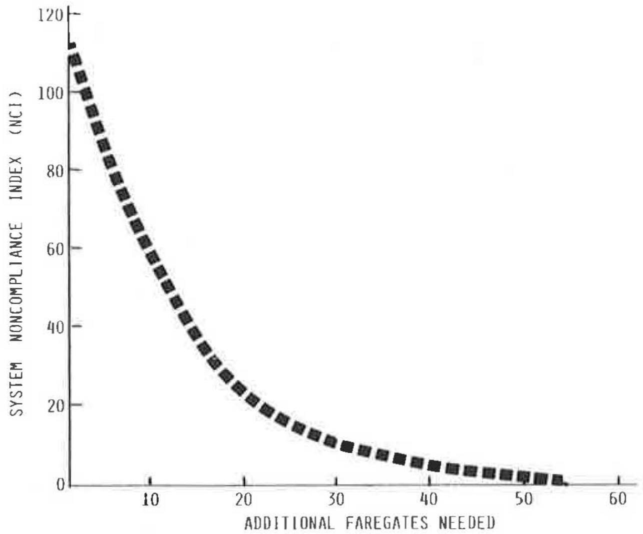

FIGURE 2 Additional faregates needed to reduce system noncompliance index.

ensure that the delays at the faregates do not exceed the headways. Based on the 1980 data, the estimated number of additional aisles needed to avoid patron delays in 1989 will probably be between 30 and 54. The actual number of faregate consoles required will be affected by the revised patronage projections for 1989 and the type of AFC equipment selected to augment the present system. These two factors could easily cause the required number of faregate consoles to double. At the same time, the exit time criteria established for the various lines have a significant impact on the number of additional faregates needed. Fairly stringent criteria were used in the current analysis to maintain equitable conditions for all the lines. Changing the exit time criteria on those lines with longer headways would reduce the number of faregates needed on the system by 20 percent or more.

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Planning an Integrated Regional Rail Network: Philadelphia Case

VUKAN R. VUCHIC and SHINYA KIKUCHI

ABSTRACT

Regional (commuter) rail systems, which serve the growing suburban areas, have had increasing ridership in many cities. In response to this growing need for high-quality regional transit service, many European and Japanese cities have upgraded their old commuter lines into regional rail systems with diametrical networks, regular schedules, and services integrated with local transit. Completion of the Center City Tunnel in Philadelphia in late 1984 connected two previously separate sets of lines (Western--formerly Pennsylvania and Northern--formerly Reading), combining them into an integrated regional rail system. The methodology, process, and major results of the planning for the regional rail systems are presented in this paper both in general terms and in their application to the Philadelphia system. Analysis of passenger requirements, operational factors, and economics has shown that the radial lines should be converted into diametrical (through) lines with fixed train routings and clear designations (such as R-1, R-2, and so forth). Extensive data concerning the system's physical characteristics, operations, and passenger volumes were collected and presented in many tables, charts, and diagrams. An elaborate methodology for selecting line pairs was developed. The guidelines for pairing included balancing of capacities and frequencies, minimizing track path conflicts, considerations of potential for through travel, capacity of tracks on the trunk section, operational characteristics of the two connected lines, and so forth. The recommended set of lines is presented with the basic data concerning its lines including their lengths, cycle times, headways, and train consists for peak and off-peak hours.

Spatial spreading of our cities has resulted in longer commuting among different points throughout metropolitan areas. For many years, the dominant opinion was that the automobile was the best mode for serving all regional trips and that transit services were being neglected by riders. However, in spite of this neglect, most regional (commuter) rail systems have recently demonstrated their strong ability to attract riders. There are two major reasons for relative success and increasing need for regional rail transit: (a) regional rail lines serve the areas of greatest growth--outlying suburbs of major cities, (b) high speed, comfort, reliability, and safety make these systems more competitive with the automobile than most other transit modes.

Although the strong ability of regional rail systems to attract ridership has now been demonstrated, the systems have, in most cities, faced severe financial problems and their role has remained far less important than their potential would indicate. Our regional rail systems carry several times fewer passengers than comparable systems in many cities in other countries, such as Cophenhagen, Hamburg, Munich, Sydney, and Toronto. The reasons for this underutilized potential and for the financial problems lie in the fact that the characteristics of regional rail systems in most of our cities have not changed much from those of the commuter railroads, which they used to be (decades ago).

This paper contains a summary of a major study that was made to provide information to be used in integrating two separate rail systems into one regional rail system in Philadelphia (1). In the process, the differences between commuter railroads and regional rail systems were defined and are included. Extensive data on physical, operational, and ridership characteristics of the Philadelphia system are also included, but the major emphasis is on the methodology for planning the new network: determination of line pairings (i.e., how the former radial lines should be interconnected into diametrical ones).

THE EVOLVING CONCEPT OF REGIONAL RAIL

Commuter Railroads' Networks, Service, and Role

Traditionally, most large North American cities had a number of commuter rail services provided by several railroad companies. Their radial lines terminated in stub-end terminals on the fringes of the central business district (CBD). The lines were often independent of each other, and their coordination and joint fares with regular transit services (bus, streetcar, and rapid transit) seldom existed. The services were heavily commuter-oriented, consisting of a large number of trains serving during the peaks, and minimal service, if any, during off-peak hours. Headways were typically irregular, with various express runs, usually also at irregular intervals. Such networks and services have existed in Boston (North and South stations), Chicago (seven different companies), New York (several systems with stub-end stations--Grand Central and Hoboken--and one through station--Pennsylvania) and Philadelphia (Suburban Station and Reading Terminal). Because of this type of network and service, these railroads were predominantly serving trips into and out of CBDs, most of them to and from work. The percentage of trips made for "other purposes" was quite small, and efforts to attract them were minimal.

In addition to the purely radial network and commuter-oriented schedules, there were organizational problems: private railroads, which were usually not fully compensated for passenger services, were either disinterested or directly opposed (Southern Pacific in San Francisco) to any improvements of their lines. Moreover, the old-time practices and mentality, typical for many of these organizations, resisted most changes.

Regional Rail System Characteristics

In many European and Japanese cities, the interest in and support for local railway services have always remained strong. Through their improvements (mostly since World War II), the concept of regional rail--a modernized version of commuter railroads--has evolved. Regional rail systems are characterized by the following features:

1. Networks consist of electrified diametrical lines through a central city with several stations in it;
2. The utilization of centrally controlled doors, high-platform stations, and several other characteristics similar to those of rapid transit;
3. Convenient transfers (joint stations, coordinated schedules, and integrated fares) with all other transit services; and
4. Clock headways and regular, reliable service throughout the day.

With these characteristics, regional rail systems become integral parts of regional transit; they still have dominant flows during the peak hours, but their role for noncommuting trips increases substantially.

The best example of a conversion from commuter to regional rail system is the S-Bahn in Munich. In 1972, its two stub-end terminals were connected with four stations by a tunnel through the CBD, and regular, electrified services were introduced that were fully integrated with rapid transit, light rail, and bus. Daily ridership on this S-Bahn, which was 150,000 in 1971, had grown to 590,000 by 1982. Similar improvements and ridership increases have been achieved in Frankfurt, Hamburg, Paris, and many Japanese cities.

REGIONAL HIGH-SPEED RAIL SYSTEM IN PHILADELPHIA

It could be said that the era of modern regional rail systems in the United States started with the opening of the Bay Area Rapid Transit (BART) system in Oakland, California. By its network, form, and service, BART is more similar to the S-Bahn in Munich or the Réseau Express Régionale in Paris than to rapid transit systems in Chicago, Philadelphia, and even New York. The Washington, D.C., Metro system will also have a somewhat regional character. However, among the cities with existing commuter railroads, Philadelphia is the first to upgrade its system into a Regional High-Speed Line (RHSL) system.

System Description

The Southeastern Pennsylvania Transportation Authority's (SEPTA) RHSL Network, shown to scale in Figure 1 and schematically in Figure 2, consists of two previously separated networks. The Western (or ex-Pennsylvania) Division consists of 6 lines that converge from the west into the 30th Street station and terminate in the underground Suburban station, west of City Hall. The Northern (or ex-Reading) Division consists of 7 lines converging from the north into the elevated Reading Terminal which is east of City Hall. The entire network has a length of 344 km (214 mi), 189 stations, and a fleet of 343

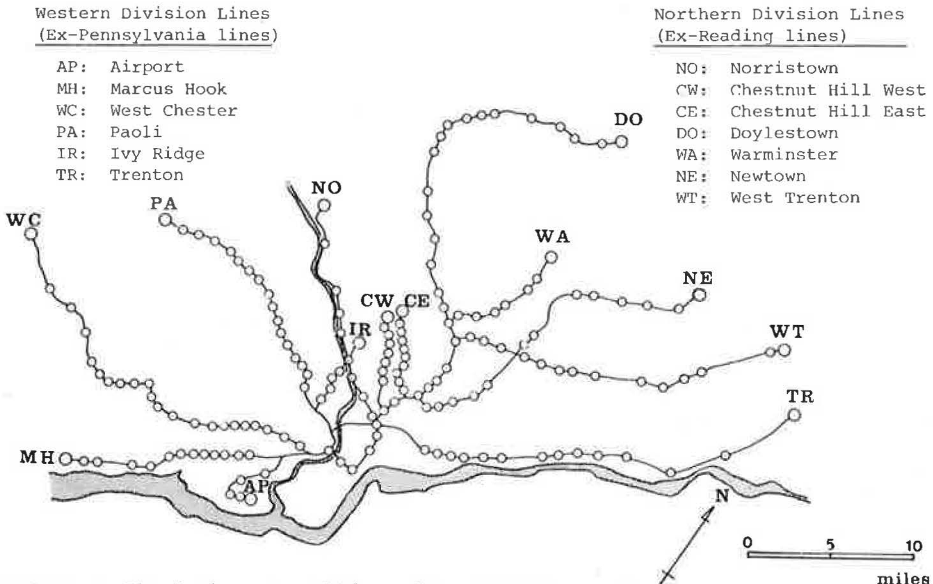


FIGURE 1 Philadelphia regional high speed lines (RHSL) network.

cars, of which 33 were built in 1931, and the others are four, 26-m (85-ft) Silverliner car models built between 1958 and 1975, with 100 to 127 seats each.

Most lines have double tracks; however, some outlying sections have single tracks, while substantial trunk sections have four tracks. Three major lines--Marcus Hook, Paoli, and Trenton--use Amtrak tracks. Headways on most lines are hourly during the day and evening, but 20 to 30 min during peaks. Paoli, Media-Elwyn, and Chestnut Hill West stations have 30-min headways and 10 to 20-min headways with various express runs during peaks.

The decrease in ridership during the 1950s was reversed as a result of some service improvements

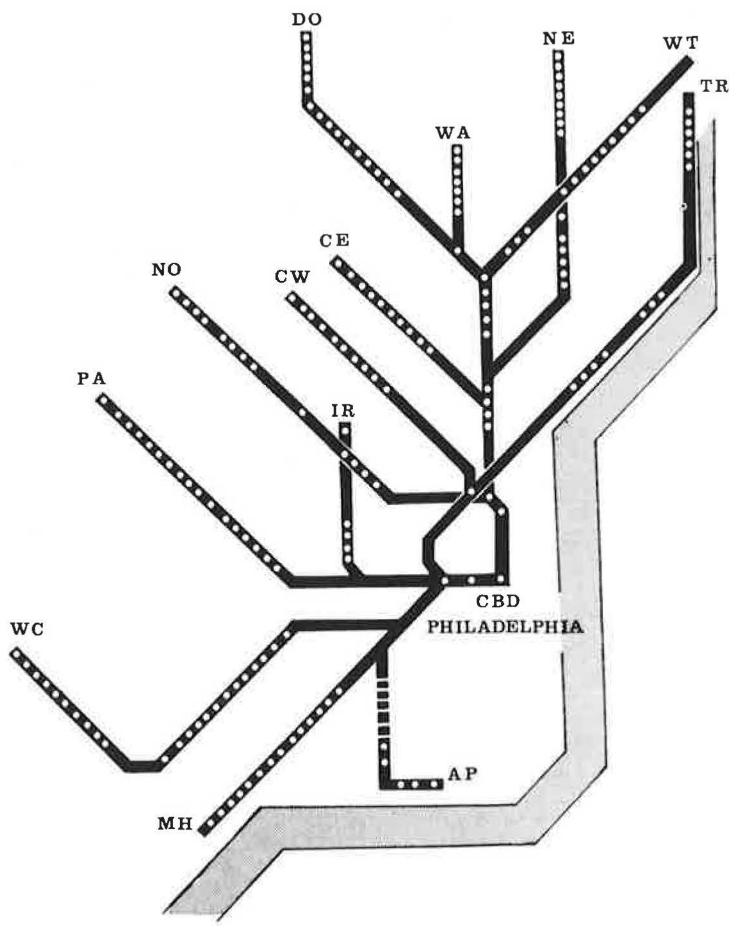


FIGURE 2 Schematic presentation of SEPTA's RHSLs.

around 1960. Between that year and the late 1970s, there was a nearly 50 percent increase in ridership, which reached a peak of 130,000 riders per day in 1979. Sharp fare increases, a drop in reliability of service, and a 105-day strike in 1983 resulted in a precipitous drop in ridership to 55,000 per day, subsequently recovering to 75,000 per day. Passenger volume is extremely peaked, as will be discussed later.

The Tunnel

A 4-track tunnel that will connect the Western and Northern Divisions (see Figure 2), and which has been in the planning stages for approximately 20 years, was completed and opened in fall 1984. The two stub-end terminals have thus been replaced by a 4-track trunk section containing three major Center City stations (30th Street, Suburban, and Market East) and several minor stations in the Northern Division. This section is shown in Figure 3. As can be seen from the figure, there is only one grade-separated junction on the trunk section; all junctions in the Northern Division and most junctions in the Western Division are at grade. This condition imposes constraints on headways and, consequently, on track capacities.

The Airport Line

Another addition to the RHSL network will be the nearly completed Airport line, which will be in the Western Division (the dashed line in Figure 2). The projected ridership for this line is quite low (approximately 2,000-3,000 per day), but its service will be significant for the city and region, as it will provide the only reliable connection between the airport and many points in the region.

BASIC LINE PATTERNS AND PLANNING PROCEDURE

There are several options in organizing the lines and method of operation in a transit network consisting of two "bunches" of radial lines connected by a single trunk section, as has been the case in Philadelphia. Three alternative concepts of lines and their operations should be considered: radial versus diametrical lines; trunk with branches versus trunk with feeders; and fixed operation of trains on individual lines versus changeable train routing among lines. These three sets of alternatives are largely independent from each other and can be combined in different ways (e.g., feeders can be operated with radial or diametrical lines).

Radial Versus Diametrical Lines

In comparing diametrical lines with radial lines (see sections a and c of Figure 4), the following advantages (+) and disadvantages (-) were observed:

+ Better connectivity--passengers from each leg are able to reach more destinations without transfers;

+ Terminals, which require space and maneuvers, are not needed in the usually congested central area of the city;

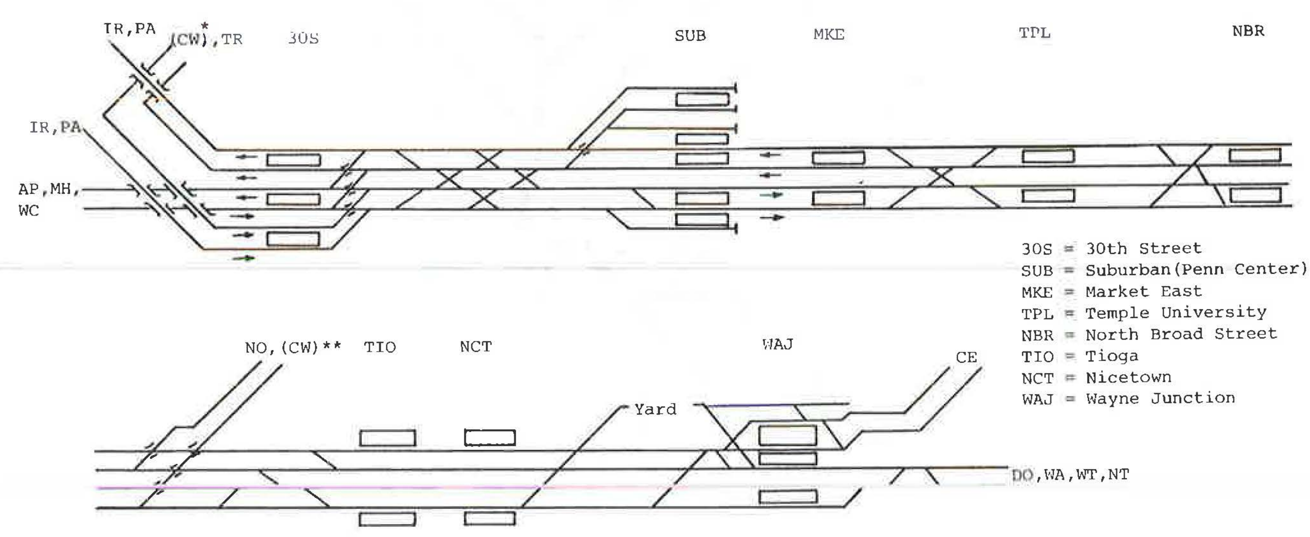
+ Terminal time may become a smaller percentage of cycle time;

- Delays from one leg are transferred to the other, reducing service reliability;

- Critical passenger volume on either leg dictates service requirements for the entire line, often resulting in lower average load factors.

In most cases, the advantages of diametrical lines heavily outweigh their disadvantages compared to radials. For that reason, many transit (streetcar and bus) networks were changed from their initial form of radial lines to a set of diametrical lines.

In the case of Philadelphia, the former two separate sets of radial lines looked as shown schematically in Figure 4 (section a). If the lines were to continue to be operated as radials after the tunnel is opened, they would have to overlap on the trunk section (see section b of Figure 4) to realize the advantages of the tunnel. This would create capacity problems. In addition, terminating trains from each network on the opposite side of the CBD would obviously result in many more train-hours and train-kilometers than if the trains are sent out from the trunk to the other division as diametrical lines



* - Stage 1: Interim Stage, Chestnut Hill West line (CW) is on the Western Division
** - Stage 2: Final Stage, Chestnut Hill West line (CW) is on the Northern Division

FIGURE 3 Future track layout of the trunk section: 30th Street station to Wayne Junction.

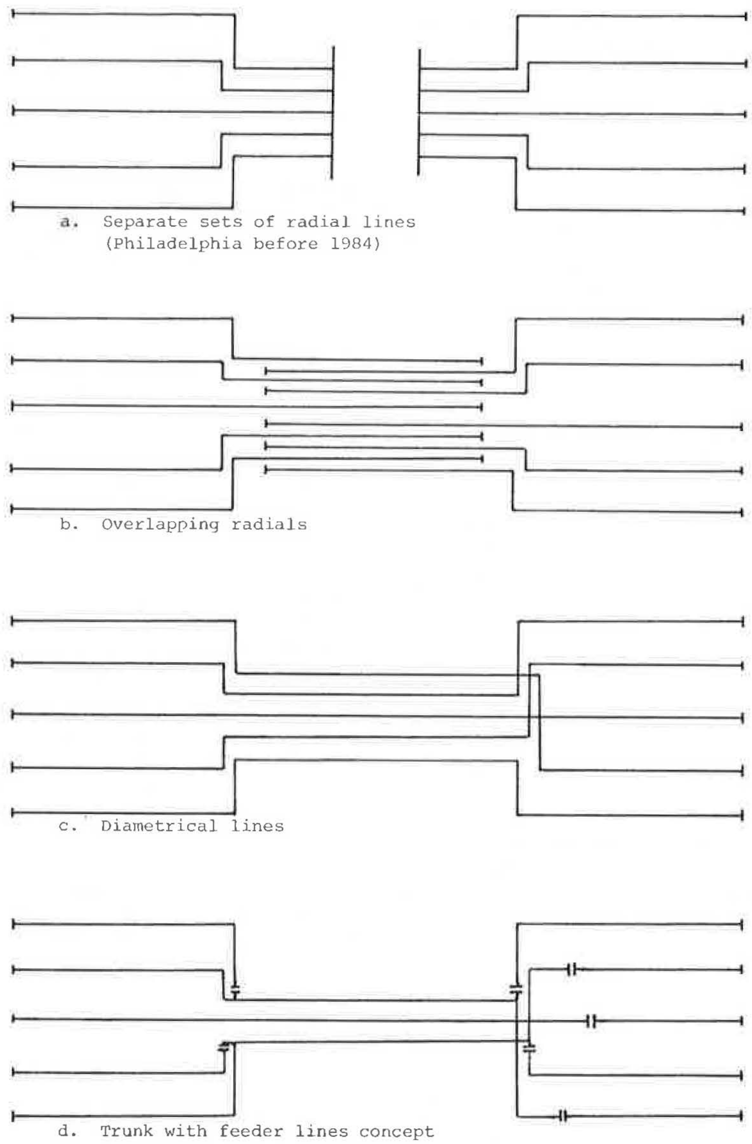


FIGURE 4 Basic line pattern concepts.

(see section c of Figure 4). This does not prevent the option of terminating, or starting in central city terminals some peak hour trains that are needed in one direction only (inbound in the morning, outbound in the evening). In other words, the lines are operated as diametrical ones, but some peak hour trains can be inserted as extra radials, serving only the peak direction.

Trunk with Branches Versus Trunk with Feeders

Another issue is whether all trains should branch out to different lines and run to their outer ends in the suburbs, or should be terminated at a major station and the outer section operated by a shuttle train as its feeder (see section d of Figure 4).

In comparing branches with feeders (shuttles), the following advantages (+) and disadvantages (-) were observed:

+ No passenger transfers are required;
+ Less terminal time is involved (longer lines);
- There is a lower average load factor because each full-size train runs the entire length of the line, while the capacity of the feeder (shuttle) train can be adjusted to the usually much lower volume than the trunk line carries;
- Delays on the outer sections affect operation on the entire line;
- Scheduling is less flexible--the shuttle can operate with headways two or three times longer or shorter than the trunk.

In most cases, the two advantages of the branch-type operation easily outweigh its disadvantages. In the case of Philadelphia, it was found that feeders are advantageous only in a few cases, such as Elwyn-West Chester, where the outer section has single track and much lower passenger volume than the trunk line (from CBD to Elwyn).

Variable Versus Fixed Train Routings

In operating trains for the three line patterns described previously, two basic train routing patterns--variable routing and fixed train routing--must be evaluated. Fixed train routings compared with variable train routings have the following advantages (+) and disadvantages (-):

+ Simplicity of operation and minimum passenger confusion as to the train destinations;
+ Operating irregularity of schedule disturbance is limited to a single line only;
- Lower fleet utilization may result if the volumes of the two sections of the line pair are not balanced.

The benefits of the variable train routings are far less significant than the advantages of greater simplicity for passengers and operating regularity of service, which the operation of independent lines would bring.

Identity of Lines

An important aspect of transit service is always its image with the public. To have a strong image, the network must be simple, its lines clearly identified. That will be achieved by the operation of fixed lines, regular headways, and clear designations. Because the headways on regional rail lines are typically long (20-60 min), only clock headways should be used. To be recognized, each line should have a clear designation, such as R-1, R-2, and so forth (R will identify "Regional Rail").

Line Pairing Procedure

The analytical procedure developed for line reorganization consists of the following steps:

1. Identification of System Characteristics and Requirements--physical and operational characteristics of the network, constraints, passenger demand, passengers' and operator's requirements are identified.
2. Development of Alternative Sets of Lines--based on the analyses and guidelines developed in Step 1, several alternative sets of lines are developed.
3. Evaluation and Selection of the Optimal Set of Lines--evaluation criteria are developed and used to evaluate alternative sets of lines; the best alternative is then selected.
4. Development of Operating Plans--detailed operating plans are prepared for the best alternative set of lines, including accelerated services, line designations, and schedule coordination with other modes.

A flow chart of this planning procedure is shown in Figure 5. The analysis, evaluations, and plan selection are, naturally, more complicated than the diagram shows and involve many iterative procedures. The previously described steps are discussed in more detail in the following two sections.

LINE PAIRINGS: CONDITIONS AND REQUIREMENTS

In the first step of the planning procedure, all relevant data concerning the RHSL system were collected, analyzed, and systematically presented in a number of charts, diagrams, and tables.

System Characteristics and Constraints

Physical and operational characteristics of the network include the following:

1. Line lengths, stations and their locations, and platform types and sizes;
2. Track layout including alignment, crossovers, signal systems, and their operation;

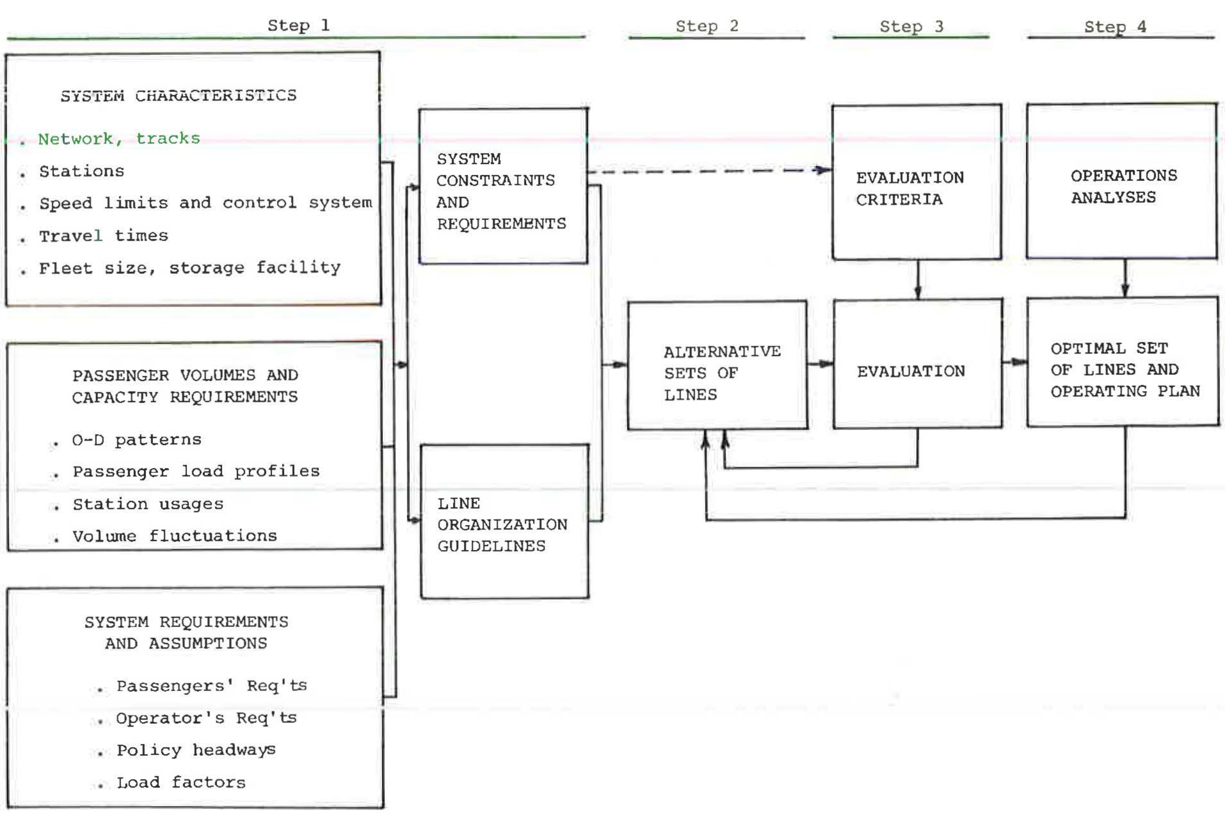


FIGURE 5 Line pairing procedure.

3. Speed limits and travel times;
4. Fleet size and storage facilities (tracks and yards).

These system characteristics determine the range of operational capabilities. One of the most important operational constraints derived is the minimum headway for each line and for each joint section. The elements determining the minimum headway may be the signal system, turnaround time at terminals, or station standing time. During the peak periods, the last factor is often the critical one. Platform lengths along each line control the maximum train consist that can be operated. The minimum headways and maximum train consist determine the capacity of each line.

Another important consideration is the pattern of track paths through the trunk section of the network. Different line pairings must be analyzed with respect to the mutual crossings (or weavings) of their train paths, to find the pairings that are the least conflicting operationally. The analysis of headways on the Philadelphia RHSL system resulted in the desirable minimum headway of 4 min on each track of the trunk section. With respect to track paths, the best combinations of line pair track assignments were identified.

Passenger Volumes and Capacity Requirements

Because both capacity and level-of-service requirements depend largely on passenger volumes, a detailed demand analysis must be performed. This analysis should include: (a) system-wide demand and its breakdown on individual lines, (b) time variations (including peaking patterns), and (c) passenger demand by station and volume profiles of lines by direction and time period. (Examples of these are shown in Figures 6 and 7, respectively.)

From these data, the maximum load section (MLS) is determined for each line. Combined with adopted load factors, which may vary among lines and time periods, capacity requirements are derived for each line segment and for each scheduling period of the day. For the SEPTA RHSL system, the policy decision was made based on past experiences, recent trends, and plans for service improvements to design for a total daily ridership of 100,000. The distribution of this volume on individual lines was based on

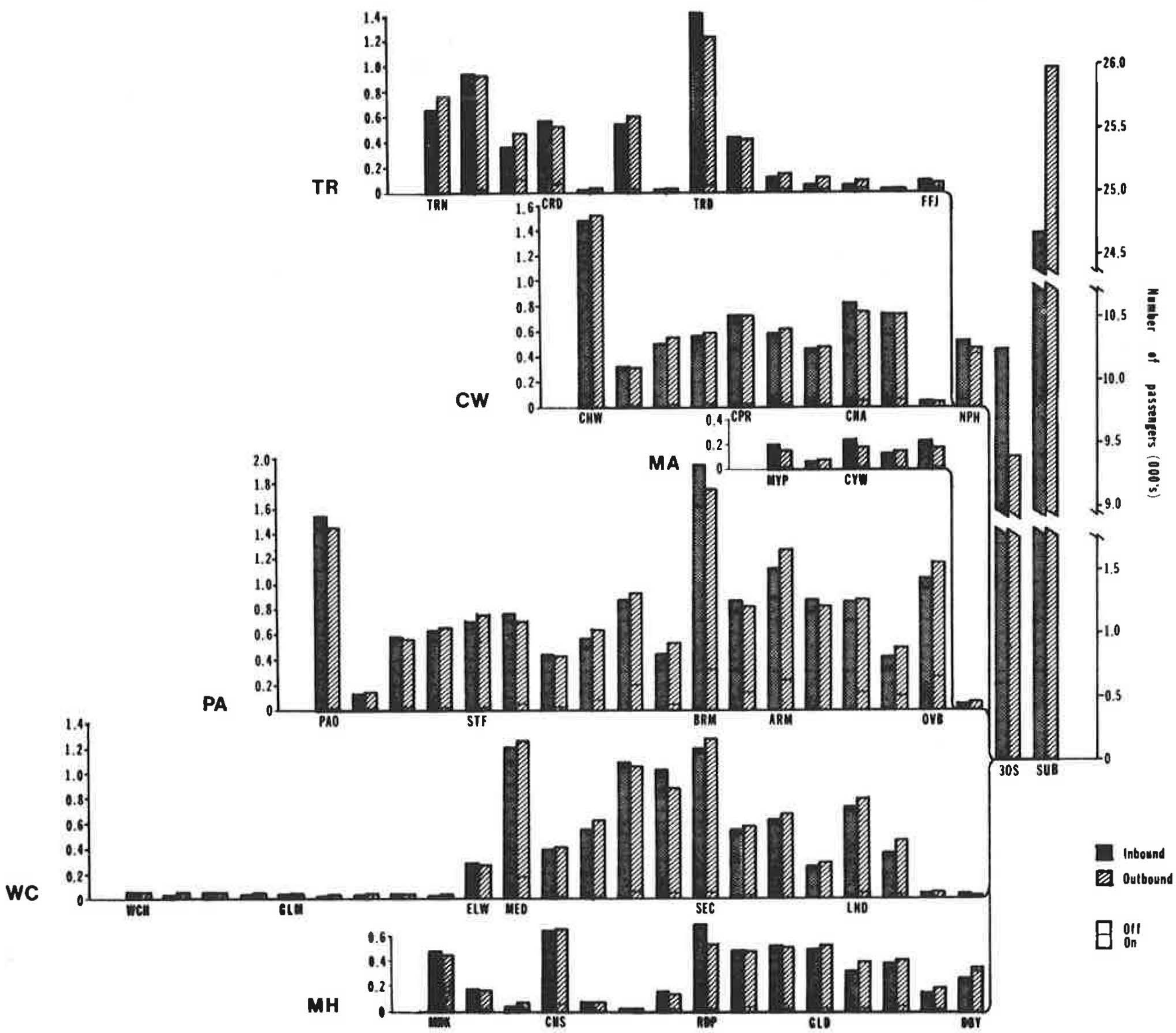


FIGURE 6 Daily station usage—ex-Pennsylvania lines (boarding and alighting).

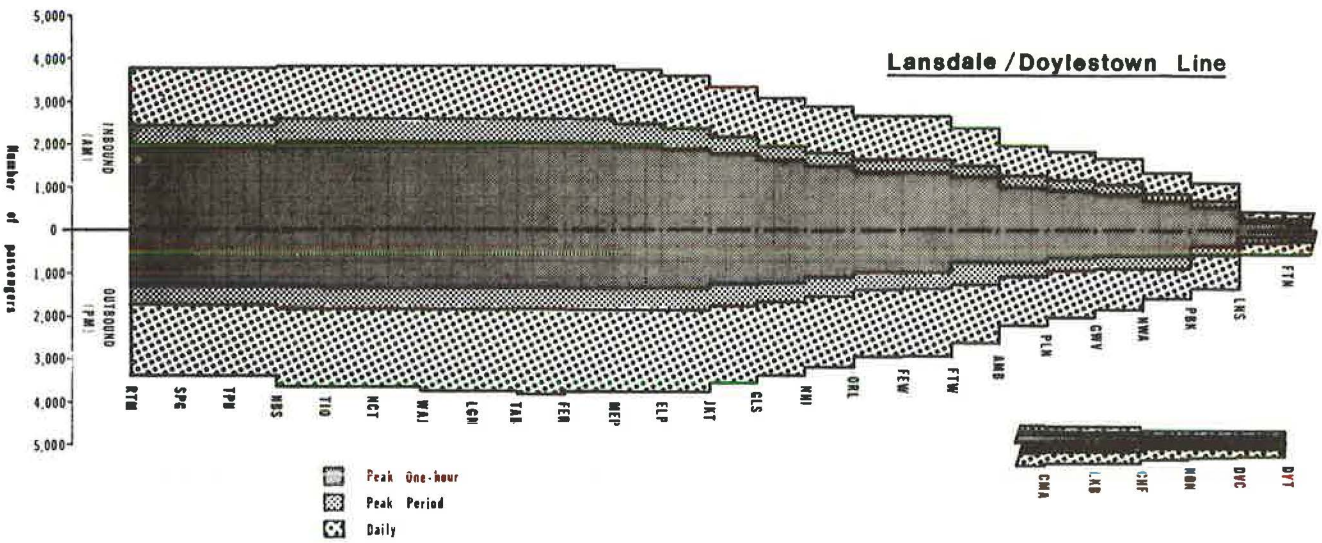


FIGURE 7 Future passenger volume profile by direction for different periods.

historical records of proportions among the lines, corrected by the trends during the recent years.

An interesting detail in the analyses of passenger volumes was a plot of fluctuations of arrivals and departures at the CBD terminals. One of these plots (see Figure 8) shows the extremely sharp peaks that create problems in pairing the lines--the heavy inbound passenger volume far outweighs the light outbound volume, resulting in low load factors on the nonpeak directions.

The required capacities in terms of cars per hour were computed by dividing the passenger volumes on each MLS by the adopted load factors (which ranged from 0.65 to 0.95), and by car capacity (120 seats). The obtained numbers of cars per hour per direction were then translated into different combinations of frequencies (headways) and train consists.

Other System Requirements and Assumptions

A number of other considerations were included in the process of analysis for line pairings. The passenger preference for reliable, convenient, and simple service is largely satisfied by the fixed lines and clock headways discussed previously. The operating agency is also concerned with passenger attraction, as well as with operating efficiency and minimum costs. These factors, together with local characteristics, were continuously considered in preparing alternative line pairs.

LINE PAIRINGS: DEVELOPMENT AND SELECTION

Having identified physical and operational characteristics of the system, passenger demand, con-

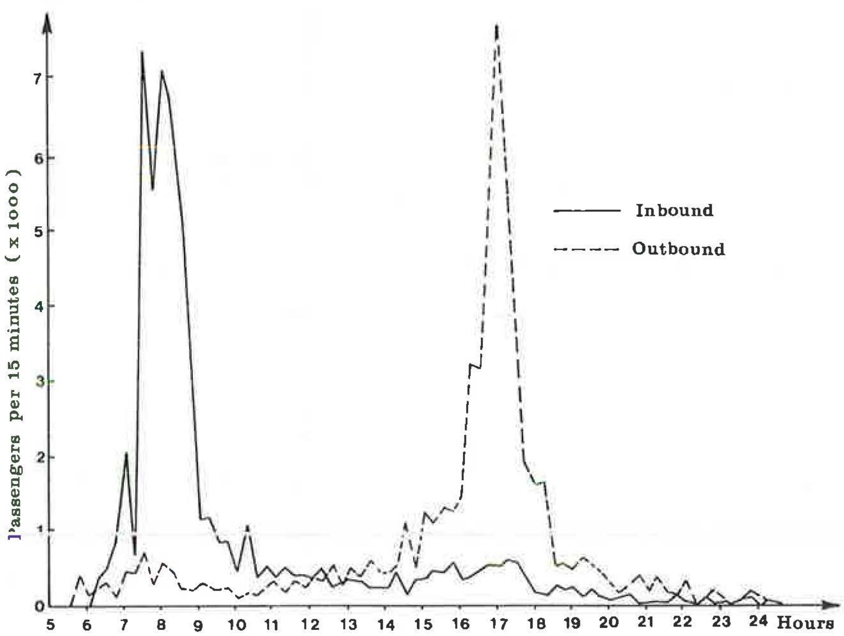


FIGURE 8 Fluctuations of 15-min passenger volumes on all RHSLs in 1979.

straints, and system requirements, and considering various aspects of radial, diametrical, and trunk-feeder line configurations described previously, several alternative sets of lines were developed.

Method of Line Pairing

The guidelines formulated for determining line pairs between the two networks are as follows:

1. Connect lines with high through-travel potential; because there are usually no past data on this travel (because such trips could not be made), the estimates must be made that consider (a) the distribution of employment and residential areas by type and volume and (b) geometric forms that are attractive for through trips (avoiding "loop" or "U"-shaped lines).
2. Connect lines with similar passenger volumes and off-peak policy headways--define the volume in cars per hour in the peak periods, peak directions, and policy headways in off-peak periods for the two sets of lines and then try to match them when forming the pairs. This is usually the most important single guideline, because it has the most direct impact on fleet utilization (i.e., achievement of balanced load factors).
3. Select pairs with minimum track path conflicts. This applies only to the cases when the trunk section has more than one track per direction. The sets of pairs that can be routed over two parallel tracks without crossing their paths are more advantageous than the line pairs that would criss-cross their paths, causing capacity constraints. Thus good selection of pairs minimizes conflicts, resulting in greater capacity, reliability, and safety.
4. Balance total frequencies on the two pairs of trunk line tracks.
5. Avoid pairing two lines that have single track sections to lessen headway limitations, propagation of delays, and so forth.
6. Avoid excessively long cycle times (crew rest and reserve time for schedule recovery also increase with longer cycle time), and, as much as possible, try to make them close to integer multiples of headways (particularly when these are long) to avoid excessive time losses at terminals.

In the case of SEPTA's RHSL, these guidelines were followed as much as the specific conditions allowed. Meeting future demand for travel through the CBD was not an important factor (except for the Airport line) because transferring among lines would be easy--the geometry of existing lines made the formation of two loop lines unavoidable.

Matching passenger volumes and policy headways was the most important single factor in determining pairs. For this purpose, the former two sets of radial lines were listed in two columns in descending order of peak hour passenger volume, as shown in Figure 9. To satisfy the second guideline, connections between radials should be as close to horizontal lines as possible. Alternatively, a heavily loaded line on one side could be split into two radials on the other side (e.g., Paoli-Bryn Mawr to Doylestown and Fox Chase).

A detailed analysis of track path conflicts was made and desirable line pairs with respect to this factor were defined. At the same time, efforts were made to achieve a balanced utilization of all four tracks on the trunk section. Furthermore, the pairing of two radials with single track sections was nearly completely avoided. Finally, a matrix of cycle times for all permutations of line pairs was developed to analyze them with respect to the requirements of the sixth guideline. The depth of this analysis was limited by the difficulties of establishing operating times on individual lines because of various and varying speed restrictions, requirements for terminal times, and so forth. Theoretically, there could be 720 different sets of lines. The guidelines greatly helped to formulate the sets that have the most favorable diametrical lines and that avoid potential problems that the guidelines warn against. Approximately a dozen line set alternatives were initially developed.

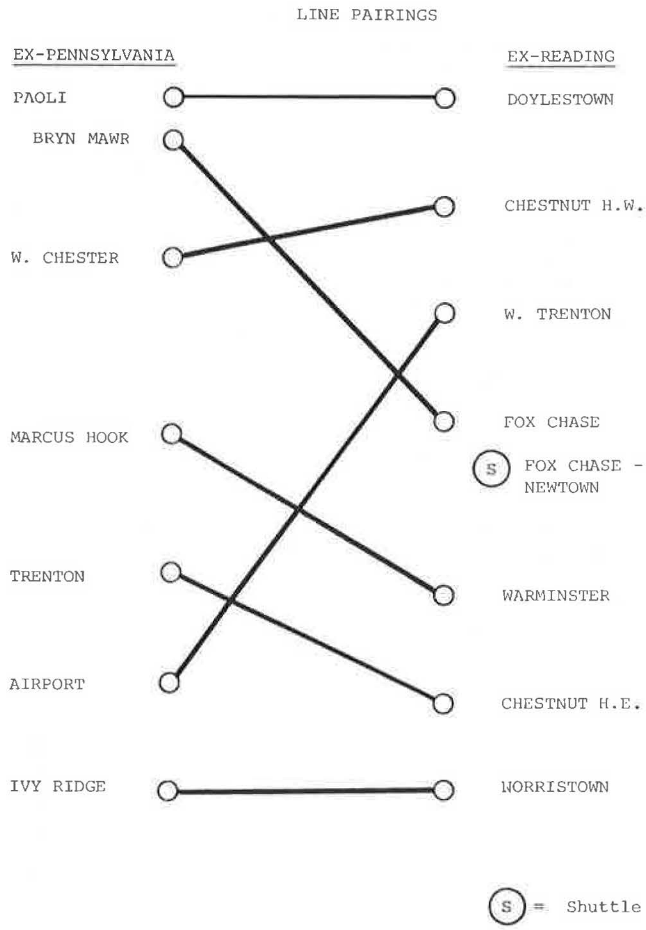


FIGURE 9 Recommended pairings.

Evaluation and Selection of the Optimal Line Set

The criteria for evaluation of line sets are based on system requirements and pairing guidelines. They include quantitative and qualitative items, the major ones being:

- Fleet size requirement
- Train frequencies on all trunk line tracks and their balance
- Headways on individual lines
- Car- and train-miles, car- and train-hours
- Platform lengths and train consists
- Possibilities of implementing accelerated services
- Crew requirements
- Other factors that influence operating costs
- Various operational aspects (reliability, capacity, conflicts, etc.)

In the SEPTA RHSL study, the initially formulated sets were reviewed and those obviously inferior to others were eliminated or modified (2). This preselection resulted in a total of three alternatives with the following dominant features: (a) as many diametrical lines as possible; (b) maximum trunk-feeder line combinations; and (c) combination of diametrical lines with a few radials for peak hours and feeders on single-track sections. These three alternatives were then evaluated with respect to all major operating and service indicators. Train travel times were computed for some lines by a train simulation model. Based on this evaluation, the third alternative was selected as the best. The lines of this alternative, recommended for implementation, are shown with their designations in Figure 10.

Development of Operating Plan

For the selected set of lines, detailed operating plans must be prepared that include: headways and train consists, line designations, accelerated service possibilities, train routings during the transitions between peak and off-peak periods, passenger information, and other operational details (such as train numbering, crew scheduling, etc.). In addition, an implementation plan for facilitating the transition to the integrated network must be developed.

For the SEPTA RHSL study, headways and train consists were prepared for each schedule period and for each direction, by carefully examining passenger capacity requirements, minimum headways, and platform lengths on the legs of of each pair. Table 1 gives a summary of the operational data of each line pair including line length, travel time, cycle time, headway, and train consist during the off-peak period, while Figure 11 shows off-peak headways on a schematic line diagram. The lines have been systematically designated by a number following the letter "R". The line numbers increase clockwise for the Western Division line from the Airport--West Trenton line (R-1) to the Trenton--Chestnut Hill East line (R-7), as shown in Figure 10.

The accelerated service (zonal, express-local, and skip-stop) possibilities were also investigated for three heavy-volume sections: Media-CBD, Paoli-CBD, and Jenkintown-CBD. Because one of the most important operating features of regional rail is the maintenance of fixed headways, accelerated service runs were considered as additions to the regular fixed schedule runs, thus not replacing the basic uniform headway pattern.

The train routings during the transition between peak and off-peak, and vice versa, were examined to

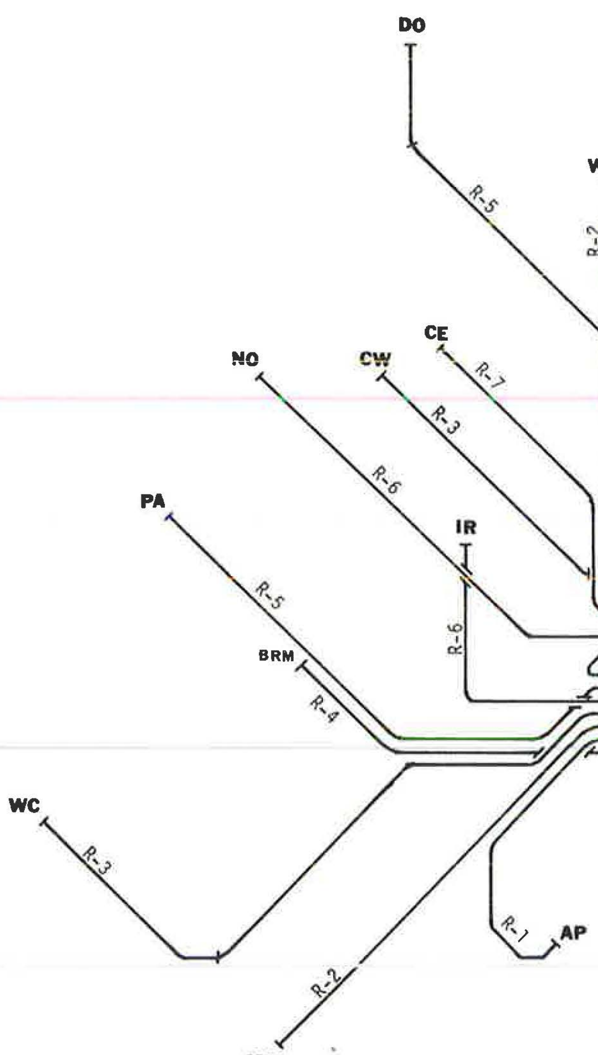


FIGURE 10 Schematic of the recommended lines—stage 2.

TABLE 1 Recommended Lines and Their Operating Data—Off-Peak

Designation	Line	Length (mi)	One-Way Travel Time (min)	Cycle Time[a] (min)	Stage 1[b] Headway (min)	Stage 1[b] Frequency (trains/hr)	Stage 1[b] Train Consist (cars/train)	Stage 2[c] Headway (min)	Stage 2[c] Frequency (trains/hr)	Stage 2[c] Train Consist (cars/train)	Comments
R-1	AIR-WTR	42.9	87	204	60	1	1	60	1	1	
R-1	AIR-JKT	21.2	47	124	20/40	2	1	20/40	2	1	
R-2	MHK-WMR	37.7	90	210	60	1	2	60	1	2	
R-2	MHK-GLN	29.5	73	176	–	–	–	–	–	–	Peak hour only
R-3	ELW-CHW	26.6	67	164	–	–	–	30/60	4/3	1	Total service
R-3	ELW-WAJ	21.2	52	134	30/60	4/3	1	–	–	–	ELW-WAJ: head-
R-3	WCH-CHW	38.9	92	214	–	–	–	90	2/3	1	way = 30 min
R-3	WCH-WAJ	33.5	77	184	90	2/3	1	–	–	–	
R-4	BRM-FXC	22.2	58	146	–	–	–	30	2	1	Total service
R-4	BRM-WAJ	16.3	40	110	30	2	1	–	–	–	BRM-WAJ: head-
R-4(S)	FXC-NWT	15.2	34	98	–	–	–	90	2/3	1	way = 15 min
R-5	PAO-DYT	55.3	105	240	60	1	1	60	1	1	
R-5	PAO-LNS	45.3	87	204	60	1	2	60	1	2	
R-6	IVR-NTE	27.5	69	168	60	1	1	60	1	1	
R-7	TRN-CHE	44.7	89	208	60	1	1	60	1	1	
R-7	TRN-WAJ	39.0	71	172	–	–	–	–	–	–	Peak hour only
R-8	CHW-FXC	23.4	64	158	30	2	1	–	–	–	

[a]Terminal times = 15 min, SUB-MKE = 4 min one-way, and MKE-WAJ = 10 min one-way.
[b]For Stage 1 (the interim stage), the Chestnut Hill West line is on the Western Division.
[c]For Stage 2 (the final stage), the Chestnut Hill West line is on the Northern Division.

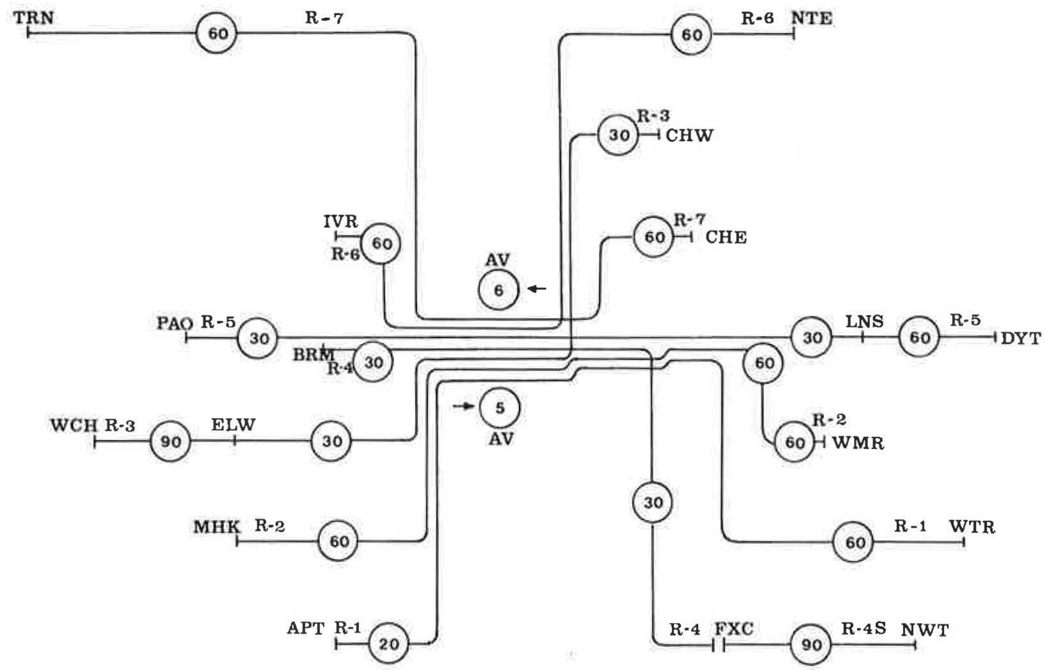


FIGURE 11 Recommended lines and off-peak headways.

minimize deadhead kilometers and operational complications. The SEPTA RHSL has two major car storage yards at both sides of the tunnel: Powelton Yard (capacity 152 cars), near 30th Street station on the Western Division, and Wayne Junction Yard (capacity 100 cars) on the Northern Division. At the end of a peak period, most excess peak trains from the Northern Division travel to Powelton Yard for storage, and, likewise, most excess trains from the Western Division travel to Wayne Junction Yard. At the end of an off-peak period, the reverse of the above movements was planned.

Other operational details and implementation plans such as the staged introduction of the Airport line and switching of the Chestnut Hill West line from a Western Division line to a Northern Division line were also prepared.

COMPLEMENTARY ACTIONS

To achieve a modern, efficient, and integrated regional rail system, the physical connection of lines must be complemented by a number of improvements in scheduling, operation, and service for present and potential passengers. A short review of the most important needed improvements and changes in operating practices follows:

1. Schedules--should have built-in reserves of 1-2 min at locations where heavy passenger loads, line merging, or other factors may cause variations in travel times, in order to ensure greater schedule reliability.
2. Basic schedules--must be regular, with constant headways (or their multiples). Zonal and ex-

press services should be provided in addition to regular local train runs, rather than replacing them, creating irregular services at many stations.

3. Station dwell times--at all busy stations must be shortened through improved boarding-alighting procedures and dispatching practices. The leisurely-type of operations prevailing today must be replaced by a faster process, similar to rapid transit operation.

4. Reliability of service--should be given top priority. In addition to the necessary changes in scheduling and station operations, procedures for handling delays must be improved and personnel trained accordingly.

5. Physical improvements--have been accelerated in recent years, must be continued; badly deteriorated systems must be brought up to higher standards if high-quality service is to be provided.

6. Modern fare collection methods--should eventually replace the present manual handling of all fares and tickets.

7. Rolling stock--should be analyzed for possible modifications needed to improve operations. A major study should precede any future order of vehicles to ensure that future cars will (a) meet the needs of the new type of operations and (b) provide conditions for maximum efficiency. This should include such items as the number and control of doors, communication systems, and public information needs. The possibility of further crew reductions, which would allow higher frequency of shorter trains, is a particularly important item.

8. Coordination of capital improvements with the planned operating practices is of utmost importance. Because of the numerous fundamental changes in the operations and organization of the RHSL in Philadelphia without adequate time for planning, present improvements of tracks, station platforms, fare collections, and so forth, are being made without full mutual coordination. A study should be made to plan for full compatibility of these (and many forthcoming) improvements and thus ensure maximum effectiveness of the investments in the Philadelphia PHSL.

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