deterministic function such as a polynomial of a high order.

Having derived a smoothed series $\hat{u}_t$, t=1,2,.., the λ_t's are obtained by simply dividing $\hat{u}_t$ by Δt, where Δt is the time elapsed between trip t-1 and t. Table 4 shows the actual schedule of the inbound trips, together with the time of arrival at each station along the line. Note also that while Δt denotes the time in minutes, the subscript t represents the trip number, which in turn can be translated into time using Table 4. Figure 6 clarifies the application of λ_t in the Poisson probability density.

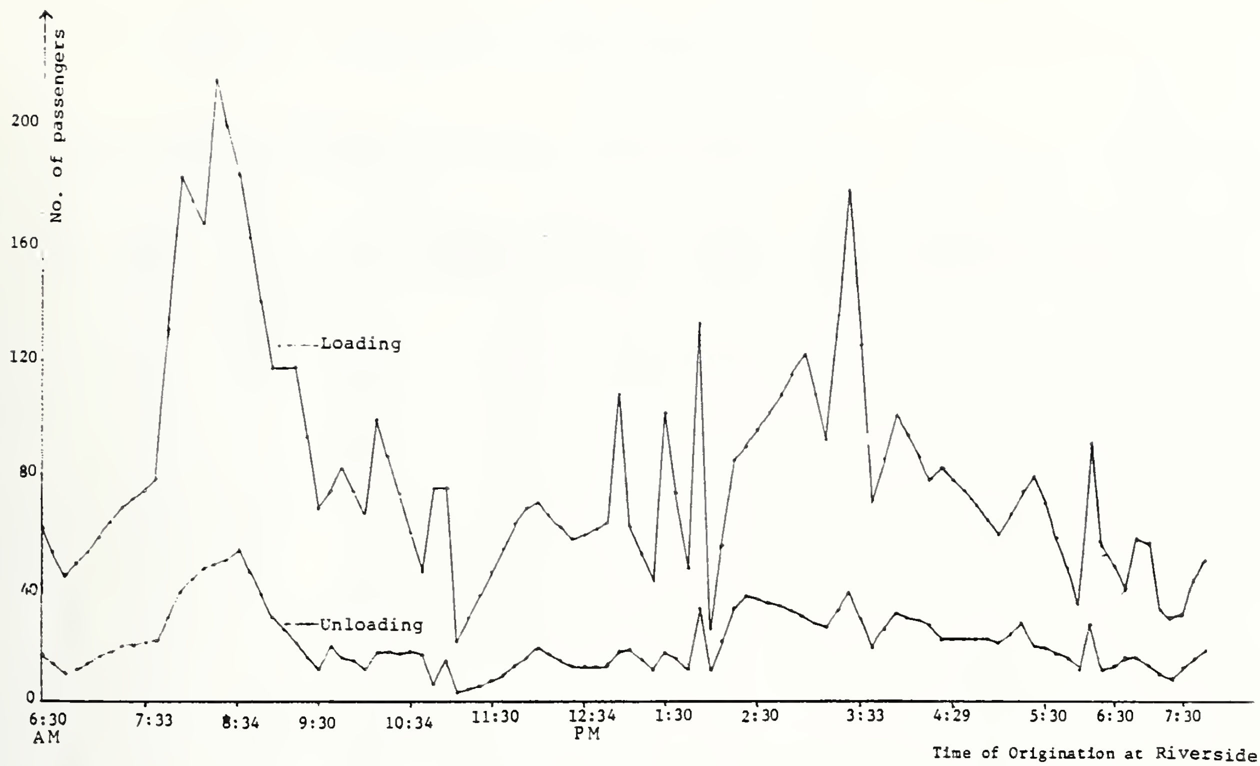


FIGURE 2. INBOUND RAW SERIES

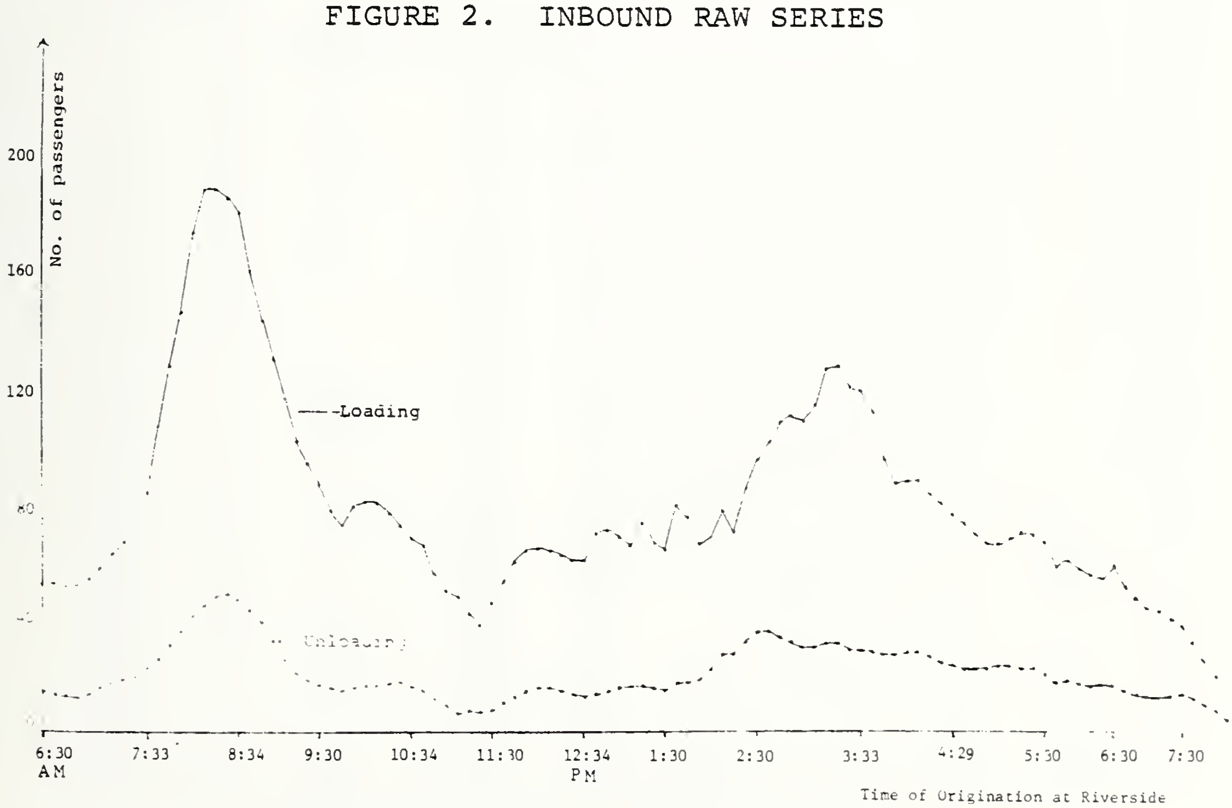


FIGURE 3. INBOUND SMOOTH SERIES
(Smoothed over a length of 5)

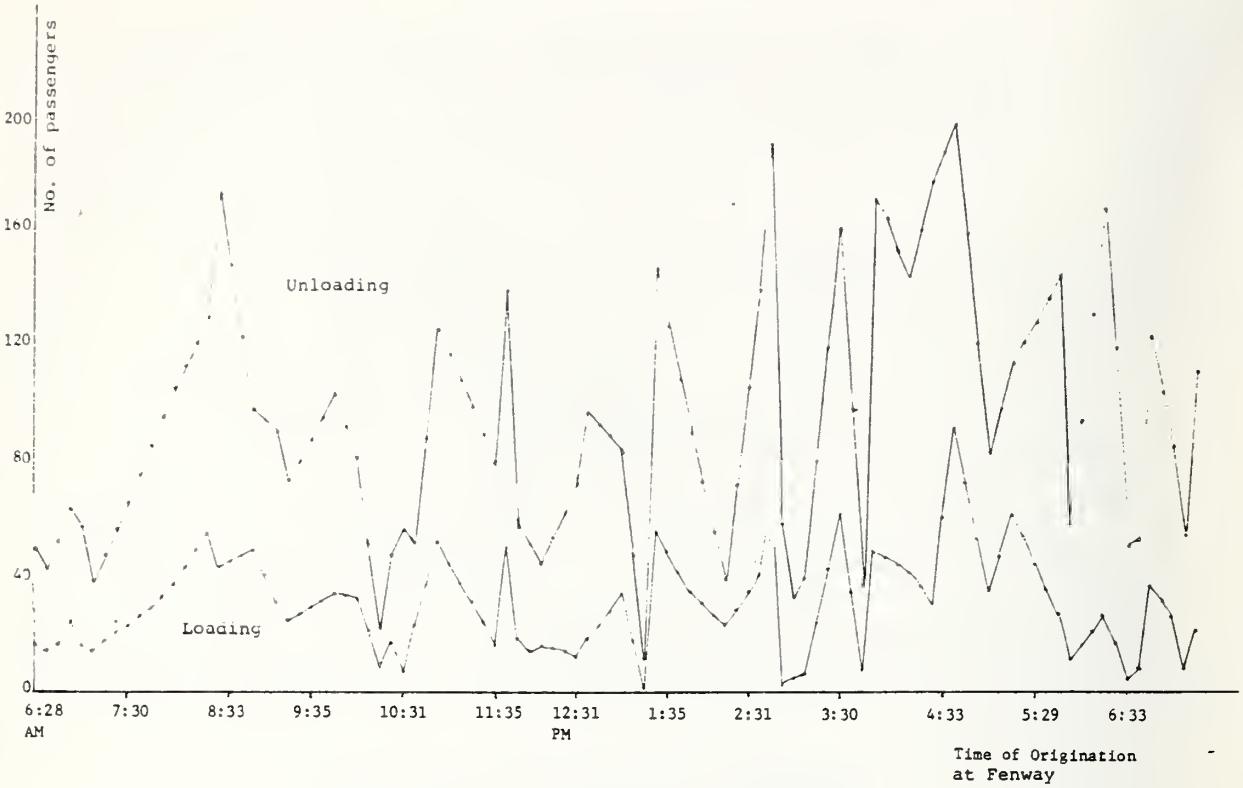


FIGURE 4. OUTBOUND RAW SERIES

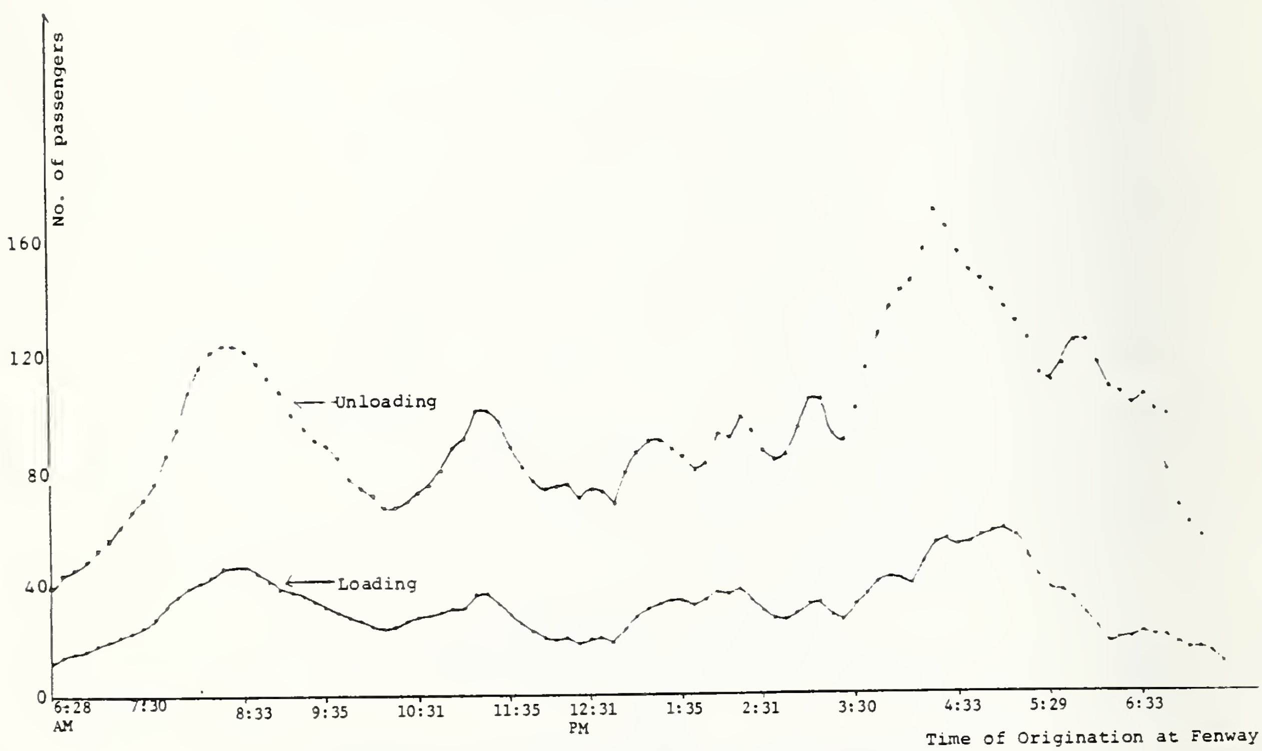


FIGURE 5. OUTBOUND SMOOTH SERIES
(Smoothed over a length of 11)

TABLE 3. SMOOTHED PASSENGER DATA FOR TOTAL TRIPS

a. Boarding/Deboarding Data Smoothed over 5 Trips (Inbound Trips)

TRIP #	SCHED. START at Riverside	HDWY	BOARDING COUNTS RAW	INTERP. u_t	SMOOTHED $\hat{u}_t$	RESID.	DEBOARDING COUNTS RAW	INTERP. u_t	SMOOTHED $\hat{u}_t$	RESID.
1	5;48	360		23	17	6		4	4	0
2	5;59	11	24	24	27	-3	5	5	7	-2
3	6; 9	10		38	37	1		11	10	1
4	6;16	7	48	48	45	3	16	16	13	3
5	6;23	7		54	50	4		16	14	2
6	6;30	7	60	60	52	8	16	16	14	2
7	6;37	7		52	52	0		13	13	0
8	6;44	7	44	44	51	-7	10	10	13	-3
9	6;51	7		48	51	-3		11	12	-1
10	6;58	7		52	53	-1		13	13	0
11	7; 5	7		57	57	0		15	15	0
12	7;12	7		62	62	0		17	17	0
13	7;19	7	67	67	66	1	19	19	18	1
14	7;26	7		70	70	0		19	19	0
15	7;33	7		73	83	-10		20	22	-2
16	7;40	7	77	77	106	-29	21	21	25	-4
17	7;47	7		129	127	2		29	30	-1
18	7;54	7	182	182	146	36	38	38	35	3
19	8; 2	8		174	173	1		42	40	2
20	8;10	8	166	166	188	-22	46	46	44	2
21	8;18	8	216	216	188	28	47	47	47	0
22	8;26	8		200	185	15		49	48	1
23	8;34	8	183	183	180	3	52	52	46	6
24	8;42	8		161	160	1		45	42	3
25	8;50	8		139	143	-4		37	38	-1
26	8;58	8	116	116	130	-14	29	29	31	-2
27	9; 6	8		116	116	0		25	25	0
28	9;14	8	116	116	101	15	20	20	20	0
29	9;22	8		92	93	-1		16	18	-2
30	9;30	8	67	67	86	-19	11	11	16	-5
31	9;38	8	73	73	77	-4	19	19	15	4
32	9;46	8	81	81	72	9	16	16	14	2
33	9;54	8		73	78	-5		14	15	-1
34	10; 2	8	65	65	80	-15	11	11	15	-4
35	10;10	8	98	98	79	19	17	17	15	2
36	10;18	8		85	76	9		17	16	1
37	10;26	8		72	72	0		17	17	0
38	10;34	8		59	67	-8		17	15	2
39	10;42	8	45	45	65	-20	16	16	14	2
40	10;50	8	74	74	55	19	6	6	11	-5
41	10;58	8	74	74	49	25	14	14	9	5
42	11; 6	8	21	21	47	-26	3	3	6	-3
43	11;14	8		29	41	-12		4	7	-3
44	11;22	8		37	37	0		5	6	-1
45	11;30	8	45	45	45	0	7	7	7	0
46	11;38	8		53	52	1		9	10	-1
47	11;46	8	62	62	59	3	12	12	12	0
48	11;54	8		65	63	2		15	14	1
49	12; 2	8	69	69	64	5	18	18	15	3
50	12;10	8		65	63	2		16	15	1
51	12;18	8		61	62	-1		14	14	0
52	12;26	8	57	57	60	-3	12	12	13	-1
53	12;34	8		58	60	-2		12	12	0
54	12;42	8		60	69	-9		12	13	-1
55	12;50	8	62	62	70	-8	12	12	14	-2
56	12;58	8	107	107	68	39	17	17	15	2

TABLE 3.a (Cont.)

TRIP #	SCHED. START	HDWY	BOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.	DEBOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.
57	13: 6	8	61	61	65	-4	18	18	15	1
58	13:14	8		52	73	-21		15	16	-1
59	13:22	8	43	43	66	-23	11	11	15	-4
60	13:30	8	101	101	63	38	17	17	14	3
61	13:38	8		73	79	-6		15	17	-2
62	13:46	8	45	45	75	-30	12	12	17	-5
63	13:54	8	132	132	66	66	32	32	18	14
64	14: 2	8	26	26	68	-42	11	11	22	-11
65	14: 9	7		55	77	-22		21	27	-6
66	14:16	7	84	84	70	14	32	32	27	5
67	14:23	7	89	89	85	4	37	37	32	5
68	14:30	7		95	95	0		36	35	1
69	14:37	7		101	101	0		35	35	0
70	14:44	7		107	108	-1		34	33	1
71	14:51	7		114	110	4		32	32	0
72	14:58	7	121	121	108	13	30	30	30	0
73	15: 5	7		107	114	-7		28	30	-2
74	15:12	7	92	92	127	-35	26	26	31	-5
75	15:19	7		135	128	7		32	31	1
76	15:26	7	179	179	120	59	38	38	29	9
77	15:33	7		125	119	6		29	29	0
78	15:40	7	71	71	112	-41	19	19	28	-9
79	15:47	7		85	95	-10		25	27	-2
80	15:54	7	100	100	87	13	31	31	27	4
81	16: 1	7		93	88	5		30	28	2
82	16: 8	7		86	88	-2		29	28	1
83	16:15	7	78	78	83	-5	27	27	26	1
84	16:22	7	82	82	80	2	22	22	24	-2
85	16:29	7		78	76	2		22	23	-1
86	16:36	7		74	73	1		22	22	0
87	16:43	7		69	69	0		22	22	0
88	16:50	7		64	66	-2		22	22	0
89	16:57	7	59	59	66	-7	21	21	23	-2
90	17: 5	8		66	68	-2		24	23	1
91	17:13	8	74	74	70	4	28	28	22	6
92	17:21	8	79	79	69	10	20	20	22	-2
93	17:29	8		70	66	4		19	20	-1
94	17:40	11		58	58	0		17	17	0
95	17:50	10		47	60	-13		15	18	-3
96	18: 0	10	35	35	57	-22	12	12	17	-5
97	18:10	10	91	91	55	36	27	27	16	11
98	18:20	10	55	55	54	1	12	12	16	-4
99	18:30	10		48	58	-10		13	16	-3
100	18:40	10	40	40	51	-11	15	15	14	1
101	18:50	10	58	58	47	11	15	15	13	2
102	19: 0	10	56	56	43	13	13	13	12	1
103	19:10	10	33	33	42	-9	10	10	12	-2
104	19:20	10	30	30	39	-9	8	8	12	-4
105	19:30	10	31	31	37	-6	12	12	13	-1
106	19:40	10	43	43	31	12	15	15	11	4
107	19:50	10	50	50	25	25	18	18	9	9
108	20: 0	10		0	19	-19		0	7	-7
109	20:10	10		0	10	-10		0	4	-4
110	20:20	10		0	0	0		0	0	0
111	20:30	10		0	0	0		0	0	0
112	20:40	10		0	0	0		0	0	0
113	20:50	10		0	0	0		0	0	0
114	21: 0	10		0	0	0		0	0	0
115	21:10	10		0	0	0		0	0	0
116	21:20	10		0	0	0		0	0	0
117	21:30	10		0	0	0		0	0	0

TABLE 3.a (Cont.)

TRIP #	SCHED. START	HDWY	BOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.	DEBOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.
118	21:40	10		0	0	0		0	0	0
119	21:50	10		0	0	0		0	0	0
120	22: 0	10		0	0	0		0	0	0
121	22:10	10		0	0	0		0	0	0
122	22:20	10		0	0	0		0	0	0
123	22:30	10		0	0	0		0	0	0
124	22:40	10		0	0	0		0	0	0
125	22:50	10		0	0	0		0	0	0
126	23: 0	10		0	0	0		0	0	0
127	23:10	10		0	0	0		0	0	0
128	23:20	10		0	0	0		0	0	0
129	23:30	10		0	0	0		0	0	0
130	23:40	10		0	0	0		0	0	0
131	23:50	10		0	0	0		0	0	0
132	24: 0	10		0	0	0		0	0	0
TOTALS										
132	18:12			8396	8384	235		2170	2167	10

TABLE 3. SMOOTHED PASSENGER DATA FOR TOTAL TRIPS

b. Boarding/Deboarding Data Smoothed Over 11 Trips (Outbound Trips)

TRIP #	SCHED. START at Fenway	HDWY	BOARDING COUNTS RAW	BOARDING COUNTS INTERP. u_t	BOARDING COUNTS SMOOTHED $\hat{u}_t$	BOARDING COUNTS RESID.	DEBOARDING COUNTS RAW	DEBOARDING COUNTS INTERP. u_t	DEBOARDING COUNTS SMOOTHED $\hat{u}_t$	DEBOARDING COUNTS RESID.
1	5:46	362		7	6	1		28	21	7
2	6: 1	15		7	8	-1		29	27	2
3	6:15	14	8	8	10	-2	31	31	32	-1
4	6:28	13	16	16	11	5	49	49	35	14
5	6:38	10	14	14	13	1	42	42	40	2
6	6:41	3	16	16	14	2	52	52	45	7
7	6:52	11	24	24	16	8	63	63	48	15
8	7: 2	12	16	16	18	-2	57	57	52	5
9	7: 9	7	14	14	20	-6	38	38	57	-19
10	7:16	7		17	21	-4		47	61	-14
11	7:23	7		20	23	-3		56	67	-11
12	7:30	7		23	26	-3		65	73	-8
13	7:37	7		26	28	-2		75	78	-3
14	7:44	7		29	31	-2		85	85	0
15	7:51	7		33	34	-1		95	97	-2
16	7:58	7	37	37	37	0	105	105	106	-1
17	8: 5	7		43	39	4		113	112	1
18	8:12	7		49	41	8		121	115	6
19	8:19	7	55	55	43	12	130	130	117	13
20	8:26	7	43	43	43	0	173	173	117	56
21	8:33	7		45	42	3		148	115	33
22	8:40	7		47	41	6		123	113	10
23	8:47	7	49	49	40	9	98	98	111	-13
24	8:55	8		40	38	2		94	108	-14
25	9: 3	8	31	31	36	-5	90	90	106	-16
26	9:11	8	25	25	36	-11	73	73	98	-25
27	9:19	8		27	34	-7		80	92	-12
28	9:27	8		29	32	-3		87	86	1
29	9:35	8		31	28	3		95	79	16
30	9:43	8	34	34	26	8	103	103	75	28
31	9:51	8		33	24	9		92	71	21
32	9:59	8	32	32	24	8	81	81	69	12
33	10: 7	8		21	25	-4		51	70	-19
34	10:15	8	9	9	27	-18	21	21	74	-53
35	10:23	8	17	17	28	-11	47	47	76	-29
36	10:31	8	7	7	29	-22	56	56	76	-20
37	10:39	8	23	23	28	-5	51	51	77	-26
38	10:47	8		37	28	9		88	78	10
39	10:55	8	52	52	27	25	126	126	80	46
40	11: 3	8		45	31	14		117	91	26
41	11:11	8		38	31	7		108	92	16
42	11:19	8		31	32	-1		99	91	8
43	11:27	8		24	31	-7		89	91	-2
44	11:35	8	16	16	29	-13	79	79	87	-8
45	11:43	8	50	50	26	24	139	139	82	57
46	11:51	8	18	18	23	-5	57	57	78	-21
47	11:59	8	14	14	21	-7	51	51	77	-26
48	12: 7	8	16	16	20	-4	44	44	76	-32
49	12:15	8		15	20	-5		53	76	-23
50	12:23	8		14	22	-8		62	76	-14
51	12:31	8	12	12	19	-7	72	72	68	4
52	12:39	8	18	18	18	0	97	97	64	33
53	12:47	8		23	21	2		93	73	20
54	12:55	8	28	28	24	4	89	89	80	9
55	13: 3	8	34	34	27	7	83	83	85	-2
56	13:11	8		18	29	-11		47	88	-41

TABLE 3.b (Cont.)

TRIP #	SCHED. START	HDWY	BOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.	DEBOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.
57	13:19	8	1	1	30	-29	11	11	88	-77
58	13:27	8	56	56	31	25	147	147	84	63
59	13:35	8		49	31	18		128	79	49
60	13:43	8		42	31	11		109	78	31
61	13:51	8	35	35	31	4	90	90	80	10
62	13:59	8		31	34	-3		73	88	-15
63	14: 7	8		27	40	-13		56	105	-49
64	14:15	8	23	23	35	-12	39	39	97	-58
65	14:23	8		29	31	-2		72	88	-16
66	14:31	8		35	28	7		106	82	24
67	14:39	8	41	41	27	14	140	140	81	59
68	14:47	8	70	70	28	42	191	191	85	106
69	14:55	8	2	2	31	-29	59	59	95	-36
70	15: 2	7	5	5	32	-27	33	33	100	-67
71	15: 9	7	6	6	30	-24	40	40	97	-57
72	15:16	7		24	31	-7		80	103	-23
73	15:23	7		43	32	11		120	105	15
74	15:30	7	62	62	30	32	161	161	102	59
75	15:37	7		35	33	2		99	109	-10
76	15:44	7	8	8	36	-28	37	37	121	-84
77	15:51	7	49	49	38	11	171	171	134	37
78	15:58	7		47	42	5		163	143	20
79	16: 5	7		45	46	-1		154	150	4
80	16:12	7	42	42	47	-5	145	145	150	-5
81	16:19	7		37	49	-12		161	152	9
82	16:26	7	31	31	51	-20	178	178	157	21
83	16:33	7		61	51	10		188	150	38
84	16:40	7	92	92	53	39	198	198	146	52
85	16:47	7		73	54	19		160	143	17
86	16:54	7		54	54	0		122	141	-19
87	17: 1	7	35	35	54	-19	84	84	139	-55
88	17: 8	7		48	53	-5		99	136	-37
89	17:15	7	62	62	49	13	115	115	125	-10
90	17:22	7		54	42	12		122	115	7
91	17:29	7		45	37	8		129	113	16
92	17:36	7		36	35	1		137	117	20
93	17:43	7	27	27	33	-6	145	145	120	25
94	17:50	7	11	11	29	-18	59	59	116	-57
95	17:58	8		16	24	-8		95	110	-15
96	18: 6	8		21	23	-2		132	110	22
97	18:14	8	26	26	21	5	169	169	108	61
98	18:22	8		17	20	-3		120	104	16
99	18:33	11	4	4	19	-15	51	51	95	-44
100	18:43	10	8	8	20	-12	53	53	100	-47
101	18:53	10	37	37	18	19	124	124	92	32
102	19: 3	10		32	16	16		105	80	25
103	19:13	10	26	26	14	12	86	86	64	22
104	19:23	10	8	8	12	-4	55	55	53	2
105	19:33	10	21	21	12	9	112	112	49	63
106	19:43	10		0	11	-11		0	44	-44
107	19:53	10		0	8	-8		0	33	-33
108	20: 3	10		0	5	-5		0	23	-23
109	20:13	10		0	3	-3		0	15	-15
110	20:23	10		0	2	-2		0	10	-10
111	20:33	10		0	0	0		0	0	0
112	20:43	10		0	0	0		0	0	0
113	20:53	10		0	0	0		0	0	0
114	21: 3	10		0	0	0		0	0	0
115	21:13	10		0	0	0		0	0	0
116	21:23	10		0	0	0		0	0	0
117	21:33	10		0	0	0		0	0	0

TABLE 3.b (Cont.)

TRIP #	SCHED. START	HDWY	BOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.	DEBOARDING COUNTS RAW	INTERP.	SMOOTHED	RESID.
118	21:43	10		0	0	0		0	0	0
119	21:53	10		0	0	0		0	0	0
120	22: 3	10		0	0	0		0	0	0
121	22:13	10		0	0	0		0	0	0
122	22:23	10		0	0	0		0	0	0
123	22:33	10		0	0	0		0	0	0
124	22:43	10		0	0	0		0	0	0
125	22:53	10		0	0	0		0	0	0
126	23: 3	10		0	0	0		0	0	0
127	23:13	10		0	0	0		0	0	0
128	23:23	10		0	0	0		0	0	0
129	23:33	10		0	0	0		0	0	0
130	23:43	10		0	0	0		0	0	0
131	23:53	10		0	0	0		0	0	0
132	24: 3	10		0	0	0		0	0	0
133	24:13	10		0	0	0		0	0	0
134	24:23	10		0	0	0		0	0	0
135	24:33	10		0	0	0		0	0	0
136	24:43	10		0	0	0		0	0	0
137	24:53	10		0	0	0		0	0	0
TOTALS										
137	19: 7			3189	3176	131		9860	9818	859

TABLE 4. A CONSOLIDATED ONE-DAY INBOUND SCHEDULE

Arriving at:

Trip	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservoir	Beacon Field	Brookline Hills	Brook. Village	Longwood	Fenway
t=1	6:30	6:32	6:34	6:36	6:38	6:40	6:43	6:45	6:47	6:49	6:51	6:53	6:54
2	6:37	6:39	6:41	6:43	6:45	6:47	6:52	6:52	6:54	6:56	6:58	7: 0	7: 1
3	6:44	6:46	6:48	6:50	6:52	6:54	6:57	6:59	7: 1	7: 3	7: 5	7: 7	7: 8
4	6:51	6:53	6:55	6:57	6:59	7: 1	7: 4	7: 6	7: 8	7:10	7:12	7:14	7:15
5	6:58	7: 0	7: 2	7: 4	7: 6	7: 8	7:11	7:13	7:15	7:17	7:19	7:21	7:22
6	7: 5	7: 7	7: 9	7:11	7:13	7:15	7:18	7:20	7:22	7:24	7:26	7:28	7:29
7	7:12	7:14	7:16	7:18	7:20	7:22	7:25	7:27	7:29	7:31	7:33	7:35	7:36
8	7:19	7:21	7:23	7:25	7:27	7:29	7:32	7:34	7:36	7:38	7:40	7:42	7:43
9	7:26	7:28	7:30	7:32	7:34	7:36	7:39	7:41	7:43	7:45	7:47	7:49	7:50
10	7:33	7:35	7:37	7:39	7:41	7:43	7:46	7:48	7:50	7:52	7:54	7:56	7:57
11	7:40	7:42	7:44	7:46	7:48	7:50	7:53	7:55	7:57	7:59	8: 1	8: 3	8: 4
12	7:47	7:49	7:51	7:53	7:55	7:57	8: 0	8: 2	8: 4	8: 6	8: 8	8:10	8:11
13	7:54	7:56	7:58	8: 0	8: 2	8: 4	8: 7	8: 9	8:11	8:13	8:15	8:17	8:18
14	8: 2	8: 4	8: 6	8: 8	8:10	8:12	8:15	8:17	8:19	8:21	8:23	8:25	8:26
15	8:10	8:12	8:14	8:16	8:18	8:20	8:23	8:25	8:27	8:29	8:31	8:33	8:34
16	8:18	8:20	8:22	8:24	8:26	8:28	8:31	8:33	8:35	8:37	8:39	8:41	8:42
17	8:26	8:28	8:30	8:32	8:34	8:36	8:39	8:41	8:43	8:45	8:47	8:49	8:50
18	8:34	8:36	8:38	8:40	8:42	8:44	8:47	8:49	8:51	8:53	8:55	8:57	8:58
19	8:42	8:44	8:46	8:48	8:50	8:52	8:55	8:57	8:59	9: 1	9: 3	9: 5	9: 6
20	8:50	8:52	8:54	8:56	8:58	9: 0	9: 3	9: 5	9: 7	9: 9	9:11	9:13	9:14
21	8:58	9: 0	9: 2	9: 4	9: 6	9: 8	9:11	9:13	9:15	9:17	9:19	9:21	9:22
22	9: 6	9: 8	9:10	9:12	9:14	9:16	9:19	9:21	9:23	9:25	9:27	9:29	9:30
23	9:14	9:16	9:18	9:20	9:22	9:24	9:27	9:29	9:31	9:33	9:35	9:37	9:38
24	9:22	9:24	9:26	9:28	9:30	9:32	9:35	9:37	9:39	9:41	9:43	9:45	9:46
25	9:30	9:32	9:34	9:36	9:38	9:40	9:43	9:45	9:47	9:49	9:51	9:53	9:54
26	9:38	9:40	9:42	9:44	9:46	9:48	9:51	9:53	9:55	9:57	9:59	10: 1	10: 2
27	9:46	9:48	9:50	9:52	9:54	9:56	9:59	10: 1	10: 3	10: 5	10: 7	10: 9	10:10
28	9:54	9:56	9:58	10: 0	10: 2	10: 4	10: 7	10: 9	10:11	10:13	10:15	10:17	10:18
29	10: 2	10: 4	10: 6	10: 8	10:10	10:12	10:15	10:17	10:19	10:21	10:23	10:25	10:26
30	10:10	10:12	10:14	10:16	10:18	10:20	10:23	10:25	10:27	10:29	10:31	10:33	10:34
31	10:18	10:20	10:22	10:24	10:26	10:28	10:31	10:33	10:35	10:37	10:39	10:41	10:42
32	10:26	10:28	10:30	10:32	10:34	10:36	10:39	10:41	10:43	10:45	10:47	10:49	10:50
33	10:34	10:36	10:38	10:40	10:42	10:44	10:47	10:49	10:51	10:53	10:55	10:57	10:58
34	10:42	10:44	10:46	10:48	10:50	10:52	10:55	10:57	10:59	11: 1	11: 3	11: 5	11: 6
35	10:50	10:52	10:54	10:56	10:58	11: [illegible]	11: 3	11: 5	11: 7	11: 9	11:11	11:13	11:14
36	10:58	11: 0	11: 2	11: 4	11: 6	11: 8	11:11	11:13	11:15	11:17	11:19	11:21	11:22
37	11: 6	11: 8	11:10	11:12	11:14	11:16	11:19	11:21	11:23	11:25	11:27	11:29	11:30
38	11:14	11:16	11:18	11:20	11:22	11:24	11:27	11:29	11:31	11:33	11:35	11:37	11:38
39	11:22	11:24	11:26	11:28	11:30	11:32	11:35	11:37	11:39	11:41	11:43	11:45	11:46
40	11:30	11:32	11:34	11:36	11:38	11:40	11:43	11:45	11:47	11:49	11:51	11:53	11:54
41	11:38	11:40	11:42	11:44	11:46	11:48	11:51	11:53	11:55	11:57	11:59	12: 1	12: 2
42	11:46	11:48	11:50	11:52	11:54	11:56	11:59	12: 1	12: 3	12: 5	12: 7	12: 9	12:10
43	11:54	11:56	11:58	12: 0	12: 2	12: 4	12: 7	12: 9	12:11	12:13	12:15	12:17	12:18
44	12: 2	12: 4	12: 6	12: 8	12:10	12:12	12:15	12:17	12:19	12:21	12:23	12:25	12:26
45	12:10	12:12	12:14	12:16	12:18	12:20	12:23	12:25	12:27	12:29	12:31	12:33	12:34
46	12:18	12:20	12:22	12:24	12:26	12:28	12:31	12:33	12:35	12:37	12:39	12:41	12:42
47	12:26	12:28	12:30	12:32	12:34	12:36	12:39	12:41	12:43	12:45	12:47	12:49	12:50
48	12:34	12:36	12:38	12:40	12:42	12:44	12:47	12:49	12:51	12:53	12:55	12:57	12:58
49	12:42	12:44	12:46	12:48	12:50	12:52	12:55	12:57	12:59	1: 1	1: 3	1: 5	1: 6

TABLE 4 (Cont.)

Arriving at:

TRIP	Riverside	Woodland	Waban	Eliot	Highland	Newton Center	Chestnut Hill	Reservior	Beacon Field	Brookline Hills	Brook. Village	Longwood	Fenway
t= 50	12:50	12:52	12:54	12:56	12:58	[illegible]	1: 3	1: 5	1: 7	1: 9	1:11	1:13	1:14
51	12:58	1: [illegible]	1: 2	1: 4	1: 6	1: 8	1:11	1:13	1:15	1:17	1:19	1:21	1:22
52	1: 6	[illegible]	1:10	1:12	1:14	1:16	1:19	1:21	1:23	1:25	1:27	1:29	1:30
53	1:14	1:16	1:18	1:20	1:22	1:24	1:27	1:29	1:31	1:33	1:35	1:37	1:38
54	1:22	1:24	1:26	1:28	1:30	1:32	1:35	1:37	1:39	1:41	1:43	1:45	1:46
55	1:30	1:32	1:34	1:36	1:38	1:4[illegible]	1:43	1:45	1:47	1:4[illegible]	1:51	1:53	1:54
56	1:38	1:4[illegible]	1:42	1:44	1:46	1:4[illegible]	1:51	1:53	1:55	1:57	1:59	2: 1	2: 2
57	1:46	1:4[illegible]	1:50	1:52	1:54	1:5[illegible]	1:59	2: 1	2: 3	2: 5	2: 7	2: 9	2:10
58	1:54	1:5[illegible]	1:58	2: 0	2: 2	2: 4	2: 7	2: 9	2:11	2:13	2:1[illegible]	2:17	2:18
59	2: 2	2: 4	2: 6	2: 8	2:10	2:12	2:1[illegible]	2:17	2:19	2:21	2:23	2:25	2:26
60	2: 9	2:11	2:13	2:15	2:17	2:19	2:22	2:24	2:26	2:28	2:3[illegible]	2:32	2:33
61	2:16	2:18	2:20	2:22	2:24	2:26	2:29	2:31	2:33	2:35	2:37	2:39	2:40
62	2:23	2:25	2:27	2:29	2:31	2:33	2:36	2:38	2:40	2:42	2:44	2:46	2:47
63	2:30	2:32	2:34	2:36	2:38	2:4[illegible]	2:43	2:45	2:47	2:49	2:51	2:53	2:54
64	2:37	2:39	2:41	2:43	2:45	2:47	2:5[illegible]	2:52	2:54	2:56	2:5[illegible]	3: [illegible]	3: 1
65	2:44	2:46	2:48	2:50	2:52	2:54	2:57	2:59	3: 1	3: 3	3: 5	3: 7	3: 8
66	2:51	2:53	2:55	2:57	2:59	3: 1	3: 4	3: 6	3: 8	3:1[illegible]	3:12	3:14	3:15
67	2:58	3: [illegible]	3: 2	3: 4	3: 6	3: [illegible]	3:11	3:13	3:15	3:17	3:19	3:21	3:22
68	3: 5	3: 7	3: 9	3:11	3:13	3:15	3:1[illegible]	3:20	3:22	3:24	3:2[illegible]	3:28	3:29
69	3:12	3:14	3:16	3:18	3:20	3:22	3:25	3:27	3:29	3:31	3:33	3:35	3:36
70	3:19	3:21	3:23	3:25	3:27	3:29	3:32	3:34	3:36	3:3[illegible]	3:4[illegible]	3:42	3:43
71	3:26	3:28	3:30	3:32	3:34	3:3[illegible]	3:39	3:41	3:43	3:45	3:47	3:49	3:50
72	3:33	3:35	3:37	3:39	3:41	3:43	3:46	3:48	3:50	3:52	3:54	3:56	3:57
73	3:40	3:42	3:44	3:46	3:48	3:5[illegible]	3:53	3:55	3:57	3:59	4: 1	4: 3	4: 4
74	3:47	3:49	3:51	3:53	3:55	3:57	4: [illegible]	4: 2	4: 4	4: 6	4: [illegible]	4:10	4:11
75	3:54	3:56	3:58	4: 0	4: 2	4: 4	4: 7	4: 9	4:11	4:13	4:15	4:17	4:18
76	4: 1	4: 3	4: 5	4: 7	4: 9	4:11	4:14	4:16	4:18	4:2[illegible]	4:22	4:24	4:25
77	4: 8	4:1[illegible]	4:12	4:14	4:16	4:18	4:21	4:23	4:25	4:27	4:29	4:31	4:32
78	4:15	4:17	4:19	4:21	4:23	4:25	4:28	4:30	4:32	4:34	4:36	4:38	4:39
79	4:22	4:24	4:26	4:28	4:30	4:32	4:35	4:37	4:39	4:41	4:43	4:45	4:46
80	4:29	4:31	4:33	4:35	4:37	4:39	4:42	4:44	4:46	4:48	4:5[illegible]	4:52	4:53
81	4:36	4:38	4:40	4:42	4:44	4:46	4:49	4:51	4:53	4:55	4:57	4:59	5: 0
82	4:43	4:45	4:47	4:49	4:51	4:53	4:56	4:58	5: 0	5: 2	5: 4	5: 6	5: 7
83	4:50	4:52	4:54	4:56	4:58	5: [illegible]	5: 3	5: 5	5: 7	5: 9	5:11	5:13	5:14
84	4:57	4:59	5: 1	5: 3	5: 5	5: 7	5:1[illegible]	5:12	5:14	5:16	5:18	5:2[illegible]	5:21
85	5: 5	5: 7	5: 9	5:11	5:13	5:15	5:18	5:20	5:22	5:24	5:26	5:28	5:29
86	5:13	5:15	5:17	5:19	5:21	5:23	5:2[illegible]	5:28	5:30	5:32	5:34	5:36	5:37
87	5:21	5:23	5:25	5:27	5:29	5:31	5:34	5:36	5:38	5:4[illegible]	5:42	5:44	5:45
88	5:29	5:31	5:33	5:35	5:37	5:39	5:42	5:44	5:46	5:48	5:5[illegible]	5:52	5:53
89	5:40	5:42	5:44	5:46	5:48	5:5[illegible]	5:53	5:55	5:57	5:59	6: 1	6: 3	6: 4
90	5:50	5:52	5:54	5:56	5:58	6: [illegible]	6: 3	6: 5	6: 7	6: 9	6:11	6:13	6:14
91	6: 0	6: 2	6: 4	6: 6	6: 8	6:1[illegible]	6:13	6:15	6:17	6:19	6:21	6:23	6:24
92	6:10	6:12	6:14	6:16	6:18	6:2[illegible]	6:23	6:25	6:27	6:29	6:31	6:33	6:34
93	6:20	6:22	6:24	6:26	6:28	6:3[illegible]	6:33	6:35	6:37	6:39	6:41	6:43	6:44
94	6:30	6:32	6:34	6:36	6:38	6:4[illegible]	6:43	6:45	6:47	6:49	6:51	6:53	6:54
95	6:40	6:42	6:44	6:46	6:48	6:5[illegible]	6:53	6:55	6:57	6:59	7: 1	7: 3	7: 4
96	6:50	6:52	6:54	6:56	6:58	7: [illegible]	7: 3	7: 5	7: 7	7: 9	7:11	7:13	7:14
97	7: 0	7: 2	7: 4	7: 6	7: 8	7:1[illegible]	7:13	7:15	7:17	7:19	7:21	7:23	7:24
98	7:10	7:12	7:14	7:16	7:18	7:2[illegible]	7:23	7:25	7:27	7:29	7:31	7:33	7:34
99	7:20	7:22	7:24	7:26	7:28	7:3[illegible]	7:33	7:35	7:37	7:39	7:41	7:43	7:44
100	7:30	7:32	7:34	7:36	7:38	7:4[illegible]	7:43	7:45	7:47	7:49	7:51	7:53	7:54
101	7:40	7:42	7:44	7:46	7:48	7:5[illegible]	7:53	7:55	7:57	7:59	8: 1	8: 3	8: 4
102	7:50	7:52	7:54	7:56	7:58	[illegible]	8: 3	8: 5	8: 7	8: 9	8:11	8:13	8:14
103	8: 0	8: 2	8: 4	8: 6	8: 8	8:1[illegible]	8:13	8:15	8:17	8:19	8:21	8:23	8:24
104	8:10	8:12	8:14	8:16	8:18	8:2[illegible]	8:23	8:25	8:27	8:29	8:31	8:33	8:34
105	8:20	8:22	8:24	8:26	8:28	8:3[illegible]	8:33	8:35	8:37	8:39	8:41	8:43	8:44
106	8:30	8:32	8:34	8:36	8:38	8:40	8:43	8:45	8:47	8:49	8:51	8:53	8:54

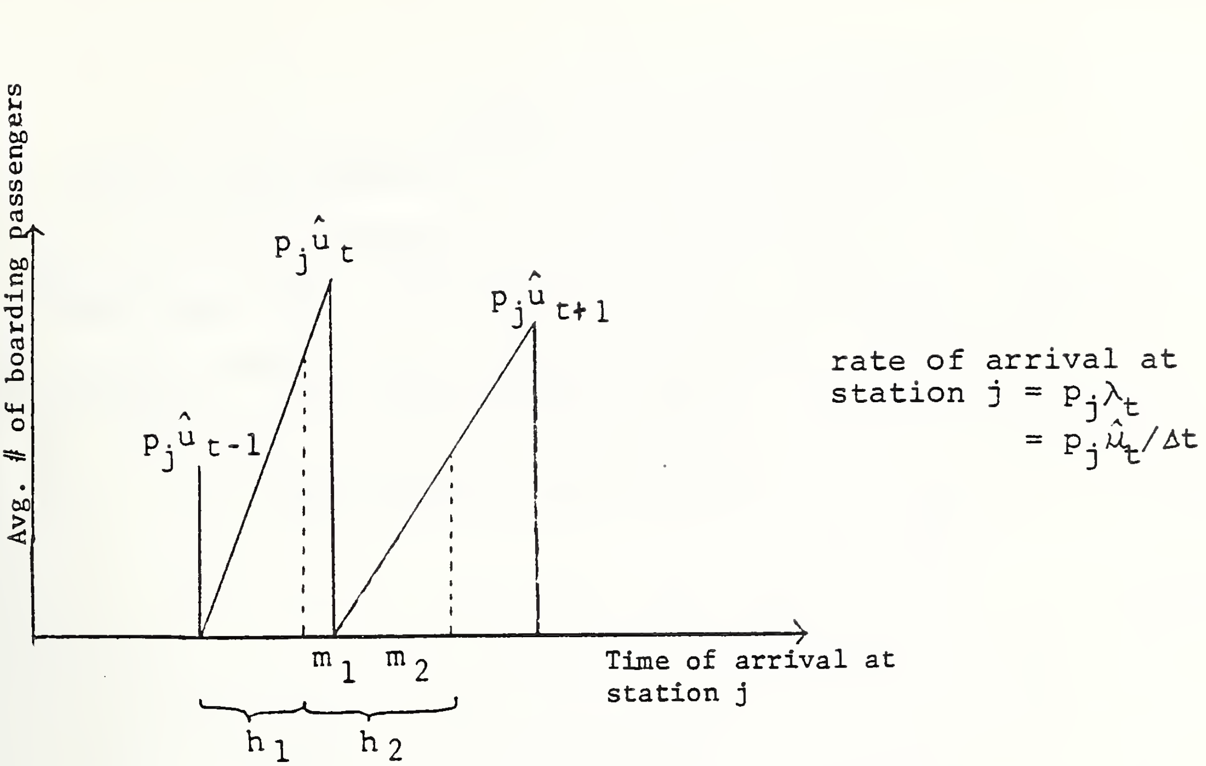


FIGURE 6. EXPECTED NUMBER OF PASSENGERS WAITING AT STATION J

1. Given a train has arrived at t-1, the second train, arriving h_1 minutes later, should expect the probability of having exactly x passengers accumulated at station j to be:

$$Pr(x;\ p_j\lambda_t h_1) = \frac{e^{-p_j\lambda_t h_1}\ (p_j\lambda_t h_1)^x}{x!}$$

2. The third train arriving h_2 $(=m_1+m_2)$ minutes later, should expect the probability of having exactly y passengers to be:

$$Pr(y;\ p_j\lambda_t m_1+p_j\lambda_{t+1}m_2) = \frac{e^{-p_j(\lambda_t m_1+\lambda_{t+1}m_2)}\ (p_j\lambda_t m_1+p_j\lambda_{t+1}m_2)^y}{y!}$$

V. DISTRIBUTION OF THE DWELL TIME

The density function for the derivation of dwell time at each station is found to be dependent on the total "on-off" movement, M, taking place while the train remains stationary. This relationship is significant regardless of the hour of the day, the direction of the trip, or even the individual station configuration.

That is,

$$T_d = \alpha + \beta M + \varepsilon$$

where α is the minimum dwell time, β the average rate of boarding and unloading, and ε, a random variable with zero mean and variance σ^2.

This relationship was first shown for the PCC (President's Conference Committee) trains. The coefficients α, β, and σ, estimated by means of simple least squares regressions for a sample of stations, are listed in Table 5. Data where extra delay is indicated by the presence of equipment or fare problems, etc., are taken out of the data base before the regression analyses were performed. The figures in parentheses below the coefficients represent their respective standard errors. All the regressions are significant and the linear trends are readily observable from the scattergrams shown in Appendix 2. The low R^2's, however, indicate the magnitude of the random fluctuation of dwell time even when a portion of it can be accounted by the delay incurred by boarding and unloading passengers.

TABLE 5. STATISTICAL ANALYSIS OF DWELL TIME (PCC TRAINS)

Station j	n_j	Regression j	σ_j	residual sum of squares, SSE_j
Highland	35	T_d= 10.75 + .89M (1.58) (.18)	4.99	821.70
Newton Center	34	T_d= 9.88 + .92M (1.88) (.15)	5.51	971.52
Brookline Village	37	T_d= 8.19 + .99M (1.08) (.07)	3.60	453.60
Reservoir	34	T_d= 8.45 + .96M (1.04) (.11)	3.65	426.32
Fenway	37	T_d= 9.88 + .77M (1.19) (.09)	4.14	599.89
Chestnut Hill	34	T_d= 9.29 +1.03M (1.16) (.13)	3.74	447.60
Woodland	37	T_d= 7.79 +1.35M (1.03) (.13)	4.72	779.74
Combined	248	T_d= 9.49 + .93M (.48) (.04)	4.47	4915.30

It is quite natural to suppose that a generalized dwell time vs. total movement relationship will be adequate for all stations and for both inbound and outbound trips. The scattergrams suggest that the seven regression lines could be pooled together to give a better precision on the estimation of the general level and slope. A formal test was accomplished to demonstrate whether they are in fact identical.

To test H_o: all α_j's are equal and
all β_j's are equal,

against H_1: either the α_j's are not equal or the β_j's are not equal or both,

we need to examine the ratio of the "between station variations" (which is the total variation minus the within station variation) to the "within station variation". Hence, the following statistic is defined.

$$F = \frac{SSE - \Sigma SSE_j}{(n-2)-\Sigma(n_j-2)} \Big/ \frac{\Sigma SSE_j}{\Sigma(n_j-2)}$$

The decision to reject or accept H_o is based on whether F is too large or too small. Compared to the 95th percentile of an $\mathcal{F}(12,234)$ distribution, F (=1.80) is small. Hence the hypothesis of the adequacy of a general relationship to represent all stations is accepted. This is also valid for the outbound trips, the details of the comparisons are shown in Appendix 2 .

To generate or simulate dwell time at any station, therefore, one may simply use:

$$T_d = 9.5 + .9 \times \text{total movement} + \varepsilon + \text{delay}$$

where ε is a random number generated from a $N(0, 4.5^2)$ distribution. The delay is an arbitrary nonnegative number, incorporated into the equation for any delay due to equipment problems, fare problems, or waiting for passengers etc.

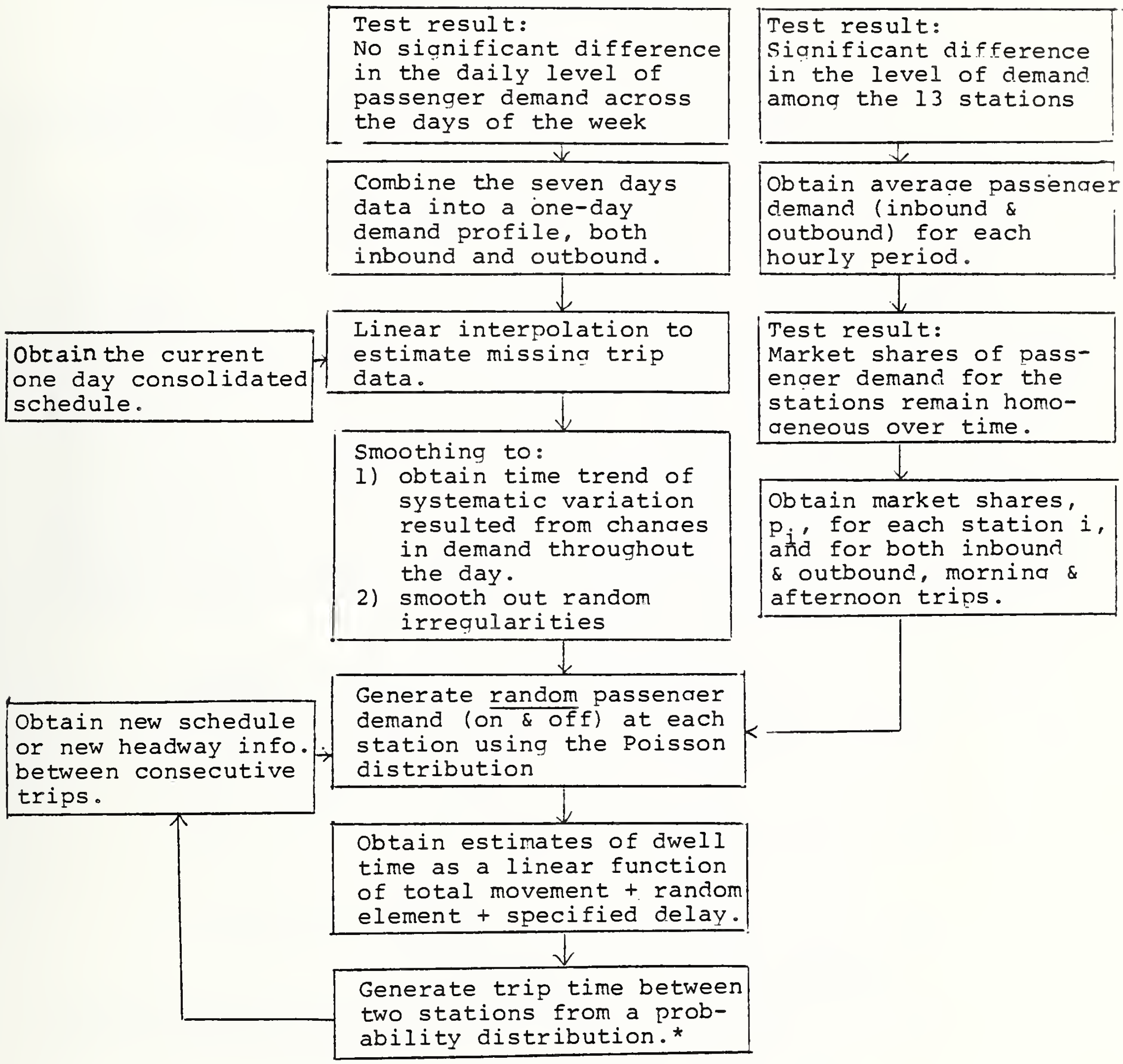
The dwell times for the Light Rail Vehicles display a different relationship, however; and are subjected to much variation. The linear regression is still significant, ($R^2 = .69$) even though it results in different coefficients. The generalized form for the LRV is:

$T_d = 10.75 + 1.46$ total movement $+ \psi +$ delay, where ψ is again a $N(0, 7.16^2)$ random variable.

VI. CONCLUSION AND SUMMARY

Generation of the passenger demands and the dwell times at the stations based on the distributions and regression equations developed is important to the operational performance model which seeks the optimum train schedule to accommodate the undulating demand throughout the day. The high variability of the trip data does not allow for the estimation of passenger demand profile for each station, nor can it be used to test the assumption that the total trip demand at a certain time follows a Poisson distribution. This is because the time series thus presented represents only a single sample out of the many possible series from the sampling population. However, the choice of the discrete Poisson distribution is a most logical one because the arrival of passengers can be thought of as a series of random events in a time continuum. Hence the number of passengers per time period would be expected to form a Poisson distribution. Figure 7 is a flow chart illustrating the steps necessary for the simulation of passenger loading and unloading activities at each station.

The estimates of the total inbound and outbound passenger volumes with their respective standard errors set the lower and upperbounds for the general level of daily passenger activity. This can be helpful in the determination of the number of trains to be dispatched on any working day when no unusual circumstance affecting the passenger load is imminent. To conclude, this study has examined the input passenger data to the model, and developed estimation procedures to meet the model requirements.



*To be estimated.

FIGURE 7. DECISION FLOW CHART

APPENDIX 1: MARKET SHARE ANALYSIS

APPENDIX 1A: AVERAGE LOADING PASSENGERS (Inbound morning trips)

Stations / Hourly Period	6-7	7-8	8-9	9-10	10-11	11-12	Row total R_i	$P_i = R_i/N$
Riverside	4	17	18	11	11	5	66	.119
Woodland	3	11	15	10	6	3	48	.086
Waban	2	6	16	6	3	4	37	.066
Eliot	4	6	11	3	3	2	29	.052
Highland	3	9	17	14	9	6	58	.104
Newton Center	5	10	19	12	10	8	64	.115
Chestnut Hill	2	7	12	4	5	4	34	.061
Reservoir	5	6	13	4	3	1	32	.058
Beacon Field	1	4	10	2	2	3	22	.040
Brookline Hill	3	9	16	7	6	10	51	.092
Brookline Village	7	13	19	8	5	6	58	.104
Longwood	2	3	7	4	1	3	20	.036
Fenway	3	7	10	4	5	8	37	.066
Column total, C_j	44	108	183	89	69	63	N=556	1.00

$$\chi^2 = \sum \frac{(O_{ij} - E_{ij})^2}{E_{ij}} = 38.2 \qquad \text{where } E_{ij} = \frac{R_i C_j}{N}$$

$$E(\chi^2) = \frac{(r-1)(c-1)\,N}{N-1} = \frac{(13-1)(6-1)\,556}{556-1} = 60.11$$

$$V(\chi^2) = \frac{2N}{N-3}(n_1-u_1)(n_2-u_2) + \frac{N^2}{N-1}u_1u_2$$

$$\text{where } n_1 = \frac{(r-1)(N-r)}{N-1}, \quad n_2 = \frac{(C-1)(N-c)}{N-1}$$

$$u_1 = \frac{N\sum R_i^{-1} - r^2}{N-2}, \quad u_2 = \frac{N\sum C_j^{-1} - c^2}{N-2}$$

Hence $V(\chi^2) = 152.0$

Under the null hypothesis that is stated on page 6, the statistic,

$$Z = \frac{\chi^2 - E(\chi^2)}{\sqrt{V(\chi^2)}} = -1.78$$

is distributed as N(0,1) and its value is compared to the 95th percentile (=1.96 or - 1.96) of a standard normal distribution. Since -1.78 is greater than -1.96, the hypothesis is accepted.

APPENDIX 1B: AVERAGE LOADING PASSENGERS (Inbound afternoon trips)

Hourly Period / Stations	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	R_i	$p_i = R_i/N$
Riverside	5	6	4	10	12	6	6	5	54	.088
Woodland	4	7	5	9	3	5	8	2	43	.070
Waban	2	4	6	6	5	3	3	3	32	.052
Eliot	4	1	2	4	4	1	4	1	21	.034
Highland	7	3	5	5	9	6	4	3	42	.069
Newton Center	11	8	13	12	6	9	8	5	72	.118
Chestnut Hill	6	4	8	11	3	14	5	3	54	.088
Reservoir	4	5	11	5	9	4	1	2	41	.067
Beacon Field	1	3	6	2	2	2	1	1	18	.029
Brookline Hill	6	6	19	7	3	2	2	4	49	.080
Brookline Village	9	5	11	12	4	7	5	5	58	.095
Longwood	7	2	6	7	2	3	3	2	32	.052
Fenway	8	8	13	23	25	9	5	6	97	.158
Column Total C_j	74	62	109	113	87	71	55	42	613	1.000

As in Appendix 1A, the Z statistic is derived.

$$\chi^2 = 112.04$$

$$E(\chi^2) = 84.14$$

$$V(\chi^2) = 163.2$$

$$Z = \frac{\chi^2 - E(\chi^2)}{V(\chi^2)} = 2.18$$

The 95th percentile of a N(0,1) distribution is 1.96. Since Z is very close to 1.96, for all practical purposes, the null hypothesis is again accepted.

APPENDIX 1C: AVERAGE NUMBER OF UNLOADING PASSENGERS (Outbound morning trips)

Hourly Period	6-7	7-8	8-9	9-10	10-11	11-12am.	Row Total R_i	$p_i = R_i/N$
Stations								
Fenway	13	11	17	9	7	10	67	.145
Longwood	3	2	9	6	4	3	27	.059
Brookline Village	2	3	18	8	6	6	43	.093
Brookline Hill	1	1	13	9	5	6	35	.076
Beacon Field	0	0	3	1	2	3	9	.019
Reservoir	2	2	3	5	2	4	18	.039
Chestnut Hill	1	5	15	7	4	6	38	.082
Newton Center	1	5	19	17	8	14	64	.139
Highland	4	5	7	5	4	6	31	.067
Eliot	1	3	2	2	2	2	12	.026
Waban	2	2	7	7	3	4	25	.054
Woodland	4	4	9	10	6	11	44	.095
Riverside	6	10	13	4	6	9	48	.104
Column Total C_j	40	53	135	90	59	84	N=461	1.000

$$\chi^2 = 56.12$$

$$E(\chi^2) = 60.13$$

$$V(\chi^2) = 115.8$$

Hence, $Z = \dfrac{\chi^2 - E(\chi^2)}{V(\chi^2)} = -.37$, which is greater than -1.96,

therefore, the null hypothesis is accepted.

APPENDIX 1D: AVERAGE NUMBER OF UNLOADING PASSENGERS (Outbound afternoon trips)

Hourly Period:	12-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	Row Total R_i	$p_i=R_i/N$
Stations										
Fenway	11	9	8	10	11	10	5	8	72	.088
Longwood	2	7	1	8	4	3	5	3	33	.040
Brookline Village	7	9	6	12	13	15	11	8	81	.099
Brookline Hill	3	4	7	8	9	12	6	8	57	.069
Beacon Field	3	3	4	4	4	7	5	3	33	.040
Reservoir	6	9	8	8	12	9	6	4	62	.076
Chestnut Hill	7	6	8	8	13	7	6	5	60	.073
Newton Center	5	12	5	11	19	23	10	13	98	.119
Highland	15	5	5	9	15	12	8	9	78	.095
Eliot	3	4	3	6	8	7	2	6	39	.047
Waban	2	4	2	5	11	11	5	5	45	.055
Woodland	7	12	7	12	18	11	4	5	76	.093
Riverside	7	9	10	12	21	12	6	10	87	.106
Column Total, C_j	78	93	74	113	158	139	79	87	821	1.000

$$\chi^2 = 63.24$$

$$E(\chi^2) = 84.10$$

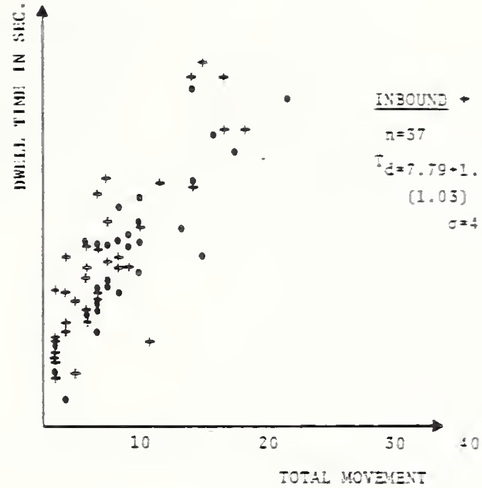
$$V(\chi^2) = 164.13$$

Hence, $Z = \frac{\chi^2 - E(\chi^2)}{V(\chi^2)} = -1.63$ which is greater than -1.96, therefore, the null hypothesis is again accepted.

APPENDIX 1E: MARKET SHARES OF PASSENGER ACTIVITIES FOR EACH STATION

	Unloading Passengers		Loading Passengers	
	Inbound Morning Trips	Inbound Afternoon Trips	Outbound Morning Trips	Outbound Afternoon Trips
Station i	P_i	P_i	P_i	P_i
Riverside	.00	.00	.00	.00
Woodland	.00	.00	.01	.00
Waban	.01	.01	.01	.00
Eliot	.00	.01	.01	.02
Highland	.01	.04	.05	.02
Newton Center	.05	.07	.06	.07
Chestnut Hill	.07	.04	.01	.07
Reservoir	.07	.18	.19	.09
Beacon Field	.01	.07	.05	.03
Brookline Hill	.08	.08	.08	.14
Brookline Village	.12	.25	.31	.14
Longwood	.43	.13	.10	.32
Fenway	.15	.12	.12	.10

APPENDIX 2: ANALYSIS OF DWELL TIME

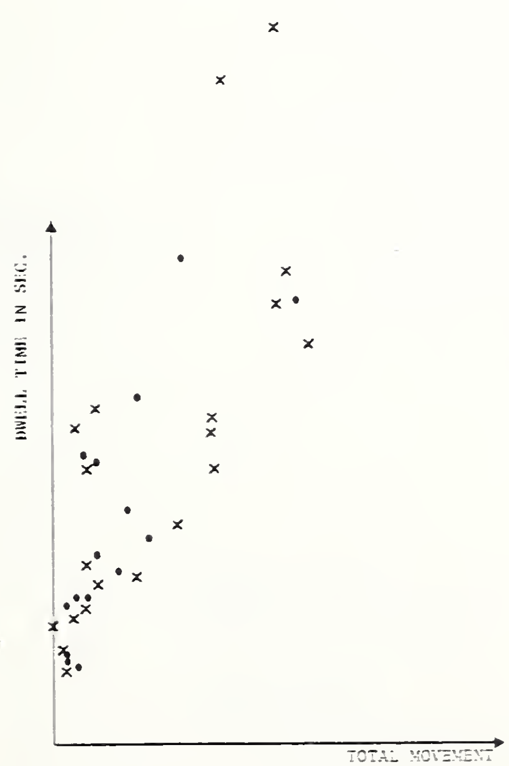


WOODLAND (PCC)

INBOUND +	OUTBOUND .	COMBINED
$n=37$	$n=28$	$n=65$ $R^2=.68$
$T_d=7.79+1.25M$	$T_d=7.54+1.10M$	$T_d=7.86+1.19M$
(1.03) (.13)	(1.27) (.13)	(.91) (.10)
$\sigma=4.72$	$\sigma=3.49$	$\sigma=4.35$

$F=2.66$

accept H_o that the regressions for the outbound and inbound trips are identical.



WOODLAND (LRV)

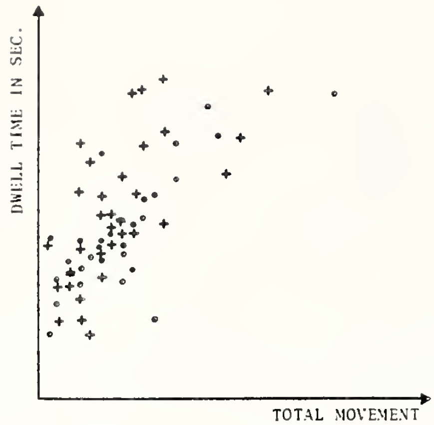
INBOUND & OUTBOUND COMBINED

$n=36$ $R^2=.62$

$T_d=11.84 - 1.61M$

(12.30) (.21)

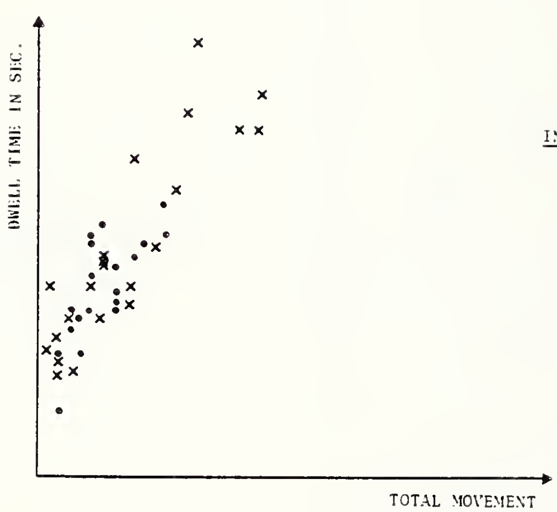
$\sigma=9.57$



HIGHLAND (PCC)

INBOUND +	OUTBOUND ·	COMBINED
n=35	n=33	n=68 R^2=.48
T_d=10.75+.89M	T_d=9.05+.83M	T_d=9.99+.85M
(1.58) (.18)	(1.19) (.13)	(1.0) (.11)
σ=4.99	σ=3.90	σ=4.56

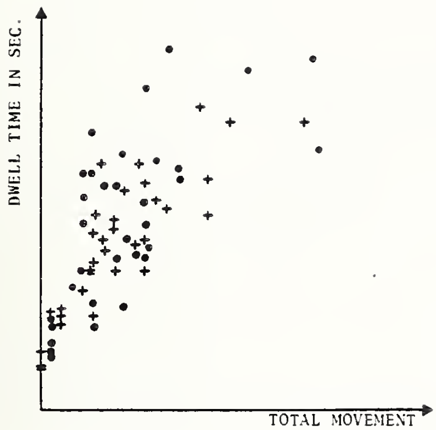
F=1.96
accept H_o that the the regressions for the outbound and inbound trips are identical.



HIGHLAND (LRV)

INBOUND AND OUTBOUND COMBINED

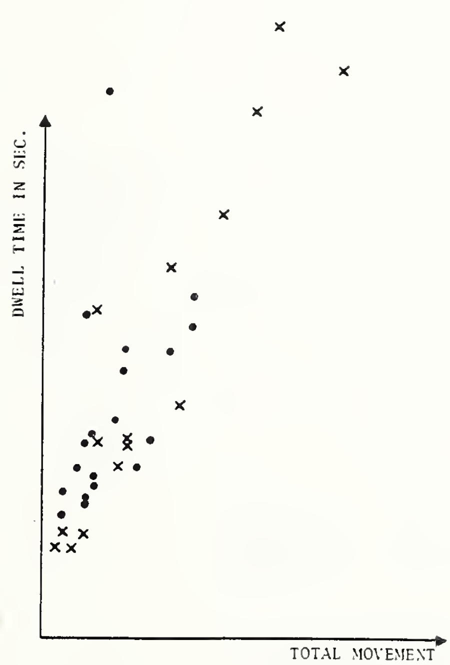
n=42
T_d=10.17 + 1.31M
(1.06) (.12)
σ =3.97



RESERVOIR (PCC)

INBOUND +	OUTBOUND •	COMBINED
n=34 R^2=.70	n=33 R^2=.44	n=67 R^2=.53
T_d=8.45+.96Mov	T_d=11.28+.85Mov	T_d=9.84+.90Mov
(1.04) (.11)	(1.73) (.17)	(1.01) (.10)
σ=3.65	σ=6.21	σ=5.11

F=1.47
accept H_o that the regressions for the outbound and inbound trips are identical.



RESERVOIR (LRV)

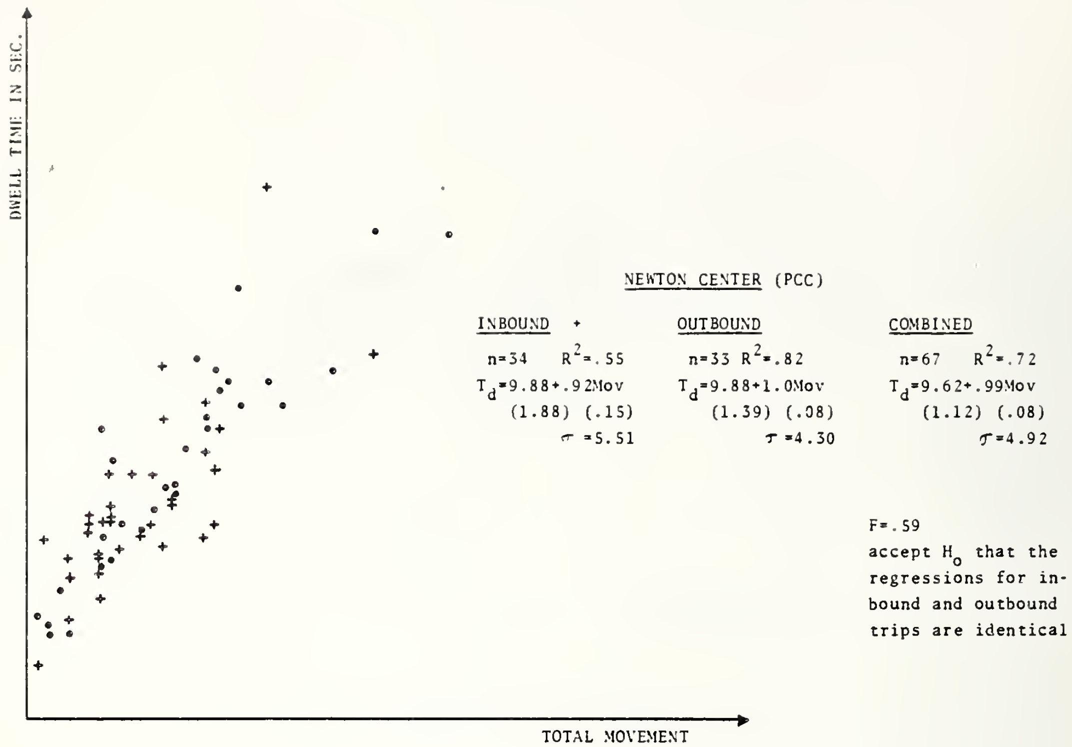
INBOUND AND OUTBOUND COMBINED

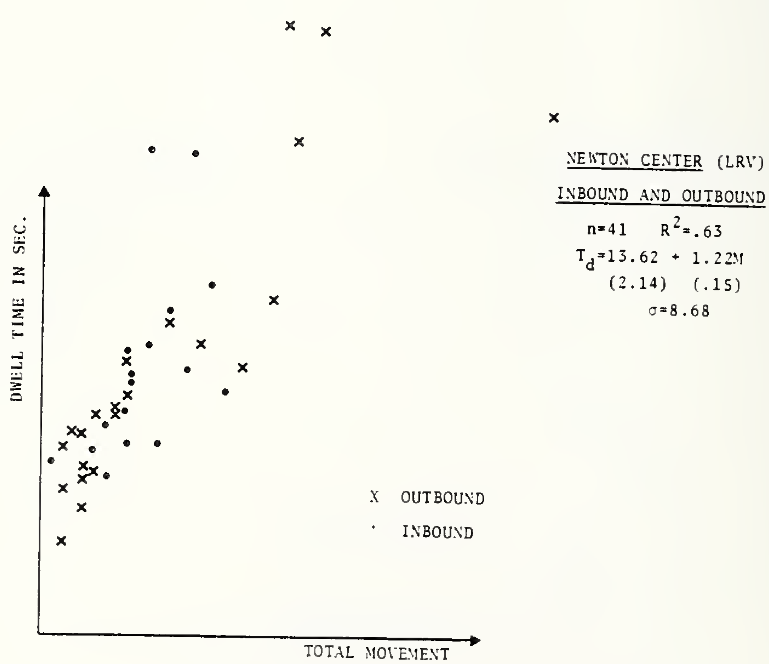
n=34 R^2=.80

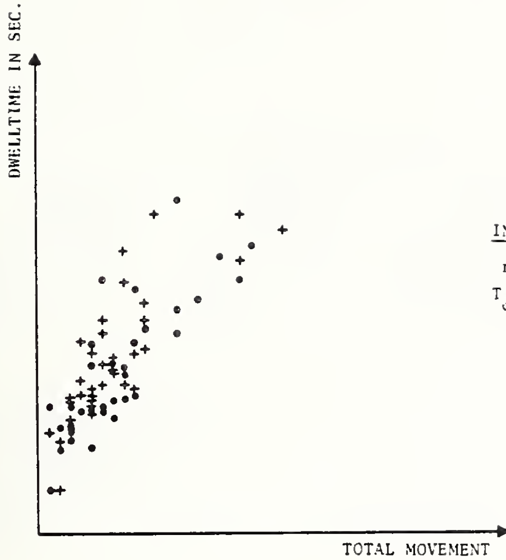
T_d=7.86 + 1.81M

(1.66) (.16)

σ=5.71


DWELL TIME IN SEC.
TOTAL MOVEMENT
NEWTON CENTER (PCC)
INBOUND +
n=34 R2=.55
Td=9.88+.92Mov
(1.88) (.15)
σ =5.51
OUTBOUND
n=33 R2=.82
Td=9.88+1.0Mov
(1.39) (.08)
σ =4.30
COMBINED
n=67 R2=.72
Td=9.62+.99Mov
(1.12) (.08)
σ=4.92
F=.59
accept Ho that the regressions for in-bound and outbound trips are identical

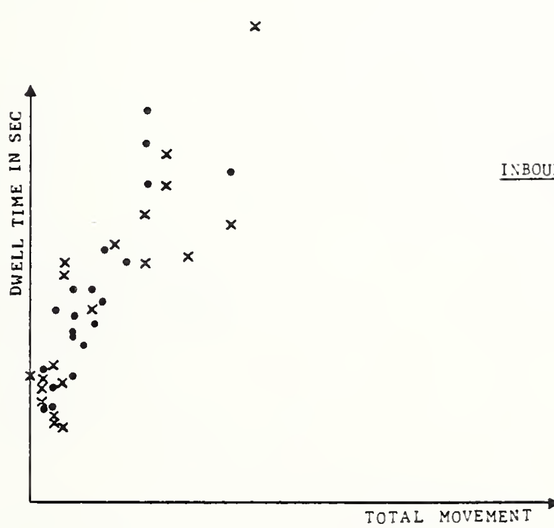

DWELL TIME IN SEC.
TOTAL MOVEMENT
X OUTBOUND
· INBOUND
NEWTON CENTER (LRV)
INBOUND AND OUTBOUND
n=41 R2=.63
Td=13.62 + 1.22M
(2.14) (.15)
σ=8.68



CHESTNUT HILL (PCC)

INBOUND +	OUTBOUND ·	COMBINED
n=34 R^2=.65	n=35 R^2=.69	n=69 R^2=.66
T_d=9.29+1.03M	T_d=7.61+1.05M	T_d=8.43+1.04M
(1.16) (.13)	(1.10) (.12)	(.80) (.09)
σ=3.74	σ=3.58	σ=3.69

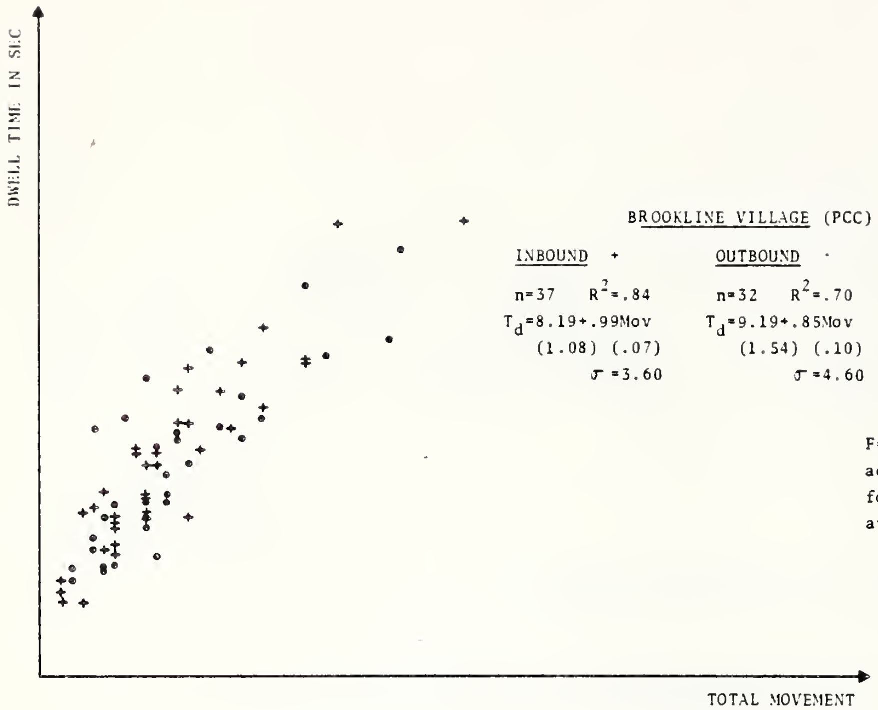
F=1.56
accept H_o that the regressions for the outbound and inbound trips are identical.



CHESTNUT HILL (LRV)

INBOUND AND OUTBOUND COMBINED

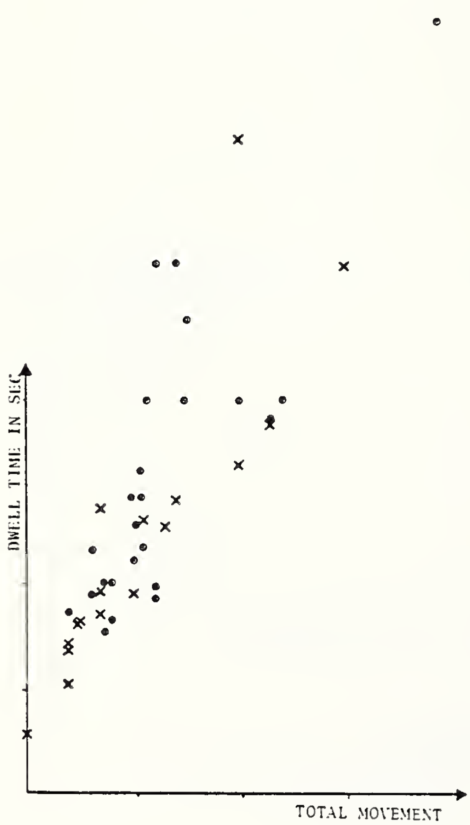
n=39 R^2=.74
T_d=10.1 x 1.38M
(1.12) (.13)
σ=4.48



BROOKLINE VILLAGE (PCC)

INBOUND +	OUTBOUND ·	COMBINED
n=37 R^2=.84	n=32 R^2=.70	n=69 R^2=.77
T_d=8.19+.99Mov	T_d=9.19+.85Mov	T_d=8.65+.93Mov
(1.08) (.07)	(1.54) (.10)	(.91) (.06)
σ=3.60	σ=4.60	σ=4.09

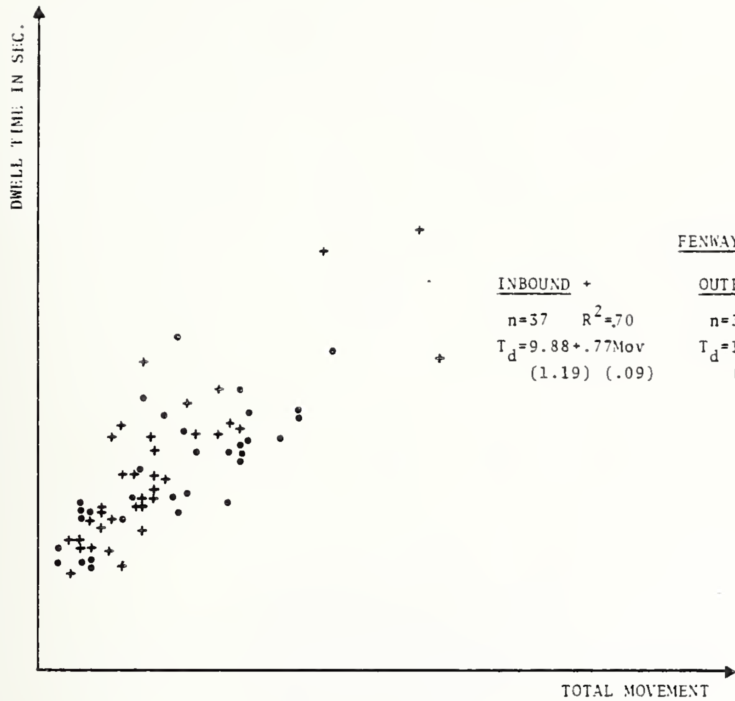
F=.97
accept H_0 that the regressions for inbound and outbound trips are identical



BROOKLINE VILLAGE (LRV)

INBOUND AND OUTBOUND COMBINED

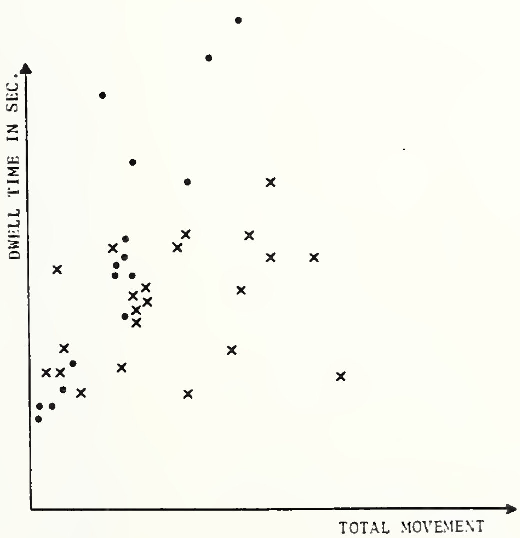
n=39 R^2=.69
T_d=9.81 + 1.53M
(2.40) (.17)
σ=8.13



FENWAY (PCC)

INBOUND +	OUTBOUND ·	COMBINED
n=37 R^2=.70	n=37 R^2=.56	n=74 R^2=.63
T_d=9.88+.77Mov	T_d=11.25+.59Mov	T_d=10.45+.68Mov
(1.19) (.09)	(1.26) (.09)	(.87) (.06)

F=1.55
accept H_o that
the regressions for
outbound and inbound
trips are identical.



FENWAY (LRV)

(INBOUND AND OUTBOUND COMBINED)

*The data vary too much for any estimation of linear relationship between the dwell time and the total movement.

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