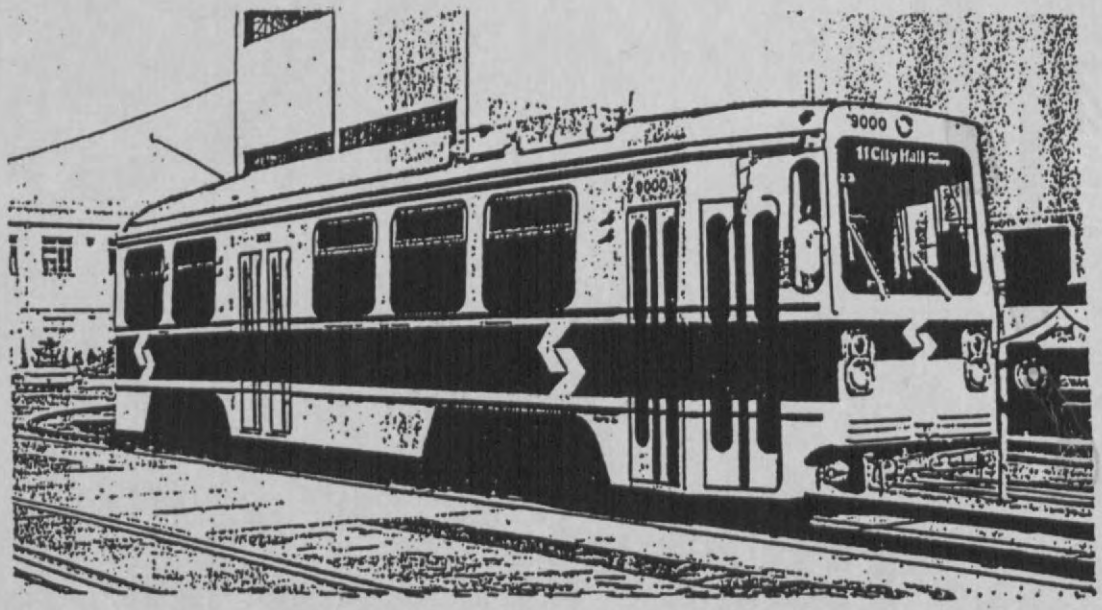
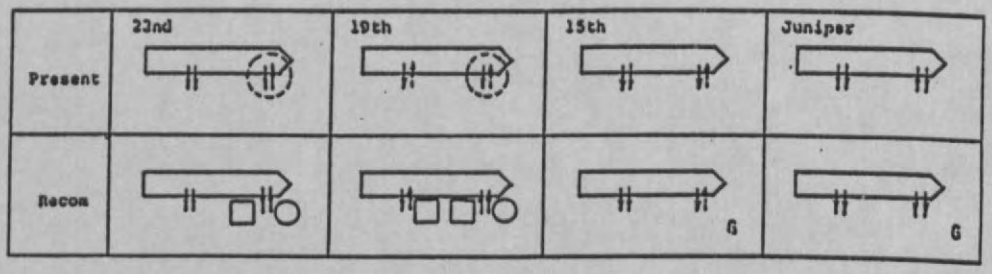
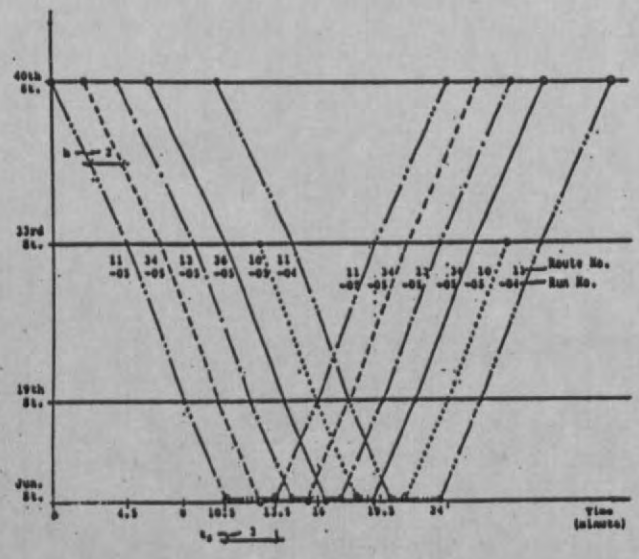


RECOMMENDATIONS FOR IMPROVEMENT OF GREEN LINES SUBWAY OPERATIONS





Report for the
Southeastern Pennsylvania
Transportation Authority
SEPTA

Prepared by the
University of Pennsylvania
and
University of Delaware

Philadelphia
June 1990

RECOMMENDATIONS FOR

IMPROVEMENT OF GREEN LINES

SUBWAY OPERATIONS

Report for the

SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY

SEPTA

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1. INTRODUCTION

Radial travel between West Philadelphia and Center City (CBD) is served by the Blue (Market-Frankford) Line, five streetcar routes known as the Green (Subway-Surface) Line or Green Lines, and several bus routes. The five streetcar routes converge at 40th and 36th Streets and enter a single subway tunnel which joins the alignment of the Blue Line at 33rd Street and follows it to the City Hall. Four of the radial streetcar (locally referred to as "trolley") routes serving West Philadelphia - 11, 13, 34, and 36 - converge at 40th Street and enter the tunnel. The fifth, Route 10, enters the same tunnel through a separate ramp at 36th Street. The tracks layout of those routes is shown in Figure 1.1.

1.1 West Philadelphia Streetcar Lines Network and Its Significance

Similar to light rail transit lines in many other cities (Boston, San Francisco, Cologne and Pittsburgh), these five lines combine street operations with fully separated right-of-way operation in the subway. The subway section provides the Green Lines with full separation from external influences, but its operation is unreliable because of high frequency created by the joint operation of different routes and the irregularity of arrivals of cars from the routes which run in the streets.

Heavy passenger volumes, particularly during the peak hours, tend to propagate delays which not only delay passengers in the tunnel, but also disturb schedules of all five lines. Low reliability and delays in the tunnel have caused dissatisfaction of the travelling public and increased operation costs for SEPTA.

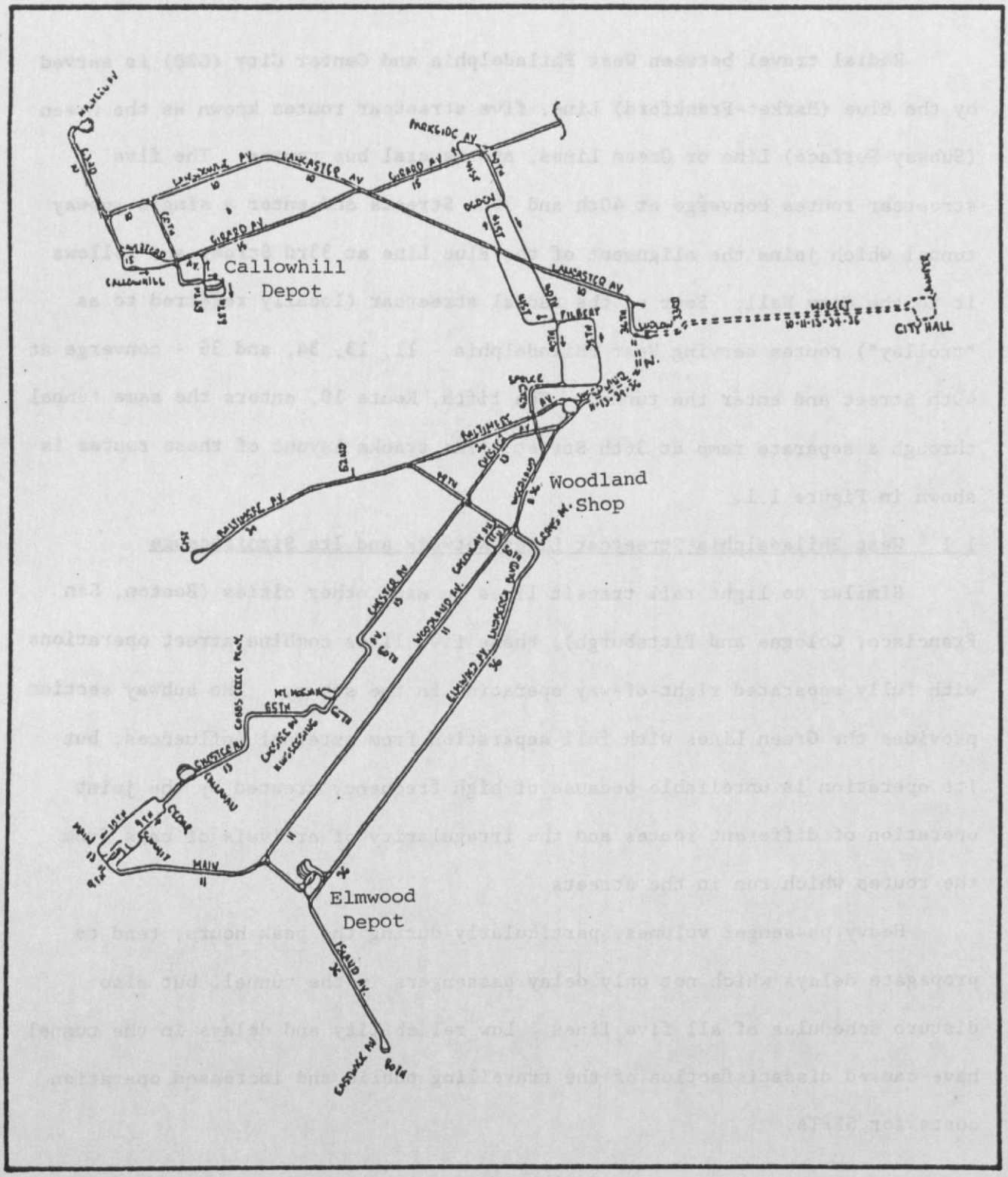


Figure 1.1 Layout of Green Lines and contiguous tracks

1.2 Layout and Operation of the Subway

The streetcar tunnel was opened in several stages. Its initial section, between City Hall and 23rd Street, was opened in 1905; sections farther to the west were opened in stages between 1933 and 1956, bringing the subway to its present state. The present subway layout is shown in Figure 1.2.

Designed for unidirectional vehicles, the subway tunnel has no crossovers, and only one short siding. Geometric standards are very low: there are several very sharp curves which require slow travel. In addition, there are numerous signals which further limit average running speeds.

In spite of these limitations, the subway allows relatively high operating speeds, frequency and reliability when compared with the route segments in street running.

Maximum frequency operated in the subway during the 1970's was considerably lower than the frequencies achieved several decades ago. With the introduction of the new Kawasaki cars, ridership on these lines has grown by over 30%. This required gradual increases in service frequencies, which led to operational problems, mainly delays and subsequent reduction of speed and reliability of service.

The purpose of this project is to analyze present operations of the Green Lines in the subway and develop solutions to the operational problems, so that the great potential of the subway for high performance and an attractive level of service for passengers can be fully realized.

Figure 1.2 Stations in the Green Line Subway

2. PRESENT OPERATION OF THE SUBWAY

2.1 Subway Tunnel and Track Layout and Alignment

Track layout of the Green Lines' subway section is shown in Figure 2.1. Geometric elements of the tracks are presented in Table 2.1 and Figure 2.2. As can be seen from these exhibits, the largest segment of the tracks, from 32nd to 15th Street, is generally straight, but the alignment around City Hall has a number of sharp curves with very limited visibility. Similarly, the tunnel and track alignment west of 32nd Street was designed to follow street alignments on the surface, and, therefore, has again several very sharp horizontal curves.

The curves around City Hall, on either side of 33rd Street Station and at the convergence of tracks from the Route 10 Portal (at 34th Street and 36th Street) are very sharp, so that cars must negotiate them at very low speeds, mostly below 15 mph. These alignment "bottlenecks" reduce the average running speed in the subway.

The gradient in the subway tunnel reaches 5.5% on the ramps from the 40th Street Portal and 5.0% under the Schuylkill River. These gradients, however, present no significant operating problems because they are protected from adverse weather and because the cars have enough power to maintain speeds of 30-40 mph.

2.2 Stations

Since the Green Lines are designed for single-directional vehicles with steps for boarding and doors on the right side only, all eight stations have low-level lateral platforms. Station layouts and dimensions (widths and lengths) vary considerably. The platforms in all stations are long enough to accommodate at least two cars. The longest stations - Juniper Street, 15th

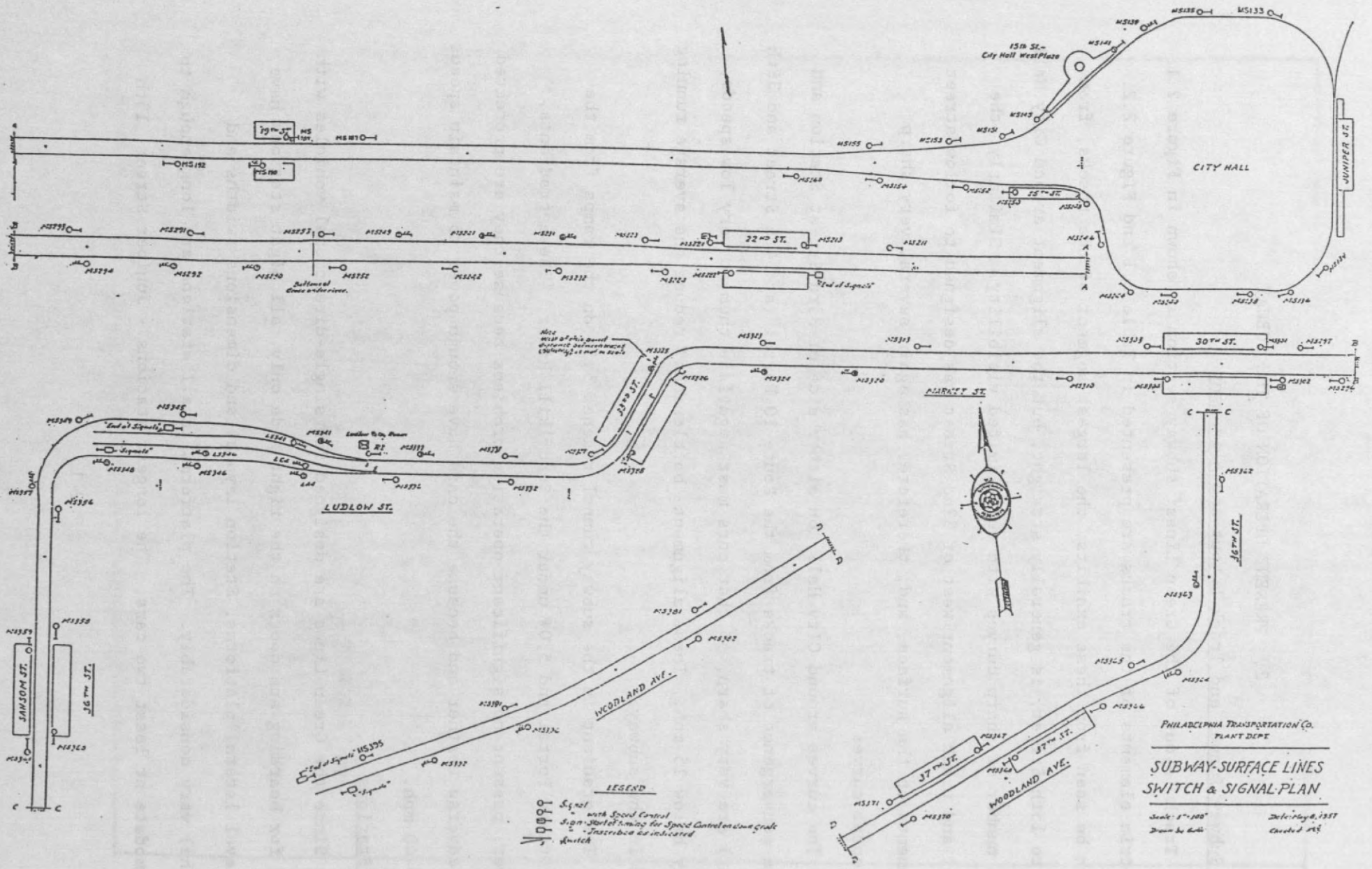


Figure 2.1 Tunnel track layout and signals

Table 2.1 Geometric Elements of the Green Line Tunnel

Stations Old	Stations New	Location/Object	Gradient Level	Radius
217+88	0+00	Potal Ent.	-.055	S
217+65	0+13	G.I.	-.018	
212+72	5+6	G.I.	L	
205+71	12+17	G.I.		
199+70	18+18	beg. 37th plat.		
197+50	20+38	end 37th plat.		
	23+15	beg. of curve		108'
	24+80	end of curve		S
24+33	31+25	beg. 36th plat.		
22+13	33+45	end of 36th plat.		
21+54	34+03	G.I.	+.030	
	37+33	beg. of curve		88'
18+00	37+47	G.I.	L	
	38+73	end of curve		S
15+90	39+46	G.I.	-.022	
5+37	49+99	G.I.	L	
	50+96	beg. of curve		108'
3+63	52+03	beg. of 33rd plat.		
	52+18	end of curve		S
	53+95	beg. of curve		93'
1+49	54+17	end of 33rd plat.		
167+78	54+91	end curve + G.I.	-.058	S
163+75	58+95	G.I.	L	
156+42	66+28	beg. 30th plat.		
153+89	68+81	end plat + G.I.	-.050	
144+29	78+41	G.I.	+.050	
135+45	87+25	G.I.	L	
134+63	88+07	beg. 22nd St. plat.		
132+51	90+19	end 22nd St. plat.		
120+15*	102+56	beg. 19th St. plat.		
119+18*	103+53	end 19th St. plat.		
101+72*	120+99	beg. 15th St. plat.		
99+88*	122+82	end 15th St. plat.		
	131+23	beg. Juniper plat.		
	134+54	end Juniper plat.		
	141+35	beg. 15th St. plat.		
	143+56	end 15th St. plat.		
119+18*	162+30	beg. 19th St. plat.		
120+15*	163+27	end 19th St. plat.		
132+51	174+67	beg. 22nd St. plat.		
134+63	176+79	end 22nd St. plat.		
135+45	177+60	G.I.	-.050	
144+29	186+45	G.I.	+.050	

S - Straight Alignment (R=infinity)
L - Level Alignment (Grad.=0%)

Stations			Gradient	
Old	New	Location/Object	Level	Radius
---	---	---	---	---
153+89	196+05	G.I.+ beg. 30th St.	L	
156+42	198+57	end 30th St. plat		
167+75	205+91	G.I.	+.058	
	209+88	beg. of curve		93'
	210+40	G.I.	L	
1+32	210+85	end curve and beg. 33rd plat		S
	213+09	beg. of curve		93'
	213+15	end 33rd St. plat.		
	213+95	end of curve		S
5+37	214+81	G.I.	+.022	
	225+39	G.I.	L	
	226+17	beg. of curve		93'
	227+73	end of curve		S
22+13	231+60	beg. of 36th St. plat.		
24+33	233+80	end 36th St. plat.		93'
	240+29	beg. of curve		S
	240+80	end of curve		
200+14	246+79	beg. of 37th St. plat.		
202+34	248+99	end 37th St. plat.		
205+71	252+36	G.I.	+.018	
212+72	259+37	G.I.	+.055	
217+65	264+30	G.I.	L	
217+88	264+53	Potal		

S - Straight Alignment (R=infinity)
L - Level Alignment (Grad.=0%)

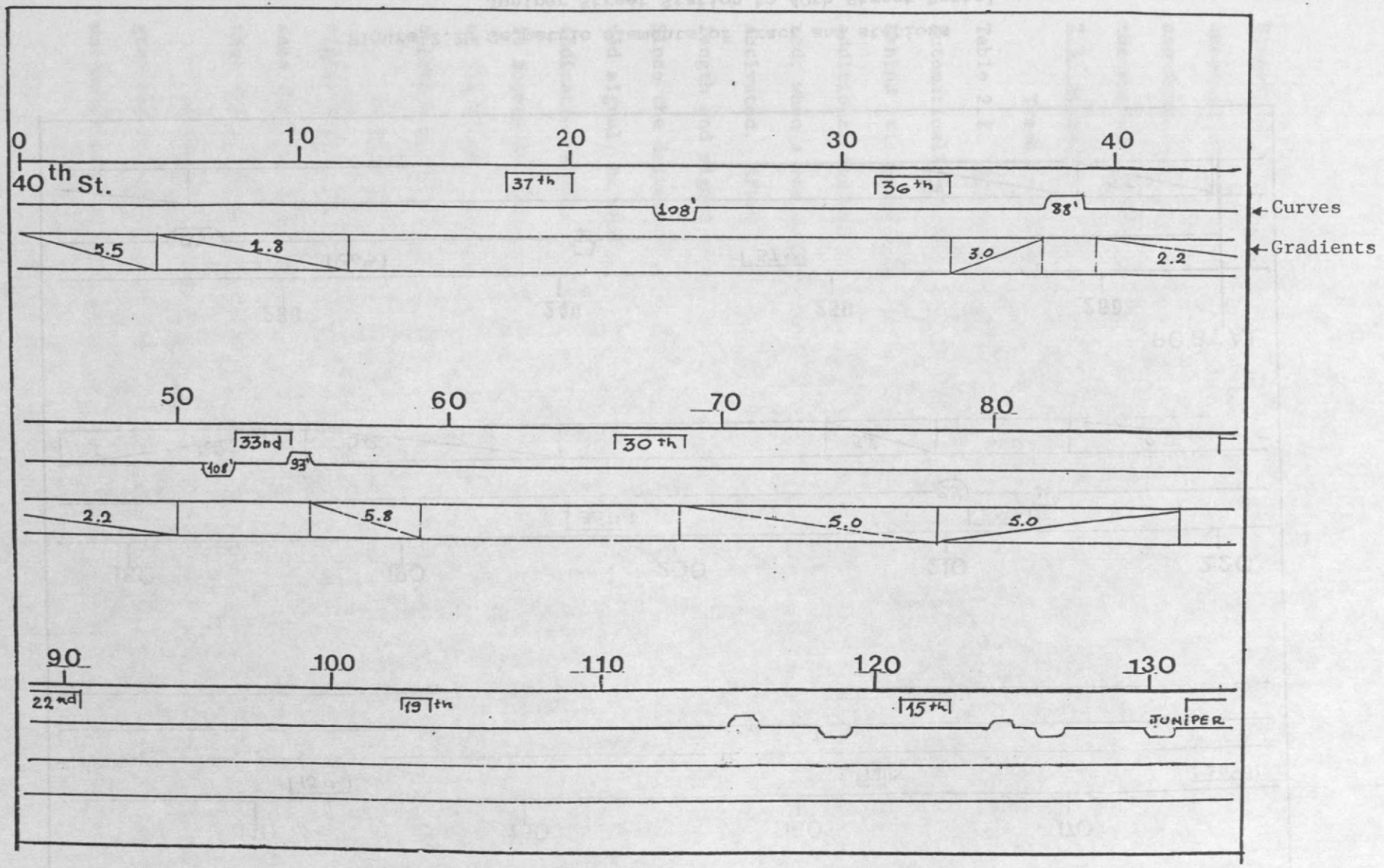


Figure 2.2a Geometric elements of track and stations

40th Street Portal to Juniper Street Station

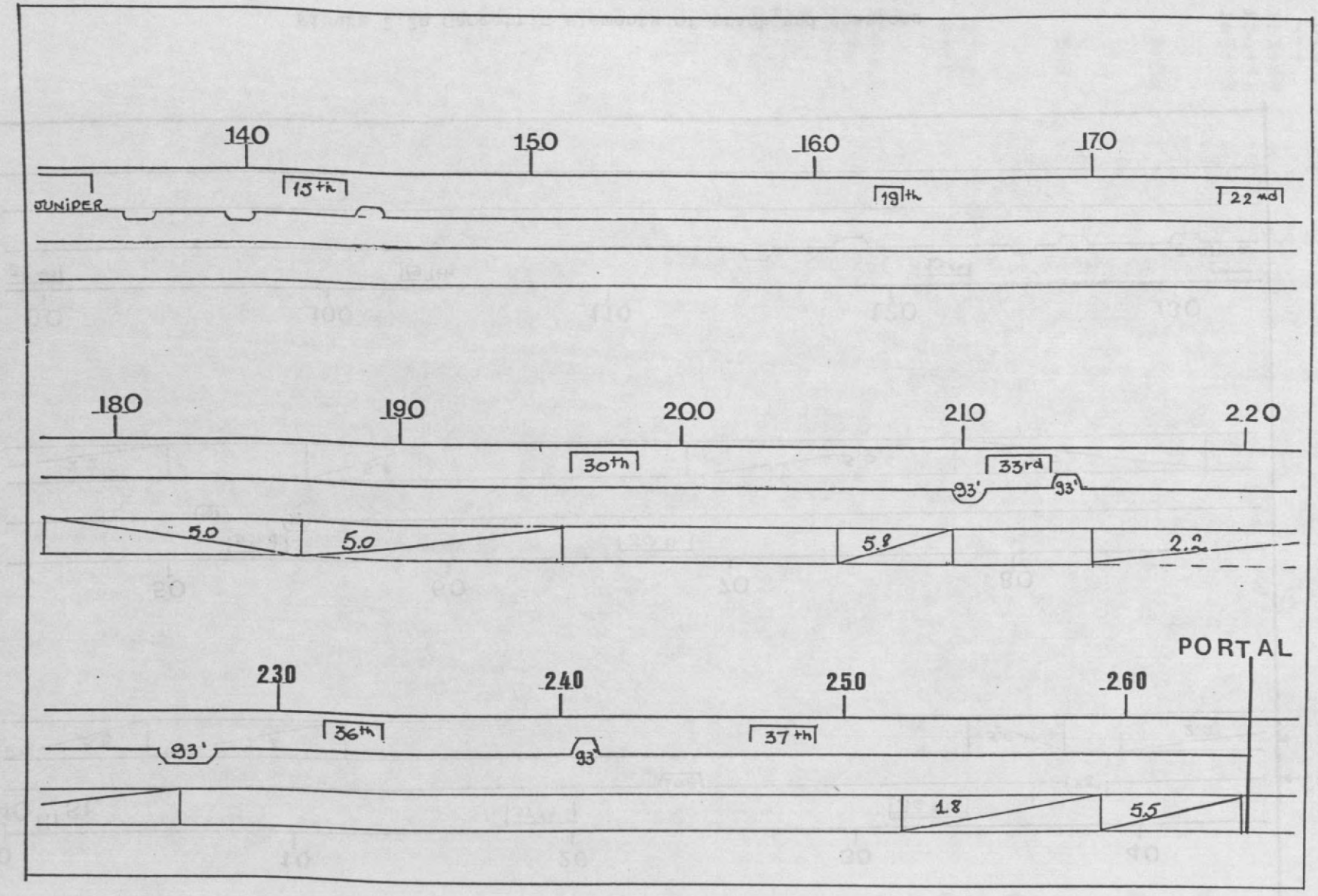


Figure 2.2b Geometric elements of track and stations

Juniper Street Station to 40th Street Portal

Street and 30th Street in both directions - have lengths sufficient to accommodate 4 cars for simultaneous boarding and alighting. Platform widths can adequately accommodate present passenger volumes, with the exception of the extreme locations in Juniper Street Station and in 19th Street Station.

2.3 Signals

Tracks are equipped with wayside signals of two types, as indicated in Table 2.2. Occupancy signals are conventional block signals which automatically protect each car with two (one red and one yellow) signals behind it. Speed signals also operate as block signals, but have an additional feature for controlling vehicle speeds. Their normal indication is red; when a car enters the block on the approach to a signal, a relay is activated. After a fixed interval (3 to 9 seconds, depending on the block length and signal location), the signal changes to yellow or green aspect. Since the driver must operate the vehicle so that he/she could stop it at a red signal, he/she is forced to apply brakes until a yellow or a green indication appears. Thus, through a setting of the relay timer, the vehicle is forced to spend at least a predetermined time interval to travel the length of the block. In this way, the speed signals limit the average speed of the approaching vehicles.

In practice, however, many drivers do not follow this driving regime rigorously. When the track beyond a signal is clearly visible, a driver who sees that the next block is empty can maintain speed because experience shows that the signal will change to green aspect before he/she reaches it.

Locations and spacings of signals vary depending on track alignment, gradient and station locations. However, on some sections, block lengths are uneven without apparent reasons. For example, on a straight alignment section

Table 2.2 Signal locations, types and timing

Signal Desig.	Station	Delay Time in Sec.	Signal Desig.	Station	Delay Time in Sec.
MS 392	2+50	4.50	MS 141	141+08	
MS 390	4+96	5.50	MS 145	143+61	
MS 382	9+60		MS 151	144+67	
MS 370	15+23		MS 153	146+05	
MS 368	18+01		MS 155	147+96	
MS 366	20+46		MS 187	160+31	
MS 364	22+37	5.00	MS 189	162+20	3.50
MS 362	27+63		MS 211	172+38	
MS 360	31+09		MS 213	174+51	
MS 358	33+62		MS 221	176+89	
MS 356	36+43		MS 223	178+37	
MS 348	38+71	7.00	MS 231	180+35	3.50
MS 346	40+78	5.00	MS 241	182+39	4.50
LA 4	43+42		MS 249	184+41	4.50
MS 336	45+83		MS 253	186+27	
MS 332	48+65		MS 291	189+48	
MS 328	51+82	7.50	MS 293	192+32	
MS 326	54+20		MS 297	194+94	
MS 324	56+38	6.00	MS 301	195+93	
MS 320	58+37	5.00	MS 303	198+66	
MS 310	63+80		MS 313	204+21	
MS 304	66+10		MS 323	208+01	
MS 302	68+89		MS 325	210+74	7.25
MS 296	70+38		MS 327	213+40	
MS 294	72+39	4.50	MS 331	215+69	
MS 292	74+38	4.50	MS 333	217+78	5.00
MS 290	76+33	5.50	R 2	219+06	
MS 252	78+45		MS 341	220+43	
MS 242	81+18		MS 345	223+80	
MS 232	84+18		MS 349	226+20	
MS 224	86+72		MS 357	228+14	9.00
MS 222	87+94		MS 359	231+42	
MS 192	100+44		MS 361	233+86	
MS 190	102+43	4.00	MS 363	239+34	4.75
MS 160	115+45		MS 365	242+34	
MS 154	117+52		MS 367	246+60	
MS 152	119+60		MS 371	249+03	
MS 150	120+85		MS 381	254+05	
MS 148	122+91		MS 391	259+27	
MS 146	124+10		MS 395	260+92	
MS 144	125+41				
MS 140	126+35				
MS 138	128+23				
MS 136	129+20				
MS 134	130+28				
MS 133	137+14				
MS 135	138+89				
MS 139	140+30	6.00			

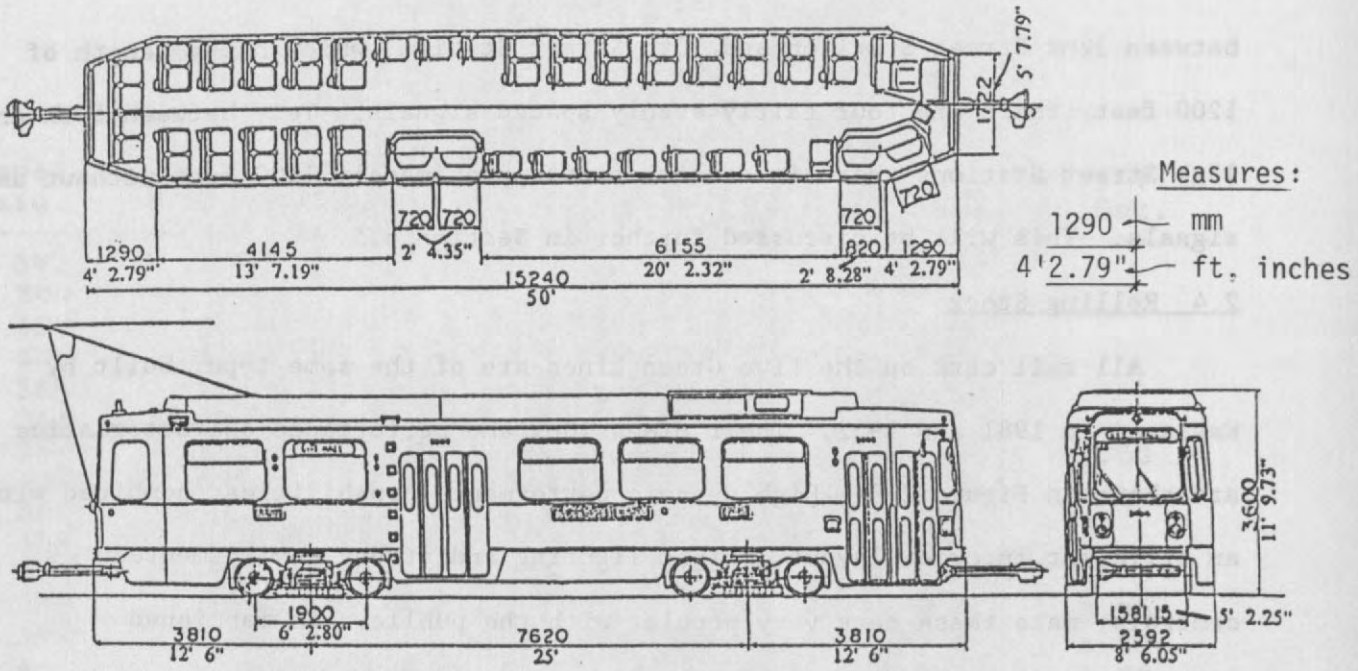
between 32nd Street Statiion and 30th Street Station, which has a length of 1200 feet, there are four fairly evenly spaced signals. Yet, between 19th and 15th Street Stations there is a section of approximately 1500 feet without any signals. This will be discussed further in Section 4.5.

2.4 Rolling Stock

All rail cars on the five Green Lines are of the same type, built by Kawasaki in 1981 and 1982. Their dimensions and performance characteristics are shown in Figure 2.3. High dynamic performance capabilities, combined with an efficient interior layout, bright lighting and strong environmental controls, make these cars very popular with the public. As mentioned previously, introduction of these cars resulted in a substantial increase of the Lines' ridership, so that service frequencies had to be increased. The resulting operation with shorter headways began to adversely impact the speed and reliability of service.

A major drawback of these vehicles is their limited capacity. At a time when virtually all cities around the world were purchasing articulated cars, SEPTA opted for the same vehicle design concept and dimensions as the cars built between the 1920's and 1950's had. While the Kawasaki cars are equipped for the multiple-unit (MU) operation, their long overhangs make such operation very complicated on the alignments with sharp curves, such as in the subway and on some outlying sections of the Green Lines.

Another obsolete feature of the Kawasaki cars is the use of trolley poles instead of pantographs. This is not an acute problem because trolley poles do not often jump off the wire in the tunnel; however, when one does, it can cause a major delay, and even damage, affecting services on all five routes. Replacement of the trolley poles by more reliable and practical



Car numbers	9000-9111
Weight	57,882 lbs (26,221 kg)
Seating capacity	51
Max. acceleration rate	3.0 mphps (1.3 m/s^2)
Max. speed on level	50 mph (80 km/h)
Max braking rate	4.0 mphps (1.8 m/s^2)
Power collection	trolley pole
Propulsion	4 DC Series motors, electronic chopper
Electrical systems	600 VDC primary, with secondary systems 230 Volts AC 3 phase, 37.5 volts DC, 12 volts DC
Braking systems	dynamic, air disc on axle and magnetic/track

Figure 2.3 SEPTA Kawasaki unidirectional light rail vehicle

pantographs, which has been done in most cities around the world, should also be planned for SEPTA's streetcar lines.

2.5 Schedules

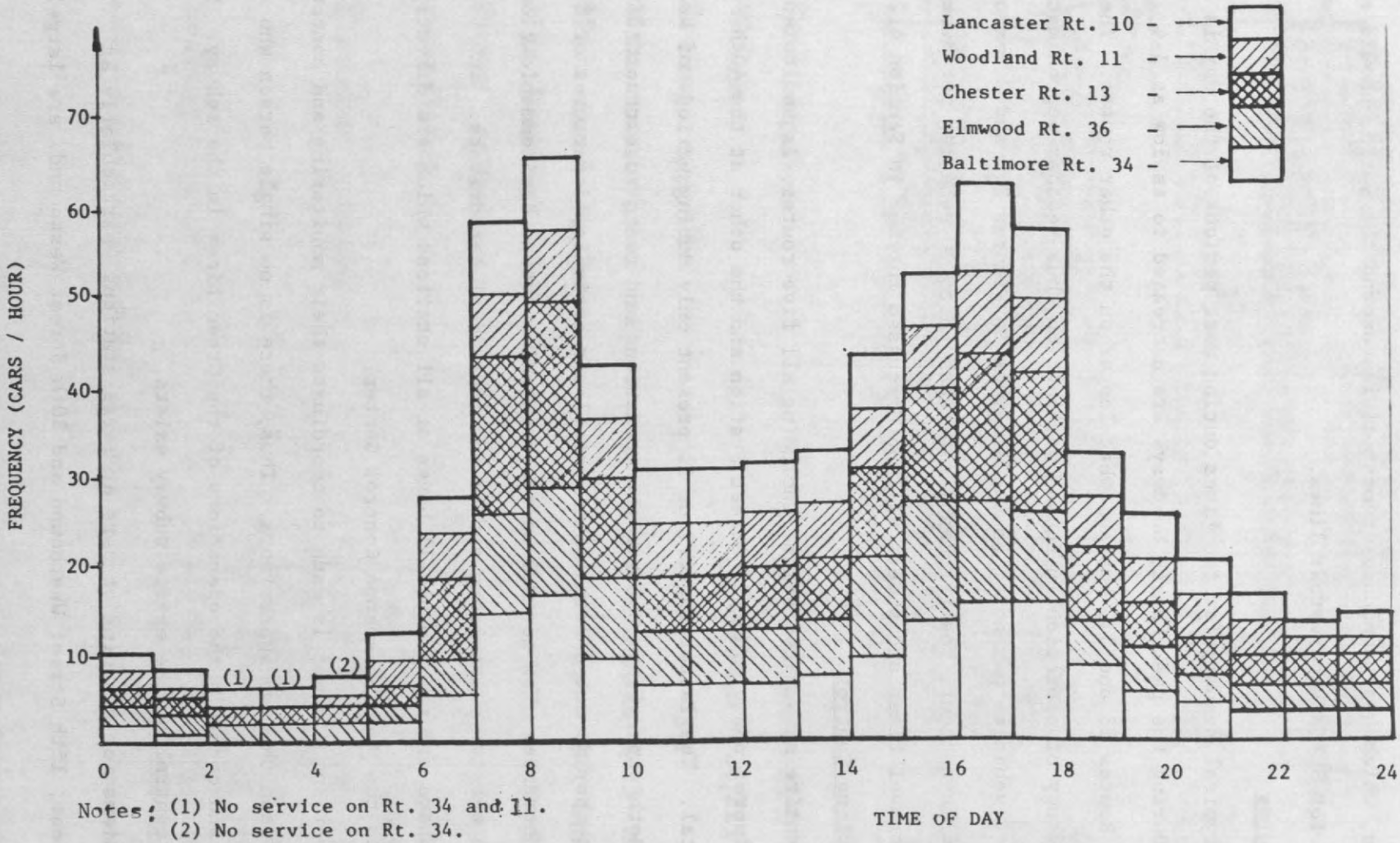
The typical headway for the Lines during most periods of the day is 10 minutes. During the peak hours, headways are decreased to as low as 3-4 minutes on Routes 13 and 34, but somewhat longer on the other routes. The joint frequency of operation in the subway section thus reaches approximately 55 scheduled vehicles per hour, as the diagrams in Figures 2.4 and 2.5 show. When some delays occur, the frequency can reach up to 70 vehicles per hour. Scheduled travel times and speeds will be discussed further in Section 4.2.

2.6 Operations Control

The entire subway operation, including all five routes, is monitored by two supervisors: one at Juniper Street Station and the other at the 40th Street Portal. The latter supervisor is present only during periods of heavy traffic. Both supervisors observe the operations and react to extraordinary events, but they do not continuously control car arrivals, departures or schedule adherence. The control center at Wyoming Avenue has communications channels to the two supervisors and to the individual car drivers. In addition, there are emergency call boxes at all stations which are directly connected to the Wyoming Avenue Control Center.

However, no attempt is made to coordinate their monitoring and control actions between the two supervisors. Thus, there is no single person who supervises and controls the operations of the Green Lines in the subway. No integrated control of the entire subway exists.

Locations for stopping of cars at large stations, particularly at Juniper Street, 15th Street Westbound and 30th Street Westbound, are largely



Notes: (1) No service on Rt. 34 and 11.
(2) No service on Rt. 34.

Source: SEPTA Employee's timetable effective September 12, 1988 (for Rts. 10, 34) and February 12, 1988 (for Rts. 11, 13, 36).

Figure 2.4 Service frequency by line and time of day

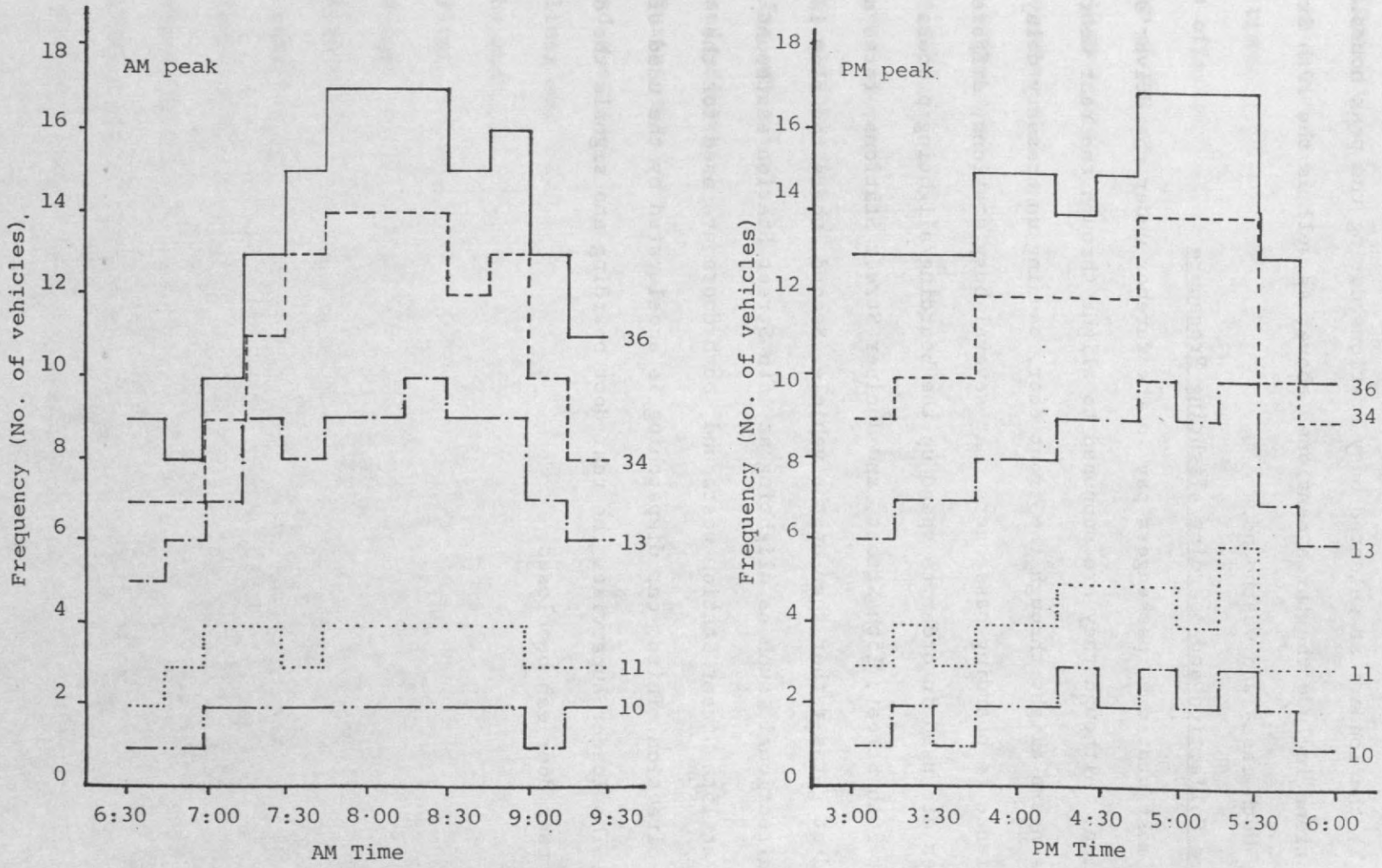


Figure 2.5 Number of cars scheduled at Juniper Street Station during 15-minute intervals

selected by individual drivers. The only assistance the drivers receive is provided by the loaders at selected busy stations during the peak hours. These stations include the three mentioned above, as well as the 19th Street Stations, both east- and westbound.

2.7 Fare Collection and Boarding/Alighting Procedure

At most stations, passengers pay in the farebox under the driver's supervision. Although they are supposed to alight through the rear door only, many passengers alight through the front door, causing unnecessary delays and inconvenience to boarding passengers. At several busy stations, different procedures are used in order to speed up the boarding/alighting process. First, at 30th Street, 15th Street, and Juniper Street Stations, fares are collected at gates rather than on the vehicle. Second, where the flow is heavily directional, such as alighting at 15th Street Station eastbound and boarding at 15th Street Station westbound, both doors are used for the dominant direction. Third, car dispatching is accelerated by the used of a "loader". The loader supervises the rear door boarding and signals the driver when the rear door can be closed.

3. PASSENGER VOLUMES AND TRAVEL PATTERNS

3.1 Travel Patterns on the Routes

As typical radial transit routes, the five Green Lines predominantly serve travel between Center City and West Philadelphia. These five branching routes offer excellent coverage of the rather large Western/Southwestern segment of Philadelphia's inner suburbs.

With increasing auto ownership and decreasing manufacturing employment in the served area, the ridership on these lines decreased rather steadily from a high point in the post-war period to a low point in the late 1970's.

A major improvement of these routes occurred in 1956 when the subway tunnel was extended westward under the Schuylkill River to the present two portals, at 36th and 40th Streets. Rolling stock remained the same (old PCC cars) for several decades. Rampant graffiti and vandalism contributed to the decreased ridership on these routes for many years.

During the last ten years, several major developments occurred which have had a strong, mostly positive influence on the quality of service of these lines and which have resulted in the increased ridership. The following were the most important developments:

First, subway stations were cleaned and renovated.

Second, the new Kawasaki cars were introduced. They are much more attractive than the old PCC cars because of their better appearance, better riding comfort, better lighting, and their good heating and air conditioning.

Third, SEPTA reestablished full control of the facilities: graffiti and other visual vandalism have been eliminated from the stations and vehicles. New rolling stock and cleaned, modernized stations have had an extremely strong positive impact on transit ridership.

Fourth, SEPTA introduced transit passes which make short trips much more attractive than before. In addition, transferring among all rapid transit and the Green Lines has been made free, so that riders of other transit modes can use the Green Lines for transferring to and from the City Hall and 30th Street Stations.

Fifth, a large number of office buildings have been built in the Market Street West area which is well served by the Green Lines at the 19th Street and 22nd Street Stations.

As a consequence of the last two developments, there is now a considerable volume of passengers who get to and from the City Hall area by rapid transit and regional rail lines and then use the Green Lines for access to the Market Street West and university campuses area. This category of trips has been added to the two more traditional ones: travel between West Philadelphia and the CBD, and relatively short intracity trips within center city, such as between City Hall, Market Street West, 30th Street Station and the campuses of the University of Pennsylvania and Drexel University.

As a result of all these developments, but primarily due to the introduction of new rolling stock, the Green Lines have experienced an increase in ridership of over 30% since the early 1980s. This increase has required increased service frequencies and longer station standing times which, in turn, require operational improvements.

3.2 Ridership by Line, Station, and Time of Day

The majority of passengers on the Green Lines either board or alight at one of the Center City stations. Figure 3.1 shows boarding and alighting volumes at stations by line, while Figure 3.2 shows boarding and alighting variations by time of day. As can be seen from both Figures, 3.1 and 3.2,

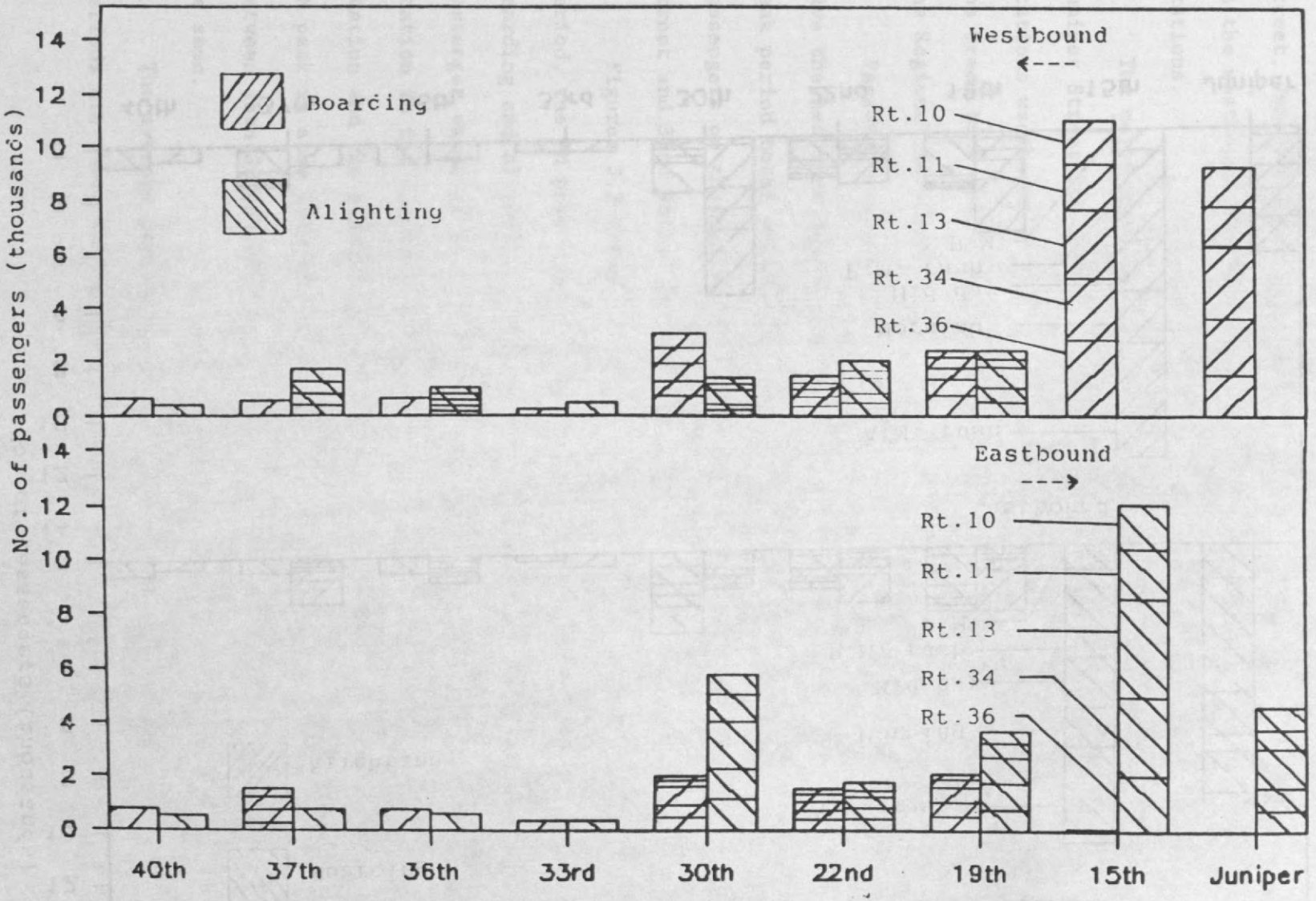


Figure 3.1 Daily passenger boardings/alightings at stations by line

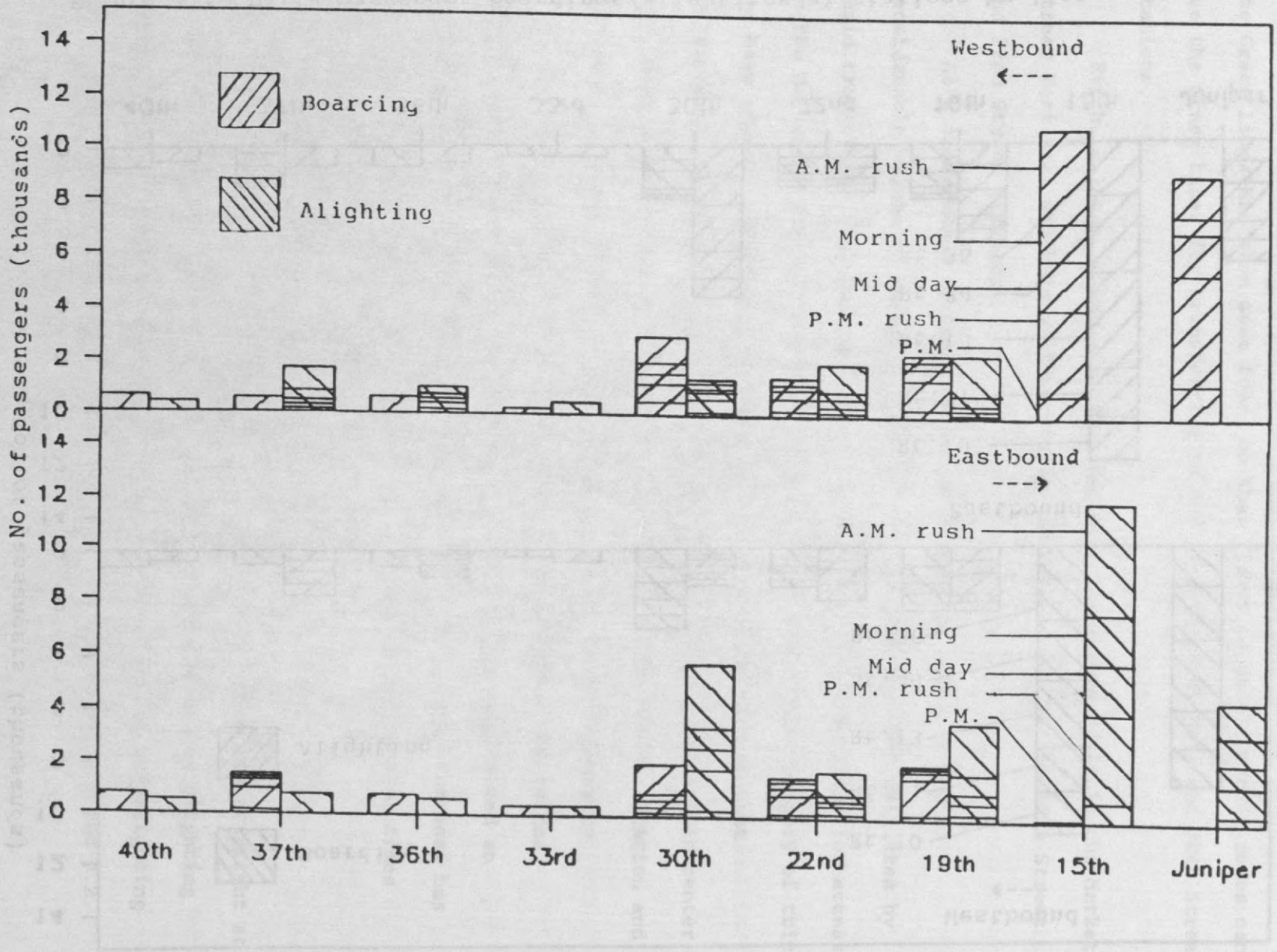


Figure 3.2 Passenger boardings/alightings at stations by period of day

most eastbound passengers alight at 15th Street; this volume is by far the largest among all stations. The next heaviest alighting volumes occur at 30th Street, Juniper Street and 19th Street Stations, in close sequence. Alighting in the westbound direction is rather heavy only at 19th Street and 22nd Street Stations.

The major boarding volumes occur in the westbound direction at 15th and Juniper Street Stations. These are followed by 30th, 19th and 22nd Street Stations westbound as well as eastbound, the latter being passengers who use the Green Line mostly for access to the Broad and Market Street Subways and the Regional Rail Lines.

Passenger volumes vary somewhat among the five lines. Routes 13 and 36 have the heaviest volumes, while Route 10 serves the lowest ridership. The peak period total volumes for all five lines together reach approximately 9000 passengers on the maximum load section, which is usually between the 36th Street and 33rd Street Stations.

Figures 3.3 through 3.5 show passenger volume profiles for the AM peak period, the PM peak period and the entire day. These profiles also show boarding and alighting volumes at each station, so that the intensity of passenger exchange at each station can be seen. The predominant alighting station in the eastbound direction in the AM peak is clearly 15th Street Station and the predominant boarding station in the westbound direction in the PM peak is also 15th Street Station. The collection/distribution of trips between 15th Street Station, and 19th Street and 22nd Street Stations can also be seen.

The average passenger volumes per vehicle for all-day and for peak periods are shown in Figure 3.6. The load factor variation along the line may

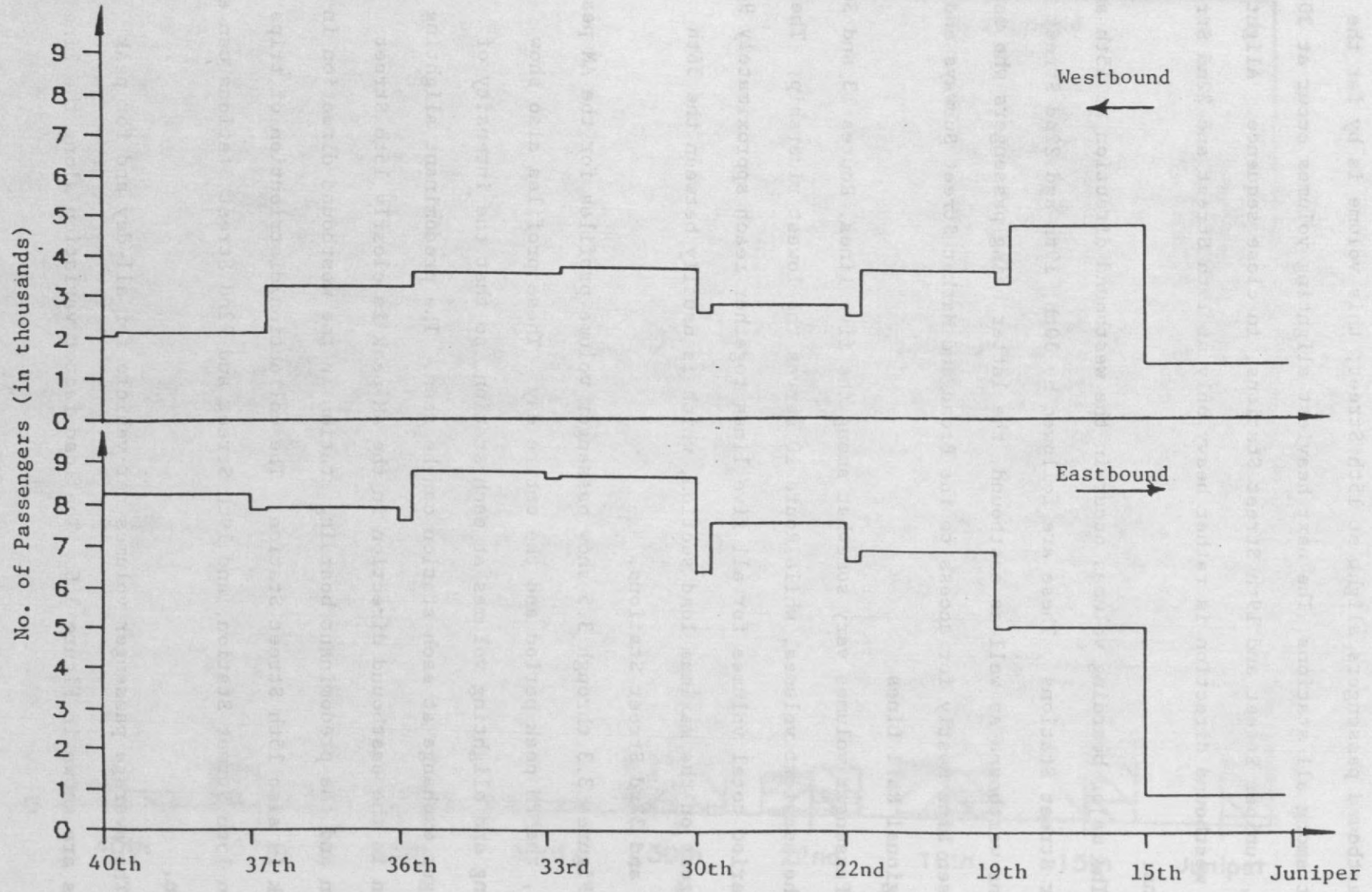


Figure 3.3 Passenger volume profile - AM peak period

Survey by SEPTA
10 February 1988

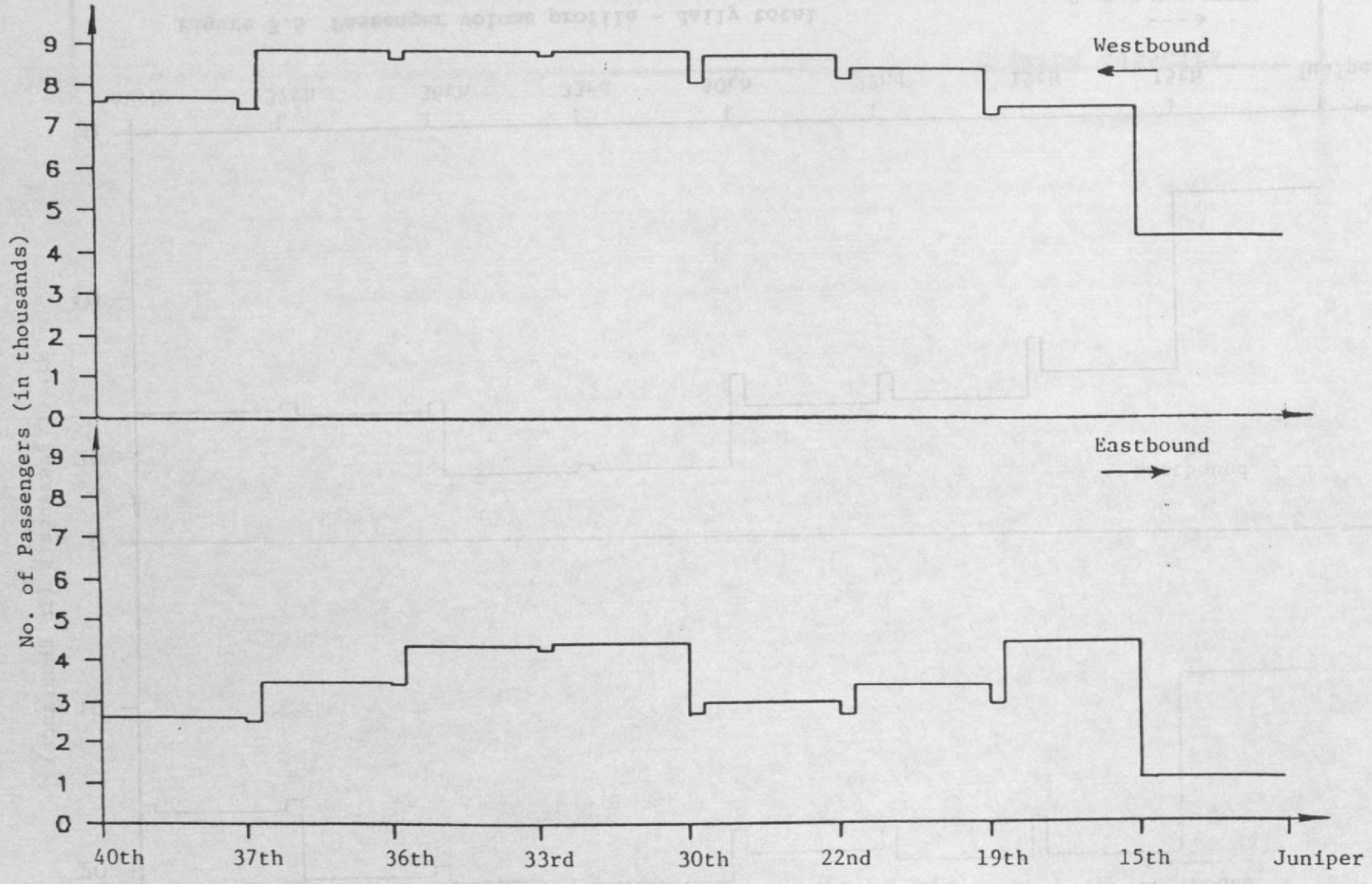


Figure 3.4 Passenger volume profile - PM peak period

Survey by SEPTA
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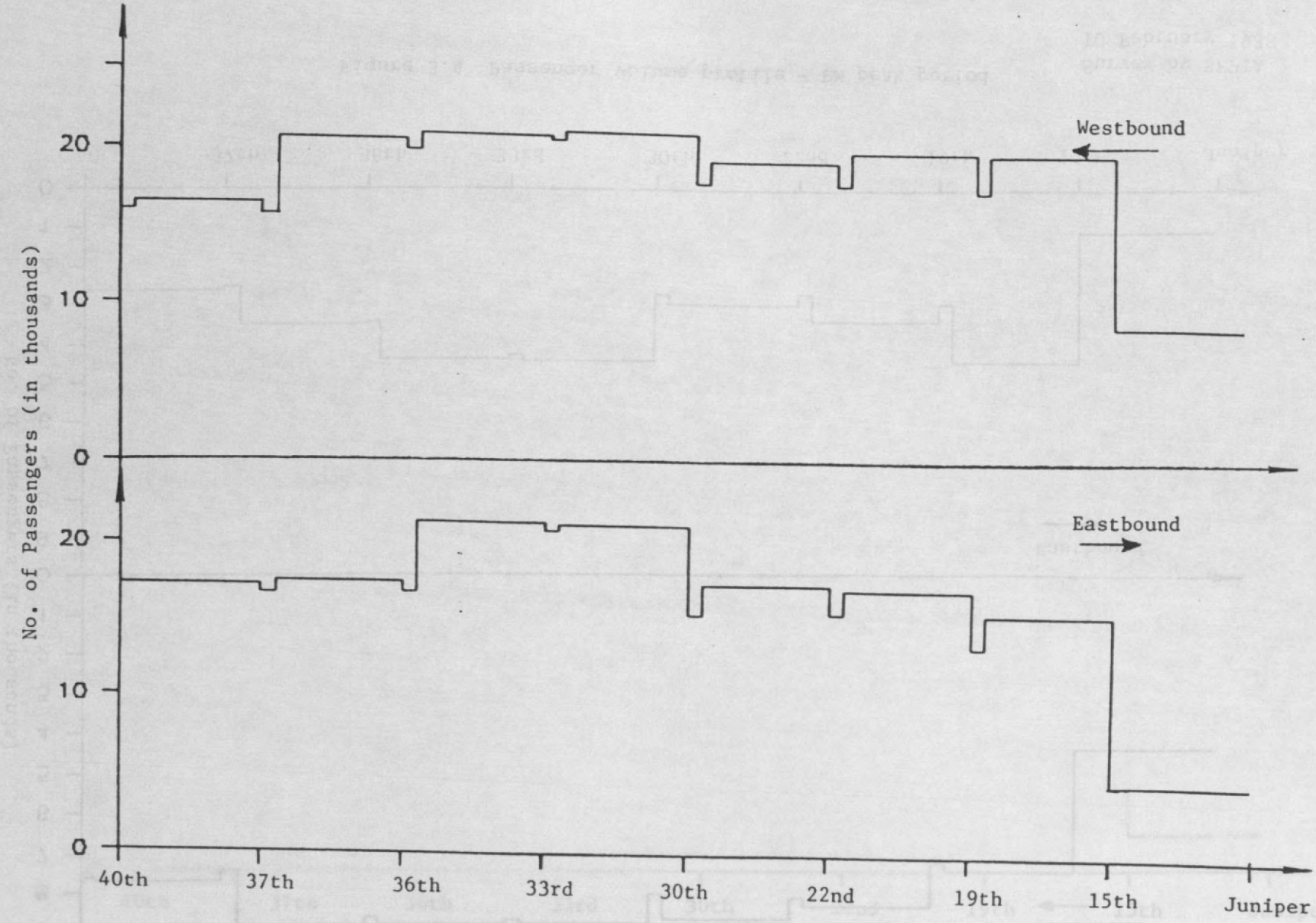


Figure 3.5 Passenger volume profile - daily total

Survey by SEPTA
10 February 1988

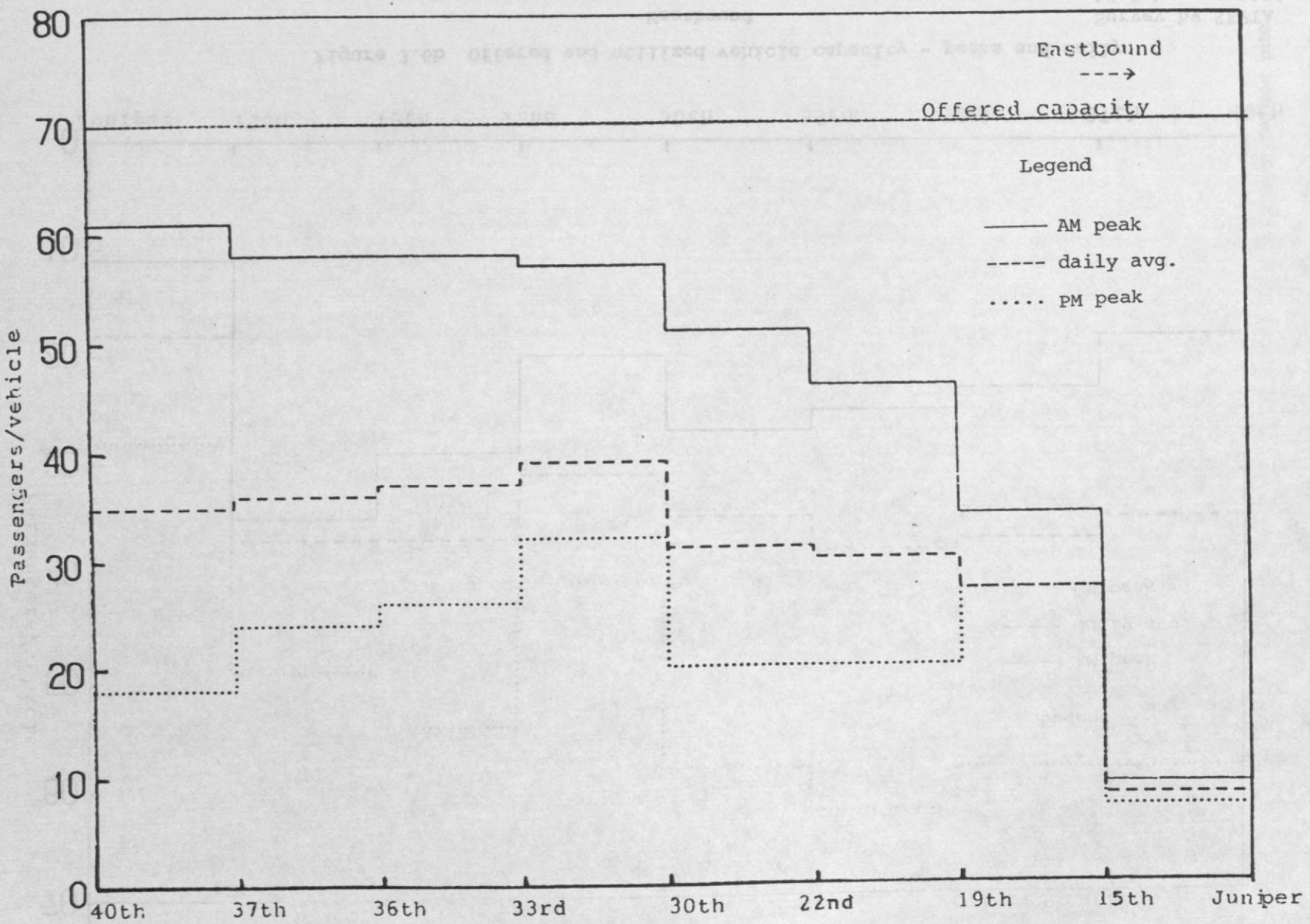


Figure 3.6a Offered and utilized vehicle capacity - peaks and daily

Eastbound

Survey by SEPTA
10 February 1988

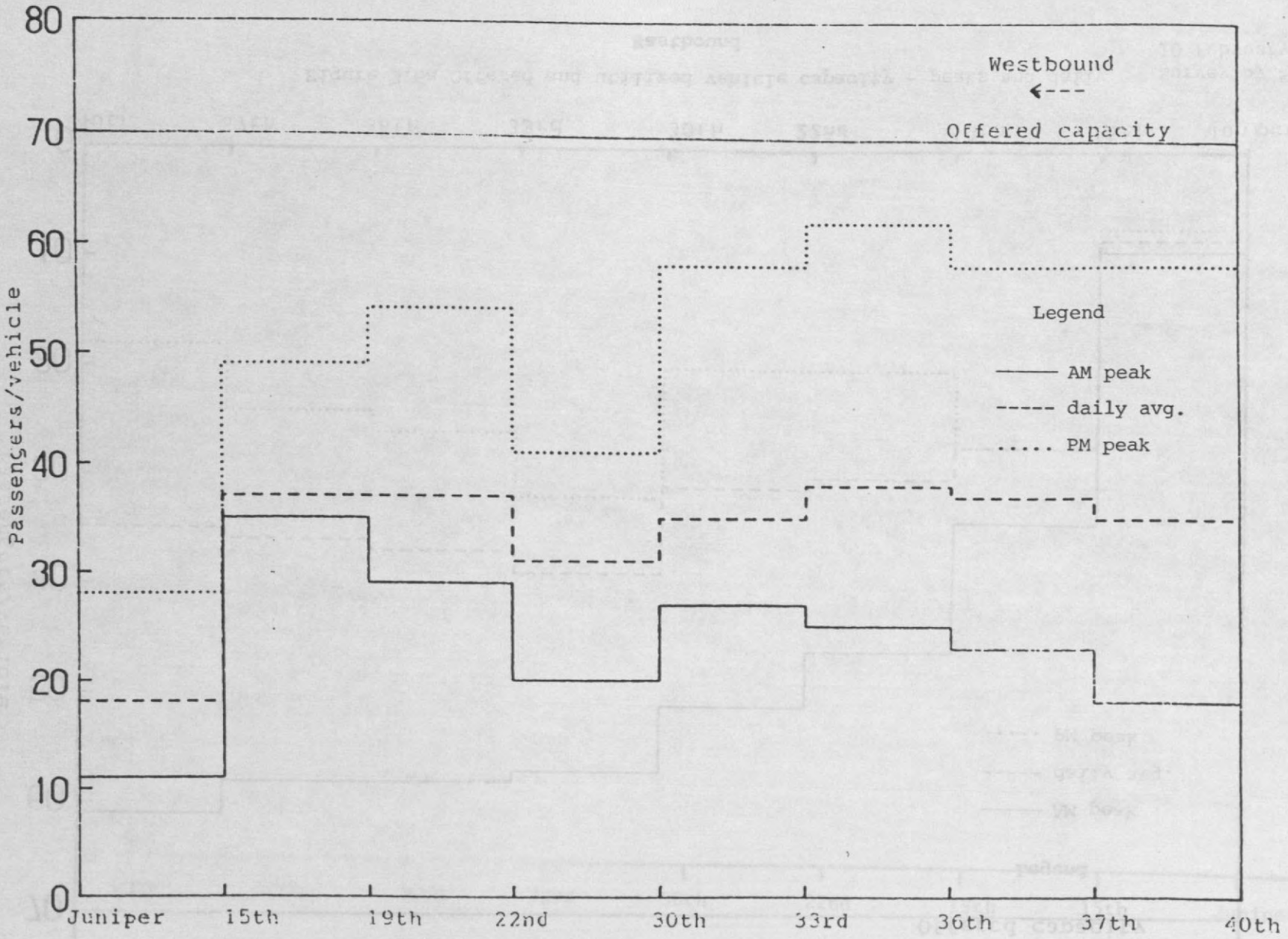


Figure 3.6b Offered and utilized vehicle capacity - peaks and daily

Westbound

Survey by SEPTA
10 February 1988

be seen by comparing these volumes with the lines indicating the offered total and seated capacities in the figure.

4. ANALYSIS OF THE PRESENT SYSTEM AND ITS PROBLEMS

4.1 Field Surveys

Information and technical data for this project were obtained in several ways. First, SEPTA provided track alignment, station locations and other physical details; second, technical details of Green Lines operations, such as schedules, passenger counts and operating procedures, were obtained through personal contact and discussion with SEPTA personnel; and third, two extensive field surveys were conducted with approximately 14 persons. These surveys were aimed at obtaining up-to-date, detailed data on Green Line operations.

The field surveys were conducted on February 15th and April 14th, 1989. The first survey covered the AM period, including the peak and midday intervals. The second survey covered from 3:00 to 6:30 PM, thus including the PM peak period.

During the first survey, the following items were recorded:

- Counts of boarding/alighting passengers and measurements of standing time at the busiest stations; and
- Travel times of the cars on their "loop trips" from 40th Street Portal to the CBD and back, and from 36th Street Portal to the CBD and back, respectively.

The second survey included:

- Counts of boarding/alighting passengers and respective vehicle standing times;
- Total travel times of the round trips from the 40th Street Portal to Juniper Street Station and back to the 40th Street Portal;
- Recording of headways and standing times at several critical

stations.

Independent personal observations were made and interviews were conducted with several managers, field supervisors, loaders and operators on these lines. In addition, the operations of the Green Line were discussed with a number of persons in SEPTA's management.

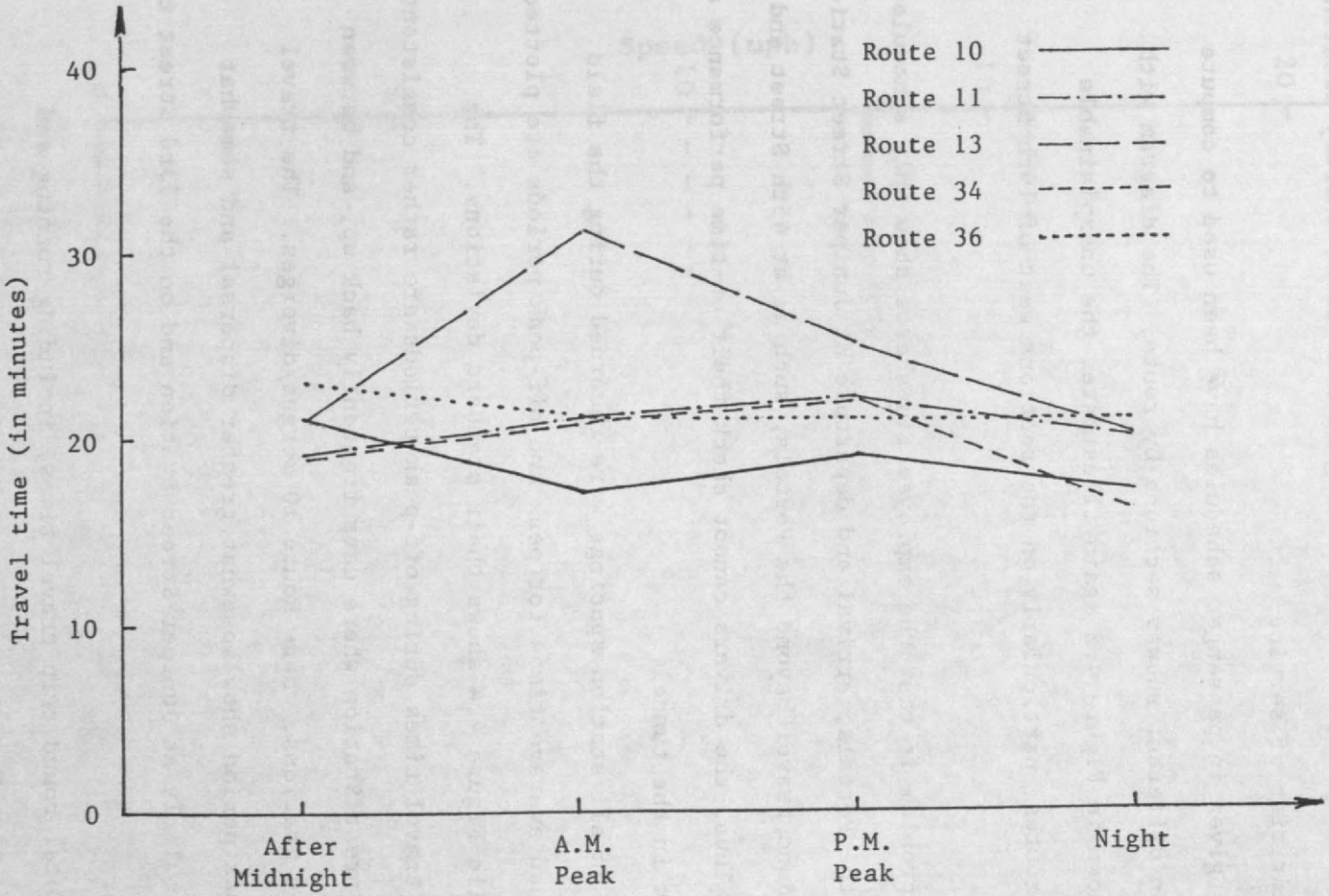
4.2 Travel Times and Speeds

A review of run sheets and passenger ("pocket") schedules has shown that there are a number of variations in scheduled travel times. For the purpose of analysis, total travel times, Portal to Portal, have been averaged for each route and for different periods of the day and plotted on a diagram in Figure 4.1. The diagram shows that the average travel times for each line vary among periods of day and that the variations are inconsistent. For example, Route 36 has the shortest times in the morning peak and at night, while afternoon and owl services have medium values. Travel times are the longest during the PM peak period.

If travel times vary among different periods of the day, it would seem logical that the peak period times should be the longest, while night and owl service times should be the shortest.

Another variation of scheduled travel time is among the different routes. The differences in travel times for the same period amount to 2-4 minutes, in one case even 13 minutes (AM peak between Route 13 and the other routes). This appears to be a scheduling error, because not only is there no justification for this difference, but it is physically impossible to operate such different travel times on a joint track.

Third, there is a difference in travel times between employee and passenger timetables. The plot made using employee timetables in Figure 4.1



Notes: Travel times are from 40th St. Portal to 40th St. Portal, except for Route 10. The travel times of Route 10 are from 36th St. Portal to 36th St. Portal. Stopping time at Juniper is included in the travel times. (Source: SEPTA Green Lines Passenger Schedules, effective September 11, 1988)

Figure 4.1 Scheduled travel time for different routes and different periods of day

shows a greater regularity than passenger timetables; yet, the employee timetables are also incorrect: the runs that are shown by the lines which cross themselves on the diagram would mean overtaking of vehicles, while excessive gaps are likely to cause overloading of some cars, thereby creating delays and irregularities of service.

Travel times given in passenger schedules have been used to compute scheduled speeds on different subway sections by route. The diagram with plots of speeds shown in Figure 4.2 again illustrates the unexplainable differences among routes, particularly on the sections west of 19th Street Station.

Yet another problem is that the employee timesheets show only scheduled time eastbound at the Portals, arrival and departure at Juniper Street Station and time for westbound travel beyond the Portals, such as at 45th Street and Baltimore Avenue. Thus, the drivers cannot check their on-time performance at individual stations in the tunnel.

Travel times on all station spacings were recorded during the field survey. The obtained average times for peak and off-peak periods are plotted in Figures 4.3, while Figure 4.4 shows their standard deviations. The diagrams show that travel times during off-peak periods are rather consistent, except at Juniper Street Station where cars frequently back up, and between 33rd and 36th Street Stations, where Route 10 merges/diverges. The travel times during the peak period show somewhat greater dispersal and somewhat longer times, particularly at Juniper Street Station and on the 33rd Street to 36th Street section.

The average total round trip travel times, including running and standing times, from Portal to Portal and from 19th Street eastbound to 19th

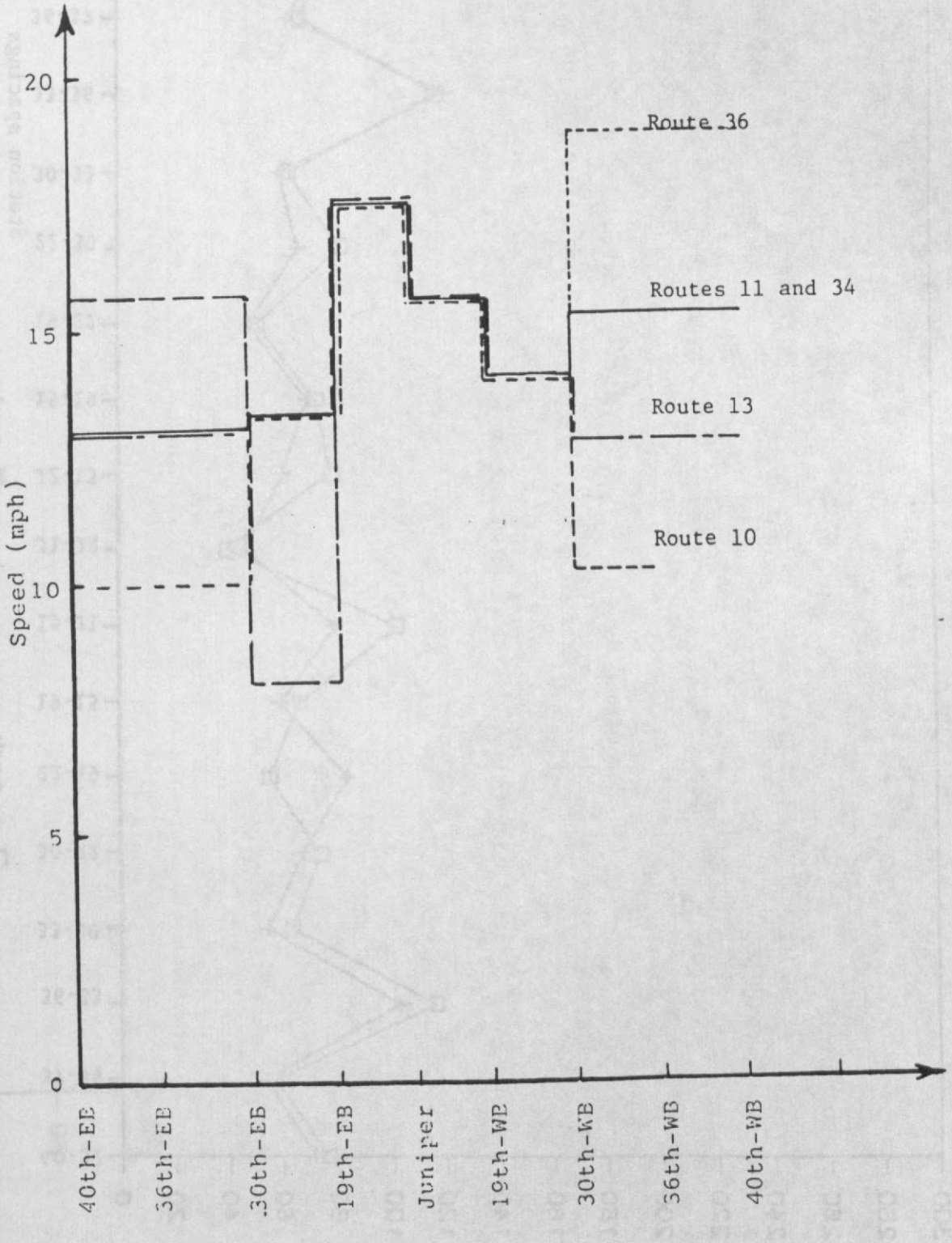


Figure 4.2 Average travel speeds for different tunnel sections and different routes - PM peak period

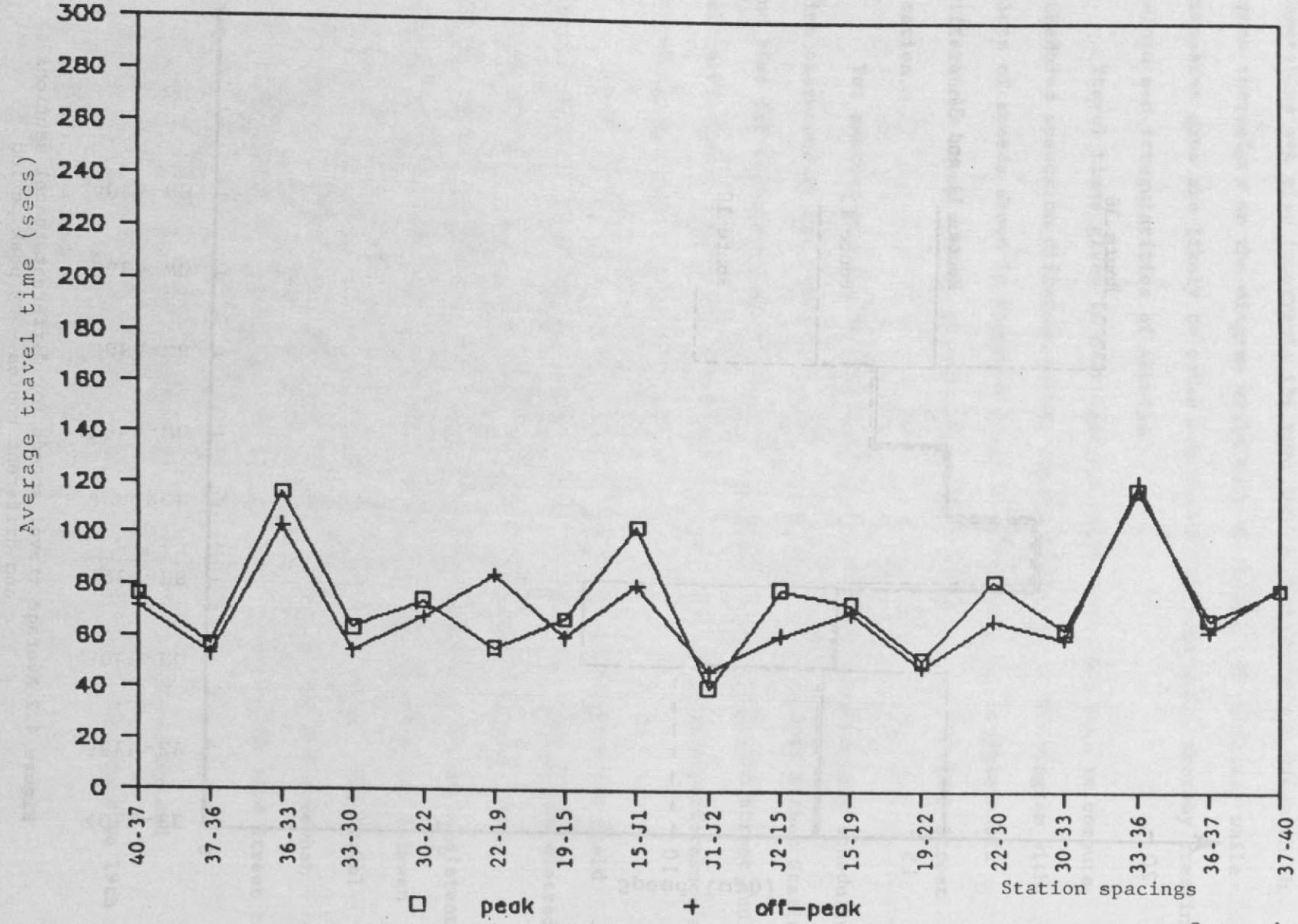


Figure 4.3 Average travel times between stations for peak and off-peak periods

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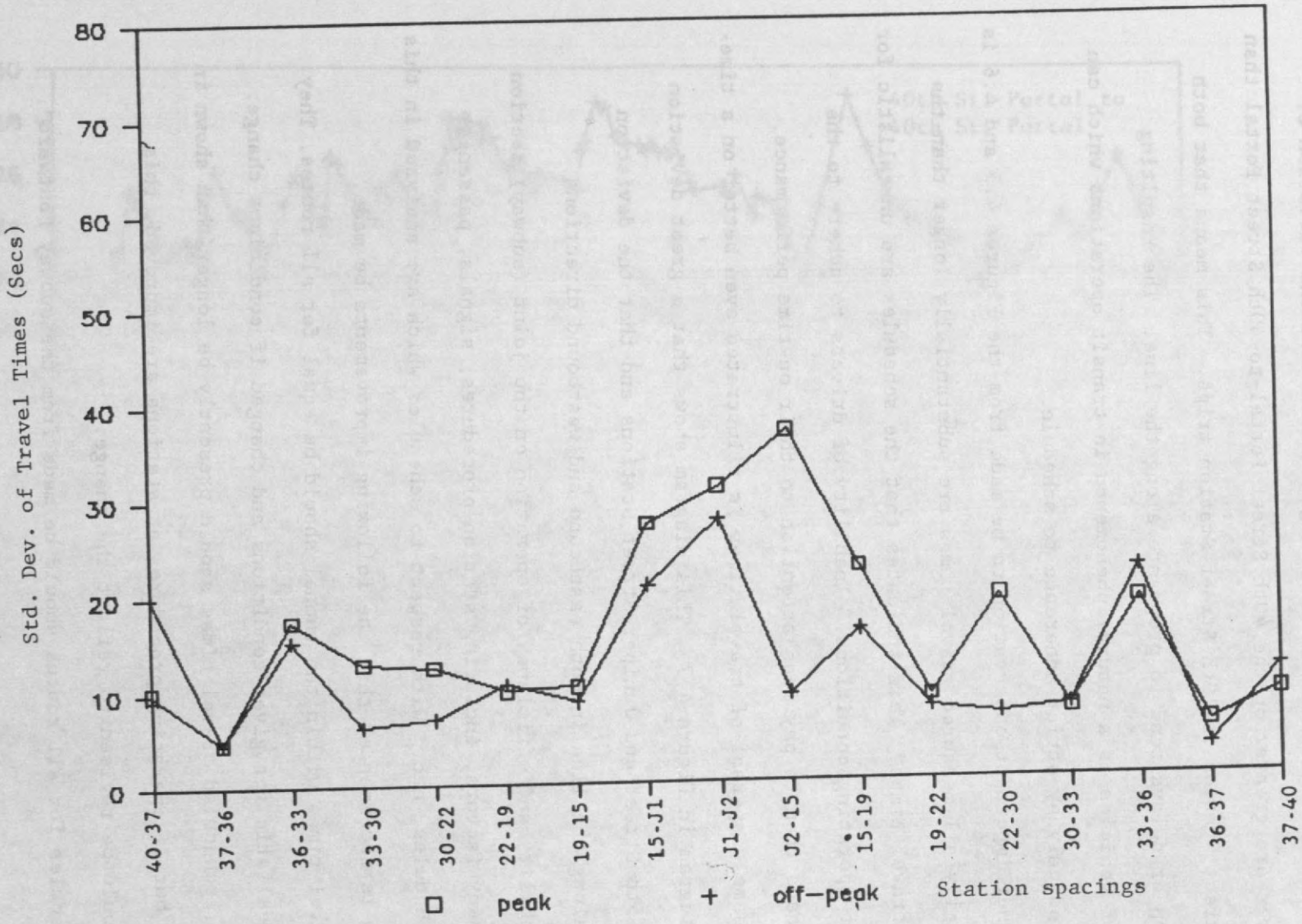
15 Feb. 1989



Survey by UP/UD
15 Feb. 1989

Figure 4.4 Standard deviations of travel times between stations

Street westbound, are plotted in Figure 4.5. Their cumulative distribution curves are shown in Figure 4.6. The diagram shows that the variation of travel times are greater on the 40th Street Portal-to-40th Street Portal than on 19th Street Station-to-19th Street Station trips. This means that both speeding up or delays tend to propagate along the line. The resulting bunching of vehicles is a natural phenomenon in transit operations which can be prevented only by strict adherence to schedule.

Another important observation to be made from the Figures 4.5 and 4.6 is that virtually all measured travel times are substantially longer than the scheduled travel times. This indicates that the schedules are unrealistic for the present operating conditions. Inability of drivers to adhere to the schedule leads them to pay less attention to their on-time performance.

The same dispersal of travel times is illustrated even better on a time-distance diagram in Figure 4.7. This diagram shows that a great deviation occurs at 15th Street and Juniper Street Stations and that the deviation increases along the line in both eastbound and westbound directions.

Reliability and efficiency of operation on the joint (subway) section depend on many factors, including station procedures, signals, passenger volumes, schedules, etc. With respect to schedules which are analyzed in this section, it is recommended that the following improvements be made:

- Travel times within the tunnel should be equal for all routes. They should be realistic for given conditions and changed if conditions change. For example, scheduled travel times should presently be longer than shown in timetables, but if operating procedures at stations are improved, this schedule should be revised to reflect the change.

- Schedules for all routes should be made from the subway "outward".

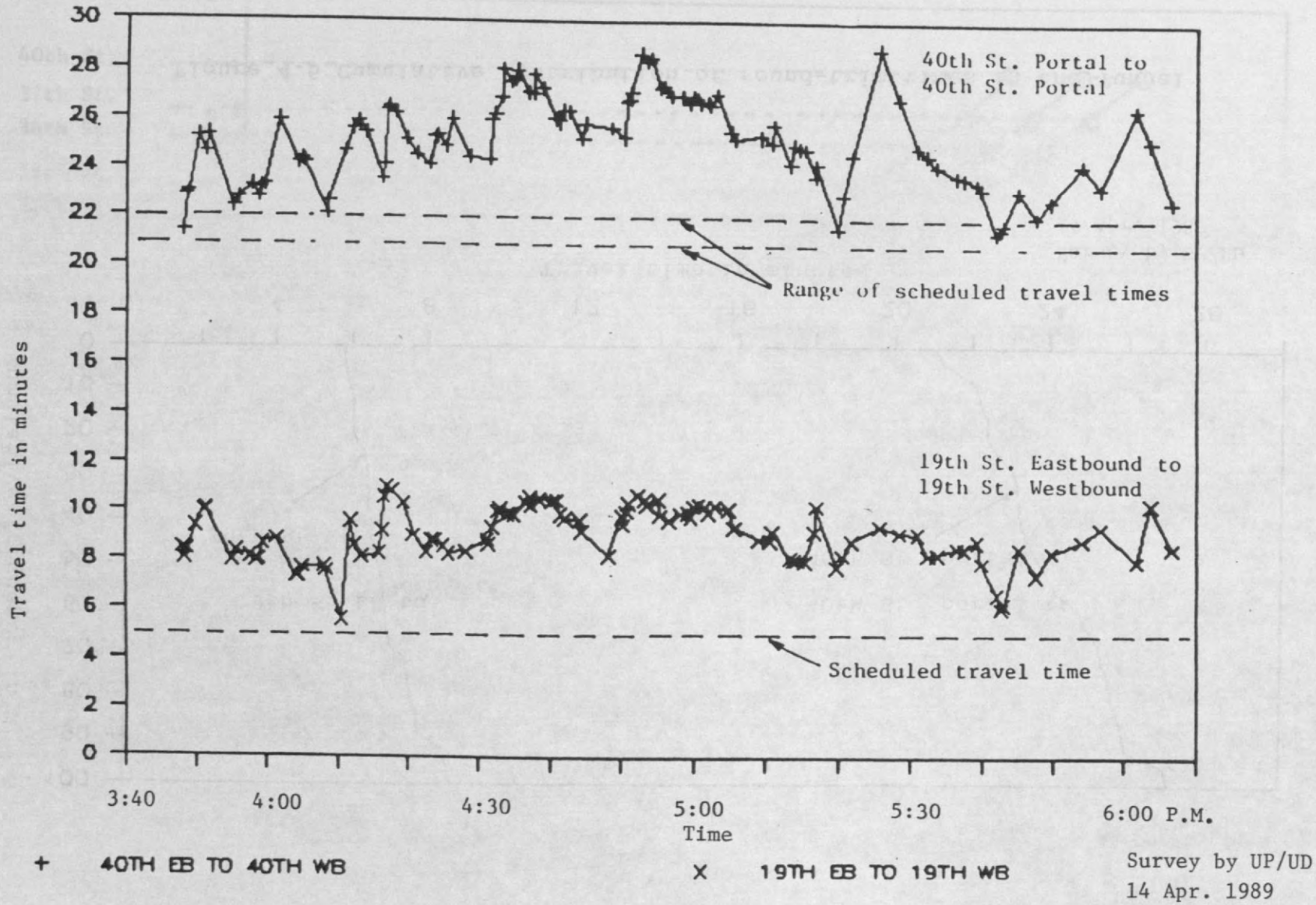


Figure 4.5 Plot of observed round trip travel times: Portal to Portal and 19th Street eastbound to 19th Street westbound

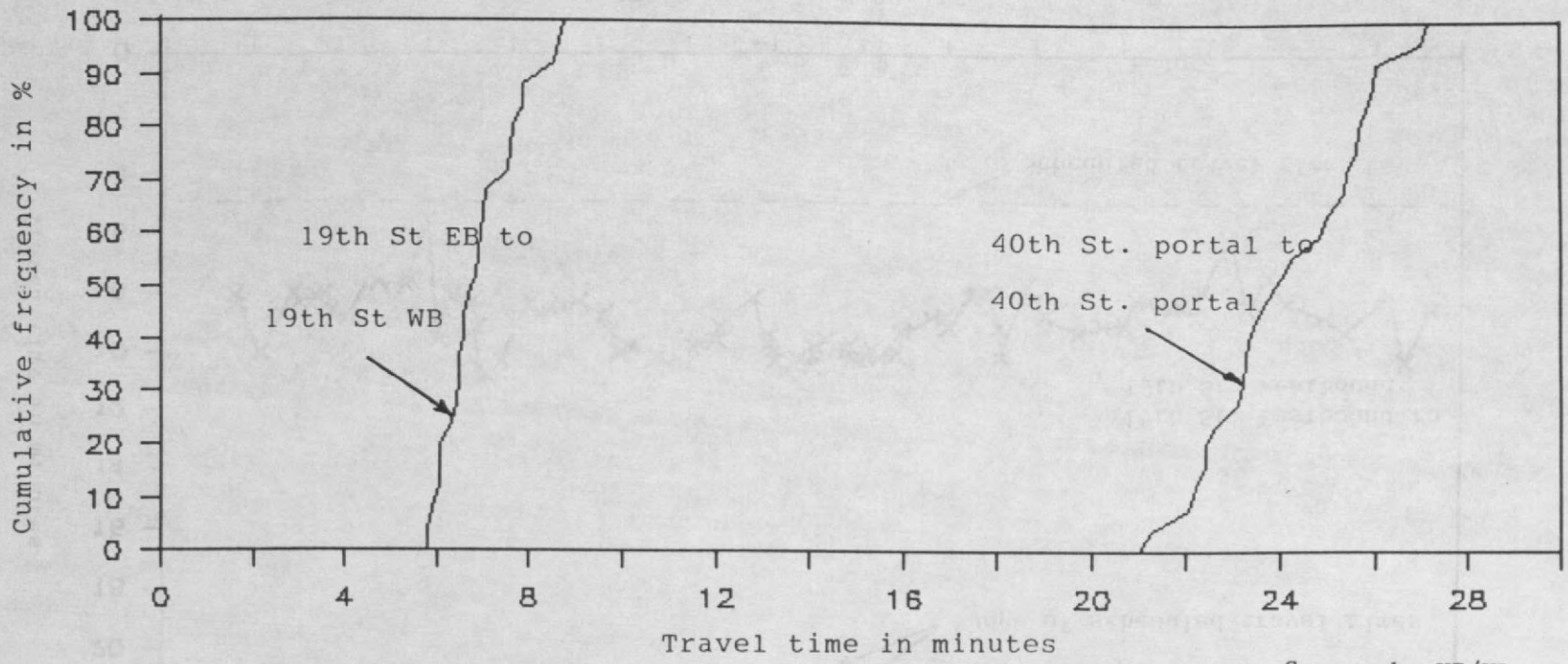


Figure 4.6 Cumulative distribution of round-trip times in the Tunnel

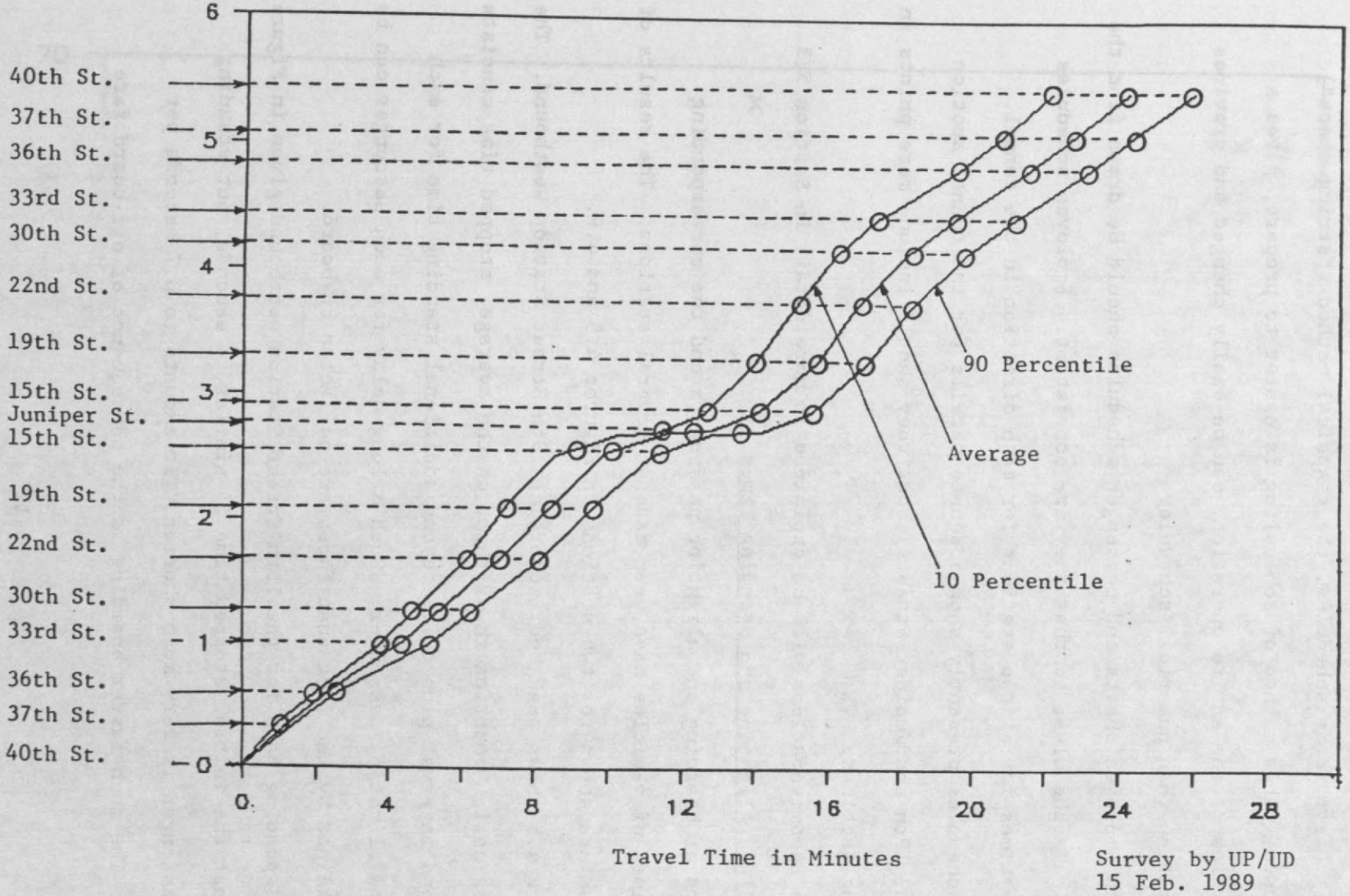


Figure 4.7 Range of peak period travel time, Portal-to-Portal, PM peak period

The joint schedule for all routes in the subway should have regular headways which vary among routes or daily periods by not more than one minute.

- To achieve these schedules, the graphical method ("string chart") should be used. This method of scheduling is easier to prepare, gives a better overview of the entire operation, can be easily changed and provides more information than numerical schedule.

- Both employee sheets and passenger schedules should be drawn from the same graphical schedules, so that they are consistent. Employee schedules should show times for at two stations for each direction in the tunnel. Passenger schedules presently show adequate details for the tunnel section (40th, 30th, 19th and Juniper Streets), but they should include more points in the outlying sections.

These recommendations will be explained in more detail in Section 5.3.

4.3 Boarding, Alighting and Standing Times

Counts of boarding and alighting passengers and the corresponding standing times of vehicles have been made at several stations. The results of these counts are shown for two stations in Figures 4.8 and 4.9.

Figure 4.8 shows peak hour counts at 19th Street Station westbound. The obtained regression equation shows that, on the average, stopped time consists of a 7 second interval plus a 1.9 second additional standing time for each boarding and alighting passenger. Such a long delay for each passenger can be partly explained by the fact that fares are collected on-board.

Corresponding data for the 15th Street Station westbound given in Figure 4.9 show that the initial stopped time is similar, 8 seconds, but standing time per passenger is very much shorter. It amounts to 0.7 seconds per passenger. The much faster boarding is the consequence of off-board fare

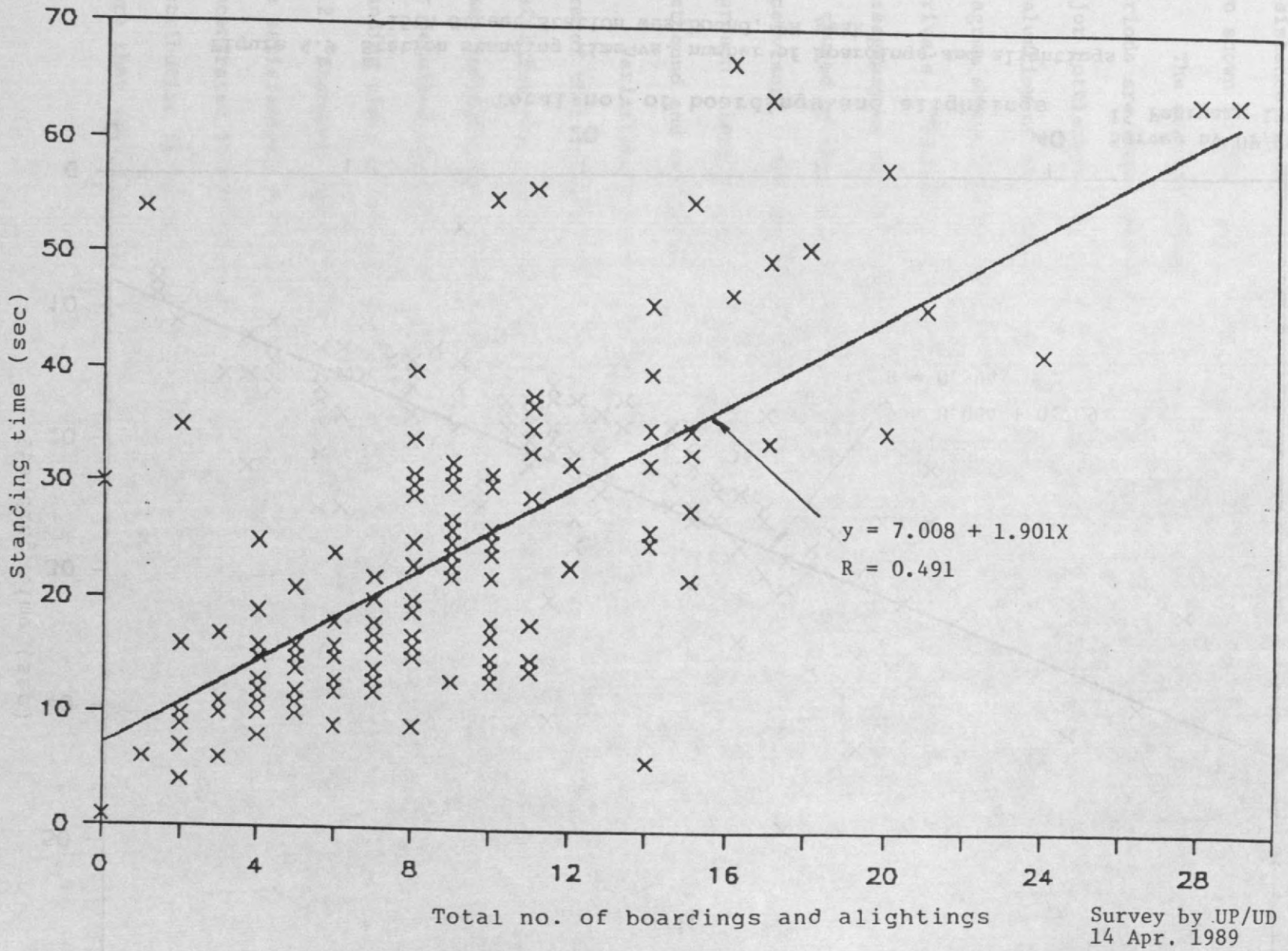


Figure 4.8 Station standing time vs. number of boardings and alightings - 19th Street Station westbound, PM peak

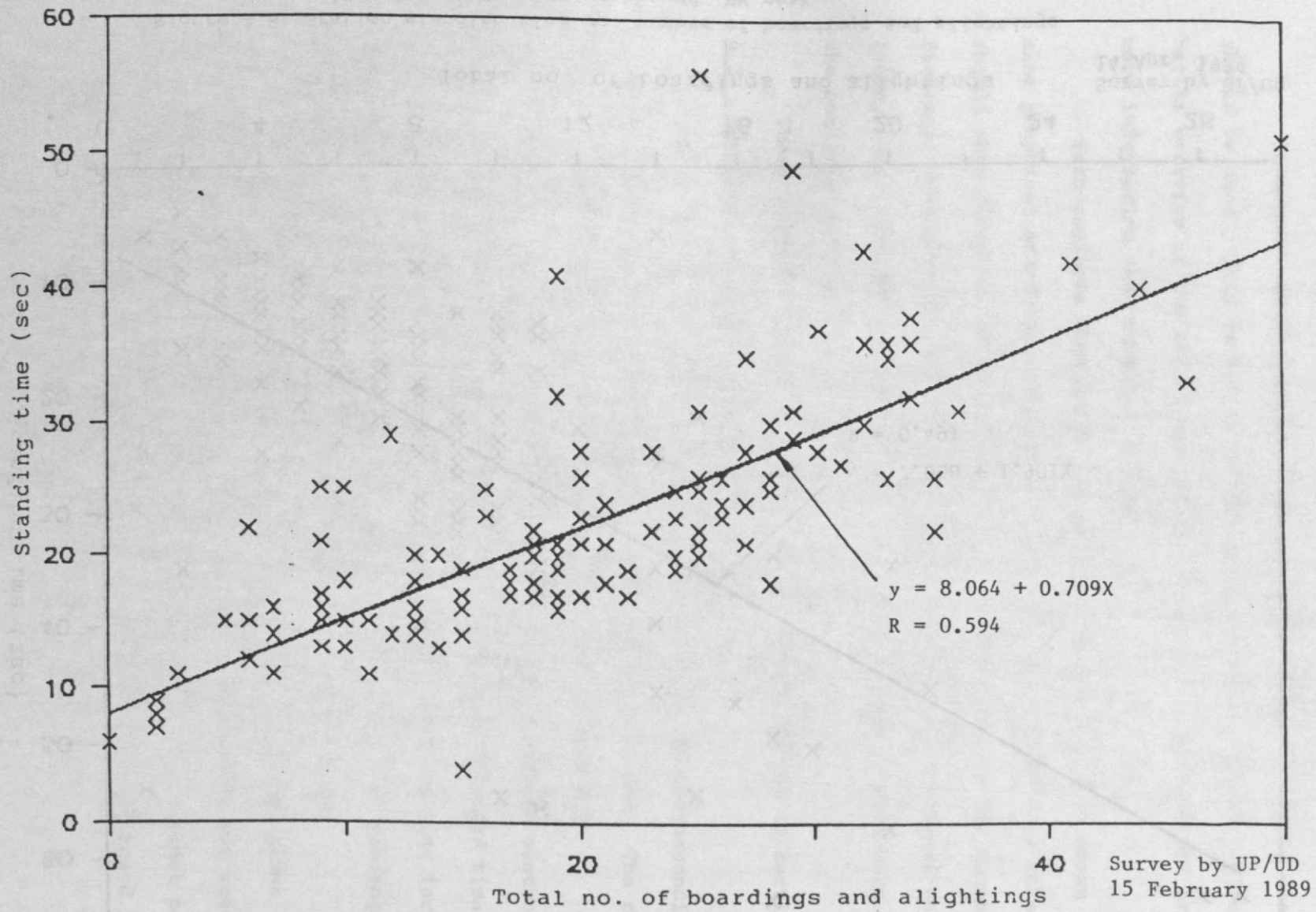


Figure 4.9 Station standing time vs. number of boardings and alightings - 15th Street Station westbound, PM peak

collection.

At both stations, there was a loader during the survey. Without such assistance, standing times at stations where boarding dominates, such as the two shown in the figures, would be considerably longer.

The average standing times at all stations during peak and off-peak periods are shown in Figure 4.10. These times indicate which stations are major bottlenecks in the capacity of the trunk line. They also permit evaluation of the impact of the off-board fare collection and loaders. The diagram shows that the longest standing time is Juniper Street Station arrivals. This delay is caused by the constrained alighting due to the narrow passageway at the south end of the unloading area. In some cases this delay is caused by the regular terminal activities (driver's rest, discussion with supervisor). The resulting delays then cause back-up of cars into the tunnel approach. Long delays are also found at 30th and 15th Street Stations eastbound and westbound.

Variations in standing times at individual stations are shown in the form of their standard deviations in Figure 4.11. The variations are very useful for the analysis of service reliability. Large variations in standing times indicate the potential to develop and propagate delays along the line. For detailed analysis of this characteristic, frequency distributions of standing times at all stations, expressed in percents, are shown in Figure 4.12. Standing time distribution patterns at 37th and 36th Street Stations are satisfactory from the operating point of view, since they are largely concentrated in the interval of between 5 and 15 seconds. The least desirable distribution of standing times is found at 30th Street Station eastbound, where they vary from 5 to 45 seconds.

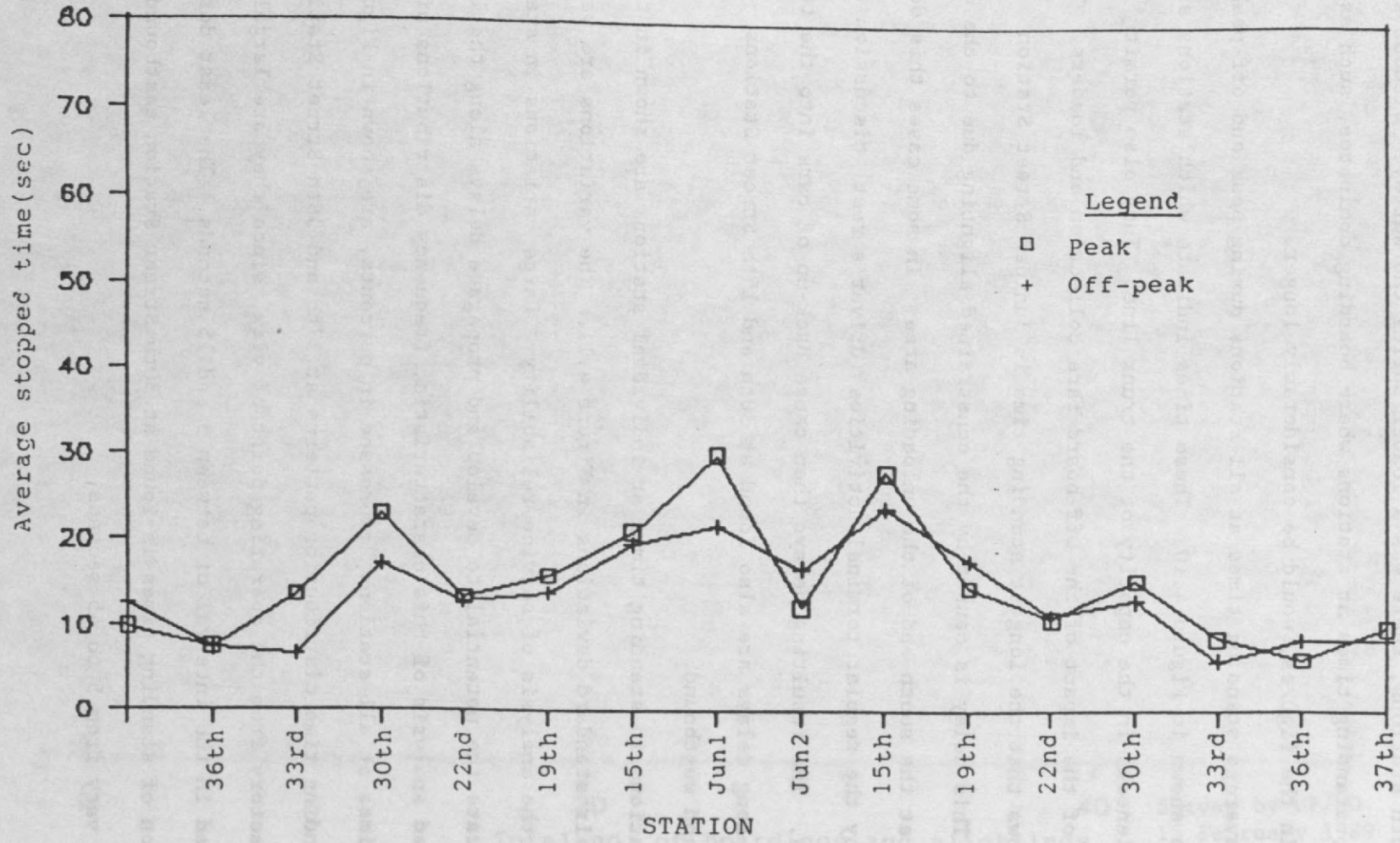


Figure 4.10 Average standing times at individual stations, peak and off-peak periods

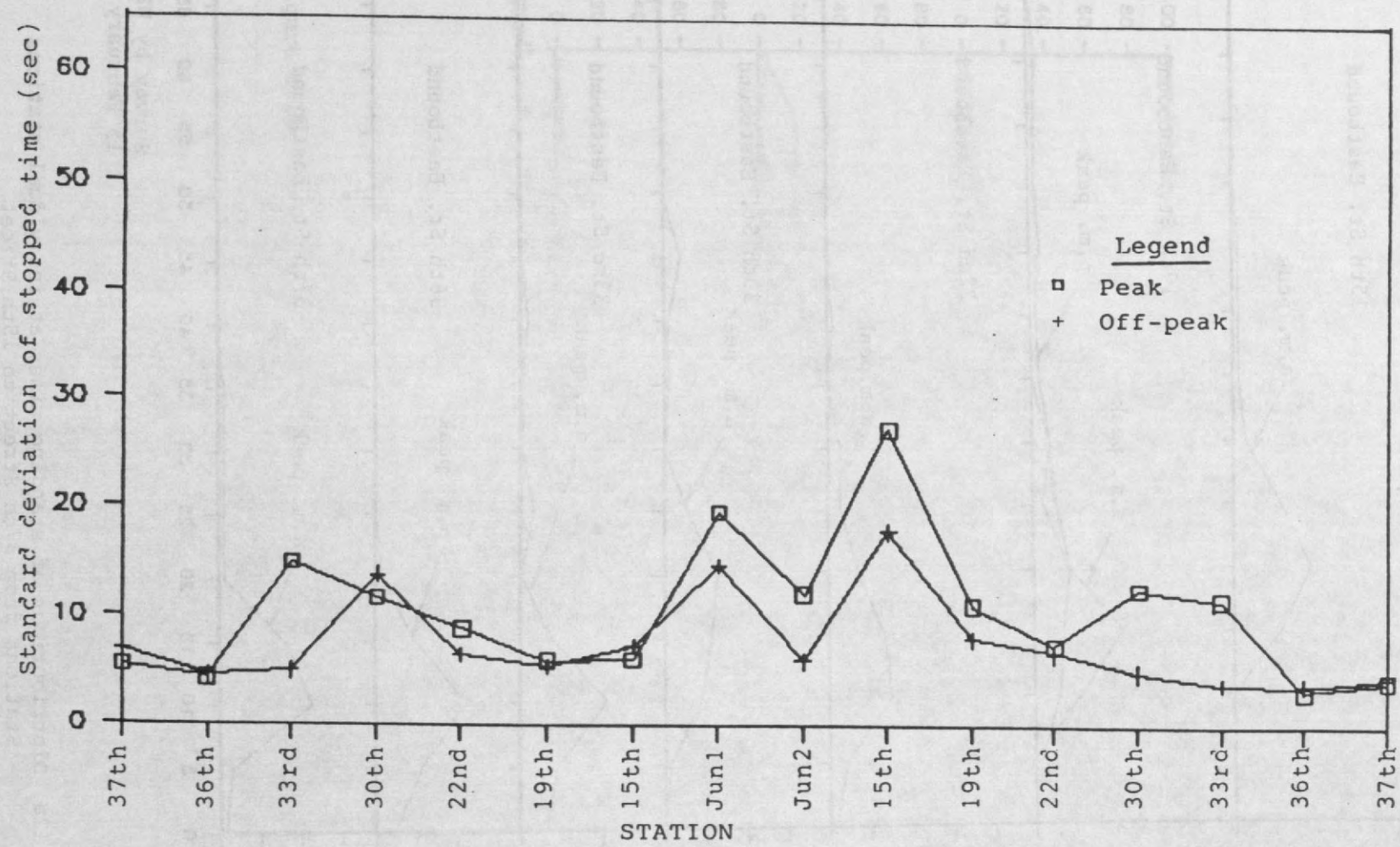


Figure 4.11 Standard deviations of standing times at individual stations, - peak and off-peak periods

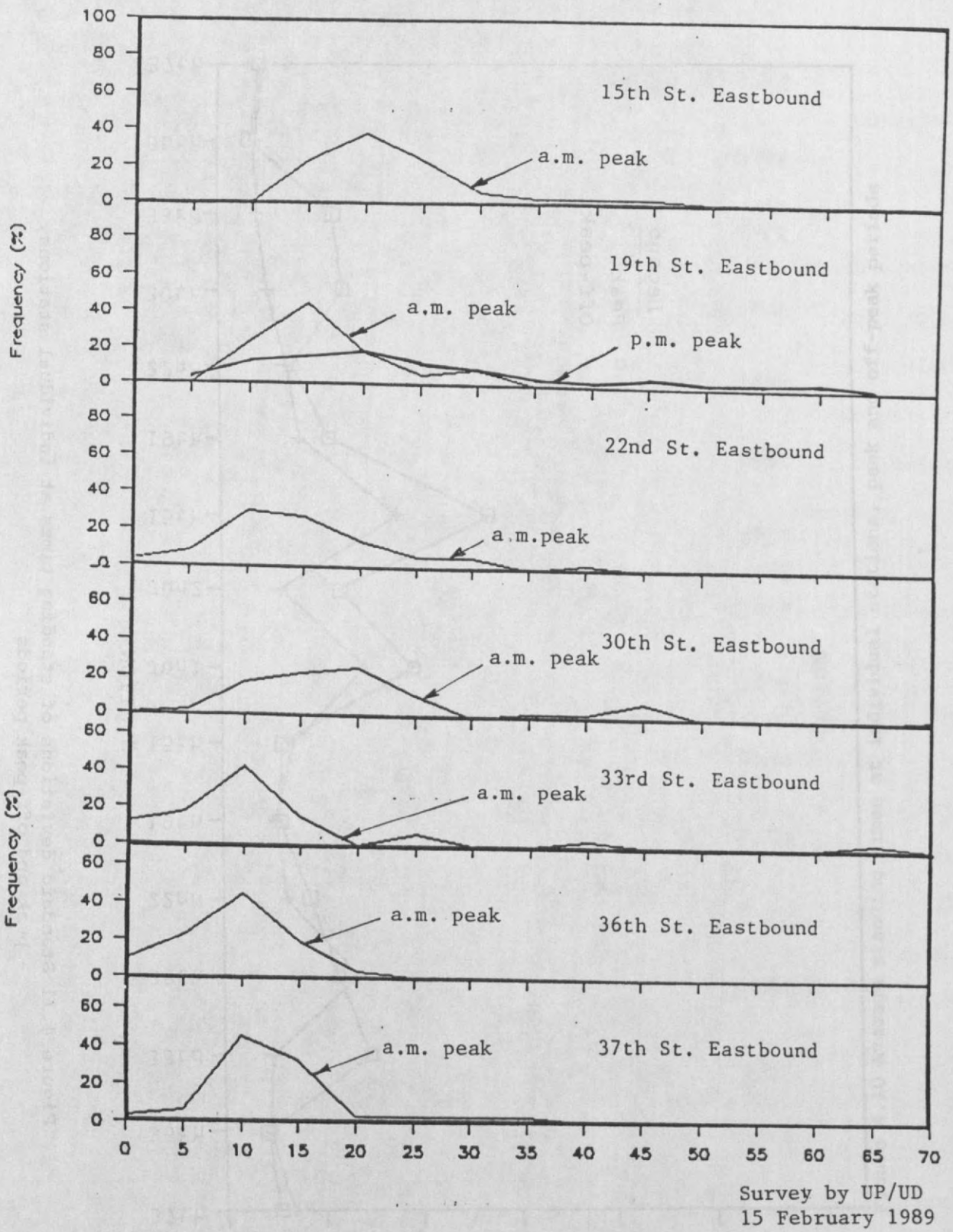
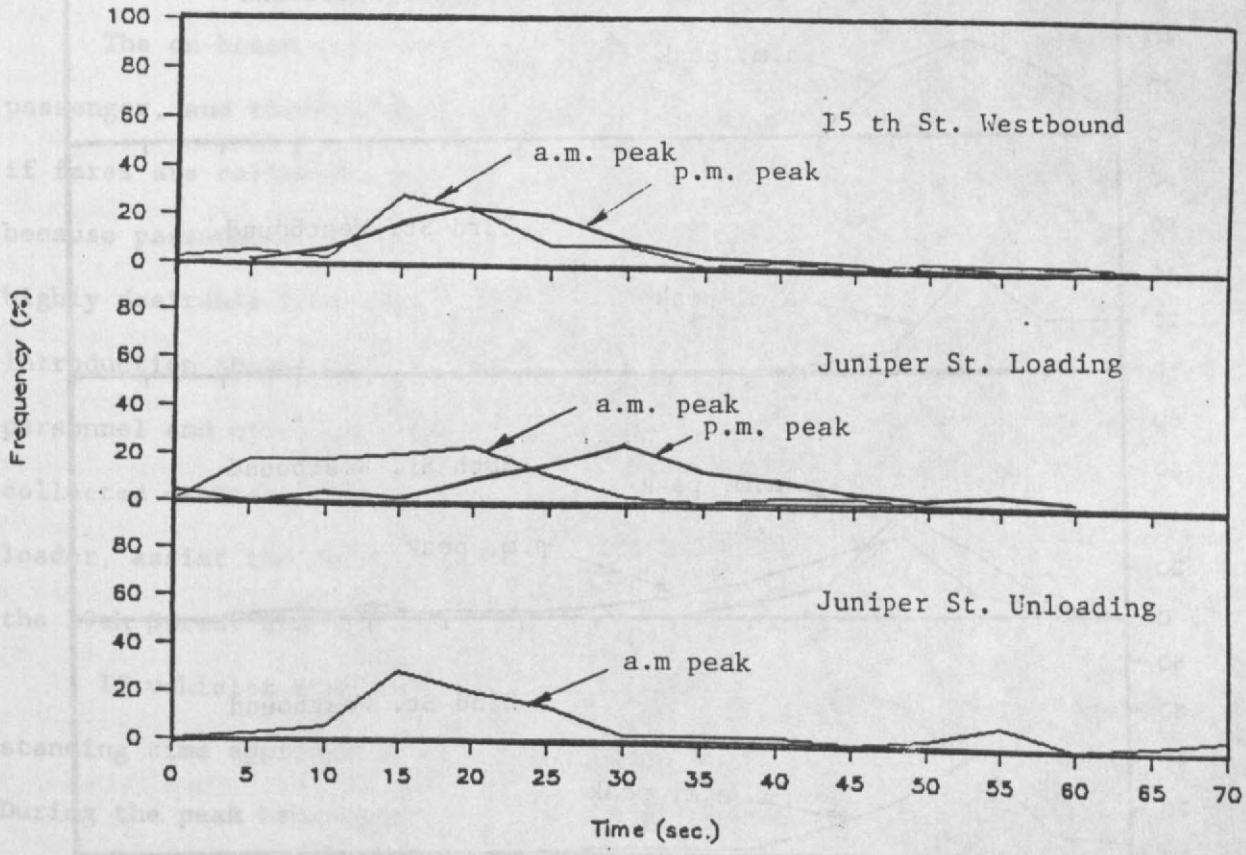


Figure 4.12a Distributions of standing times at individual stations - Stations from 37th Street to 15th Street



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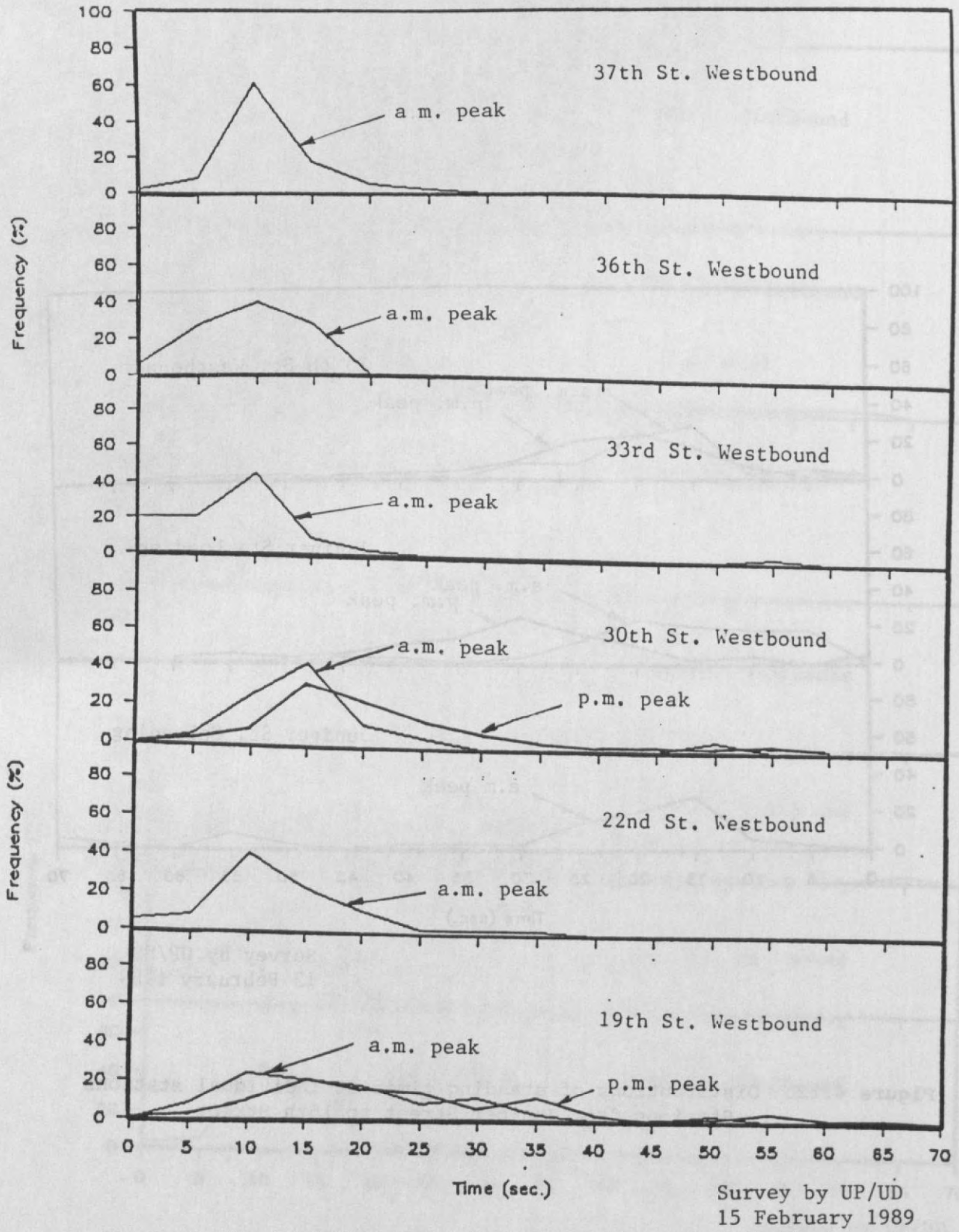
15 February 1989

Figure 4.12b Distirbutions of standing times at individual stations - Stations from Juniper Street to 15th Street



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15 February 1989

Figure 4.12c Distributions of standing times at individual stations - Stations from 19th Street to 37th Street

4.4 Station Operations: Fare Collection, Stopping Locations and Departure Control

Station standing times and their distribution are also strongly influenced by the method of operation. The major elements of the station operation are fare collection, stopping location, control of passenger boarding/alighting, and vehicle departure.

The on-board fare collection requires fare transaction by each boarding passenger, and thereby increases the variations in standing time. Moreover, if fares are collected off-board at the gate, boarding is also speeded up because passengers can use all doors. Fare collection at gates is therefore highly desirable from the operating point of view, but the decision about its introduction should include an evaluation of these benefits vs. the increased personnel and other operating costs. A "middle solution" is that fares are collected or Transpasses checked by a platform attendant who can also act as a loader, assist the drivers and dispatch the vehicles, as is now practiced at the 19th Street Station.

If vehicles stop at a station one at a time, every time when the standing time approaches the headway, the following vehicle is delayed. During the peak hour operations, this causes major delays and lower reliability of service, lower operating speed, jerky ride and increased energy consumption.

All stations are designed to accommodate at least two vehicles and many stations can accommodate three or four vehicles (see Table 2.2). Presently, these locations are not fully utilized, nor is there a regular pattern of vehicle stopping. At the busiest station, 15th Street westbound, all vehicles actually stop at the point where the platform is the narrowest, i.e., the

worst location from the operating point of view.

Station operations can be greatly improved if multiple stop locations would be marked at every station. The operating procedure should then be that every vehicle coming to an empty station stops at the first location; the vehicle arriving while the first one stands should stop at the second location, and so forth. If a vehicle arrives while the last location is occupied, it must wait and pull into the first location.

The use of simultaneous stopping of two or more cars in a station to shorten the dwell times should become standard practice. This is the single most effective measure for increasing line capacity in the tunnel. Such practices were used at the critical stations several decades ago. The best example of a very efficient operation of multiple stopping of cars was at 15th Street Station westbound. Assisted by changeable electric signs which indicated the forthcoming sequence of car arrivals by route, this station was operated so efficiently that frequencies of over 120 cars/hour were achieved every day in regular operations.

The electric signs showing arrivals of cars by route and location still exist at Juniper Street and 15th Street Stations westbound, but they have not been used for more than 10 years. They should be improved and reactivated.

The procedure of alighting and boarding in the tunnel stations is at present quite disorganized. The drivers are generally instructed where they should stop, but often do not follow those instructions and nothing is done to correct such irregular behavior. The resulting operation is extremely inefficient: drivers stop irregularly, often two or three times along the same platform, following the cars stopped ahead of them. Moreover, they often stop at the worst possible location from the operational point of view; for

example, at 15th Street Station westbound they stop at the location where the platform is the narrowest, and the concentration of waiting passengers is the greatest, so that boarding passengers have to fight the crowd to get to the doors. The loaders do not correct this inefficient operation.

At all tunnel stations two stopping locations should be marked by overhead signs and pavement markings and consistently used. The distance between the stopping locations is so small, that no announcements about the stopping locations of cars will be needed. The public will easily understand that if one car stands, the following one will stop and open doors behind it.

The exceptions to this operating pattern will be the heavily used 15th Street and Juniper Street Stations, where four locations should be used on both east- and westbound platforms. On the eastbound platforms the locations should be marked primarily for drivers' convenience, since alighting passengers do not care exactly where the car stops. For the westbound direction, the electric overhead boards should announce the forthcoming sequence of cars by route and their stopping locations. These signs should be controlled by the Juniper Street supervisor, who observes the sequence of routes on the incoming cars.

Departure control is needed at heavy boarding stations during the peak hours. The platform attendant who dispatches vehicles has several other important duties: he checks prepaid tickets at stations with on-board fare collection; he redistributes passengers among the doors; cuts off boarding, etc. In addition, he should be equipped and instructed to make necessary announcements in the station.

Platform attendants are needed at the peak hours at the following stations: 19th Street eastbound, Juniper Street, 15th Street, 19th Street and

30th Street westbound. The exact duration these attendants should work will vary somewhat with the fluctuation in passenger volumes.

Effectiveness of the platform attendant depends greatly on the conditions as well as on their training and supervision. The surveys performed for this project have discovered that some attendants were very inactive and had virtually no influence on passenger boarding and vehicle dispatching, while others were energetically intervening and speeding up the operation considerably.

In conclusion, the present operations at stations are highly inefficient. They are unplanned, largely random and practically without any supervision either at individual stations or along the line. Since station operations represent the main element determining capacity and reliability of transit services, this condition at stations is detrimental to the performance of the entire Green Line network.

4.5 Signal Control and Vehicle Travel

Although vehicles on the Green Line operate on streets without any track signals, their tracks in the tunnel section are signalized. This is a common practice on streetcar/light rail systems. Vehicle travel in a tunnel requires strict control of operation for the following reasons:

- Visibility in tunnel is not as good as on the surface due to the lack of daylight;
- Running speeds are higher due to the lack of other traffic and interferences, so that a higher degree of safety is required;
- Signals are needed to provide advance information on the track conditions to the drivers in sharp curves where visibility is short due to tunnel walls;

- Regularity is more important on the trunk section than on the outlying branches.

The present signals in the Green Lines tunnel have three deficiencies. First, the distribution of track signaling in the tunnel is rather uneven and inconsistent. There are sections in which drivers see no signals ahead, e.g., between the 19th Street and 15th Street eastbound. Some other sections, however, such as those between 33rd Street and 32nd Street, have a very large number of short signal blocks. Another example of inconsistency is that there is a signal at the entrance to the 19th Street Station westbound, but there is no such signal at the corresponding point at the 22nd Street Station westbound.

Second, design of speed signals is excessively conservative; there are too many of them and they are timed with excessive delays. For example, on the straight alignment section between 33rd Street and 30th Street Stations eastbound, which has a length of 1200 ft. and very good visibility, there are four signals which prevent vehicles from reaching the speed that is feasible for such an alignment without compromising safety. Similarly, vehicles leaving 30th Street Station in the eastbound and those leaving 22nd Street Station in the westbound direction face a number of speed signals with the red indication. The vehicles therefore travel at lower than optimum speeds down the hill and then accelerate at the bottom for the uphill sections.

The conservative operating regime results in an unnecessary decrease in operating speed, in a less comfortable ride and in increased energy consumption. The advantage of this alignment to substitute motor propulsion by the gravity force is thus not utilized. It should be mentioned that many rail transit systems have deliberately built this type of vertical alignment

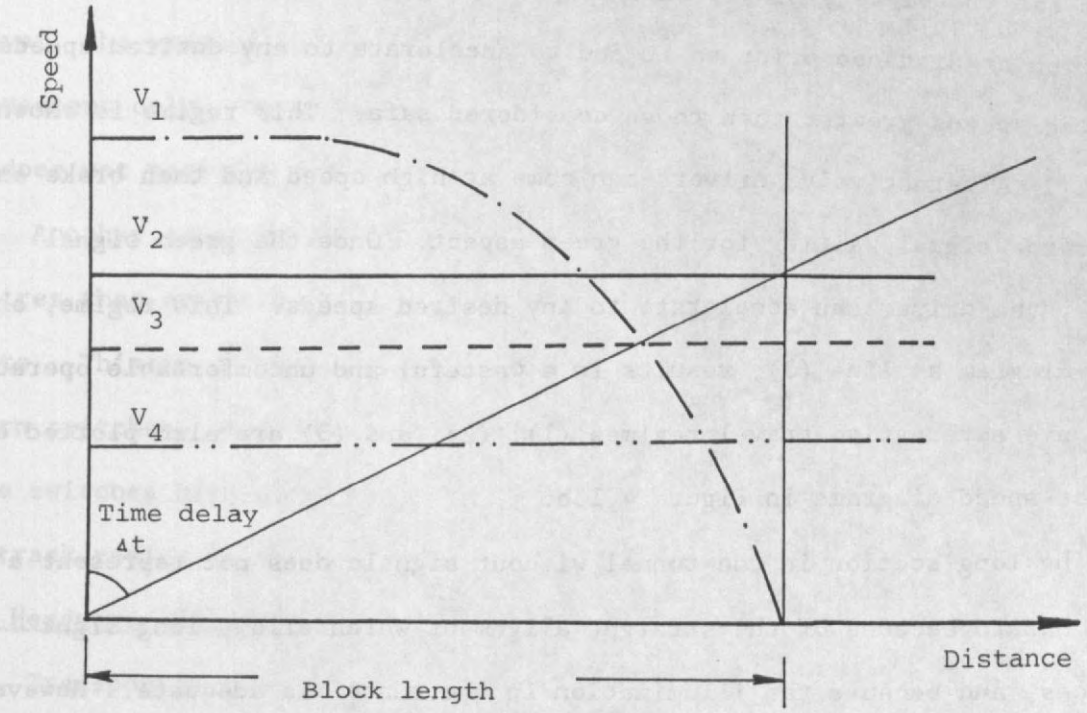
between many stations in order to achieve lower energy consumption and vehicle wear and tear through less intensive brakings.

Third, a flaw of the present signals is that they are purely advisory. If a driver, by mistake or intention, drives through a red signal, (s)he faces only a disciplinary action if the incident is noticed, but there is no automatic prevention of accidents. This absence of a fail-safe back-up has probably been one of the reasons for the conservative design of the signals. It also permits rear-end collisions, which have sometimes happened in the subway.

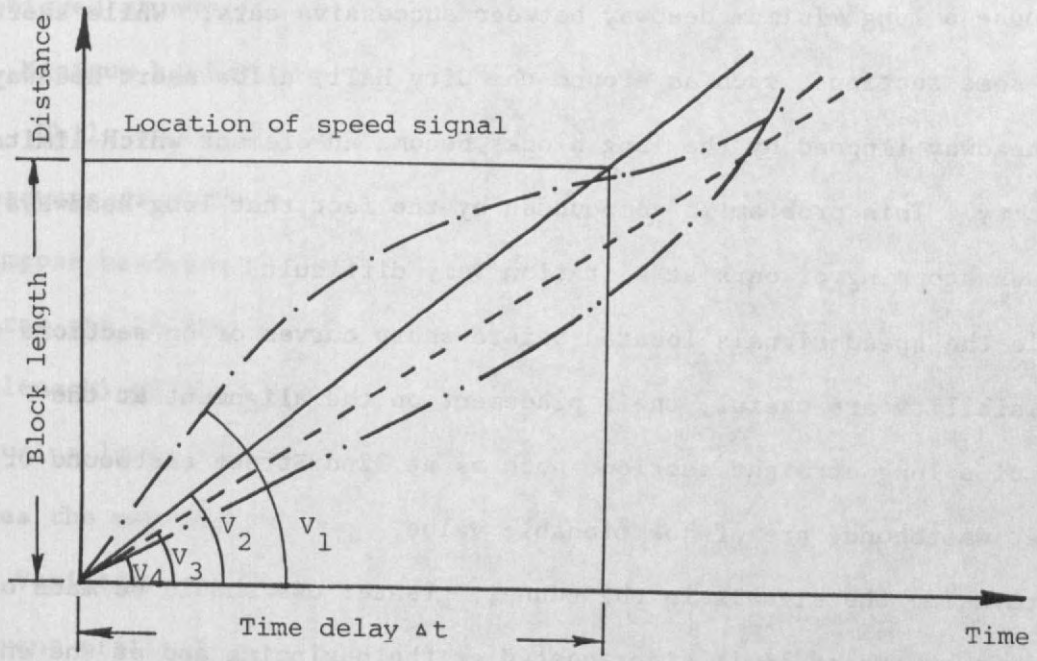
It is suggested that the entire signal system be checked and redesigned so that there will be a reduced number of signals with less conservative timing. In the future, the forced stopping feature should be introduced. Benefits from such improvements would include higher operating speed, higher riding comfort, lower energy consumption, vehicle wear and tear, and higher safety.

While the basic intention of speed signalization is to induce the driver to operate at a desired constant speed on a certain track section, their limitation is that this control is exerted at individual points only. Actually, speed is controlled indirectly by setting the fixed time between the moment a vehicle enters a signal block and the moment the signal changes to green. This mechanism has the limitation that it allows any type of driving regime on the controlled section as long as the total travel time on it is not shorter than the prescribed signal delay.

Two diagrams in Figure 4.13 show different travel regimes that can be operated with this control. As the time-distance diagram in Figure 4.13a shows, in addition to the "design regime" travel shown by the line (1),



(a)



(b)

Figure 4.13 Different regimes of travel under speed signal control

drivers can travel very slowly while approaching the signal, obtain green indication at distance prior to it and to accelerate to any desired speeds, including speeds greater than those considered safe. This regime is shown by line (2). Alternatively, drivers can come at high speed and then brake and stop at the signal waiting for the green aspect. Once the green signal appears, the driver can accelerate to any desired speeds. This regime, shown in the diagram as line (3), results in a wasteful and uncomfortable operation. These same alternative travel regimes (1), (2), and (3) are also plotted on a distance-speed diagrams in Figure 4.13b.

The long section in the tunnel without signals does not represent a safety hazard because of the straight alignment which allows long sight distances, and because the illumination in the tunnel is adequate. However, since the drivers are not allowed to drive through red signals, these long blocks impose a long minimum headway between successive cars. While short blocks on some sections, such as around the City Hall, allow short headways, the long headway imposed by the long blocks become an element which limits the line capacity. This problem is compounded by the fact that long headways make simultaneous stopping of cars at a station very difficult.

While the speed signals located before sharp curves or on sections with limited visibility are useful, their placement on the alignment at the beginning of a long straight section, such as at 32nd Street eastbound or at 16th Street westbound, are of questionable value.

In revising the signals in the tunnel, greater use should be made of simple stationary speed-limit signs posted at the beginning and at the end of the section. If these signs are obeyed, they would insure more constant speed on the individual sections and prevent the possibility of excessive speeding.

The enforcement of stationary signs may appear to be a problem. However, the present system of speed signals also relies on disciplinary enforcement only. And, as explained above, it results in inefficient driving and does not positively prevent exceeding the maximum allowable speed.

Another cause of low running speeds is SEPTA's operating rule which requires that every car must stop prior to negotiating any switch against points. This is an obsolete rule and it is unnecessary, particularly at modern switches, such as those installed in the 40th Street Portal area. Those switches have two movable points and are designed for speeds as great as the track radius in the switch, i.e. the switch number, allows.

4.6 Headways, Reliability and Capacity

Transporting capacity of a line and efficiency of its operation depend mostly on two factors: the minimum average value of the longest headway that is achieved at any point along the line, and on its variations.

Minimum headways at which vehicles can operate vary considerable along a line. While on track sections with moderate speeds cars can follow each other at headways as short as 10-20 seconds, their standing times at busy stations may impose headways as long as 50-100 seconds. The point along a line which requires the longest minimum headway represents the controlling point (bottleneck) of the line capacity. If headways at that point can be reduced to a value lower than the minimum headway at another point, this other point becomes the new determinant of the line capacity.

Variations of headways at the critical points, as well as among different critical points along the line, also cause fluctuations in line capacity.

Measurements of headways at different points in the subway have shown

that although signals maintain certain minimum headways on most sections, vehicles often "catch-up" with each other. This is particularly the case in stations, where drivers having stopped at the entrance signal proceed to drive on visibility.

Figure 4.14a shows the time-distance diagram of the tunnel operation during the peak 30 minutes. The overall regularity appears to be fairly good, but that is deceptive. Actually, due to the very short headways, travel of vehicles is fairly uniform, but it is delayed: the average round trip travel time from 40th Street Portal to Juniper Street and back amounts to 26-28 minutes. Thus, peak hour operation represents a "forced flow" of vehicles, similar to travel on a congested freeway when traffic is "steady" but slow. Figure 4.14b shows that during the "shoulder" period headways are longer, but irregularity increases. The tendency of vehicles to "catch-up" with each other in pairs can also be seen in this diagram.

Frequencies of vehicle arrivals were measured at several stations. A summary of these frequencies at 30th Street Station westbound is shown in Figure 4.15. The diagram shows that there were two five-minute intervals during which the maximum frequency of 9 vehicles were recorded. This means that at some point in the tunnel vehicles operate at headways as short as 33 seconds.

The problem of delays and irregularities of service is also illustrated in Figure 4.16, which shows actual arrivals and scheduled departure times at Juniper Street Station during the PM peak by route. Vehicles operating on-schedule would be shown on this diagram by vertical lines. The fact that virtually all lines are tilted means that the entire operation suffers from delays. Typical delays are 3 to 6 minutes, but actually, they are even longer

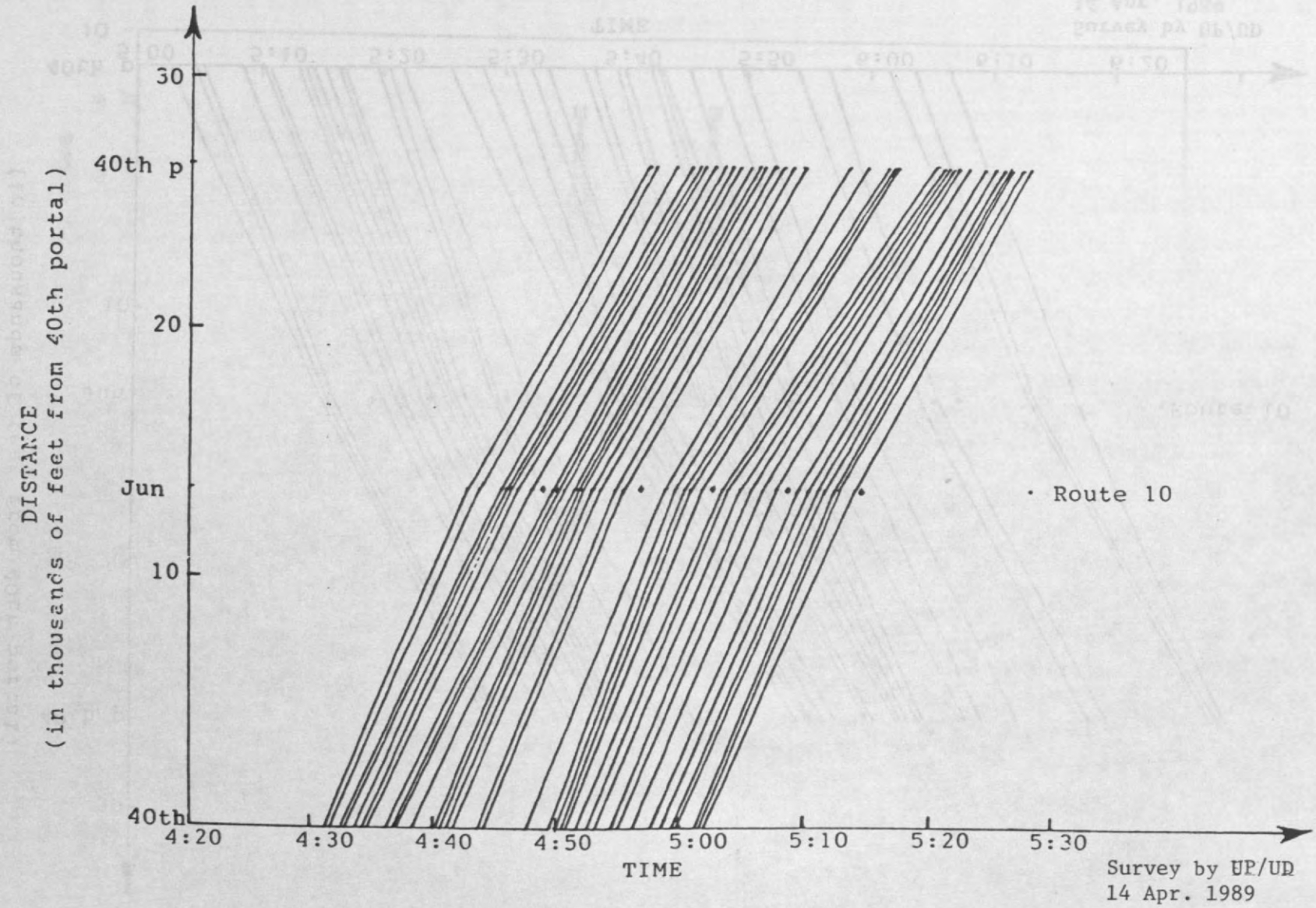


Figure 4.14a Time-distance diagram of vehicle operations in the tunnel - PM peak period

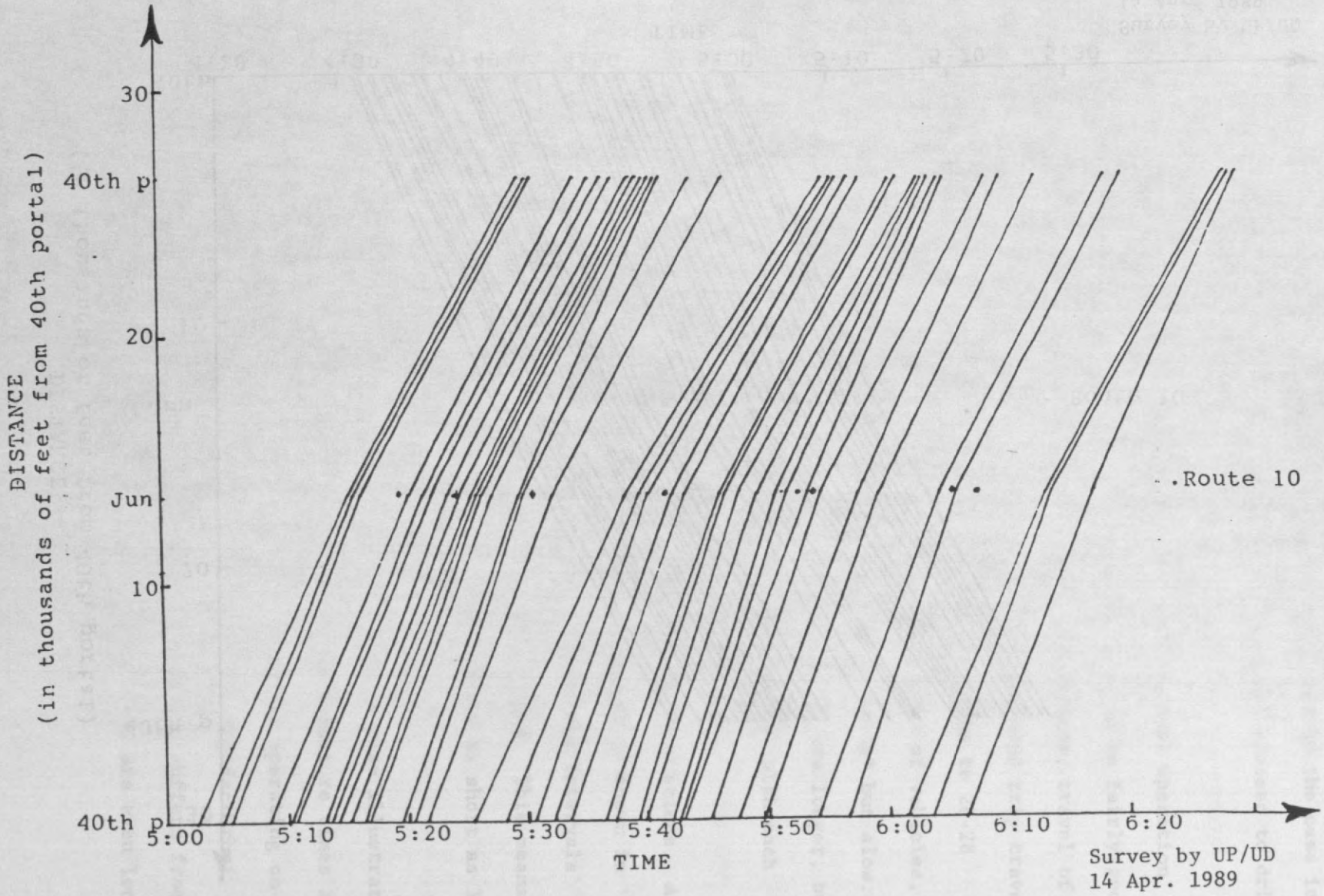


Figure 4.14b Time-distance diagram of vehicle operations in the tunnel - PM peak and shoulder periods

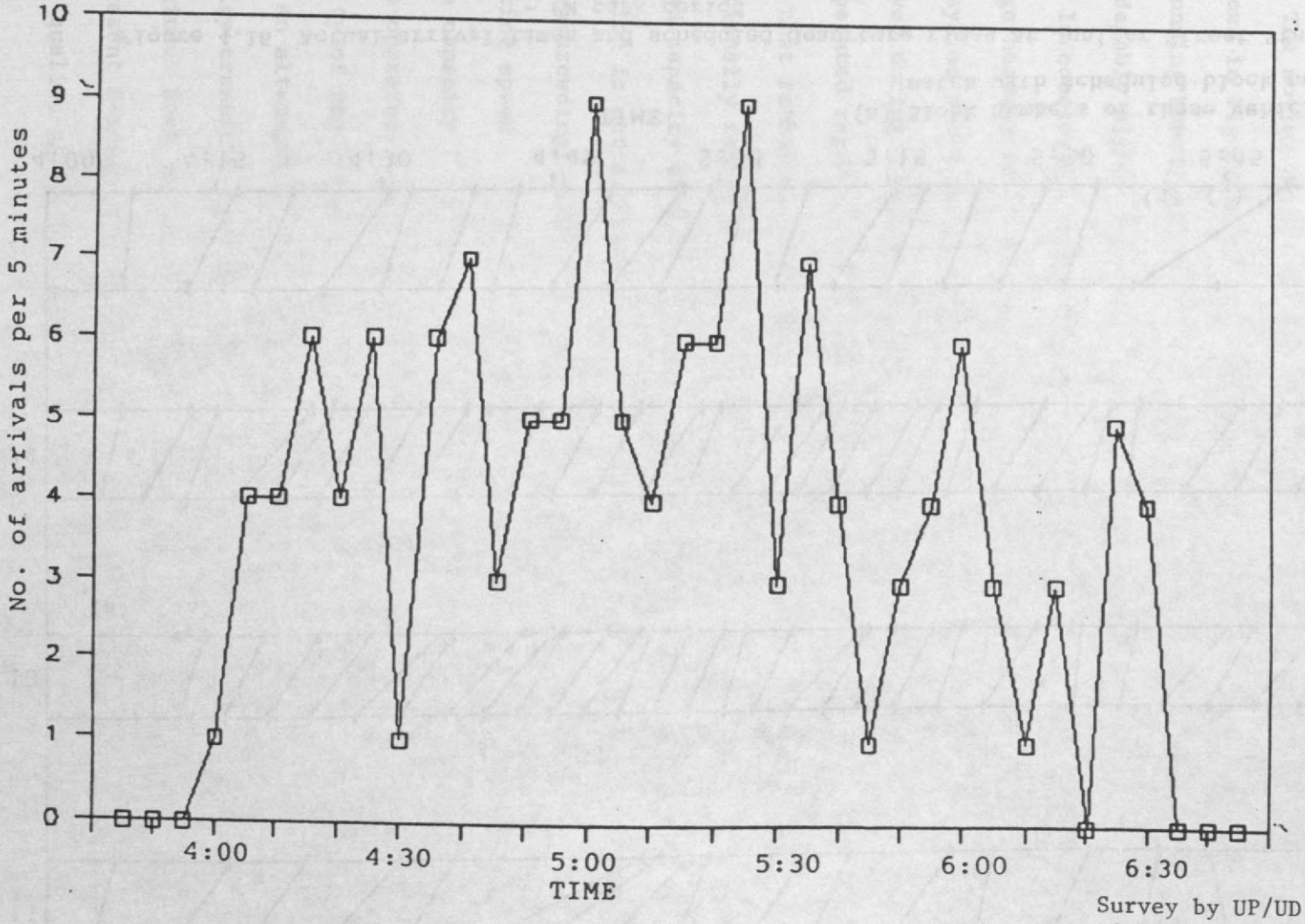
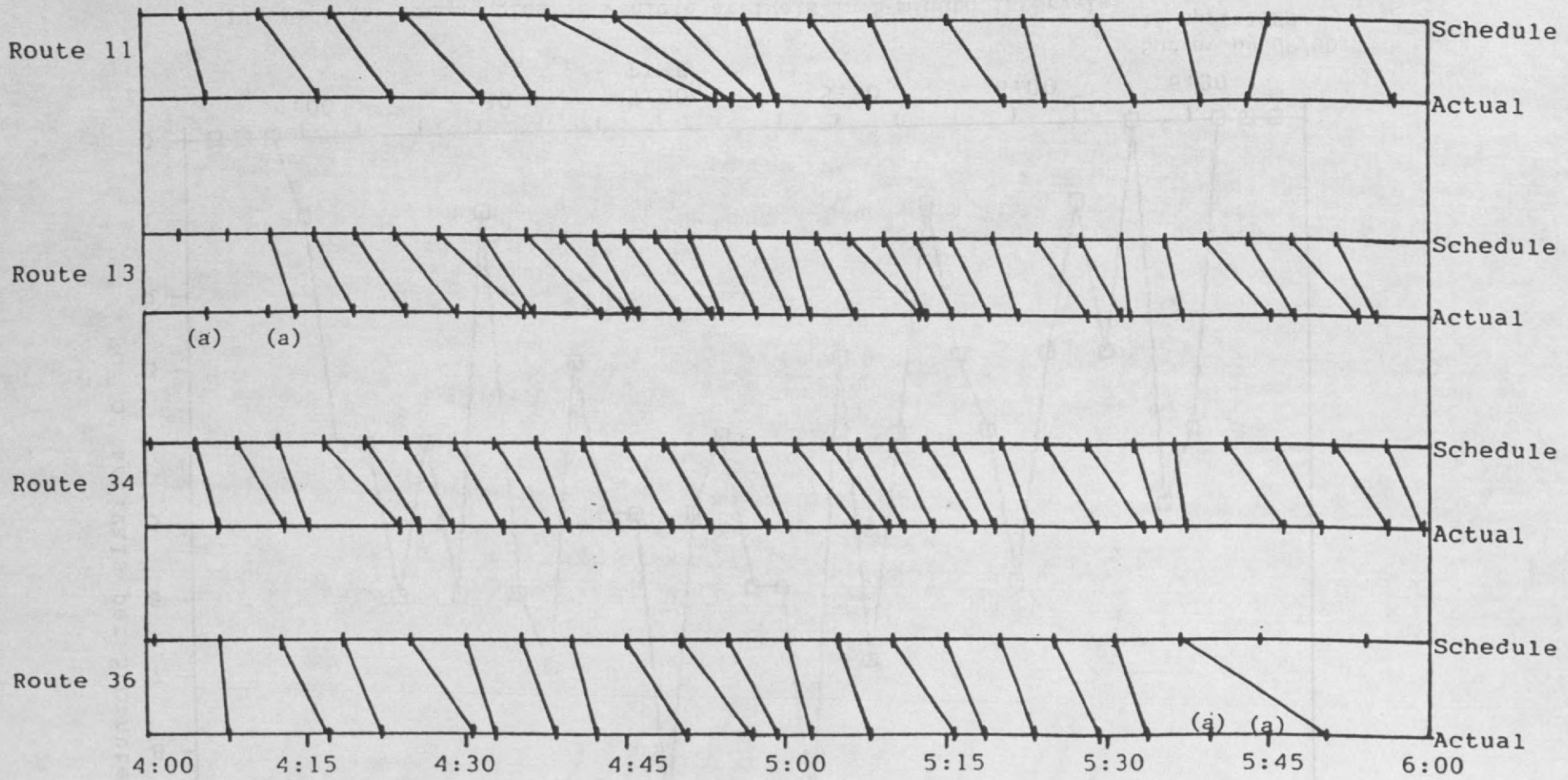


Figure 4.15 Frequencies of vehicle arrivals in 5-minute intervals - 30th Street Station, westbound



(a) Block numbers of these vehicles do not match with scheduled block numbers.

Figure 4.16 Actual arrival times and scheduled deaprture times at Juniper Street Station - PM peak period

Survey by UP/UD
14 Apr. 1989

because the plots connect scheduled departures with actual arrivals. Thus, actual delays are even greater than those shown by the duration of the dwell times.

The moving hourly total of vehicle departures at Juniper Street Station is shown in Figure 4.17. The diagram shows that the Green Lines operate at the running hourly total of 70 vehicles. During shorter intervals considerably higher flow rates are achieved.

In conclusion, the Green Lines presently operate in the tunnel with the average headway of 51 seconds (70 vehicles per hour), but at many locations headways as short as 33 seconds (a frequency of 109 vehicles per hour) are achieved during 5 minute intervals. Actually, several decades ago the tunnel was operated regularly with average headways as short as 30 seconds; this fact shows that rather drastic improvement of present operation is physically and operationally feasible. The hourly operation of 70 vehicles translates to an offered capacity of 7,000 spaces per hour. However, reliability of this operation is not satisfactory. Frequent delays cause uneven vehicle loadings and overcrowding, vehicle pairing and bunching, and reduce the average operating speed. Further, the present irregularity imposes a practical limit on the capacity. If irregularities are decreased, a shorter average headway can be operated. This would decrease overcrowding and increase speed and capacity of the line.

An alternative to increasing capacity would be to introduce higher capacity transit units: articulated vehicles or the present vehicles coupled in trains. Such larger units would substantially increase capacity even if the present headways are maintained. Actually, to obtain higher capacity and higher quality of service both increased transit unit capacity and improved

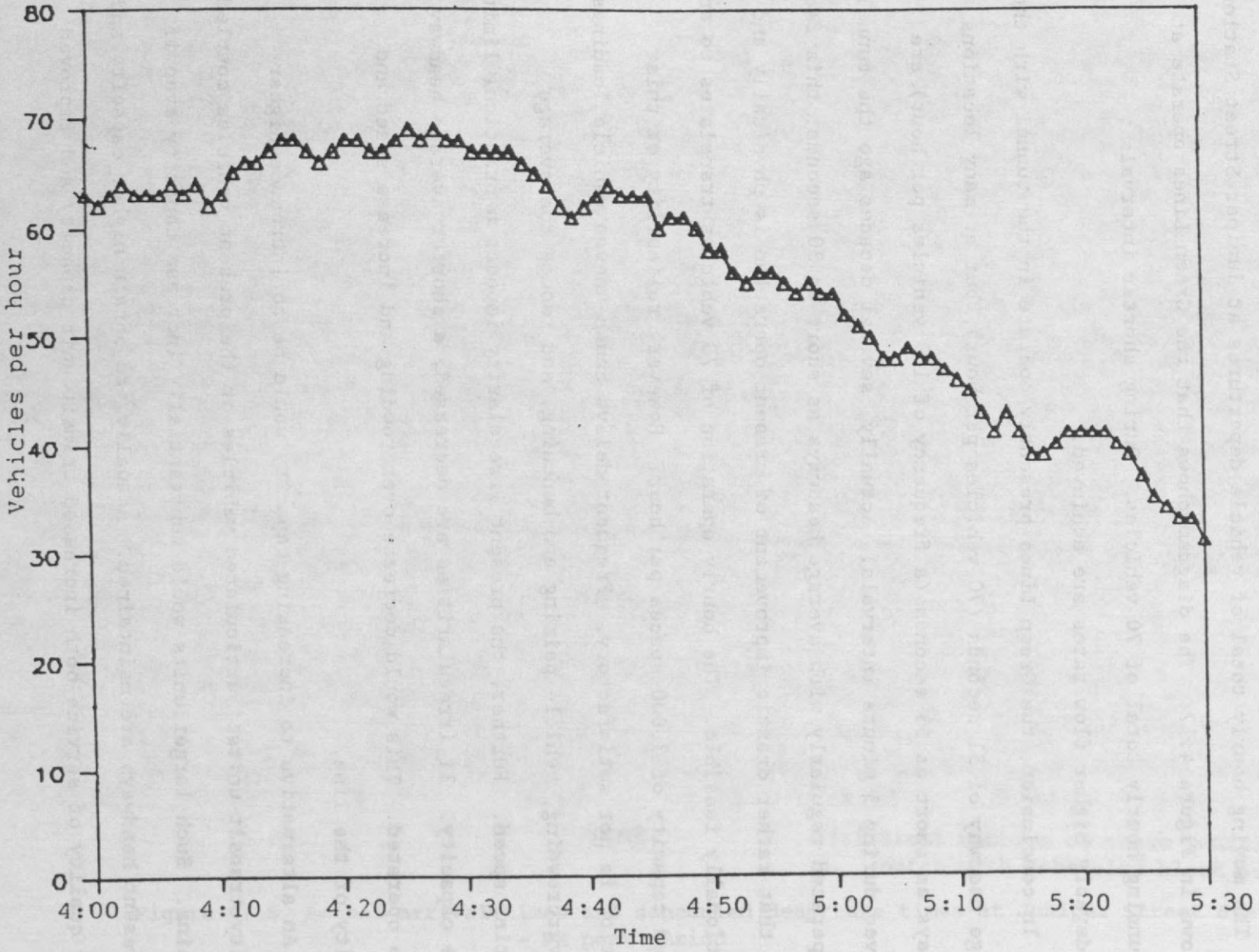


Figure 4.17 Sliding total of vehicles arriving in 60 minutes following the plotted time at Juniper St. Station - p.m. peak period

service regularity are recommended. The potential impact of increased transit unit capacity on the service quality is shown in Figure 4.18 by the illustration of the queue of vehicles at Juniper Street Station during the peak hour. The solid line shows the present typical queue, while the dashed line shows the back up if two-car trains were operated on only one of the lines, namely Route 34.

Consequently, benefits due to the introduction of higher capacity transit unit would include not only higher comfort and faster travel for passengers, but also increased reliability, which translates into a smaller required fleet of rolling stock and reduced capital and operating costs.

Briefly stated, operation of two-car trains on some routes would have the following advantages (+) and disadvantages (-) over the present operation of single cars:

+ Increased line capacity and reliability of service;

+ Possibility to offer higher comfort (more spaces offered per hour);

= No change in labor cost per offered vehicle capacity;

- Complicated coupling/uncoupling operations with possible delays;

- Somewhat lower dispatching at stations (coordination between the two motormen);

- Possible operational difficulties with long couplers/tow bars.

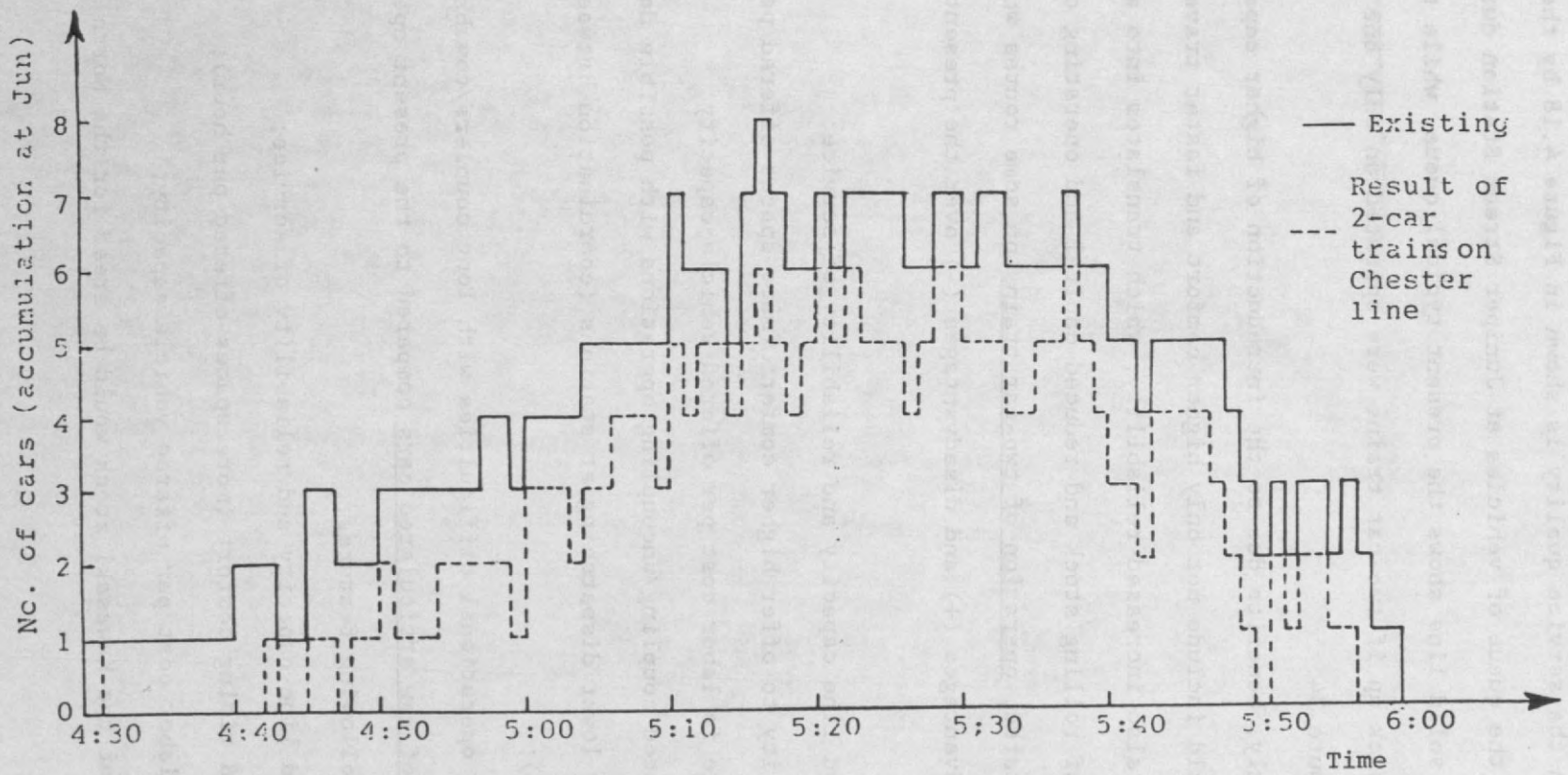
Operation of new articulated cars compared to the present operation would have the following features:

+ Increased line capacity and reliability of service;

+ Increased riding comfort (more spaces offered per hour);

+ Reduced labor cost per offered vehicle capacity;

+ Portion of the Kawasaki stock would be freed for the North



Note:-Standing time of a car is assumed to be 1 minute.
-All 5 lines (Woodland, Chester, Elmwood, Baltimore and Lancaster Avenue lines) are included.
-Two-car trains operate on Chester line, and one car trains on all other lines.

Figure 4.18 Impact of increased transit unit capacity on vehicle queuing at Juniper Street Station, PM peak period

Philadelphia streetcar lines;

= No major change in operations (single vehicle, one driver controls all doors);

- A major investment required for the purchase of articulated cars.

Consequently, coupling of cars in trains would bring relatively few advantages, while it could cause operational difficulties. That solution should therefore be used only when all operational improvement measures are exhausted.

Introduction of articulated cars would require a significant investment, but it would represent a far better solution: improved operation and service at lower unit operating cost, coupled with an excellent solution for modernizing the North Philadelphia streetcar lines. Thus, purchase of new articulated vehicles would be a more costly but superior solution, not only for the Green Lines, but also for the imminent major problem of how to modernize the North Philadelphia streetcar lines.

4.7 Supervision, Operations Control and Management Organization

Surveys and discussions with SEPTA employees, ranging from drivers and loaders to supervisors and managers, has uncovered a number of organizational and managerial problems that need correction. Major deficiencies which need improvements are outlined here.

Drivers. Run sheets which should give each driver exact instructions about the schedule (s)he should follow do not contain sufficient details. For example, Route 34 sheets give only times at 40th Street Portal, Juniper Street and then at 45th Street and Baltimore Avenue westbound. Thus, the driver cannot easily find out whether (s)he is on-time at any intermediate points. Moreover, the computed times are inaccurate, showing in some instances,

overtaking of cars in the tunnel (see Figure 4.19) More detailed schedules should be given to all drivers.

Supervisors. Joint operation of five routes on a single track requires careful, strict supervision and frequent intervention to reduce delays or prevent their creation. Supervisors of the Green Lines both at Juniper and 40th Street are often passive. They observe the operations, often without looking at schedules or taking any notes. They observe drivers stopping at wrong locations, but do not intervene.

It is important that supervisors regularly communicate with each other so that they can coordinate actions in the cases of delays. The control/communication system for the tunnel provides good communications capability between supervisors, the control center at Wyoming Avenue and the drivers on the lines. However, supervisors cannot communicate among themselves.

Improved supervision through more precise and active control and better "horizontal" communication among supervisors are needed to improve the control function in the tunnel.

Station Operations Control. Among all the deficiencies on the Green Line system, this is the most serious one. Busy stations such as Juniper Street, 15th Street, 19th Street and 30th Street are critical points for regularity, capacity and efficiency of the service. Yet, operations in these stations are practically uncontrolled. Cars stop one at a time at the most congested locations, with the least visibility, creating unnecessary congestion. Electric signs, which could potentially greatly improve operations, have been out of operation for many years, but they confuse passengers. Some of the loaders perform their job competently and assist

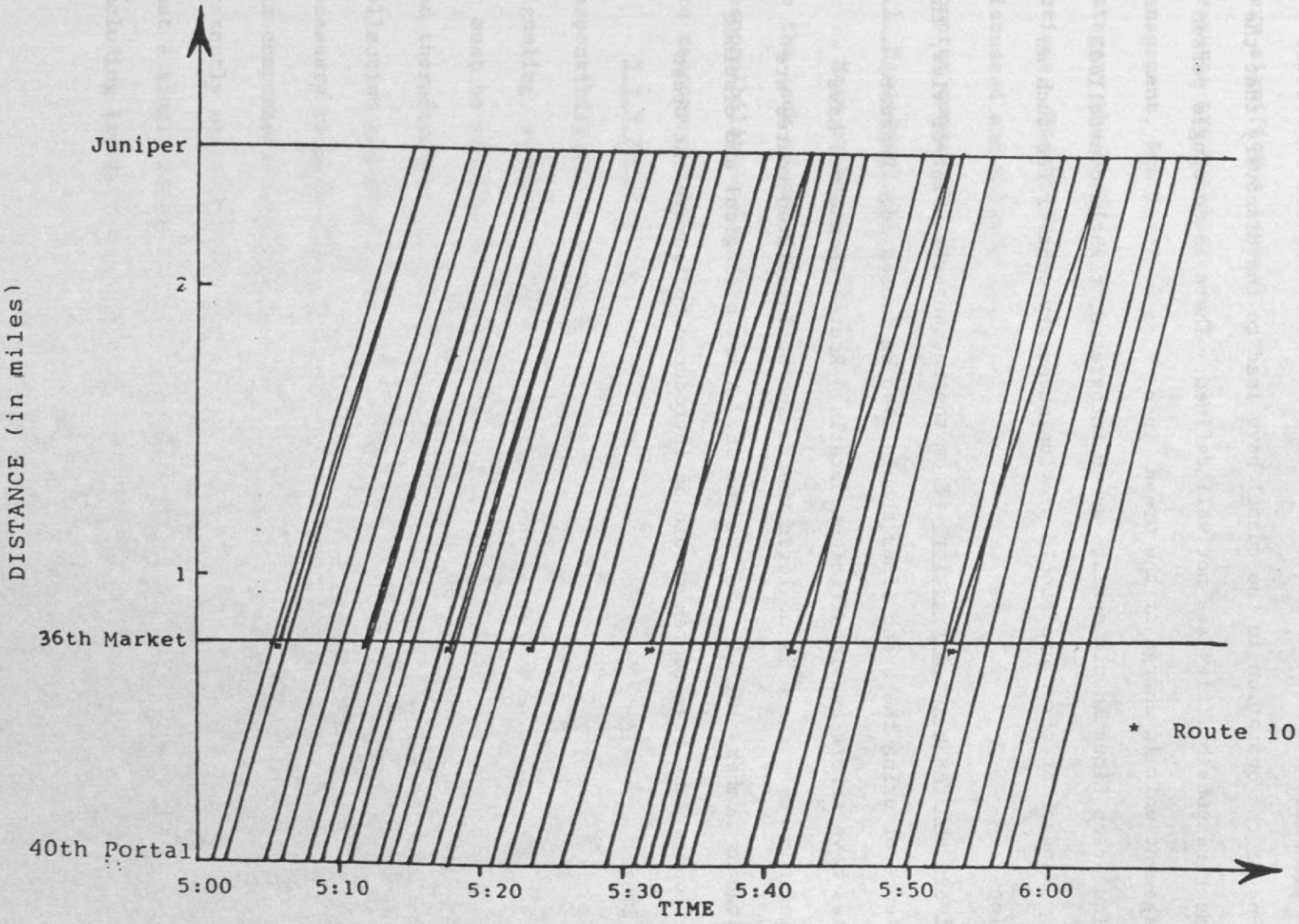


Figure 4.19 Time-distance diagram of tunnel operation

operations, but some do not perform sufficiently well to correct the problems of disorganized operation and chaotic conditions when they occur.

Management. The attempt to identify responsibilities for individual functions of the operation in the tunnel have lead to the discovery that the management responsibilities are not well defined. There is no single person or management unit in charge of the Green Lines.

The Green Lines should operate as an integrated, tightly controlled system. Management structure should provide necessary control for such an operation.

Image and Passenger Attraction. From the passenger's point of view, the convenience of using the Green Lines should also be increased. Present schedules have errors and insufficient details. Routes themselves have confusing numbers: there is no logic that a set of integrated routes are designated as numbers 10, 11, 13, 34, and 36. A set of logical and distinct designations of the five routes should be introduced to improve the Green Lines' image.

5. RECOMMENDED IMPROVEMENT MEASURES

Based on the surveys and analyses performed in this project, it is concluded that a number of measures should be undertaken which will result in very significant improvements of the Green Lines tunnel operations. The measures are presented in this chapter in four different categories: Management, Station Operations, Vehicle Travel and Rolling Stock. For each category the measures are given, followed by a description of the required actions. Then, expected results of all actions in the given category are discussed and their effectiveness is evaluated. The final section in the chapter summarizes these recommendations.

5.1. Management and Supervision

Many problems and deficiencies in the present operations can be traced to the lack of an adequate management/supervision structure and assignment of responsibilities for the Green Lines operations. The following three measures are recommended to correct this problem.

5.1.1 Appoint a System Manager and Chief Supervisor. Presently, responsibilities for different functions of the Green Lines (operations, signaling, station communications, etc.) are divided among several managers. It must be recognized that these lines operate together as a complex system, and therefore require full coordination of their supervision, signals, fare collection and other components. To achieve such coordination, it is necessary to have a manager responsible for this entire system, including all its components and functions. He should take overall responsibilities presently distributed among several managers. It is therefore recommended that a single person be appointed manager of the entire Green Lines system, including its facilities, rolling stock, scheduling and operational

supervision.

For similar reasons, it is important that one supervisor on the Lines be in charge of their operation at all times. It is logical that this person should be the supervisor at Juniper Street Station.

These recommendations do not mean appointments of new persons; positions can be filled by redefining responsibilities of the persons in management and supervision, respectively.

5.1.2 Introduce Communications among Supervisors. "Vertical" communications, between the control center at Wyoming Avenue, field supervisors and drivers, are generally adequate; however, "horizontal" communications among the field supervisors are missing. The present communications system should be reviewed and adjusted so that the supervisors can also talk to each other directly.

Figure 5.1 shows the schematic for the proposed communications network versus the present system.

5.1.3 Improve Supervision/Control. Presently, the quality of supervision varies greatly. Depending on the individual, some field personnel perform superbly, while others are doing the "minimum required".

The Green Line system operates at such a high frequency and without possibilities of diverting any vehicles off line, that a more precise and well supervised operation is necessary. To achieve this, it is recommended that the following actions be undertaken:

- Review and update operating rules and manuals for drivers and supervisors;
- Improve training of the supervisors;
- Conduct regular control of the field supervisors to ensure that they

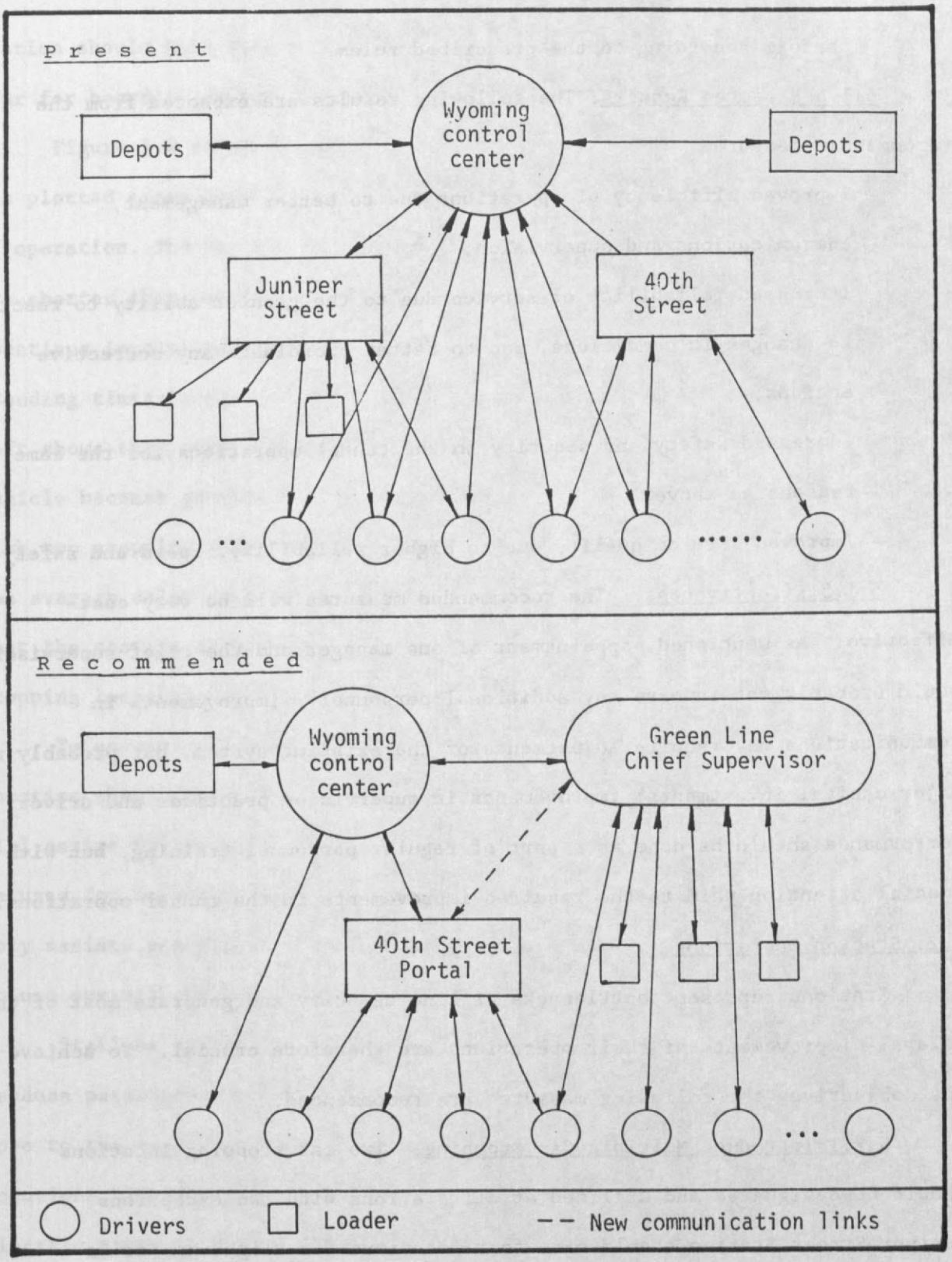


Figure 5.1 Schematic diagram of the present and recommended communications network

perform according to the prescribed rules.

5.1.4 Expected Results. The following results are expected from the recommended measures:

- Improved efficiency of operations due to better management, communications and supervision;
- Increased reliability of service due to the greater ability to react to changes in conditions, and to better coordinate any corrective actions;
- Increased safety and security in the tunnel operations for the same reasons as above;
- Improved service quality due to higher reliability, speed and safety.

5.1.5 Effectiveness. The recommended measures will be very cost-effective. As mentioned, appointment of one manager and the chief supervisor would probably not involve any additional personnel: improvements in communications may require adjustments of the existing system, but probably no major capital investments; improvements in supervision practices and driver performance should be done as a part of regular personnel training, but with special attention paid to the required improvements in the tunnel operations.

5.2. Station Operations

Stations represent bottlenecks of line capacity and generate most of the delays. Improvements of their operations are therefore crucial. To achieve that objective, the following measures are recommended.

5.2.1 Introduce Multiple Car Stopping. Two car stopping locations should be designated and utilized at all stations with two exceptions. Juniper Street Station should have four locations for alighting (as is sometimes practiced now) and four locations for boarding. The 15th Street

Station should have four locations for alighting at the eastbound platform and four for boarding at the westbound platform.

Figure 5.2 shows the influence of multiple stopping on station delays. The plotted cases have regular operations to clearly illustrate the two types of operation. The top two diagrams show operation when station standing times are shorter than headways -- operation with single and with double stopping locations involve no extra delays. The lower two diagrams show operations with standing times longer than headways of arriving vehicles. The diagram on the left shows that with a single stopping location the delay of each subsequent vehicle becomes greater, i.e., station capacity is exceeded. On the right, with two stopping locations, there are some delays to incoming vehicles, but the average delay remains shorter than the headway of arriving vehicles, so that the station capacity is not exceeded. Clearly, provision of the second stopping location decreases delays and increases throughput of stations.

To ensure efficient operation of multiple stopping locations, each location should be designated by a line marking the front of the car which will assist the driver to stop precisely. Locations of all doors which should be used for boarding should also be designated by pavement markings. This not only assists passengers to wait at the correct locations but also induces them to use one or both doors, as appropriate, in each station (see next section).

Stations with two stop locations do not require any additional signs because passengers can easily recognize the destination of incoming cars and move to the correct location. At the two stations with four boarding locations, Juniper Street and 15th Street westbound, the existing changeable electric signs should be corrected, reactivated and used regularly. They should be operated by the supervisor at Juniper Street Station.

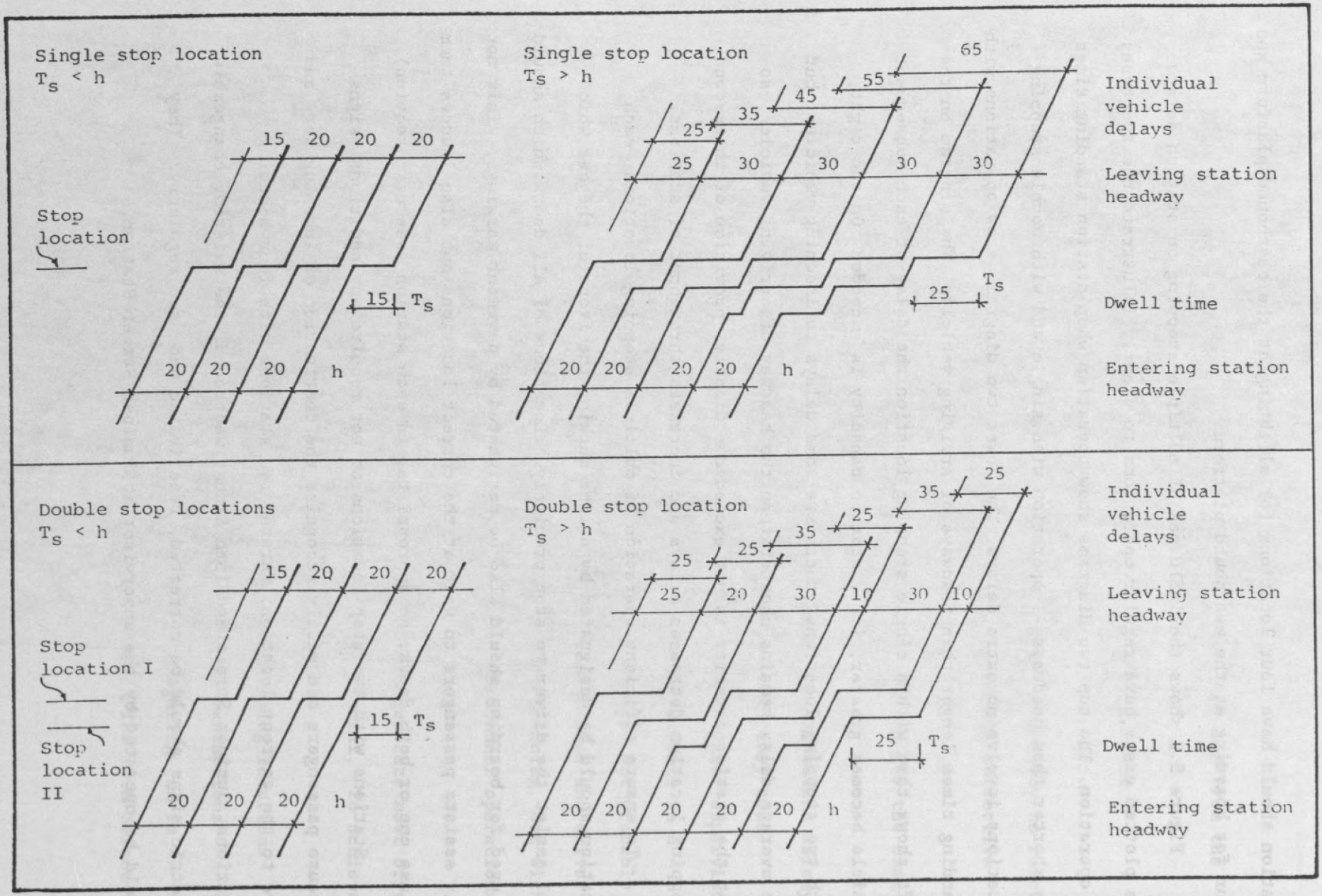


Figure 5.2 Increase of station capacity through double stop locations

5.2.2. Accelerate Boarding/Alighting. Boarding/alighting should be speeded up by three types of improvements:

- Improved fare collection can be achieved at the 19th Street Station, both eastbound and westbound, only if sufficient space is found for construction of fare collection gates. At stations with loaders, passengers with passes should be encouraged to board through the rear doors;

- Optimum door usage should be achieved by directing passengers to follow the best pattern based on the specific conditions at each station. For example, passenger alighting should be prevented from using the front door at the 19th Street and 22nd Street Stations, while use of both doors for alighting should be encouraged at 15th Street eastbound. A review of boarding/alighting distributions on different doors is given in Figure 5.3.

- Loaders/dispatchers should continue to be used during peak hours at stations with large volumes of boarding passengers. Improved instructions and supervision of their performance should be used to ensure that their performance is effective in boarding supervision as well as in vehicle dispatching.

5.2.3 Improve Passenger Information. To ensure compliance of passengers with these procedures, the system must provide clear and ample information that is adequate not only for regular users, but also for incidental passengers. In addition to pavement markings and electric signs, each station should have a board explaining boarding locations and fare collection procedures. Because of different alighting patterns among stations, the drivers should follow their station announcement for each station by instructions as to which door(s) should be used for alighting.

5.2.4 Introduce Logical Route Designations. In order to decrease

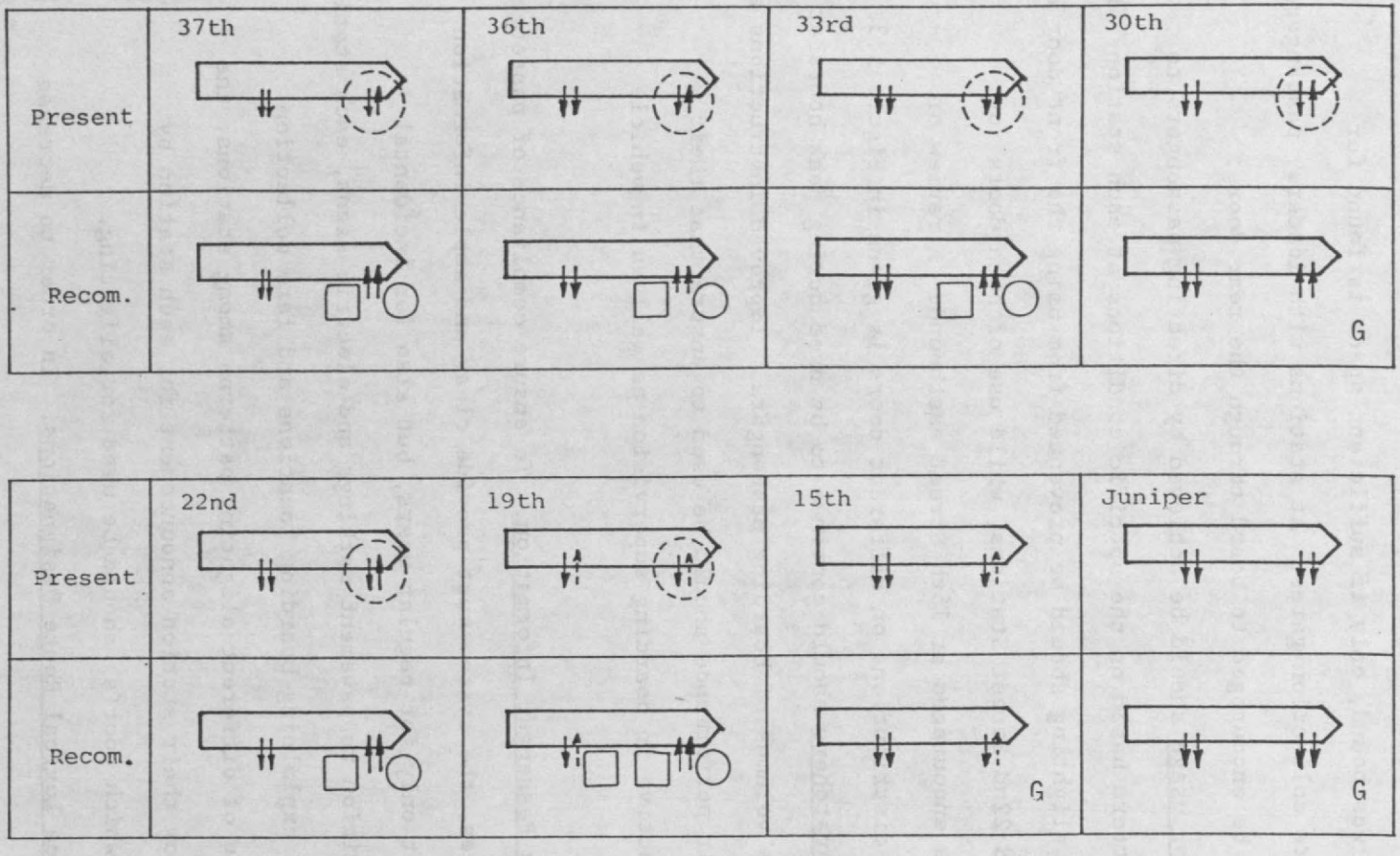


Figure 5.3a Present and recommended boarding/alighting procedures at individual stations - east bound

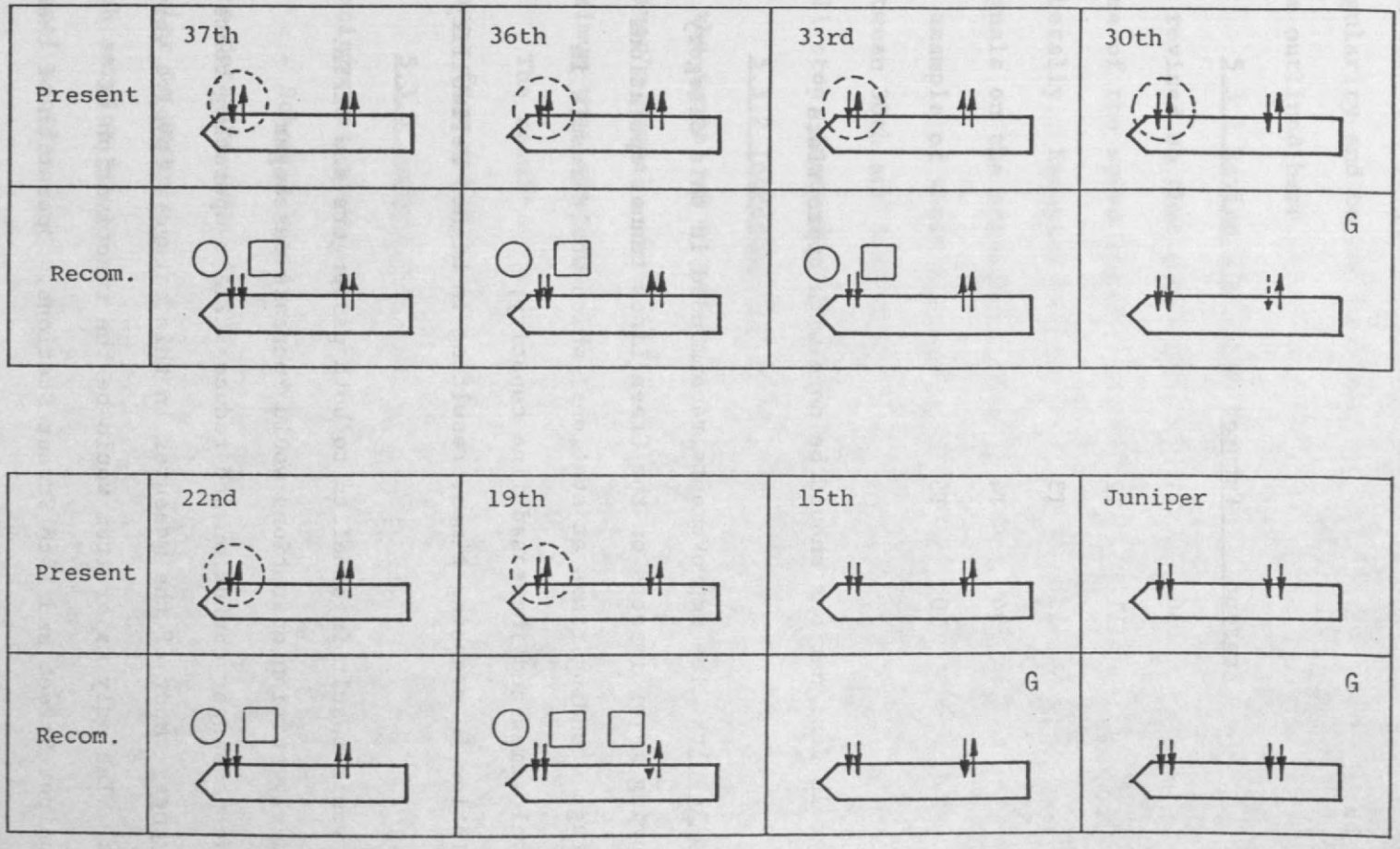


Figure 5.3b Present and recommended boarding/alighting procedures at individual stations - west bound

passenger confusion and enhance the image of the Green Lines, the designations should be changed to T-1 through T-5. The sequence of route designations should be logical from the south toward the north (clockwise), so that the new designations should be:

Present	Future
36	T1
11	T2
13	T3
34	T4
10	T5

Naturally, the change in designations should be done with appropriate publicity.

5.2.5 Expected Results. The improvements recommended in this category would have the following major impacts on the Green Lines tunnel operations:

- Reduced average standing times at stations, which would result in shorter travel times and increased line capacity;
- Reduced variation in standing times, resulting in higher reliability of service;

These changes would result in benefits to both passengers and SEPTA. More precise and orderly station operations would increase passenger convenience, decrease passenger confusion and reduce SEPTA's operating costs.

5.2.6 Effectiveness. Most of the measures in this category involve very low investment costs. The only major item would be the reactivation of electric signs at Juniper Street and 15th Street Stations. Operation of these

signs would not require additional personnel.

5.3 Vehicle Travel

Several changes in tunnel infrastructure should be undertaken to improve regularity and to increase speed of vehicle travel. The recommended changes are outlined here.

5.3.1 Revise Signal Locations and Timings. Signal block design should be revised so that more uniform travel times in different blocks are achieved. Some of the speed signals should be eliminated, others should be timed more liberally. Examples of the signals which should be eliminated are the two signals on the straight alignment entering 30th Street Station from the west. An example of where timing revision is needed is the signal in the curve between 30th and 33rd Streets westbound which forces each car to come to a full stop, instead of just slowing the cars down.

5.3.2 Introduce Speed Limit Signs. An overall speed limit for traveling in the tunnel of 45 or 50 mph should be introduced and specified in the Driver's Manual. On all sections where the speed limit is lower than the maximum that speed limit should be displayed by track-side signs.

The result of the changes suggested under 5.3.1 and 5.3.2 would be a change from speed control at points to speed control on line sections.

5.3.3 Improve Scheduling and Operating Practices. Regularity and precision of operation should be improved by the following measures:

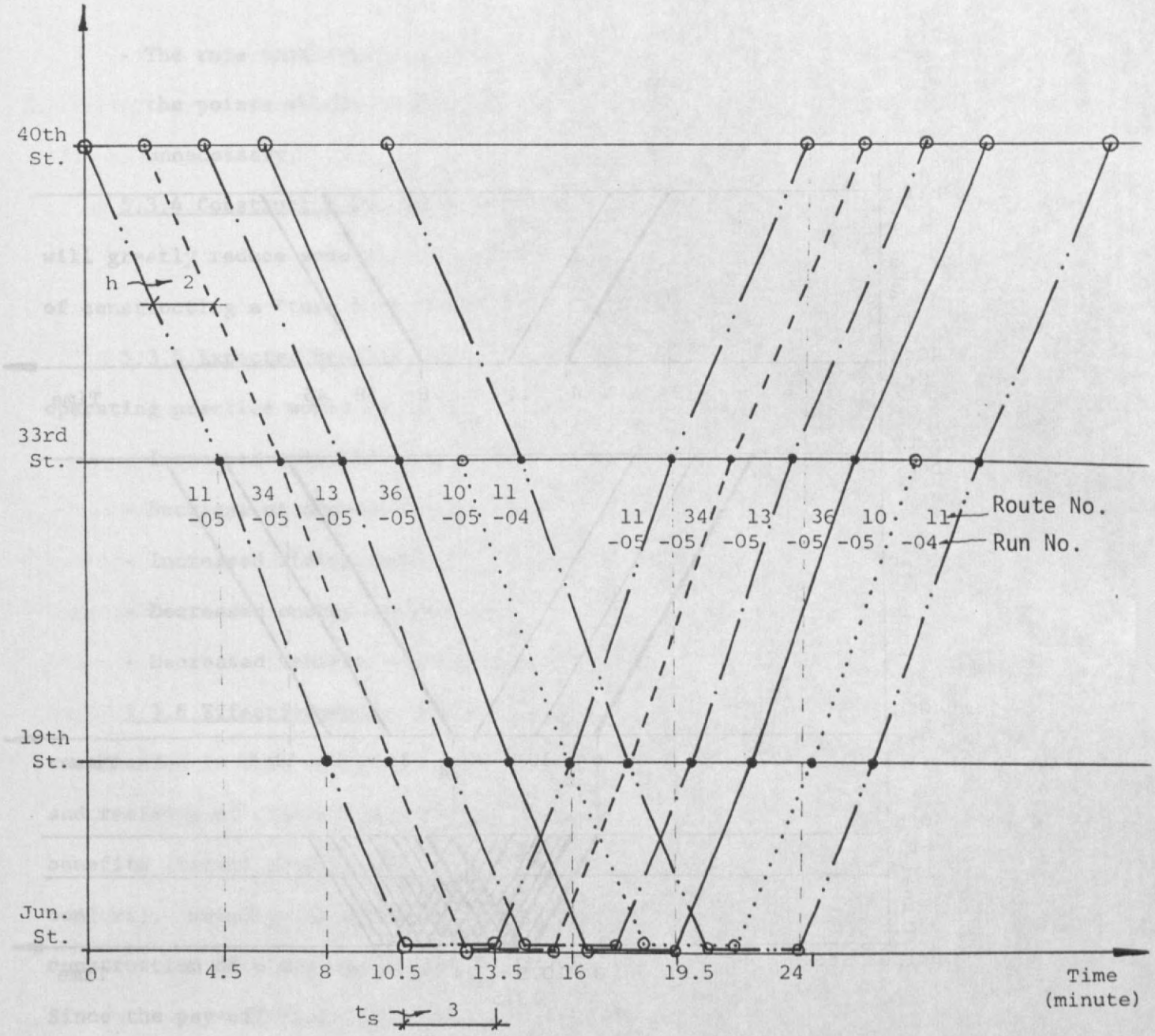
- Schedules for the Green Lines should be done with more clarity and more details, using graphical schedules ("string charts"). These diagrams are easier to prepare for complex operations (convergence of several branches, high service frequency) which exist on the Green Line network. Since the tunnel section is the most critical portion of the network, scheduling should

be done first for all five routes on that section ensuring regular headways among them. All scheduling for the remainder of each route should be done so as to maximize the likelihood of each car reaching the portal at its appointed time. As illustrated in Figure 5.4, the diagram should show the scheduled times for three points along the tunnel in each direction (east- and westbound).

Using the diagram for tunnel operations as a basis, diagrams for each route should also be graphically plotted, as shown in Figure 5.5. These diagrams allow much easier scheduling, with more details and lower possibility of errors than numerical schedules. As the two illustrations show, the diagrams clearly display such details as different speeds on different line sections, turnaround times, meeting locations of all cars, etc. These diagrams also allow easy assembly of drivers' schedules for each run, containing all key points along the line. In addition, schedules of all vehicles at a given location are easily assembled, for use by the supervisor at that location.

The following is a summary of recommended changes to scheduling and operating practices:

- Each driver should know his/her schedule at least at the following points along the tunnel: Portal, 30th Street, 19th Street, and Juniper Street -arrival and departure. Supervisors at these stations should have schedules with times for each car. These schedules can easily be constructed by moving horizontally along the string chart.
- The VETAG installations should be utilized to identify cars and this information should be used for checking schedule adherence, observing vehicle sequence, for planning/operations, and for informing the public when significant delays occur.



Headway h = 2 min Terminal time t_s = 3 min

⊙ Supervisor check time points • Driver check time points

Figure 5.4 Recommended design of graphical schedule for the tunnel section

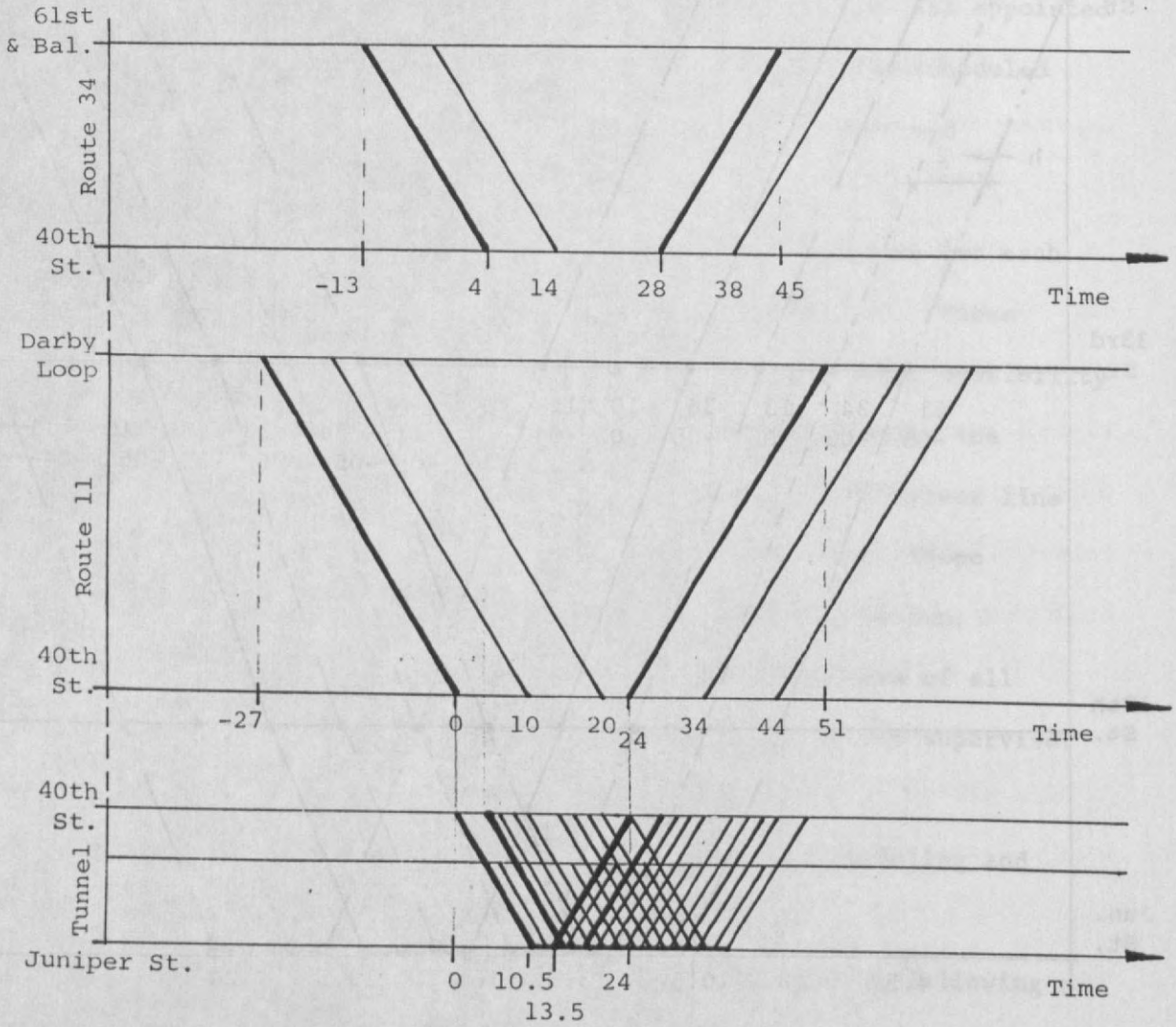


Figure 5.5 Illustration of the graphical schedule design for individual Green Line routes

- The rule that every car must stop before negotiating a switch against the points should be abandoned because it is very costly and unnecessary.

5.3.4 Construct a Storage Track. Since availability of storage track will greatly reduce some of the major delays, possibilities should be examined of constructing a "turn-out" track on the south side of the City Hall.

5.3.5 Expected Results. The recommended changes of infrastructure and operating practice would bring the following improvements:

- Increased reliability of service
- Decrease of average travel time
- Increased riding comfort
- Decreased energy consumption
- Decreased vehicle wear and tear.

5.3.6 Effectiveness. Investment cost and effectiveness of the measures recommended in this category vary greatly. Elimination of some speed signals and retiming of others would involve minimum effort and result in considerable benefits (travel time saving, reduced energy consumption, increased riding comfort). Redesign of signal blocks involves considerably higher cost. While construction of a storage track would represent a significant capital project. Since the pay-off from redesign and construction would be realized in the long term, these measures would require considerably more detailed planning.

Apart from the measures requiring capital investment, revision of scheduling and operating practices would require minimal investment, but would still have a significant positive effect on operations.

5.4 Rolling Stock

The most effective way of increasing capacity of a rail line is to increase the capacity of transit units (vehicles or trains) on it. There are two ways of achieving this goal on the Green Line network: operation of two-car trains and introduction of articulated vehicles.

5.4.1 Introduce Two-car Trains. Due to the extremely restrictive geometric alignment of the Green Lines, coupling of cars is very difficult. Operation of cars connected by tow-bars may prove to be unreliable and impractical. Moreover, operation of two-car trains with two drivers does not result in operating cost reduction. Increase of line capacity and/or increase of minimum headway would therefore be the only benefit.

5.4.2 Introduce Articulated Vehicles. Operation of articulated vehicles would result in increased line capacity without any increase in labor cost. Spaciousness of articulated cars and their good riding comfort have made these vehicles the standard type in nearly all recently built or modernized light rail transit system. Therefore, this is an effective way of improving both operating efficiency and the level of service.

Regardless of which type of rolling stock is used, the obsolete trolley poles should be replaced by pantographs in the foreseeable future. The benefit will be the elimination of service delays and physical damage caused by dewired poles.

5.4.3 Effectiveness. Changes in rolling stock for the Green Lines will not be necessary in the immediate feature if the improvement suggested in the first three categories are introduced. Yet, it may be necessary to consider increased capacity of transit units in the future either for improvement of service quality or to cope with further ridership increases.

If it becomes necessary to increase transit unit capacity, introduction of articulated vehicles is a significantly superior solution to the operation of coupled cars. Introduction of articulated vehicles would require purchase of new rolling stock, but it would free the existing stock to be shifted to street car lines presently operated by the obsolete PCC cars which have very limited remaining economic life. A policy decision to rejuvenate the North Philadelphia streetcar lines would greatly strengthen the case for buying new articulated cars.

5.5 Summary of Recommended Measures and Their Prioritization

The recommended improvement measures, described in the preceding sections, are presented in a condensed manner in Table 5.1. The measures are listed in the first column of the table in the same sequence as they are discussed in the preceding text. The second column shows costs or efforts required for implementation of each measure. In the third column, expected improvements resulting from the measures are given by each category of measure since improvements may be difficult to define precisely for each individual measure.

Evaluation of each measure is given in the column Effectiveness, and it is expressed by the words very high, high, moderate or marginal. These qualitative terms are used because most measures cannot be evaluated quantitatively as a cost/benefit ratio, investment/time saved ratio, or any other exact measurement. The effectiveness given in the table has been estimated considering the relationship between the total preparations, costs and other efforts needed for the implementation of the measure and the worthiness of the resulting improvements. Thus, a measure with a relatively moderate impact on the operations may be evaluated as having very high

Table 5.1 Summary, evaluation and prioritization of the recommended improvement measures

Improvement measure	Cost/effort	Improvements	Effectiveness	Priority
1. Management/Supervision				
1.1 Appoint a system manager and chief supervisor	Reassign responsibilities	Improved: - Organization & efficiency of operations - Reliability of service - Safety & security - Service quality	Very high	A
1.2 Introduce communications among supervisors	Upgrade communications system		High	A/B
1.3 Improve supervision/control	Improve training and performance of supervisors		Very high	A
2. Station Operations				
2.1 Introduce multiple car stopping	Implement new stopping patterns	- Reduced standing times & variations - Increased line capacity - Improved service reliability - Reduce pass. confusion - Create distinct image	Very high	A
2.2 Accelerate boarding/ alighting	Improve boarding/ alighting control practices		Very high	A
2.3 Improve passenger information	Introduce accurate information for passengers		Very high	A
2.4 Introduce logical route designations	Change designations		High	B

Table 5.1 Summary, evaluation and prioritization of the recommended improvement measures (cont'd)

Improvement measures	Cost/effort	Improvements	Effectiveness	Priority
3. Vehicle Travel				
3.1 Revise signals	Plan & implement signal improvements	- Increased reliability - Decreased average travel time - Increase riding comfort - Decreased energy consumption, wear & tear	Moderate	B
3.2 Introduce speed limit signs	Post the signs		High	B
3.3 Improve scheduling & operating practice	Prepare more detailed driver schedules Increase use of VETAG		Very high	A
3.4 Construct storage track	Construction of siding at City Hall		Moderate	C
4. Rolling Stock				
4.1 Introduce 2-car trains	Test & introduce 2-car train operation	- Increased line capacity, reliability - Improved comfort in articulated vehicles	Marginal	C
4.2 Introduce articulated vehicles	Purchase articulated vehicles		Moderate	B/C

effectiveness if it requires only a minor effort for implementation; a measure with major results may have only moderate effectiveness if it requires a major investment, etc.

The last column in the table presents priorities, classified as A, B and C. These priorities have been determined considering the effectiveness of each measure as well as their required implementation times. Thus, the measures given priority A are the ones that are both effective and can be introduced in the immediate future, B will involve somewhat longer implementation time period, while C are the projects that involve a significant capital allocation.

All the measures having priority classification A are recommended for immediate implementation -- their introduction will greatly improve the operations and service quality of the Green Lines. Measures classified as B priority should be planned for introduction in the foreseeable future. Finally, measures with priority C should be introduced in the capital plans; their urgency will depend partly on the results from the measures with higher priorities.