Infrastructure and Operational Improvements of the SEPTA Regional Rail System

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Infrastructure and Operational Improvements of the SEPTA Regional Rail System

Abstract
Since its takeover of the Regional Rail System from Conrail in 1983, SEPTA has made numerous efforts to adjust its facilities and operations to the needs of a modern regional rail system. In order to meet the needs of a modern transit-type operations of regional rail with shorter headways and greater operational flexibility, the infrastructure, such as track layout and signals, is one of the elements that require changes. The current infrastructure was originally designed for freight and long distance railroad operations. This study represents part of SEPTA's efforts to modernize its regional rail infrastructure and operations in a cost effective way.

Disciplines
Electrical and Computer Engineering | Engineering | Operations Research, Systems Engineering and Industrial Engineering | Systems and Communications | Systems Engineering | Transportation Engineering

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Southeastern Pennsylvania Transportation Authority

Infrastructure and Operational Improvements of the SEPTA Regional Rail System

UNIVERSITY OF PENNSYLVANIA
UNIVERSITY OF DELAWARE
MAY, 1987
INFRASTRUCTURE AND OPERATIONAL IMPROVEMENTS
OF THE SEPTA
REGIONAL RAIL SYSTEM

Report for the
SOUTHEASTERN PENNSYLVANIA TRANSPORTATION AUTHORITY
SEPTA

FINAL REPORT

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May 1987
EXECUTIVE SUMMARY

Since its takeover of the Regional Rail System from Conrail in 1983, SEPTA has made numerous efforts to adjust its facilities and operations to the needs of a modern regional rail system. In order to meet the needs of a modern transit-type operations of regional rail with shorter headways and greater operational flexibility, the infrastructure, such as track layout and signals, is one of the elements that requires changes. The current infrastructure was originally designed for freight and long distance railroad operations. This study represents part of SEPTA's efforts to modernize its regional rail infrastructure and operations in a cost effective way.

The study consists of three major projects:

**Project 1** - Development of an improved track layout and signal plan for the Wayne Junction - Jenkintown section of the ex-Reading Trunk Line.

**Project 2** - Analysis of track layout, signals, and operations on the single track section of the Warminster branch.

**Project 3** - Examination of the present operation of the Airport Line.

The methodology used in each project consisted of the following steps:

- Description of the present layout and operations;
- Definition of present and projected deficiencies and improvement requirements;
- Development of a set of alternatives and their detailed evaluation;
- Recommendations for improvements, usually consisting of several alternatives with their relative advantages and disadvantages.

**Project 1: Wayne Junction - Jenkintown**

This project consisted of three major parts: Wayne Junction, Jenkintown Junction, and the trunk section between both interlockings.

**Newtown Junction.** The major problems are blocking of the main tracks by
the outbound Fox Chase trains due to their conflict with Conrail freight trains, and by the slow turn-back maneuver of the Airport trains. Alternative track layout improvements, shown in Fig. 1.4, have been developed; a summary of their evaluation and recommended improvement combinations are given in Table 1.2.

**Jenkintown Junction.** Several major shortcomings have been analyzed in great detail. They include long minimum headways for southbound trains, time consuming turnback maneuvers from any one of the three directions, lack of flexibility that allows efficient single-track operation, and the lack of convenient storage tracks. A composite drawing of all considered track and signal improvements is given in Fig. 1.19, and a summary of their evaluation is presented in Table 1.3.

**Trunk Line.** A detailed analysis of minimum headways (i.e. line capacity) between Wayne Junction and Jenkintown was performed with special attention to the impact of express and skip-stop operations on the headways. To achieve higher capacity and greater reliability of operations on this section, three groups of recommendations are made.

First, the addition of several signals to create shorter blocks and thus increase line capacity is recommended as a more cost-effective solution than the construction of an entirely new signal system. Second, capacity of the line can also be increased by improving the sequence of express and local trains on the section. Third, interlocked crossovers should be maintained at Tabor and a new one constructed at Melrose Park to increase flexibility and reliability of operations.

**Project 2: Warminster Branch**

The present problems of low average speed and the vulnerability to delays in the operation were analyzed. The Warminster Branch has numerous problems,
including grade crossings with speed limits as low as 5 mph, low speed limit on the open track, stations located on single track (not on siding), and schedule constraints dictated by the Marcus Hook branch, which shares tracks with Amtrak trains. These factors make reliable operations on the single track section very difficult to achieve.

The present operating headway of 30 min. and possible shorter headways of 20 and 15 min. were analyzed in detail considering passing locations for different terminal times, signal blocks, station locations and other elements. A number of possible improvements, including faster terminal activities by the crews, increased speed limits at the crossings, extension of double track sections, and changes in signal block, were analyzed and evaluated.

Table 2.2 gives the summary of all analyzed improvements and evaluation of their relative effectiveness with respect to increased speed and flexibility of operation and ability to recover delays.

Project 3: Airport Line

The present operation of the Airport Line was examined and evaluated to develop possible measures to increase efficiency. Specifically, the question was whether the present level of service can be provided at a lower cost.

The most obvious present problem is that the Airport Line connects the Airport basically with the three Center City stations (a distance of 10 miles approximately), and yet its trains must travel another 6 miles to turn back. Moreover, to guarantee highly reliable service, one reserve train is kept ready for service at each terminal; thus, six trains are required for the operation with relatively low ridership.

Various possible pairings of the Airport Line with other lines, extension to Jenkintown Junction (which would attract additional riders and possibly eliminate some peak trains from other lines needed to satisfy ridership between
Jenkintown and Center City), and schedule changes were analyzed. The recommendations can be summarized as follows:

- “Floating reserve train” concept, reducing the reserve to one train through rescheduling, should be introduced.¹

- Extension of the Airport Line to Jenkintown is recommended since it would bring significant reduction in fleet size for the current three lines serving Jenkintown and Center City.

- Pairing the Airport Line with the Norristown Line should be analyzed further and possibly tested, since it has some operational and cost advantages.

- Shortening of the Airport Line to Suburban Station should be considered only as a last resort in a crisis, but not as a satisfactory solution.

- The Airport Line should be designated 'RL', while the West Trenton Line, already paired with the Media Line, should be designated 'R3'.

¹ Subsequent to the completion of the draft report of this study, SEPTA has eliminated both reserve trains, since the operation has been proved reliable even without them.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>SECTION</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td></td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1. PROJECT 1: WAYNE JUNCTION-JENKINTOWN TRUNK LINE</td>
<td></td>
</tr>
<tr>
<td>1.1 NEWTOWN JUNCTION</td>
<td></td>
</tr>
<tr>
<td>1.1.1 Present Layout and Operations</td>
<td>1-2</td>
</tr>
<tr>
<td>1.1.2 Problems and Limitations</td>
<td>1-6</td>
</tr>
<tr>
<td>1.1.3 Alternative Track Layout Improvements</td>
<td>1-6</td>
</tr>
<tr>
<td>1.1.4 Recommended Improvements</td>
<td>1-8</td>
</tr>
<tr>
<td>1.2 JENKINTOWN JUNCTION</td>
<td></td>
</tr>
<tr>
<td>1.2.1 Present Layout Operations and Problems</td>
<td>1-11</td>
</tr>
<tr>
<td>1.2.2 Analysis of Headways</td>
<td>1-13</td>
</tr>
<tr>
<td>1.2.3 Analysis of Turnback Movements</td>
<td>1-19</td>
</tr>
<tr>
<td>1.2.4 Single Tracking</td>
<td>1-26</td>
</tr>
<tr>
<td>1.2.5 Summary of Proposed Improvement</td>
<td>1-26</td>
</tr>
<tr>
<td>1.3 WAYNE JUNCTION-JENKINTOWN TRUNK SECTION</td>
<td></td>
</tr>
<tr>
<td>1.3.1 Present Operations</td>
<td>1-33</td>
</tr>
<tr>
<td>1.3.2 Track Layout and Signals</td>
<td>1-33</td>
</tr>
<tr>
<td>1.3.3 Problems and Limitations</td>
<td>1-39</td>
</tr>
<tr>
<td>1.3.4 Analysis of Signal Blocks and Headways</td>
<td>1-39</td>
</tr>
<tr>
<td>1.3.5 Crossovers and Storage Tracks</td>
<td>1-53</td>
</tr>
<tr>
<td>1.3.6 Recommendations</td>
<td>1-55</td>
</tr>
<tr>
<td>2. PROJECT 2: WARMINSTER BRANCH LINE</td>
<td></td>
</tr>
<tr>
<td>2.1 PRESENT CONDITIONS AND OPERATION</td>
<td></td>
</tr>
<tr>
<td>2.1.1 Line Description</td>
<td>2-1</td>
</tr>
<tr>
<td>2.1.2 Schedule and Operations</td>
<td>2-3</td>
</tr>
<tr>
<td>2.1.3 Problems and Limitations</td>
<td>2-3</td>
</tr>
<tr>
<td>2.2 POSSIBLE IMPROVEMENTS OF SERVICE</td>
<td></td>
</tr>
<tr>
<td>2.2.1 Meeting Point Analysis</td>
<td>2-7</td>
</tr>
<tr>
<td>2.2.2 Sidings and Double Track Extensions</td>
<td>2-11</td>
</tr>
<tr>
<td>2.2.3 Speed Limits at Grade Crossings and on Open Line Sections</td>
<td>2-14</td>
</tr>
<tr>
<td>2.2.4 Signal Improvement</td>
<td>2-15</td>
</tr>
<tr>
<td>2.3 POSSIBLE HEADWAY DECREASES</td>
<td></td>
</tr>
<tr>
<td>2.3.1 20-Minute Headways</td>
<td>2-20</td>
</tr>
<tr>
<td>2.3.2 15-Minute Headways</td>
<td>2-23</td>
</tr>
<tr>
<td>2.4 EVALUATION AND RECOMMENDATIONS</td>
<td>2-23</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>3. PROJECT 3: THE AIRPORT LINE</td>
<td></td>
</tr>
<tr>
<td>3.1 PRESENT OPERATION</td>
<td></td>
</tr>
<tr>
<td>3.1.1 Schedule</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1.2 Operating Characteristics and Limitations</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1.3 Conclusions and Evaluation</td>
<td>3-3</td>
</tr>
<tr>
<td>3.2 DEVELOPMENT AND ANALYSIS OF POSSIBLE IMPROVEMENTS</td>
<td></td>
</tr>
<tr>
<td>3.2.1 Increased Efficiency</td>
<td>3-7</td>
</tr>
<tr>
<td>3.2.1.1 &quot;Floating Reserve Train&quot;</td>
<td>3-8</td>
</tr>
<tr>
<td>3.2.1.2 Turnback on Norristown Line</td>
<td>3-11</td>
</tr>
<tr>
<td>3.2.1.3 Turnback at Suburban Station</td>
<td>3-13</td>
</tr>
<tr>
<td>3.2.2 Increased Ridership Through Line Extension</td>
<td></td>
</tr>
<tr>
<td>3.2.2.1 Pairing with an Ex-Reading Line</td>
<td>3-14</td>
</tr>
<tr>
<td>3.2.2.2 Extension to Jenkintown</td>
<td>3-20</td>
</tr>
<tr>
<td>3.3 EVALUATION AND SELECTION OF ALTERNATIVE IMPROVEMENTS</td>
<td></td>
</tr>
<tr>
<td>3.3.1 Comparative Evaluation</td>
<td>3-25</td>
</tr>
<tr>
<td>3.3.2 Recommendations</td>
<td>3-27</td>
</tr>
<tr>
<td>Figure No.</td>
<td>Title</td>
</tr>
<tr>
<td>-----------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>1.1</td>
<td>Newtown Junction Present Layout</td>
</tr>
<tr>
<td>1.2</td>
<td>Schematic of Train Movements and Headways</td>
</tr>
<tr>
<td>1.3</td>
<td>Freight Train Movements</td>
</tr>
<tr>
<td>1.4</td>
<td>Alternative Track Layout Improvements</td>
</tr>
<tr>
<td>1.5</td>
<td>Jenkintown Junction</td>
</tr>
<tr>
<td>1.6</td>
<td>Through Movements and Conflict Points</td>
</tr>
<tr>
<td>1.7</td>
<td>Graphical Presentation of Through Movements at Jenkintown Junction</td>
</tr>
<tr>
<td>1.8</td>
<td>Comparison of Calculated Minimum Headways and Scheduled Headways</td>
</tr>
<tr>
<td>1.9</td>
<td>Turnback of Northbound Trains, Existing Layout, Alt. 1 (Chelten Hill)</td>
</tr>
<tr>
<td>1.10</td>
<td>Turnback of Northbound Trains, Existing Layout, Alt. 2 (Northbound Layoff)</td>
</tr>
<tr>
<td>1.11</td>
<td>Turnback of Northbound Trains, Improved Layout, Alt. 1a,b,c (Southbound Layoff)</td>
</tr>
<tr>
<td>1.12</td>
<td>Turnback of Northbound Trains, Improved Layout, Alt. 2 (Southbound Layoff)</td>
</tr>
<tr>
<td>1.13</td>
<td>Turnback of Northbound Trains, Improved Layout, Alt. 3 (Using Track 2 - Ideal Layout)</td>
</tr>
<tr>
<td>1.14</td>
<td>Turnback of Southbound Trains</td>
</tr>
<tr>
<td>1.15</td>
<td>Single-Tracking Toward Center City - Existing Track Layout</td>
</tr>
<tr>
<td>1.16</td>
<td>Single-Tracking Toward Center City on Track 2 - Improved Track &amp; Signal Layout</td>
</tr>
<tr>
<td>1.17</td>
<td>Single-Tracking Between Jenkintown and Glenside or West Trenton - Existing Track Layout</td>
</tr>
<tr>
<td>1.18</td>
<td>Single-Tracking Between Jenkintown and Glenside or West Trenton on Track 2 - Improved Track Layout</td>
</tr>
</tbody>
</table>
## List of Figures Cont'd.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19</td>
<td>Analyzed Improvements of Track Layout and Signals</td>
<td>1-31</td>
</tr>
<tr>
<td>1.20</td>
<td>Ex-Reading Trunk Line Train Movements and Conflicts - P.M. Peak Period</td>
<td>1-34</td>
</tr>
<tr>
<td>1.21</td>
<td>Time-Distance Diagram of Existing Train Movements from Market East to Jenkintown - A.M. Period</td>
<td>1-35</td>
</tr>
<tr>
<td>1.22</td>
<td>Time-Distance Diagram of Existing Train Movements from Market East to Jenkintown - P.M. Period</td>
<td>1-36</td>
</tr>
<tr>
<td>1.23</td>
<td>Diagram of Train and Car Frequencies Between Market East and Glenside</td>
<td>1-37</td>
</tr>
<tr>
<td>1.24</td>
<td>Existing Track Layout and Signals</td>
<td>1-38</td>
</tr>
<tr>
<td>1.25</td>
<td>Signal Block Lengths Between Wayne Junction and Jenkintown</td>
<td>1-40</td>
</tr>
<tr>
<td>1.26</td>
<td>Comparison of Scheduled and Actual Train Passing Times at Jenkintown</td>
<td>1-41</td>
</tr>
<tr>
<td>1.27</td>
<td>Train Performance Curves - Silverliner IV</td>
<td>1-43</td>
</tr>
<tr>
<td>1.28</td>
<td>Time Intervals for Train Stopping at Station</td>
<td>1-44</td>
</tr>
<tr>
<td>1.29</td>
<td>Distance-Speed Diagrams for 3- and 4-Aspect Signals</td>
<td>1-45</td>
</tr>
<tr>
<td>1.30</td>
<td>Signals and Headways: Existing</td>
<td>1-46</td>
</tr>
<tr>
<td>1.31</td>
<td>Signals and Headways: Improved Existing</td>
<td>1-47</td>
</tr>
<tr>
<td>1.32</td>
<td>Signals and Headways: Desirable Arrangement</td>
<td>1-48</td>
</tr>
<tr>
<td>1.33</td>
<td>Stopping Schedules and Frequencies of Different Lines - Ex-Reading Trunk</td>
<td>1-50</td>
</tr>
<tr>
<td>1.34</td>
<td>Impact of Express/Local Train Sequences on Minimum Headways</td>
<td>1-52</td>
</tr>
<tr>
<td>2.1</td>
<td>Warminster Branch Line Layout</td>
<td>2-2</td>
</tr>
<tr>
<td>2.2</td>
<td>Train Speed Profile</td>
<td>2-4</td>
</tr>
<tr>
<td>2.3</td>
<td>Present Schedule</td>
<td>2-5</td>
</tr>
<tr>
<td>2.4</td>
<td>Train Meeting Points for Different Terminal Times</td>
<td>2-9</td>
</tr>
</tbody>
</table>
List of Figures Cont'd.

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>Summary Diagram of Meeting Points for Different Headways as a Function of Terminal Time</td>
<td>2-10</td>
</tr>
<tr>
<td>2.6</td>
<td>Impact of Extending Double Track Through Willow Grove Station</td>
<td>2-12</td>
</tr>
<tr>
<td>2.7</td>
<td>Summary Diagram of Meeting Points for Increased Speed on Grade Crossings as a Function of Terminal Time</td>
<td>2-16</td>
</tr>
<tr>
<td>2.8</td>
<td>Summary Diagram of Meeting Points for Increased Maximum Speed as a Function of Terminal Time</td>
<td>2-17</td>
</tr>
<tr>
<td>2.9</td>
<td>Impact on Train Operations of Adding a Signal and Increased Speed on Willow Grove Siding</td>
<td>2-19</td>
</tr>
<tr>
<td>2.10</td>
<td>Train Operation with 20 Minute Headways</td>
<td>2-22</td>
</tr>
<tr>
<td>2.11</td>
<td>Train Operation with 15 Minute Headways</td>
<td>2-24</td>
</tr>
<tr>
<td>3.1</td>
<td>Time-Distance Diagram of a Train Running on the Airport Line</td>
<td>3-2</td>
</tr>
<tr>
<td>3.2</td>
<td>Travel Time-Time Diagram of the Present Schedule of Airport-Newtown Junction Line</td>
<td>3-5</td>
</tr>
<tr>
<td>3.3</td>
<td>Work Schedule of Airport Line Crews</td>
<td>3-6</td>
</tr>
<tr>
<td>3.4</td>
<td>Airport Terminal Term Limitations Due to Single Track Section</td>
<td>3-10</td>
</tr>
<tr>
<td>3.5</td>
<td>The &quot;Sitting&quot; vs. &quot;Floating Reserve Train&quot; Concepts for the Airport Line</td>
<td>3-12</td>
</tr>
<tr>
<td></td>
<td>a. &quot;Sitting Reserve Train&quot; (present schedule)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>b. &quot;Floating Reserve Train&quot; (Proposed)</td>
<td></td>
</tr>
<tr>
<td>3.6</td>
<td>Comparison Between Train and Car Frequencies on Airport and Individual Ex-Reading Lines</td>
<td>3-16</td>
</tr>
<tr>
<td>3.7</td>
<td>Detailed Schedule Comparison of the Airport with West Trenton and Norristown Lines</td>
<td>3-18</td>
</tr>
<tr>
<td>3.8</td>
<td>Schedule for Airport-Jenkintown Line with Floating Reserve Train</td>
<td>3-22</td>
</tr>
<tr>
<td>Table No.</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>----------</td>
<td>----------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>1.1</td>
<td>Review of improvements and their results</td>
<td>1-9</td>
</tr>
<tr>
<td>1.2</td>
<td>Final review of alternative improvements</td>
<td>1-10</td>
</tr>
<tr>
<td>1.3</td>
<td>Analyzed improvements for Jenkintown Junction, their impacts and evaluation</td>
<td>1-32</td>
</tr>
<tr>
<td>1.4</td>
<td>Minimum headways under different signal sets and stopping schedules</td>
<td>1-51</td>
</tr>
<tr>
<td>1.5</td>
<td>Minimum headways on critical sections for single-track operations with different sets of interlocked crossovers</td>
<td>1-54</td>
</tr>
<tr>
<td>2.1</td>
<td>Impact of speed increases on travel time</td>
<td>2-18</td>
</tr>
<tr>
<td>2.2</td>
<td>Summary review of possible improvements classified by purpose</td>
<td>2-26</td>
</tr>
<tr>
<td>3.1</td>
<td>Impacts of Airport Line extension to Jenkintown on trunk line operations</td>
<td>3-23</td>
</tr>
<tr>
<td>3.2</td>
<td>Schedule elements of alternative improvements</td>
<td>3-26</td>
</tr>
<tr>
<td>3.3</td>
<td>Overall evaluation of alternative improvements</td>
<td>3-28</td>
</tr>
</tbody>
</table>
INTRODUCTION

The regional rail system in Philadelphia has undergone several major changes in recent years. As a result of these changes the system has acquired a character rather different from the "commuter" lines which were operated several years ago. The most important changes have been the construction and opening of the Center City Tunnel and takeover by SEPTA, followed by a number of changes in the types of services. These changes include more frequent and regular services, improved information, diversified types of line pairs and increased integration of rail services with other transit in the region.

The new type of operation of the regional rail system requires a number of changes, improvements and modernization in its infrastructure and operational practices.

The deficiencies which presently exist on the regional rail system and which greatly limit its optimal operation and economic efficiency are numerous. As an illustration, a few will be mentioned here.

- The location of yards and storage tracks is such that storing of unnecessary cars from the trains on the western sections of lines (former Pennsylvania) between peak hours, needed to reduce car-miles, involves deadheading of several miles and very complicated switching operations on the Ex-Reading trunk line section.

- Track layout, developed for predominantly long-distance operation of freight trains, does not permit easy change of tracks or turning back of trains.

- Types of signals and their locations on some lines prevent high-capacity operations and convenient maneuvers.
Some "details" required in operations, such as the time-consuming brake test, take considerable time and prevent many efficient operations.

The subject of the present study is to analyze these problems on several components of the regional rail system and recommend improvements in service and efficiency of operation. The study consist of three major projects.

**Project 1** - development of an improved track layout and signal plan for the Wayne Junction - Jenkintown Junction section of the Ex-Reading Trunk line.

**Project 2** - an analysis of track layout, signals and operations on the single-track section of the Warminster branch.

**Project 3** - examination of the present operation of the Airport Line, its interrelationship with other lines and an examination of possible improved services and increased operating efficiency.

The report covers the three projects in the given sequence.
PROJECT 1

WAYNE JUNCTION - JENKINTOWN TRUNK LINE

The network of the former Reading lines is characterized by a long trunk line from which individual branch lines diverge. To accommodate high frequency of trains, this trunk line has four tracks from Center City to Wayne Junction. North of Wayne Junction, there are only two tracks.

Several serious deficiencies have been inherited on this trunk line, including the following ones:

- All track branching is at grade; track crossings limit line capacity;
- There are no center tracks which would facilitate turnback maneuvers or serve for train storage;
- Track layouts at interlockings do not allow flexible operations;
- Long and variable signal block lengths limit line capacity;
- Much of the infrastructure and equipment including switches, signals and train control installation is obsolete.

Consequences of these deficiencies are limited capacity, unforeseeable delays and low reliability of service.

This project covers the Wayne Junction-Jenkintown section of the trunk line and focuses on infrastructure and equipment modifications which are needed to improve performance of the line. It is divided into three sections:

- Newtown Junction;
- Jenkintown Junction; and
- Wayne Junction - Jenkintown trunk section
1.1 NEWTOWN JUNCTION

Most of the traffic through this junction travels in the north-south direction. One branch, to Fox Chase/Newtown, diverges to the right and in the vicinity of the junction joins CONRAIL's New York Short Line.

1.1.1 Present Layout and Operations

The track layout of Newtown Junction is shown in Fig. 1.1. In addition to the basic "Y" of the main tracks, the two tracks of the New York Short Line join the Fox Chase branch from the south. There are several crossovers between tracks and a long siding on the east side of the northbound track (NTSG). This siding is currently used for turnback and layover of Airport Line trains.

With trains travelling to different branches and one turning back in the siding, there are six types of regularly scheduled passenger train movements through this interlocking. Fig. 1.2 shows schematically the six conflict points (crossings, diverging and converging switches), and the six scheduled through movements. The figure further shows diagramatically which movement occupies which conflict points. Actual schedule of trains is shown in this manner at the bottom of the figure.

In addition to these passenger train movements, Conrail freight trains also negotiate this interlocking. They do not interfere with the two main line tracks, but they share branch tracks with Fox Chase Line. Frequency of the freight trains and their distribution among daily hours are shown in Fig. 1.3. The statistical data for 27 days show that on the average four trains travel per day in each direction. The interference of these trains with SEPTA trains rarely occurs during mid-day hours, but it appears likely to occur sometimes during the morning peak.
Figure 1.2 Schematic of train movements, conflict points and scheduled headways at Newtown Junction
Figure 1.3 Freight train movements at Newtown Junction – April 1-27, 1986

Source: SEPTA train sheets

SB = Southbound
NB = Northbound
1.1.2 Problems and Limitations

Major problems which occur presently in operation at Newtown Junction are the following:

- Any freight train movement on the New York Short Line delays outbound Fox Chase trains, which, if they are not retained at Wayne Junction, block the main line track 2 and stop all northbound movements;

- Departing Airport Line trains travel southbound through the limits of the interlocking at restricting speed. This again causes delays to northbound trains.

- Terminating Airport trains cannot by-pass each other easily if they have overlapping terminal times ("floating reserve trains");

- Southbound freight trains occupy SL1 through most of the interlocking, preventing northbound Fox Chase trains from using either SL track.

- Northbound Fox Chase trains cannot get to SL1.

1.1.3 Alternative Track Layout Improvements

Extensive analyses of possible track improvements have been performed. The most effective ones have been selected and they are shown in Fig. 1.4.

**Improvement 1** is a northbound crossover between ML2 and SL1. This crossover allows Fox Chase trains to travel northbound on SL1 (single tracking); combined with some additional improvements (as described below), this crossover will permit bypassing of Airport trains as well as removing waiting northbound Fox Chase trains from ML2 to SL1.

**Improvement 2a** replaces the crossing on SL1 by a single slip switch, creating a crossover between SL1 and SL2. This additional switch would allow northbound Fox Chase trains to wait on SL1 and then cross to SL2.

**Improvement 2b** represents an alternative crossover between SL1 and SL2 farther out on the branch.
Improvement 3a is a connector between NTSG and SL1, which would provide for a much shorter travel path for getting Airport trains from the siding into ML1. This faster maneuver would shorten blockage to the Main Line tracks and permit simultaneous travel of southbound Airport trains and northbound Fox Chase trains. Moreover, bypassing of the incoming and outgoing Airport trains with overlapping terminal times would be simplified.

Improvement 3b constructs a single slip switch instead of the crossing on ML2 (see Fig. 1.4). This improvement is an alternate to improvement 3a and it would serve the same purposes.

Improvement 4 is a new crossover between SL1 and SL2 on the Fox Chase branch, as shown in Figure 1.4.

As explained above, some of these improvements would alone permit new maneuvers. Other new movements require various combinations of the two of the listed improvements. In several cases alternative sets of improvements can achieve the same goals. A review of different sets of improvements and new movements which they allow are presented in Table 1.1.

1.1.4 Recommended Improvements

A complete summary of the selected improvements and their impacts on individual project objectives is presented in a form of a matrix in Table 1.2.

For each improvement listed in the first column, its impact on any one objective is designated by an "X". For example, Improvement 1 will contribute to the removal of Fox Chase trains from ML2, accelerate Airport train maneuvers and permit single track operations on SL1 (objectives i, ii and iii). Alternative improvements are designated by the same number (e.g. 2a and 2b) and the boxes in the table indicate that either one of these improvements would have the same effect.
<table>
<thead>
<tr>
<th>Combination of Improvements</th>
<th>Trains</th>
<th>New Movements Accommodated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>FXC NB</td>
<td>ML2 - SL1 (Single tracking)</td>
</tr>
<tr>
<td>1 + 2a</td>
<td>FXC NB</td>
<td>ML2 - SL1 - SL2</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + 2b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + 3a</td>
<td>APT NB</td>
<td>ML2 - SL1 - NTSG</td>
</tr>
<tr>
<td></td>
<td>APT SB</td>
<td>NTSG - SL1 - ML2 - ML1</td>
</tr>
<tr>
<td></td>
<td>APT SB</td>
<td>NTSG - SL1 - ML1</td>
</tr>
<tr>
<td>1 + 3b</td>
<td>APT SB</td>
<td>NTSG - ML2 - ML1</td>
</tr>
<tr>
<td>1 + 3a</td>
<td>APT SB</td>
<td>Simultaneous maneuver</td>
</tr>
<tr>
<td>or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 + 3b</td>
<td>FXC NB</td>
<td>SL1 - SL2</td>
</tr>
</tbody>
</table>

**NOTE:** FRT: Conrail freight train
<table>
<thead>
<tr>
<th>Improvements</th>
<th>Objectives</th>
<th>i</th>
<th>ii</th>
<th>iii</th>
<th>iv</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fast removal of Fox Chase trains from ML2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3a</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3b</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

Recommended improvement combinations:

---

Desirable combination

Acceptable combination
The table shows clearly that Improvement 1 would be effective in achieving Objectives I, II and V (to achieve Objective I, improvement 2a or 2b would also be required). Improvements 3a and 3b would have an impact on Objectives II and III. Finally, Improvement 4 would achieve Objective IV.

Between the two pairs of alternative improvements, 2a and 3a are preferable to 2b and 3b, since they would result in simpler train maneuvers. If the Airport Line terminus is relocated to Jenkintown or any other location, the importance of Improvements 3a and 3b would become much smaller. They would only be useful for maneuvers.

In summary, the recommended combination of improvements is shown graphically at the bottom of Table 1.2. With the present train operations the recommended set of improvements is 1-2a-3a-4, allowing 2b and 3b as possible alternatives to 2a and 3a. If the Airport Line terminus is removed, the recommended set is 1-2a-4, with improvement 3a desirable but much less important.

1.2 JENKINTOWN JUNCTION

Jenkintown Station is an important junction in the RRD network. It is served by three major lines, so that its efficient functioning is vital to the reliable operation of the entire Ex-Reading trunk line. In addition to its operational importance, Jenkintown is one of the busiest stations in the RRD system.

1.2.1 Present Layout, Operations and Problems

Track layout of Jenkintown Junction including all signals and insulated joints are shown schematically in Fig. 1.5. In addition to the through tracks in the "Y" form, there are sidings on the west side of the trunk line from the south and on both sides of the West Trenton branch. The inner switches of all
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

Chelten Hill Sdg.

≤ Center City

a. Present track layout and signals

THROUGH MOVEMENTS

TURN - BACK OF TRAINS:

From center city
From Glenside
From W. Trenton

SINGLE - TRACKING BETWEEN JENKINTOWN AND:

Center city

b. Present and desired movements

On track 1
On track 2

Glenside

West Trenton

On track 1
On track 2

Figure 1.5 Jenkintown Junction
three sidings are powered and interlocked, but the outer switches are not. There is only one interlocked crossover, just south of the station platforms.

The lower part of Fig. 1.5 shows all possible train movements in the Junction. They are grouped in three categories: through movements, which are regularly scheduled; turnback movements, which are presently not scheduled; and movements required for single-tracking in special situations (track maintenance, blocked track, etc.).

Present track and signal layout allow short headways for northbound trains. Southbound movements, with trains following each other on the same tracks or merging from two tracks, require longer headways because of longer blocks and insufficient number of signals.

Turnbacks of trains from Center City cannot be easily made; required maneuvers are numerous and time consuming. Turnbacks from the two branches to the north can be easily made.

Absence of a northbound crossover in the station area makes maneuvers for single track operations on one of the tracks on each pair difficult.

The sidings at Jenkintown Junction have considerable length for the storage of trains. However, since storage space is available on the sidings rather than on the middle tracks between main line tracks, they do not have easy access to/from each main line track.

1.2.2 Analysis of Headways

Through movements and their conflicting points are shown in Fig. 1.6. The conflict points are different in nature; each one, involving a different conflict (diverging, merging, crossing), requires different computation of headways. To analyze these conflicts, they are defined and schematically presented in Fig. 1.7. Passage of each one of the four train movements, desig-
Through movements:

1 - Southbound R5 (Doylestown) and R2 (Warminster)
2 - Southbound R1 (West Trenton/Media-Elwyn)
3 - Northbound R5 (Doylestown) and R2 (Warminster)
4 - Northbound R1 (West Trenton)

Conflict points:

A - Crossing
B - Merging
C - Diverging

Figure 1.6 Through movements and conflict points
THROUGH MOVEMENTS, CONFLICT POINTS (A, B, C), AND THEIR SCHEMATIC PRESENTATION

THROUGH MOVEMENT SEQUENCES

Figure 1.7 Graphical presentation of through movements at Jenkintown Junction
nated by numbers 1 to 4, through conflict points, designated as A, B and C, is shown schematically. The bottom part of the figure shows all permutations of conflict movements sequences (marked by shaded areas); non-conflicting movements are shown only in one sequence each.

Minimum headways, defined as time intervals between departures from station platforms of two trains in the analyzed sequence pair, were calculated for each of the conflict movements sequences. These calculations were made for two types of minimum headways:

a. Minimum headway assuming no delays to the following trains;

b. Absolute minimum headway which involves some delay to the following train

For all calculations it was assumed that all trains stop at the stations and that the speed limit of 35 mph exists within the interlocking limits. For headways without delays, station standing times of 60s were assumed. Performance elements used were those of Silverliner IV cars.

Fig. 1.8 gives comparison of calculated minimum headways without delays, for all conflicting movement sequences, with scheduled train movements during the two peak periods. Several scheduled headways are actually shorter than the calculated minima. This implies that in actual operation some trains are scheduled to follow preceding ones at reduced speeds. To analyze this operation, absolute minimum headways (defined as b above) were computed along with associated delays.

A condensed description of results of these calculations is presented in the framed text on page 1-18.

Minimum headways for southbound trains were found to be considerably longer than those for northbound trains. This is caused by longer signal blocks and location of signals in relation to station platform in the southbound direc-
Movement designations: 1 - Southbound R2, R5; 2 - Southbound R1
3 - Northbound R2, R5; 4 - Northbound R1

Movement sequences

<table>
<thead>
<tr>
<th>Conflict points</th>
<th>1-1</th>
<th>1-2</th>
<th>2-1</th>
<th>2-2</th>
<th>2-3</th>
<th>3-2</th>
<th>3-3</th>
<th>3-4</th>
<th>4-3</th>
<th>4-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
h \text{[min]} \quad 4.1 \quad 3.75 \quad 4.1 \quad 3.75 \quad 1 \quad 3.6 \quad 2.6 \quad 2.4 \quad 2.4 \quad 3.25
\]

a. Calculated minimum headways

\[
6^{\text{AM}}:10 :20 :30 :40 :50 \quad 7^{\text{AM}}:10 :20 :30 :40 :50 \quad 8^{\text{AM}}:10 :20 :30 :40 :50 \quad 9^{\text{AM}}
\]

b. AM peak period schedule (effec. 1/86)

\[
4^{\text{PM}}:10 :20 :30 :40 :50 \quad 5^{\text{PM}}:10 :20 :30 :40 :50 \quad 6^{\text{PM}}:10 :20 :30 :40 :50 \quad 7^{\text{PM}}
\]

c. PM peak period schedule (effec. 1/86)

Figure 1.8 Comparison of calculated minimum headways and scheduled headways
(Time scale is the same in all diagrams.)
Calculated minimum headways at Jenkintown station:

Designation of train movements:
1 - Southbound R5 (Paoli) and R2 (Marcus Hook);
2 - Southbound R1 (Media-Elwyn);
3 - Northbound R5 (Doylestown) and R2 (Warminster);
4 - Northbound R1 (West Trenton);

Sequence of conflicting movements:
1-1 | 1-2 | 2-1 | 2-2 | 2-3 | 3-2 | 3-3 | 3-4 | 4-3 | 4-4

Minimum headways assuring no delays for following train, with existing signals:
- In seconds (plus ST - station time):
185+ST 165+ST 185+ST 165+ST 201 155+ST 95+ST 85+ST 85+ST 135+ST
- In minutes, including 60 s station time:
4.1 | 3.75| 4.1 | 3.75| 0-11 | 3.6 | 2.6 | 2.4 | 2.4 | 3.25

Absolute minimum headways, plus associated delays to the following train, with existing signals, in seconds:
170 | 75 | 75 | 160 | 20* | 160* | 60* | 60* | 60* | 60*
+ + + + + + + +
80-115 60-100 80-115 60-100 0 30 20 20 20 120-145
(* - Assumes station time of 45 s)

Decreased minimum headways if new signal at the exit of southbound station platform (improvement 1 in figure 1.19) is implemented, in seconds:
145+ST 125+ST 145+ST 125+ST " 115+ST " " "

Further decreased minimum headways if new signals on the approach from Glenside and W. Trenton (improvements 9 and 10 in figure 1.19) are implemented:
- In seconds:
105+ST 95+ST 105+ST 95+ST " 85+ST " " "
- In minutes, including 60 s station time:
2.75| 2.6 | 2.75| 2.6 | " | 2.4 | " | " | " | "

If new signal toward W. Trenton is implemented (improvement 11), delays to train 4 following 4 at absolute minimum headway are reduced to 30 - 55 s.

Headways were calculated from the departure of first (leading) train in sequence, to the departure of second (following) train from the corresponding station platform.

---

1 - This interval is from the arrival of the first train to the departure of second train from station. They can be scheduled to depart both at the same time, or with very short (1 min.) headway.
tion. Consequently, to reduce headways (and increase line capacity) in the southbound direction, additional signals should be constructed. The proposed new signals are included in the recommended improvements in section 1.2.5. Among these new signals the most important one is at the exit of the southbound station platform (listed as improvement 1).

Effects of the proposed new signals are also included in the summary of results in the framed text.

1.2.3 Analysis of Turnback Movements

All turnback movements were exhaustively analyzed and they are presented in a series of figures.

At present, turnbacks from Center City can be performed on two sidings: Northbound Layoff and Chelten Hill siding. These two movements, with several possible maneuvers, are shown in Figs. 1.9 and 1.10 along with brief descriptions of conditions and deficiencies. As mentioned before, all presently possible turnback maneuvers from the south are very complicated and time consuming if the train is required to stop at the southbound platform.

The following three illustrations, Figs. 1.11, 1.12 and 1.13, show turnback from Center City with several alternative track layout improvements. These improvements are shown by circles in the figures. Simplification of the turnback maneuver due to each set of improvements can be clearly seen in the respective figure. Turnbacks of trains from either one of the branches can be easily performed with present track and signal layout using the Chelten Hill siding, as Fig. 1.14 shows.
2 & 4 - Station stops; 3 - Changing ends and terminal time;

Deficiencies: Complicated, requires 4 route-settings and 3 changes in direction, one of which is backing-up into the station; blocking both main tracks on arrival;
Since there is no signal at the southbound station exit, train is delayed going on Restricted, unless cab signals are in operation.

Figure 1.9 Turnback of northbound trains, existing layout, alternative 1 (Chelten Hill siding)
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

1. Sequence of movements
2. Station stop on arrival and departure
3. Changing ends and terminal time
4 & 5. Alternative movements for stopping at southbound platform on departure;

Deficiencies: If train is stopping at the southbound platform on departure, 3 route-settings and backing-up into the station are required; blocking both main tracks on departure;

Unless cab signals are operational, train is delayed starting southward on Restricted (5')

Figure 1.10 Turnback of northbound trains, existing layout, alternative 2 (Northbound Layoff)
Alternative 1a - using new crossover (improvement 2 in summary of analyzed improvements)
Alternative 1b - using MPF converted to slip switch (improvement 3 in summary)
Alternative 1c - using new connection (improvement 4 in summary of analyzed improvements)

Alternatives 1b and 1c are slightly better from the operational standpoint, because track 1 toward Glenside is not blocked.

Figure 1.11 Turnback of northbound trains, improved layout, alternatives 1a, b & c (Southbound Layoff)
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

JENKINTOWN JUNCTION

- Improvements required: powering & interlocking of switches, new dwarf signal

Note: This alternative provides another access to the Southbound Layoff and allows 2 or more trains in the Layoff at the same time, with departures independent of arrivals, if implemented together with one of the alternatives 1a, b or c.

Figure 1.12 Turnback of Northbound trains, improved layout, alternative 2 (Southbound Layoff)
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

1 - Sequence of movements
2 - Additional track, signals & power operation & interlocking of switches required

Chelten Hill Sdg.

Tr.1
L32

Tr.2
L36

L38

R2

RC24

RC24

L2

R2

R16

RA16

Northbound Layoff

Note: In this alternative Northbound Layoff is used as a through track, and track 2 as a layoff.

Figure 1.13 Turnback of northbound trains, improved track layout, alternative 3 (Using track 2 - Ideal track layout for turnback of trains from c. city)
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

JENKINTOWN JUNCTION

1. Sequence of movements

Deficiencies: None, no improvements are required.

Figure 1.14 Turnback of southbound trains, existing layout
1.2.4 Single-Tracking

Single-tracking operations on each track toward Center City are shown in Fig. 1.15. The major problem is the movement opposite to the direction of traffic on track 2 toward Center City: it requires reversing maneuvers. Two alternative improvements to solve this problem are shown in Fig. 1.16.

Single-tracking operations on the branches with existing layout are shown in Fig. 1.17. The problem analogous to the problem in single-tracking toward Center City on track 2, occurs for operations on track 1 of each branch. The solution to this problem is the same as presented in Fig. 1.16.

Another problem is that in single-tracking on track 2 of each branch, trains cannot stop at the southbound platform. This can be solved by the improvements shown in Fig. 1.18.

1.2.5 Summary of Proposed Improvements

All analyzed alternative improvements for Jenkintown Junction are presented in a composite manner in Fig. 1.19. The figure also contains a listing of improvements with brief descriptions and priority rating.

The rating of individual improvements is based on the analysis of impacts of each improvement on solutions of the defined present problems and deficiencies. This evaluation is presented in a summarized form in Table 1.3. The last column in the table gives brief rating description and general priority category, A, B or C. The final selection must be made taking into account costs involved and available funding. It should be noted that many of the listed improvements are alternatives, so that only a subset of them may be sufficient to achieve desired goals.
Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint
- Movable point frog crossing

JENKINTOWN JUNCTION

Route & sequence of movements of trains going opposite to traffic on:

1 → - Track 1
1 → - Track 2
SS - Station stop

Chelten Hill Sdg.

Deficiencies:
- Going opposite to current of traffic south of Jenkintown on track 1: None;
- Going opposite to current of traffic south of Jenkintown on track 2: Entering the station platform in backward move, 3 route-settings required, time consuming, blocking northbound platform on departure.

Figure 1.15 Single-tracking toward center city - existing track layout
Figure 1.16 Single tracking toward center city on track 2 - improved track & signal layout
Deficiencies:
- Going opposite to current of traffic north of Jenkintown on track 1: Requires 3 route-settings and one backward move, complicated and time consuming, blocking northbound platform on departure;
- Going opposite to current of traffic north of Jenkintown on track 2: Southbound trains stopping at northbound platform, unless it enters southbound platform backward.

Figure 1.17 Single tracking between Jenkintown and Glenside or West Trenton - existing track layout
JENKINTOWN JUNCTION

Legend:
- Station platforms
- Signal & its code
- Dwarf signal & code
- Insulated joint

Improvements: MPF converted to slip switch, powered and interlocked previously manual switches.

Alternative improvement for single-tracking from W. Trenton

Note: These improvements allow trains coming from north opposite to current of traffic to make station stops at southbound, rather than at northbound station platform.

Figure 1.18 Single-tracking between Jenkintown and Glenside or West Trenton, on track 2, improved track layout
Figure 1.19 Analyzed improvements of track layout and signals
<table>
<thead>
<tr>
<th>IMPROVEMENT NUMBER AND DESCRIPTION</th>
<th>RELATIONSHIP WITH OTHER IMPROVEMENTS</th>
<th>IMPACT ON OPERATIONS</th>
<th>ADDITIONAL CHANGES REQUIRED</th>
<th>OVERALL EFFECTIVENESS &amp; RATING (A, B, C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 New signal at the exit of the south-bound platform</td>
<td>Assumes 1; partial alternatives: 3 or 4</td>
<td>Decreased min. highways (40s) &amp; delays; Slightly faster</td>
<td>Interlocking logic</td>
<td>Very Good -A</td>
</tr>
<tr>
<td>2 Crossover from track 2 to 1 immediately after north-bound platform</td>
<td>Assumes 1; partial alternatives: 3 or 4</td>
<td>Easier, faster, more flexible</td>
<td>Interlocking logic</td>
<td>Excellent -A</td>
</tr>
<tr>
<td>3 Convert M/F to double slip switch</td>
<td>Assumes 1; alternatives: 2 or 4</td>
<td>Faster, more flexible</td>
<td>Interlocking logic</td>
<td>Very good but expensive maintenance -A</td>
</tr>
<tr>
<td>4 Connection between south-bound layoff &amp; track 2</td>
<td>Assumes 1; alternatives: 2 or 3</td>
<td>Easier, faster, more flexible</td>
<td>Interlocking logic</td>
<td>Very Good -A</td>
</tr>
<tr>
<td>5 Use of NB lay-off as thru-track &amp; crossover 2-1</td>
<td>Partially alternative with 2 or 3 or 4</td>
<td>Excellent, more flexible</td>
<td>Interlocking logic</td>
<td>Good -B</td>
</tr>
<tr>
<td>6 Interlocking of north end of SB layoff &amp; &quot;Steel&quot; crossover</td>
<td>Assumes 1 &amp; 2 or 3</td>
<td>More flexible</td>
<td>Int. logic, 1 new dwarf signal, powering 3 switches</td>
<td>Sufficient, good if 2, 3, or 4 also implemented -C</td>
</tr>
<tr>
<td>7 Crossover from tr. 2 to 1 toward Glenside</td>
<td>Redundant if 2 is implemented</td>
<td>Much faster &amp; easier</td>
<td>2 new switches, 1 new dwarf signal (or reлок. of RC24)</td>
<td>Sufficient, but redundant if 2 implemented -A</td>
</tr>
<tr>
<td>8 Crossover from tr. 2 to 1 toward Trenton</td>
<td>Redundant with 2 or 3 or 4 &amp; 6</td>
<td>Much faster &amp; easier</td>
<td>Sufficient but redundant with 2 or 3 or 4 &amp; 6</td>
<td>Very Good -B</td>
</tr>
<tr>
<td>9 Add. signal on the approach from Glenside</td>
<td>Assumes 1</td>
<td>Decreased min. headways (40s) delays, from Glenside</td>
<td>Slt. impr. if 4 &amp; 5 implemented</td>
<td>Good -C</td>
</tr>
<tr>
<td>10 Add. signal on the approach from W. Trenton</td>
<td>Assumes 1; interlocking signal if 5 implemented</td>
<td>Decreased min. headways (30s) delays from W. Trenton</td>
<td>If 5 implemented then interlocking signal, otherwise automatic</td>
<td>Good -C</td>
</tr>
<tr>
<td>11 Add. signal toward W. Trenton</td>
<td>Assumes 1; interlocking signal if 5 implemented</td>
<td>Decreased delays toward W. Trenton</td>
<td>Slightly improved if 5 imp.</td>
<td>Good -C</td>
</tr>
</tbody>
</table>
1.3 WAYNE JUNCTION-JENKINTOWN TRUNK SECTION

The Wayne-Jenkintown section carries considerable frequency of trains per track because the four-track trunk line south of it converges into two tracks at Wayne Junction. Operation of five and farther north three different lines on this section creates uneven headways and increased probability of delay generation.

1.3.1 Present Operations

Fig. 1.20 shows a schematic layout of the entire Ex-Reading trunk line with branches. The number of trains travelling through each switch and crossing point at branching locations during the PM peak, is given by line and designated for inbound (I) or outbound (O) direction. It can be derived from this figure that the section between Wayne and Newtown Junctions carries about 22 outbound and 32 inbound trains during the 3-hour peak; while the section north of Newtown Junction carries 20 outbound and 12 inbound trains.

Time-distance diagrams for the morning and afternoon peaks, presented in Figs. 1.21 and 1.22, respectively, show that trains operate with uneven headways and often "catch-up" with each other. Cumulative diagrams of offered service expressed by car and train frequencies are shown in Fig. 1.23.

Travel times between Wayne Junction and Jenkintown are given in schedules as 9 min for northbound trains and 10-11 min for southbound trains. It is not clear why all northbound trains have the same travel time although some of them stop at different numbers of stations.

1.3.2 Track Layout and Signals

As Fig. 1.24 shows, there are three sets of crossovers between Wayne Junction and Fern Rock, but no crossovers between Fern Rock and Jenkintown.
Figure 1.20  Ex-Reading trunk line train movements and conflicts - PM peak period

Source: SEPTA Schedule
(3:30PM - 6:30PM)
Effective Oct. 27, 1985
Source: SEPTA Schedule
Effective October 27, 1985

Notes: "EX" = Express
• = Stopping
1A,1B,2A,etc. = Platform location at Market East

Figure 1.22 Time-distance diagram of existing train movements from Market East to Jenkintown-PM peak period
Figure 1.23 Train and car frequencies between Market East and Glenside

Direction of train movements (7:30 - 8:30AM)
Figure 1.24 Existing track layout and signals between Wayne Junction and Jenkintown
The same figure shows signal locations and block lengths on each track. Unevenness of block lengths along this section can be seen more clearly in the diagrams in Fig. 1.25. Most blocks are rather long, the longest one exceeding one mile in length. Both the considerable size and variability of the signal block lengths limit line capacity, since the longest block influences the minimum headway.

1.3.3 Problems and Limitations

Major operating problems on this section of the regional rail network can be summarized into three groups:

- Signal block lengths impose limitations on headway reduction. Train operations are very vulnerable to delays when the actual headways approach the limits imposed by the signal system. A comparison of the scheduled and actual train passing times at Jenkintown, shown in Fig. 1.26, illustrates this problem; most trains are delayed and one delayed train causes subsequent trains to fall behind schedule.

- Operational complexities and track layout deficiencies at both Newtown and Jenkintown Junctions create delays which have negative impacts on the operating reliability of this line section.

- Insufficient number of crossovers between the two tracks reduces flexibility of train operations, which is particularly important when delays or service disruptions occur. In the following sections, all these limitations on minimum headways and flexibility of operations are analyzed.

1.3.4 Analysis of Signal Blocks and Headways

In order to determine required signal block length for 2- or 3-block protection, train performance curves were computed and they are presented in
Figure 1.25  Signal block lengths between Wayne Junction and Jenkintown
Figure 1.26 Comparison of scheduled and actual train passing times at Jenkinstown

Source: SEPTA train sheet
April 7, 1986

The diagram illustrates the comparison between scheduled and actual train passing times at Jenkinstown.
Fig. 1.27. The diagrams show change of speed in time and in space (distance) during acceleration and deceleration of trains, assuming $V_{\text{max}} = 75$ mph. The performance plotted is for Silverliner IV cars. These curves, naturally, allow performance analysis for any speed up to 75 mph.

The old "Blue Cars" have inferior performance to Silverliner IV cars, so that it may be necessary to impose a lower speed limit for them than for Silverliner IV cars. This may not be a serious problem since the "Blue Cars" have short periods of running at $V_{\text{max}}$ due to their lower acceleration rate. Travel time increase caused by lower $V_{\text{max}}$ would, therefore, not be great.

Utilizing performance curves in Fig. 1.27, a time-distance diagram for a train travelling at 60 mph, making a stop and accelerating back to 60 mph was developed. The diagram with all computed time intervals and deceleration/acceleration distances is shown in Fig. 1.28.

Figure 1.29 shows speed profiles of a train for 2- and 3-block protection signals. These operating requirements were used for analysis of headways along the line.

In order to analyze the minimum headways under 2- and 3-block protection signal, a microcomputer program which plots the paths of two consecutive trains was developed. The program plots the zone of protection behind the first train and the path of the second train which follows the first one as close as the given protection scheme allows.

This program was used to make computations of the minimum headways on the Wayne Junction-Jenkintown section under different signal set-ups and modes of operation. The sequence of computations was in the following three steps, illustrated in Figs. 1.30, 1.31 and 1.32.

First, computations and diagrams were made for two consecutive trains travelling northbound and southbound assuming three block protection with
Figure 1.28  Time intervals for train stopping at a station
Figure 1.29 Distance-speed diagrams for 3- and 4-aspect signals
Notes: 1) Assumes 60 sec standing time at JKT and WAJ, 30 sec at ELP and MEP, 20 sec at FER, TAB and LGN
2) Assumes the train acceleration/deceleration performance shown in Figure 1.28

FIGURE 1.30 SIGNALS AND HEADWAYS: EXISTING
Notes:  
- Assumes 60 sec standing time at JKT and WAJ;  
- 35 sec standing time at all other stations.  
- Assumes the train acceleration/deceleration performance shown in Figure 1.28.

Figure 1.31 Signals and headways: improved existing
Notes: Assumes 60 sec standing time at JKT and WAJ; 35 sec standing time at all other stations. Assumes the train acceleration/deceleration performance shown in Figure 1.28.

Figure 1.32 Signals and headways: desirable arrangement
proceeding on "approach medium". As shown in Fig. 1.30, the minimum headways computed for this case were 4.2 min for northbound and 4.8 min for southbound travel.

Second, several new signals were added in the block which were critical in the preceding computations. The new signals are shown by dashed lines in the diagrams (Fig. 1.31). The minimum headway was found to be 3.0 min for each direction. This represents a very significant improvement in line operation and capacity.

Third, the existing signals were disregarded and a new set of signals was designed based on the train performance data presented earlier. The results, shown in Fig. 1.32, are the minimum headways of 2.6 and 2.8 min for northbound and southbound directions, respectively.

The conclusions of these computations is that adding a few signals at the present critical locations would be very effective in increasing line capacity; total reconstruction of all signals to achieve an optimum system would bring marginal additional improvements.

Presently different lines on this section have different stopping patterns, as shown in Fig. 1.33. The minimum headways for all permutations of train sequences from different lines and stopping patterns were calculated with the computer. The results for the three cases with all-stop operation (existing, improved and desirable) and for train sequences from different existing lines are summarized in Table 1.4. The table is self-explanatory.

These computations have shown that the sequence of trains which have different stopping patterns represents another factor which strongly influences minimum headways on the Wayne Junction–Jenkintown line. This influence is clearly illustrated in Fig. 1.34. Diagram (a) shows operations at minimum headways of three trains from three different presently operated lines in the
Table 1.4 Minimum headways under different signal sets and stopping schedules

<table>
<thead>
<tr>
<th></th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&quot;Clear&quot;(1)</td>
<td>&quot;AM&quot;(2)</td>
</tr>
<tr>
<td><strong>Existing signals</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- All-stop</td>
<td>5.0 min</td>
<td>4.2 min</td>
</tr>
<tr>
<td>- Non-stop</td>
<td>3.0</td>
<td>2.3</td>
</tr>
<tr>
<td>- R1-R5</td>
<td>---</td>
<td>3.0</td>
</tr>
<tr>
<td>- R2-R5</td>
<td>---</td>
<td>6.0</td>
</tr>
<tr>
<td>- R1-R2</td>
<td>---</td>
<td>4.0</td>
</tr>
<tr>
<td>- R2-R1</td>
<td>---</td>
<td>6.0</td>
</tr>
<tr>
<td>- R5-R1</td>
<td>---</td>
<td>3.0</td>
</tr>
<tr>
<td>- R5-R2</td>
<td>---</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Improved existing(3)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-stop</td>
<td>---</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Desirable arrangement (4)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All-stop</td>
<td>---</td>
<td>2.6</td>
</tr>
</tbody>
</table>

(1) Train enters a new signal block only under "clear" indication (3-block separation).

(2) Train may enter a new signal block under "Approach Medium" (operation under cab-signal).

(3) Improvements to the existing signals (relocations and additions to the existing signals).

(4) Entirely new signals.
Figure 1.34 Impact of express/local train sequences on minimum headways

(a) Existing stopping patterns (R1-R2-R5)

(b) Existing stopping patterns (R1-R5-R2)

(c) Assumed stopping pattern: Alternative 1

(d) Assumed stopping pattern: Alternative 2
sequence of R1-R2-R5. The total "Platoon headway" for the three trains is $T_1$. Diagram (b) shows the same trains in different sequence: R1-R5-R2. The "platoon headway" $T_2$ is shorter than $T_1$. Diagrams (c) and (d) show different stopping patterns of individual trains which result in further decreases of the "platoon headway".

Stopping patterns for different lines are usually determined so that their passenger loads are evenly distributed or their travel times adjusted. To increase capacity of the line, the impact of stopping patterns on minimum headways should also be considered.

1.3.5 Crossovers and Storage Tracks

Crossover and storage tracks between main tracks are usually not needed for regular operations. However, they have great importance for special operations, such as single tracking during track maintenance work, track blockages, train breakdowns, special events, etc. The Wayne Junction–Jenkintown line section is so long that the availability of crossovers and storage tracks is very important for reliable operation on it. This importance was examined by comparing operations with different sets of crossovers.

When single-tracking must be performed for any reason, it is very important to keep the length of the single track section as short as possible. The importance of the existing crossover at Tabor and the possible one at Melrose Park has been examined through computations of minimum headways which could be operated on the longest section between crossovers in several different cases.

As presented in Table 1.5, Case (a) assumes the presence of the Tabor (TAB) and Melrose Park (MEP) crossovers. The critical section in this case is MEP–JKT with the minimum headway of 550s (over 9 min). In Case (b) there is no TAB crossover; the critical section remains MEP–JKT with the same headway.
Table 1.5 Minimum headways on critical sections for single-track operations with different sets of interlocked crossovers.

<table>
<thead>
<tr>
<th>Interlocking Set</th>
<th>Critical Section</th>
<th>Minimum Headway (Seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. NTJ - TAB - MEP - JKT</td>
<td>MEP - JKT</td>
<td>$60 + 2 \cdot 170 + 60 + 2 \cdot 45 = 550$</td>
</tr>
<tr>
<td>b. NTJ - MEP - JKT</td>
<td>MEP - JKT</td>
<td>$60 + 2 \cdot 170 + 60 + 2 \cdot 45 = 550$</td>
</tr>
<tr>
<td>c. NTJ - TAB - JKT</td>
<td>TAB - JKT</td>
<td>$60 + 2(56 + 170) + 60 + 2 \cdot 45 = 752$</td>
</tr>
<tr>
<td>d. NTJ - JKT</td>
<td>NTJ - JKT</td>
<td>$60 + 2(70 + 56 + 170) + 60 + 2 \cdot 45 = 892$</td>
</tr>
</tbody>
</table>

Assumptions:
- Headways are between two trains travelling in the same direction, with one train in the opposite direction between them (trains in opposite directions travel alternatively).
- Signal clearance at each train meet takes 60s.
- Stopping at a station adds 45s to travel time.
However, this does not imply that the TAB crossover is useless, because the single track section need not be MEP-JKT, but one involving TAB. The minimum headway for such a case would be shorter than 550s. and it would be reduced by the presence of the TAB crossover. Case c is without the MEP crossing; the critical section becomes TAB-JKT and the minimum headway increases to 750 s, or over 12 min. Finally, Case (d) is without either the TAB or MEP crossover. The minimum operating headway for single track operation in this case is 892 s, or close to 15 min.

1.3.6 Recommendations

The preceding analyses give numerous insights in the relative importance and effectiveness of various improvements on the Wayne Junction-Jenkintown section. The three most important recommendations resulting from these analyses are particularly emphasized here.

1. Construction of several additional signals in the critical blocks is recommended because it would result in a significant increase of line capacity and it would be more cost-effective than the construction of an entirely new set of relocated signals.

2. Changes in stopping patterns on individual lines which reduces minimum (critical) headway should be prepared and implemented. Similar to the effects of the improved signals, the ability to operate with shorter headways would increase capacity and reliability of service.

3. Interlocked crossovers should be maintained at Tabor and constructed at Melrose Park to increase capability for maintaining regular services under extraordinary conditions.
PROJECT 2
WARMINSTER BRANCH LINE

Track and other infrastructure elements on the Warminster Line (R2) are presently in poor condition and their reconstruction is planned for the near future. This project is intended to examine physical and operational characteristics of the Warminster Line in order to define any changes or improvements in present design which should be included in the plans for reconstruction.

2.1 PRESENT CONDITIONS AND OPERATION

2.1.1 Line Description

Warminster Line (R2) branches off from the Lansdale-Doylestown Line (R5) at Carmel Junction, north of Glenside Station. From the branching point at Carmel there is approximately 10,700 ft. of double track. Just before Roslyn station the two tracks merge into a single track. The remaining section of the line, with a length of about 32,000 ft, has single track with one used siding (Willow Grove), one unused (Hatboro) and a double track with an extra crossover at Warminster Station. The track layout of the line with signals is presented schematically in Fig. 2.1.

Starting from Carmel Junction, R2 line has 7 stations, 6 of which are located along the single track section. The station platforms are low except Warminster, their lengths vary from 2-6 car lengths.

Presently maximum speed limit on the line is 40 mph. There are 16 grade crossings, 9 of which have speed limits varying from 5 to 30 mph. Most crossings are adjacent to stations.
2.1.2 Schedule and Operations

Speed-distance profile of the train movement on the Warminster Line is shown in Fig. 2.2. The profile has been developed assuming maximum acceleration and service braking rates of Silverliner IV cars.

The base headway on the line is 60 min and the peak hour headway is 30 min. Schedule diagrams for the A.M. and P.M. peaks are shown in Fig. 2.3. As can be seen in the diagrams, three outbound trains in the A.M. peak have extra waiting of about 12 min. at the Willow Grove siding. This is caused by the scheduling restriction on the Marcus Hook branch of the line, which is shared with Amtrak. The diagrams also show that three trains are stored at Warminster overnight.

2.1.3 Problems and Limitations

Single track lines have very sensitive operation. Train movements in the two directions on such lines are strongly interdependent, so that reliability and flexibility of operations are even more important than on double track lines. Major elements that affect operations on the Warminster Line are analyzed here.

Meeting points for trains affect schedules: for any given set of meeting points and speeds, there are only a few headways which can be operated. On Warminster Line there is only one operational meeting point (Willow Grove) on the single track section. Two other locations with two tracks, Hatboro siding and Warminster, cannot be used for regular meetings of trains because of their physical limitations (manual switches, no platform for the western track at Warminster).

Single meeting point represents a limitation on operation: it allows only headways of 30 min, and any delay of one train affects running of other trains.
Figure 2.2 Train speed profile
Figure 2.3 Present schedule
In other words, as long as 30 min headways are operated and service is regular, the present track layout with Willow Grove siding is adequate. But change of headway or any service delays cause service disruptions.

*Speed limit of 10 mph on the Willow Grove siding is usually not a problem because the train on it must stop anyway to allow the opposite train to pass.* When no meeting takes place, the one train utilizes the main track which has a speed limit of 40 mph.

*Track layout at Warminster allows storage of 14 cars, which is adequate for present needs; however, single platform and manual switches make terminal operations for stored trains quite complicated and time-consuming.*

*Station locations are in two cases (Roslyn and Willow Grove) inconvenient: they are on single track sections although double track starts in their immediate vicinity. These station locations increase the impact of a delayed train on the train it meets at the track convergence points.*

*Grade crossings reduce train speeds severely, particularly in those located away from stations. In two cases the speed limit is only 5 mph. These limitations are caused by the complexity of the streets they cross (in two cases there are adjacent intersections), poor visibility from them and absence of barriers.*

*Track condition is so poor that the maximum speed allowed even on open line sections is only 40 mph. Another factor contributing to this limitation is inadequate protection of the track along several sections.*
2.2 POSSIBLE IMPROVEMENTS OF SERVICE

The examination of the Warminster branch line and analysis of its present problems and limitations, described above, have led to the conclusion that the improvements are necessary in two major directions:

1) Improvement of the present service quality consisting of such changes as speed increase (reduction of travel times), increase reliability, improved flexibility of operations and ability to recover delays;

2) Create possibility for operation of shorter headways, which would result in more attractive service for passengers and increased capacity of the line.

The first set of improvements actually is relevant to the existing as well as to any modified service with shorter headways. The improvements aimed at improved service quality are presented in this section: an examination of possible headway reduction is covered in the following section.

2.2.1 Meeting Point Analysis

Physical relationship of distance, time and speed impose the requirement that on single track lines travel time between the points where trains meet must be equal to one half of the operated headway. The distance of the last passing point before the end of the line and the terminal point depends on the required terminal time for trains. If, in one extreme, terminal time is zero (instant return), travel time between the siding and terminal must be one half of the headway; if, in the other extreme, terminal time is equal to the headway, the meeting of trains must take place at the terminals. In most cases travel time between the last meeting point and the terminal is somewhat
shorter than one half of the headway and the terminal time is strictly determined by the distance, speed and operated headway.

An analysis of operations and meeting points on the Warminster Line is presented in Fig. 2.4. Diagram (a) in this figure shows travel of four south-bound trains (S index 1 through 4) operating at a headway of 15 minutes. The interrelationship between the headway, travel and terminal times is best seen on the example of train $S_4$ which leaves Warminster at time A. If this train had a terminal time of 6 min ($t_c = 6$ min), it would have met the preceding trains at locations designated as $X_1^6$, $X_2^6$, $X_3^6$. If train $S_4$ had $t_c = 10$ min, train $S_4$ would have met trains $S_1$, $S_2$, and $S_3$ at locations $X_1^{10}$, $X_2^{10}$, $X_3^{10}$, respectively. The third possibility is with $t_c = 14$ min; the corresponding meeting points are also shown on the diagram.

The diagram shows that as terminal time is lengthened, all three meeting points move closer to the terminals, i.e. Warminster.

The diagram in Fig. 2.4b shows the same operation for headway of 20 min. The meeting points again move toward the end of the line as terminal time increases, but they are farther apart among themselves because of the longer headway.

To summarize the findings of this analysis, a diagram showing locations of meeting points as functions of terminal times $t_c$ on the Warminster Line for headways of 15, 20 and 30 min. is presented in Fig. 2.5. The irregularity of the lowest line for $h = 15$ min is caused by the fact that when meeting of the trains takes place on the Willow Grove siding, the lower speed of one train extends travel of that train so significantly (due to the length of the siding) that the next meeting point to the south must be brought closer. If the line is operated with $h = 15$ min and $t_c$ of 10 min, the diagram shows the three points at which the trains would meet; that means that the sidings should be
Figure 2.4 Train meeting points for different terminal times
Figure 2.5 Summary diagram of meeting points for different headways as a function of terminal time
provided at those locations. Similarly, for any other terminal time a vertical line above that time would show the three meeting locations; or, for any given terminal time and a headway of 20 or 30 min one can draw a vertical line above the respective terminal time and obtain the required meeting points. This diagram will therefore be used in further examination of possibilities for using shorter headways presented in section 2.3.

2.2.2 Sidings and Double Track Extensions

Meeting of trains at Willow Grove Siding, which is critical for reliable operation of the line, always causes delay to at least one of the meeting trains. The problems at this siding are:

- Willow Grove station is located adjacent to the siding, but on the single track section, so that waiting on the siding does not coincide with standing at the station; many trains have to stop twice.

- The southbound train approaching the siding has the last signal (# 512) at Fulmor, 5741 ft. north of Willow Grove siding. This signal controls the speed of the southbound train depending on the position of the northbound train. The assumption throughout this and subsequent analyses is that the southbound train is scheduled to travel on "Clear" aspect on signal 512, which means that the northbound train has already entered the siding and has cleared the insulated joint (cut) corresponding to signal #50A. Under this assumption, the southbound train is given absolute priority at the expense of slowing down the northbound trains. If the southbound train is scheduled to travel on "Approach" aspect on signal 512, it could leave Fulmor earlier but would travel at a slower speed and would be vulnerable to delays. This situation can be improved by extending the siding to the south past Willow Grove station. The impact of this improvement on train travel times is illustrated in Fig. 2.6.
Figure 2.6 Impact of extending double track through Willow Grove Station.
Case (a) shows a time-distance diagram of a meeting, under the described conditions and assuming that the southbound train gets the "Clear" aspect at signal 512 $t_d$ interval after the northbound train has entered the siding. This interval is measured from the instant that the rear axle of the northbound train clears the cut at the south end of the siding to the instant the southbound gets "Clear" on signal 512. It accounts for reaction times of the tower operator and engineer, as well as for the time required for switches to be positioned and the signal to be displayed.

With the siding extended past Willow Grove station, the southbound train will be released by the signal at Fulmor and be able to leave $\Delta t_s$ time sooner (all train movements for the condition when the siding is extended past Willow Grove station are shown by dashed lines). Assuming, as before, that both trains run at prescribed speed limits, the southbound train will enter the double track section and clear its northern end before the northbound train has arrived. The latter therefore can proceed without stopping.

Consequently, extension of the siding results in faster release of the southbound train and a saving of $\Delta t_s$ time to it, while the northbound train saves $\Delta t_r$ time as compared to the present operation.

The case when northbound train is delayed is shown in the same figure as Case b. With operating rules as described above, the diagram shows that the delay to the southbound train induced by the northbound train is reduced by $\Delta t_j$, while running time of the northbound train is shortened by $\Delta t_r$.

Case (c) in Fig. 2.6 shows that in the situation when the southbound train is delayed, thus inducing a delay of a northbound train, the extension of the siding does not have any impact on the total travel time of either train.

The conclusion from this analysis is that the impact of extending the siding past Willow Grove station has variable impacts on train travel times,
depending on arrival times of the two meeting trains, but in most cases this improvement will shorten travel times and decrease train delays, thus increasing reliability of service.

2.2.3 Speed Limits at Grade Crossings and on Open Line Sections

An increase of the average speed on the Warminster Line is desirable not only to reduce passengers' travel times, but also to enable operation of shorter headways for increased line capacity. The section most critical for line capacity is the one from Willow Grove siding to Warminster, since it involves travel times in both directions plus terminal time of trains. For this purpose, an analysis was made of the impacts of an increase of the speed limits at grade crossings, and in open line sections.

First, computations of speeds and travel times were made assuming that the speed limit at each grade crossing is raised by 5 mph. It was found that travel time between Carmel and Warminster was reduced by 90 s. It is significant to note that more than two thirds of that saved time interval (68 s) occurs on the section between Willow Grove and Warminster, which is critical for capacity.

Second, travel time computations were made assuming that the speed limit in open line sections is increased from the present 40 mph to 50 mph. The total time saving is 78 s. This is a very similar amount of saving as in the case of increased grade crossings speeds; however, in the case of increased open line speeds most of the time savings (36 s) occurs on the section south of Willow Grove, rather than north of it.

The conclusion of these analyses is that it is more effective to raise speed limits on grade crossings than on open line (although the latter is also desirable) of the significant number of grade crossings (9), some of which have speed limits as low as 10 and 5 mph. The benefits of open line speed increases
are limited due to relatively short sections on which trains can develop speeds over 40 mph.

To examine the impacts of these two sets of speed increases on meeting points of trains and feasible headways, a summary diagram of meeting points, similar to the one in Fig. 2.4, has been drawn for each of the two cases. The two diagrams, shown in Figs. 2.7 and 2.8, show that increased speeds move the meeting points farther apart from each other and from the line terminal, Warminster.

A summary review of the travel time computations is presented in Table 2.1. The columns in the table show, in sequence: present computed travel times (exact, based on present conditions); present scheduled travel times; travel times with increased speeds on grade crossings; and travel times with open line speed increase. The significance of the increase of speed limits at grade crossings, particularly for those in the vicinity of Hatboro station, is obvious.

2.2.4 Signal Improvement

Long signal blocks always reduce capacity; this is particularly the case on the approaches to the sidings which are meeting points for trains. Potential impacts of an additional signal block on train operations was analyzed on the critical section along the line - north of Willow Grove siding. As Fig. 2.9 shows, two cases were compared, each one for the present conditions and for the situation with a new signal 2925 ft north of the siding. Case (a) shows that addition of the new signal results in travel time reductions to both, northbound and southbound trains (Δt_r and Δt_s, respectively). Case (b) is with the same new signal plus a speed increase from 10 to 20 mph in the siding. The diagram for Case (b) shows that the additional time saving due to this speed
Figure 2.7 Summary diagram of meeting points for increased speed on grade crossings as a function of terminal time.
Figure 2.8 Summary diagram of meeting points for increased maximum speed as a function of terminal time.
<table>
<thead>
<tr>
<th></th>
<th>Present running $V_{\text{max}}=40\text{mph}$</th>
<th>Present scheduled (ts included)</th>
<th>With speed on crossings increased by 5 mph</th>
<th>With $V_{\text{max}}=50\text{mph}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP Carmel</td>
<td>172</td>
<td>240</td>
<td>165</td>
<td>166</td>
</tr>
<tr>
<td>Ardsley</td>
<td>162</td>
<td>180</td>
<td>162</td>
<td>148</td>
</tr>
<tr>
<td>Roslyn</td>
<td>148</td>
<td>180</td>
<td>148</td>
<td>133</td>
</tr>
<tr>
<td>Crestmont</td>
<td>141</td>
<td>180</td>
<td>126</td>
<td>135</td>
</tr>
<tr>
<td>Willow Grove</td>
<td>44* 202</td>
<td>60</td>
<td>44* 202</td>
<td>39* 202</td>
</tr>
<tr>
<td>CP Grove Nth</td>
<td>149</td>
<td>120</td>
<td>149</td>
<td>129</td>
</tr>
<tr>
<td>Fulmor</td>
<td>137</td>
<td>180</td>
<td>124</td>
<td>130</td>
</tr>
<tr>
<td>Hatboro</td>
<td>300</td>
<td>300</td>
<td>245</td>
<td>295</td>
</tr>
<tr>
<td>Warminster</td>
<td>1253</td>
<td>---</td>
<td>1163</td>
<td>1175</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Station standing (30 s)</td>
<td>180</td>
<td>--</td>
<td>180</td>
<td>180</td>
</tr>
<tr>
<td>Total travel time</td>
<td>1433</td>
<td>1440</td>
<td>1343</td>
<td>1355</td>
</tr>
<tr>
<td>Total reduction</td>
<td>--</td>
<td>--</td>
<td>90</td>
<td>78</td>
</tr>
<tr>
<td>Reduction CP Grove Nth - Warminster section</td>
<td>--</td>
<td>--</td>
<td>68</td>
<td>32</td>
</tr>
</tbody>
</table>

*Travel time on Willow Grove siding*
Figure 2.9 Impact on train operations of adding a signal and increased speed on Willow Grove siding.
increase is quite small. It is concluded that the implementation of a new signal to shorten the long block north of Willow Grove siding would be very effective for increasing speed and reliability of the line; an increase of speed limit in the siding is desirable, but not essential.

2.3 POSSIBLE HEADWAY DECREASES

In the future it may be desirable to operate shorter headways than 30 min. on the Warminster Line. If shorter headways are needed, it is assumed that they will be 20 min. or 15 min. A 20 min. headway may be necessary if some other portions of the RRD network are changed to schedules based on 20 - 40 - 60 min. Headways of 15 min might be desirable in the present operation based on 30 min, it would be necessary to "insert" a train between two regularly scheduled trains. Therefore both 20 - and 15 - min headways were examined for this line.

2.3.1 20-Minute Headways

The diagram of train meeting points as a function of terminal time is plotted for several different headways in Fig. 2.5 (described in section 2.2.1). This diagram gives an overall picture of the relationship of train speed, headway and meeting locations. However, since the diagram is based on a number of simplifying assumptions about train travel speeds, stoppings, signal block clearances and other elements, an exact analysis of feasibility of using different headways requires computations and plotting of a more precise time-distance diagram.

Observing the diagram in Fig. 2.5, we can see that in the plotted range for $t_t$ of 6 - 14 min, the first meeting point for $h = 20$ min south of Warminster is in the vicinity of Hatboro, but the second meeting point is always
on the single track section. Extrapolating these lines we can see that for \( t_c = 0 \) the first meeting point for \( h = 20 \) approaches Willow Grove siding and the second meeting point line enters the double track section south of Roslyn. The detailed time-distance diagram, shown in Fig. 2.10, has therefore been drawn for \( t_c = 0 \).

Point \( D_1 \) on the diagram shows the departure of the southbound train \( S_1 \) at presently operated speeds. If the northbound train is waiting at the northern end of Willow Grove siding and proceeds immediately after the southbound train has cleared the switch, it would arrive at Warminster at time \( D_2 \), which is 20 min plus \( \delta \) later than \( D_1 \). This shows that under the given conditions it would not be possible to meet trains at both the Willow Grove siding and Warminster.

If it is assumed that speed limits on grade crossings are increased by 5 mph, average travel speed on the northern end of the line is increased as shown by dashed lines on the diagram, and operation with \( h = 20 \) min and \( t_c = 0 \) becomes feasible. However, since turnback with no terminal time cannot be operated, operation must be with \( t_c = h = 20 \) min, so that trains meet at Warminster. To achieve this, an additional platform would have to be constructed so that trains can leave from either one of the two tracks.

Increase of maximum speed to 50 mph would not result in sufficient time savings on the Willow Grove - Warminster section to make 20 minute headway possible; however, this speed increase combined with speed increase in grade crossings would increase reliability of operation with \( h = 20 \) min.

In conclusion, 20 - min headways are presently not feasible. To achieve them, speed on grade crossings should be increased by at least 5 mph and Warminster station should be upgraded to allow efficient meeting of trains.
Legend:
- Train operation under present conditions
- Train operation with increase in grade crossing speed of 5 mph
  - $D_1$: Departure time of southbound train $S_1$
  - $D'_1$: New departure time of southbound train $S_1$
  - $D_2$: Departure time of second southbound train
  - $\Delta t$: Delay of southbound train due to slow operating speed in CP Grove North-Warminster section

Figure 2.10 Train operation with 20 minute headways
2.3.2 15-Minute Headways

It was shown in Fig. 2.5 that adjacent meeting points should be separated by distances which require travel time to be equal to $h/2$. For operation of $h = 15 \text{ min}$ on the Warminster Branch, shown in Fig. 2.11, Hatboro siding would have to be used; however, since the distance between Willow Grove and Hatboro sidings is rather short, this operation would involve waiting of one train in that siding for 270 $s$ as the diagram in Fig. 2.11 shows.

Train operation plotted by solid lines in the diagram assumes the present conditions. Operation for the case where double tracks have been extended at Roslyn and Willow Grove is shown by dashed lines. As can be seen by the diagram, these extensions of double track result in travel time savings to northbound trains and a small increase in available terminal time, since southbound trains can leave Warminster $\Delta t_s$ earlier. Certain waiting at Hatboro remains, but it can be reduced from 4.5 to 3 min approximately.

In conclusion, 15 min headways cannot be presently operated. If Hatboro siding is upgraded for regular use, operation with 15 min headway becomes possible but not very reliable and it involves substantial waiting and short terminal times. With the extensions of double track at Roslyn and Willow Grove, this operation becomes more reliable, although not ideal due to the delay at Hatboro and the short terminal time.

2.4 EVALUATION AND RECOMMENDATIONS

A number of possible improvements to train operations on the Warminster Line have been analyzed in this project. While all of them would be beneficial, the present difficult funding situation makes it impossible to clearly separate the improvements that are recommended for immediate implementation.
Legend:

- Train operation under present conditions
- Train operation with proposed improvements

$\Delta t_s$: Change in earliest moment for scheduling of inbound train

Figure 2.11 Train operation with 15 minute headways
To facilitate the selection of improvements which will be made on the basis of financial capabilities, effectiveness of individual improvements has been evaluated using three categories: most important – A; important – B; desirable – C.

Table 2.2 lists all major analyzed improvements, including the reduction of station standing times through faster activities of the crew - a very obvious "low cost" improvement. Evaluations are made with respect to the three major objectives for increase of present quality of service and for the importance of each improvement in achieving headways of 15 or 20 minutes.

Evaluation of each improvement given in the table is self-explanatory, but it is pointed out that it has been found that the most important single improvement is the extension of the siding past Willow Grove station, since that improvement would have a very positive impact on all considered objectives.
Table 2.2  Summary review of possible improvements classified by purpose

<table>
<thead>
<tr>
<th></th>
<th>h=30min</th>
<th>Increase in speed</th>
<th>Increase in flexibility of operation</th>
<th>Ability to recover delays</th>
<th>h=20min</th>
<th>h=15min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase V_max to 50 mph</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>A</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Increase speed on crossings by 5 mph</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Station standing time reduction</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Extension Willow Grove siding</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Extension double track at Roslyn</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Upgrade of Hatboro siding</td>
<td>C</td>
<td>A</td>
<td>A</td>
<td>C</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Upgrade of Warminster terminal</td>
<td>B</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Additional signal block</td>
<td>B</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>B</td>
<td></td>
</tr>
</tbody>
</table>

A - Most important  
B - Important  
C - Desirable
PROJECT 3

THE AIRPORT LINE

This project analyzes possible improvements of the Airport Line operations and economics. A variety of possible measures, including revised schedules, extension or shortening of the Line are considered.

3.1 PRESENT OPERATION

The Airport Line presently operates from the Philadelphia International Airport to Center City and then continues to North Broad Street Station, where it officially terminates. However, since there are no adequate tracks for turning trains back and allowing layover time at North Broad Street Station, all trains continue to Newtown Junction, where they turn back on a siding (a few trains turn back at Roberts yard).

Since the vast majority of passengers travel between the Airport and Center City stations, this 10-mile section is actually the useful part of the line; travel of trains to North Broad and later Newtown Junction, amounting to about 6 miles, is thus unproductive, performed only to turn trains back.

3.1.1 Schedule

The line is presently operated by single-car trains running at 30-minute headways from approximately 6:00 A.M. to midnight. As the time-distance diagram in Figure 3.1 shows, travel time from the Airport to Newtown Junction amounts to 43 minutes, while terminal time at each end of the line amount to 17-18 minutes (variations of 1-2 minutes exists between the two directions and two terminals). The cycle time of the line is 120 min; four trains are used.
Figure 3.1 Time-distance diagram of a train running on the Airport Line

Source: SEPTA Airport line timetable
Effective October 27, 1986.
In order to ensure very high reliability of operation on the line, a reserve train is placed at the Airport terminal and another at Roberts yard. The purpose of these trains is to be "inserted" in the schedule should a delay occur. Consequently, the total number of trains on the line is six.

This policy of ensuring reliable service has achieved its goal: reliability on the Airport Line is higher than on any other line and amounts usually to 96-99 percent.\(^2\)

3.1.2 Operating Characteristics and Limitations

By its character, the Airport Line is somewhat different from other regional rail lines because of several features. First, it carries a large percentage of air travellers who use the line once or a few times per year, while on other lines most riders are daily commuters. Second, to provide adequate service for air travellers, the line has relatively short headways (30 min) in relation to its ridership. For a ridership of some 2000 passengers per day this frequency would otherwise be difficult to justify. Third, because of the importance of reliability for air travellers and for its acceptance by passengers, high reliability is even more important than on other regional rail lines; for that purpose, two extra trains are kept in reserve. This requirement, combined with the problem of very long deadheading travel to Newtown Junction, results in extremely low utilization factor of the rolling stock: when the actual time of travel between the Airport and Market East station by the four running trains is divided by the total time spent in service by all six trains, one obtains a utilization factor of only 0.32.

Naturally, this character of the line, requiring relatively short headways and short trains, make the line quite different from other lines and therefore

---

\(^2\) Subsequent to the completion of technical work on this project, SEPTA has eliminated the two reserve trains because recent experience has shown that adequate service reliability could be provided without them.
difficult to pair with any other line without creating a very high number of empty car-miles and even lower utilization of the rolling stock.

Finally, the line has a short section of single track operation approximately halfway between 30th Street Station and the Airport. This single track is short and travel time on it amounts to only about 90 seconds, but with additional time intervals required for signal block clearance this single track imposes certain limitations in making schedule for this line.

A diagram of travel time versus real time ("time-time diagram"), which is convenient for showing characteristics of schedule without complexities of different speeds along different sections of the line, is given in Figure 3.2. The approximately location of the single track section is shown at about 10 min travel time from the Airport terminal point (some variations in this time exist depending on the assumed travel speed on the line and operation of its signals). The two reserve trains are shown as horizontal lines at each terminal.

Fig. 3.3 shows work schedules of engineers and conductors on the Airport Line. As the diagram shows, at most times six, and at some overlapping times seven crews are on duty on the line.

3.1.3 Conclusions and Evaluation

The Airport Line has in its rather short history of about one year obtained a very good reputation as a fast, reliable and very convenient connector between Center City and the Airport. In addition to serving the three major Center City stations, the line also connects with trains from 12 other radial directions throughout the Philadelphia region, as well as with a number of major transit lines in the city.

Present problems with the line and its limitations can be summarized into several items. First, its operation is extremely expensive because of the
Figure 3.2 Travel time-time diagram of the present schedule of Airport-Jenkintown Junction line
limitations of track layout and the need to keep two extra trains as reserves. Second, the line serves directly only Center City stations; the desirable connection of the Reading trunk line with the Airport, which is a distinct possibility, has not yet been materialized. And third, the line passes through the Eastwick area with substantial population and potential for additional ridership without serving it because of the absence of stations. The present study focuses on possible improvements of the first two of these limitations.

3.2 DEVELOPMENT AND ANALYSIS OF POSSIBLE IMPROVEMENTS

A large number possible improvements of the Airport Line economics and its service have been developed and analyzed. These improvements can be divided into two categories:

- Improvements which would reduce costs of the existing line operation; and

- Improvements which would extend the line and thus increase direct services to the Airport, resulting in an increased number of passengers and, consequently, revenue.

The description of various improvements which follows covers first the improvements aimed at decreasing costs and then improvements through line extension. The division into these two categories is not, however, very exact, since some of the improvements involved both line extension and cost reduction; actually, one concept of more economical scheduling ("floating reserve train") is valid as an operational alternative for any one of the considered line extensions.

3.2.1 Increased Efficiency

As was pointed out in section 3.1, the extremely low utilization factor
for the Airport Line fleet and crews is caused mostly by two factors: first, the requirement that one train "sits" in reserve at each end of the line; and second, the remoteness of the turnback facility at the north end of the line. The first improvement which follows here deals with the first problem (excessive idle times for trains and crews), and the subsequent two items deal with the second (reduction of deadheading).

3.2.1.1 "Floating Reserve Train"). The present system for providing a reserve train for every train run consists of placing a "sitting train" at each end of the line. This results in a total terminal time of 35 minutes out of the cycle time of 120 minutes for each running train, plus 100 percent of "terminal time" for each one of the two "sitting trains".

An alternative to this is to extend cycle time of all trains to 150 minutes and thus obtain terminal times of 32 and 33 minutes at the two terminals. Actually, since there are several minutes of "reserve time" in the schedule at present, reduction of these reserves by 2–3 minutes per direction could extend terminal times even to 34–35 minutes at each terminal.

The purpose of extending terminal times to over 30 minutes is to have "overlapping" terminal times of subsequent trains, so that at any one time there is at least one train at each terminal, and for the short "overlapping time" of 4–5 min there would be two trains standing. This arrangement would thus result in availability of one train as a reserve at any one time, but that would be each one of the trains in sequence rather than two trains "sitting" all the time.

The impact of this schedule change on the cost of service is obvious from the following computations. If we designate the number of trains on the line as N, cycle time as T, headways as h and number of trains in reserve as R, then
we have the following situation:

**Present schedule:**

\[
N = \frac{T}{h} + R = \frac{120}{30} + 2 = 6.
\]

**"Floating Reserve Train" schedule:**

\[
N = \frac{150}{30} = 5 \text{ trains.}
\]

Obviously one train is saved, which in the course of the day results in saving of approximately 2.5 train crews. In comparison with the present service this would reduce the running costs of trains on the line by 16.7 percent.

To plan modifications of the Airport Line schedule, it was necessary to establish the limitations imposed by the single track section. An analysis of the terminal time intervals which are possible without trains meeting on the single track section is shown in Fig. 3.4. It is assumed that two subsequent trains depart from the Airport terminal station at times \(D_1\) and \(D_2\). Travel of train 1 is plotted through the single track section and the time interval during which this train occupies it (including 1 min for signal clearances at each end) represents the "blocked time" for passage of trains toward the Airport.

The diagram shows paths of the latest train (3) which can go through the single track section prior to the passage of train 1, and the earliest train (4) which can pass after it. The arrivals of these two trains at the Airport, shown as points \(A_3\) and \(A_4\), determine the "blocked range", i.e. the range of terminal times which should not be used to avoid delays on the single track: they are between 6 and 11 min.

It should be noted that this "blocked range" repeats itself in increments of line headway, so that in this case the range of 36-41 min, starting at the
Figure 3.4 Airport terminal time limitation due to single track section.
arrival time $A_5$, is also blocked.

The time distance diagrams illustrating the differences between the present "sitting reserve train" schedule and the proposed "floating reserve train" schedule are shown for the existing Airport Line in Fig. 3.5. Both schedules avoid terminal times at the Airport between 6-11 and 36-41 min.

There is presently a problem at the Newtown Junction turnback facility: it consists of a single track so that if one trains arrives while the preceding train is still at the terminal, they could not bypass each other. There are several possible solutions to this problem:

- Electrify a short section of the New York Short Line track 1; so that the arriving train can back into that track to let the preceding one clear the siding. Then the incoming train would enter the siding.

- Several of the recommended changes in track layout at Newtown Junction would also solve this problem; (see section 1.1).

- Every other train would turn back in Roberts yard, so that this maneuver would be required only once an hour rather than once every 30 min.

- Extend the terminal time at the Airport to about 36 min and reduce it at Newtown Junction to about 32 min, so that with short waiting on the incoming track the problem of bypassing would be solved.

- Change the location of the northern turnback from Newtown Junction to a location which permits this maneuver more efficiently; this is one of the considerations in several improvements discussed below.

3.2.1.2 Turnback on Norristown Line. It is logical to examine carefully all possibilities which could reduce the deadheading of the Airport trains. Turning trains back on the four tracks of the trunk line, such as at Diamond or 16th Street, is impossible without involving an unacceptable disruption of
a. "Sitting reserve train" (present schedule).

b. "Floating reserve train" (proposed).

Figure 3.5 The "sitting" vs. "floating reserve train" concepts for the Airport Line.
through traffic. Therefore, the branching from the trunk line has been examined first. The diverging of the Norristown Line is that location and it has a crossover between the two tracks in the vicinity of the branching point.

Turning trains back at the beginning of the Norristown branch line would shorten deadheading of trains so significantly that it would reduce operations by 222 car-miles per day. Since the total of operating times for both directions would be decreased from 85 to 71 min, it would be possible to use a 90 min cycle and have a total of 19 min available for the two terminal times. This would result in the required fleet of only three operating trains, so that even with the present schedule including two "sitting reserve trains", the number of required trains would be decreased to 5.

Evaluation of this possibility has had negative results, however. The main problem is that there are no sidings that could be used for terminal layover by trains; being on the main track of the Norristown branch, the Airport trains would then impede the regular operation of this line. Moreover, the switches on this section are manual. Thus, this improvement of shortening the line to the Norristown branch would only be feasible with construction of the siding and inclusion of switches into the interlocking with the E&W-Reading trunk line.

3.2.1.3 Turnback at Suburban Station. Turning Airport trains back at the Suburban Station would involve even greater savings: travel time per direction would be reduced from 43 min at present to 23 min on the shortened line. The number of trains would be reduced to 4 if the "floating reserve train" concept is used.

However impressive these savings are, the problem of operating trains only
into Suburban Station is that Market East Station would not be served directly and, in addition, a sizable number of passengers transferring to most Ex-Reading lines (except those changing to R2 and R3 at 30th Street Station on the same platform) would have to change platforms at Suburban Station. These shortcomings were the reason that the initial proposals, prior to the opening of the Tunnel, to terminate the Airport Line in Suburban Station were rejected.

Consequently, operating the Airport Line only into Suburban Station should not be considered as a valid alternative except in the case of a drastic financial emergency in which some reduction of travel convenience on the regional rail system could not be avoided.

3.2.2 Increased Ridership Through Line Extension

Transferring from any regional rail line to the Airport Line is presently already rather easy. In most cases it involves transfer on the same platform, while in a few cases passengers have to negotiate stairs to change the platform and get to the Airport train. Yet, passengers do prefer a ride without transferring, particularly if they carry luggage, which is often the case with the Airport Line. In addition, there is a certain image created by providing service from various station "direct to Airport". It is therefore logical to consider the possibility of extending the Airport Line through its pairing with another branch line, or at least extending the Airport line along the main Ex-Reading trunk line to Jenkintown. All these possibilities have been analyzed and they are reported here.

3.2.2.1 Pairing with an Ex-Reading Line. The pairing of former Pennsylvania and Reading Lines was planned on the basis of analysis of their operating elements, number of potential trips on the paired lines, various aspects of the character of different urban areas, and a number of other
factors. In the current review of the Airport Line all these elements were again considered, but particular attention has been given to the aspects of operations and costs. The current and future position of the regional rail system requires particularly careful attention to be given to rolling stock requirements (fleet size is limited for the foreseeable future), and operating costs which are very serious problems.

To obtain an overview of the basic operating characteristics of all Ex-Reading lines as compared to the Airport Line, the diagram presented in Fig. 3.6 was developed. This diagram presents the total number of trains operated per day on individual Ex-Reading lines (above the horizontal line) and the corresponding number for the Airport Line (plotted below the horizontal line). The second bar, immediately next to it, represents the number of car trips per day for the respective two lines. These two numbers, train trips and car trips, are given for southbound direction and the upper part of the diagram and for northbound direction in the lower part of the diagram.

The first (left) bar on this diagram in each case reflects the requirements for trains crews; the second (right) reflects the total car-miles operated and to some extent the size of the crew required. The more similar is the size of these bars, the more "compatible" the two lines would be, i.e., their schedules could be easily connected without requiring a large number of additional train runs. The same is with the right hand bars: the more similar their sizes are, the easier it would be to connect the two lines without causing a large number of additional car-miles. In other words, the unevenness of the sizes of the bars in each case reflects the additional costs (train run, car-miles runs, crew hours paid, etc.) which would be created by pairing the two respective lines.
Careful attention was given to possible pairing of the Airport and West Trenton Lines, since this was proposed in the initial plan. To examine this possibility in greater detail, another diagram was developed and presented in Fig. 3.7a. The figure shows not only total numbers of train runs and car-miles operated, but also exact timings of all runs. The figure shows that there is little compatibility between the Airport and West Trenton Lines as far as their schedules are concerned. If the two were merged, the new line would have to operate with the (higher) frequency of the Airport Line and with (longer) train consists of the West Trenton Line. The result would be considerable increase in frequency and size of trains, involving a considerable increase of operating costs.

Taking into account also the danger of decreasing the reliability of the Airport Line because of the delays caused by construction on the West Trenton Line, it is concluded that the pairing of the Airport with West Trenton Line would not be advantageous either from the economic or from the reliability point of view. This potential improvement was not considered any further.

The diagram in Fig. 3.6 shows that the greatest compatibility with respect to the required number of train and car-runs is found between Airport and Norristown Lines. To examine further this possibility, the schedules of the two lines have been plotted in Fig. 3.7b. This diagram shows that the Airport Line has shorter headways and shorter trains than the Norristown Line. Their pairing would necessitate increased frequency on the Norristown Line, but because of its light passenger volume, its trains could be shortened to single cars, so that the two schedules could very easily be "matched" without causing many additional car-miles.

Computations have been made for operation of the Airport–Norristown Line
with 30 min headways throughout the day and running of a "truncated" Ivy Ridge Line from Ivy Ridge into Suburban Station (due to its very low ridership this change would not be highly objectionable). The computations show that these two lines, in comparison with the present Airport-Newtown Junction and Norristown-Ivy Ridge Lines, would have a slight increase in train-miles, but there would be a decrease in car-miles and in the number of trains required for the line. This finding may appear illogical, but it is caused by the fact that the line between Airport and Norristown would be longer (28 miles one way), but trains would be shorter (higher frequency would compensate for fewer cars per train) and fleet utilization would be greater because of shorter terminal times. Incidentally, in this case, like on the present line, there would be additional benefits by using the "floating reserve train" instead of the "sitting reserve train" concept.

Briefly summarized, the advantages of this alternative improvement would be:

- Decrease in operating costs;
- Improved level of service on the Norristown Line; and
- Direct Airport access for the Norristown and surrounding Montgomery and Chester county areas.

There are, several serious shortcomings of this pairing. The main problem is that the Norristown Line serves an area which has a small number of residents, a lot of vacant land, and a general character which is not compatible with the Airport Line. Moreover, the line is in a physically poor shape, with the low geometric standards and poor track quality. The terminal in Norristown is not in a very attractive area for the airport passengers, except that it is in the vicinity of the major suburban growing area in Montgomery and Chester
counties, the "202 Corridor", which has a very substantial potential airport ridership. Although Paoli Line offers a far higher physical quality of service, the line from Norristown would offer a direct, no-transfer ride which, although longer in running time would offer passengers a shorter travel time because of no time loss for transferring.

A variation of this line modification would be to run trains alternately to Norristown and to Wissahickon Station, where they would decrease train and car-miles appreciably and thus reduce operating costs at the expense of offering Norristown only hourly service. Since travel time between Wissahickon and Norristown is 28 min, it would be easy to make an efficient schedule for the line operating with 30 min headways. The details of crossover control, location of reserve train and others would have to be worked out.

3.2.2.2 Extension to Jenkintown. Presently the Airport Line trains run over most of the ex-Reading trunk line without offering any useful service. Extension of the line from Newtown Junction to Jenkintown would introduce a very useful service to both Center City and the Airport.

Since the maximum load section of the ex-Reading trunk lines is south of Jenkintown, introduction of the Airport Line train with two cars per hour would reduce the capacity requirements on the other lines by the corresponding amount. Computations have shown that due to the fact that in the peak hours, most trains make only a single peak direction trip, the introduction of the Airport Line would reduce the number of required cars on other lines by 6.

Travel time between Newtown Junction and Jenkintown amounts to 7 min per direction, so that every cycle would involve 14 additional minutes of travel. Since the total of terminal times at present amounts to 35 min, shortening those times by 14 min would still leave 21 min for new terminal times. By
reducing some of the time reserve in the present schedule, a few minutes could be added to this time. This would allow a 6 min terminal time at the Airport (to remain outside the range imposed by the single track section), and the remainder of 15 min (plus reduced schedule reserves) for the Jenkintown terminal times.

To retain the present degree of service reliability, one train would have to be held in reserve at each terminal. Thus the total number of trains for the line would remain the same as presently: 6.

Alternatively, the schedule can be based on the "floating reserve train" concept as shown in Fig. 3.8. Again only 6 trains are required, but they would have more "comfortable" terminal times. This schedule involves "overlap" of terminal times at Jenkintown by 6 min. Presently this maneuver can be handled by use of either Northbound Siding or Cheltenham Siding, causing some blockages of through trains (to West Trenton or Southbound trains for Cheltenham Siding) of up to 6 min.

With the improved track layout at Jenkintown, discussed in section 1.2, this maneuver would be simplified.

If the Airport Line is extended to Jenkintown only during peak periods, this would result in a reduction of car-miles by approximately 950 miles per day. If all Airport Line trains would go to Jenkintown all day, the total savings of the number of car-miles would be by about 730. The difference is caused by the fact that in off-peak periods extending the Airport Line would not result in car-mile reduction on other lines because capacity is not critical. A summary of schedule and operating statistics for the Airport Line extension to Jenkintown is given in Table 3.1.

The present severe limitations due to the track layout at Jenkintown
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<tr>
<th></th>
<th>Inbound</th>
<th></th>
<th></th>
<th>Total</th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) 1985 Daily passenger demand between JKT and WAJ(a)</td>
<td>- NA -</td>
<td>1297</td>
<td>- NA -</td>
<td>1392</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2689</td>
</tr>
<tr>
<td>2) Adjusted passenger demand ((1) x 1.1)(b)</td>
<td>- NA -</td>
<td>1430</td>
<td>- NA -</td>
<td>1540</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2970</td>
</tr>
<tr>
<td>3) Peak period demand (AM: 0.70 x (1) PM: 0.56 x (2))(c)</td>
<td>- NA -</td>
<td>1001</td>
<td>- NA -</td>
<td>862</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1863</td>
</tr>
<tr>
<td>4) No. of cars required between JKT and WAJ ((4) ÷ 111)</td>
<td>- NA -</td>
<td>9.0</td>
<td>- NA -</td>
<td>7.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16.8</td>
</tr>
<tr>
<td>5) Scheduled no. of cars during peak period (January 1986)</td>
<td>25 22 24</td>
<td>71</td>
<td>21 18 19</td>
<td>58</td>
<td>136</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6) Reduction of no. of cars due to Airport Line extension</td>
<td>2 2 2</td>
<td>6</td>
<td>2 1 1</td>
<td>4</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7) Car-miles reduction for the present lines during peak period</td>
<td>205 151 268</td>
<td>624</td>
<td>205 75 134</td>
<td>414</td>
<td>1038</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8) Additional car-miles to Airport Line</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>49</td>
<td></td>
<td></td>
<td>33</td>
<td>82</td>
</tr>
<tr>
<td>- peak period only operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>152</td>
<td></td>
<td></td>
<td>152</td>
<td>304</td>
</tr>
<tr>
<td>- all-day operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9) Net car-miles saving per day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>575</td>
<td></td>
<td></td>
<td>381</td>
<td>956</td>
</tr>
<tr>
<td>- peak period only operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>472</td>
<td></td>
<td></td>
<td>262</td>
<td>734</td>
</tr>
</tbody>
</table>

Notes: (a) Source: 1985 Fall weekday ridership by station, SEPTA Operations Department Statistics.
(b) Assumed 10% increase of the 1985 volume.
(c) Factors are based on the numbers used for the 1984 SEPTA General Operations Plan report
AM peak: 6:30 - 9:30AM, PM peak 4:00 - 6:00PM.
create problems for termination and turnback of the Airport trains. After unloading passengers on the northbound platform, the train could not simply cross over and enter the southbound station platform. There are several solutions to this problem; the most efficient ones are listed here.

- **Southbound departure from northbound platform.** Airport trains would come to the northbound platform, unload passengers and then continue to travel into the northbound siding. There they would perform a brake test and have layover. Passengers would be informed that the Airport train will leave from the northbound platform. The train would come to the platform, board passengers and continue southbound using the existing crossover.

  This operation is presently entirely feasible without any reconstruction and the only objection to it would be that every half hour a southbound train to Center City and Airport would depart from the "wrong" platform. This inconvenience to passengers can be solved by appropriate announcement to the passengers.

- **Turnback Utilizing Chelten Hill Siding.** After unloading passengers, Airport trains would back up into Chelten Hill Siding, perform a brake test and have layover there, and then back into the southbound platform track. A detailed analysis of this maneuver is given in section 1 of this report.

  This operation would be preferable for passengers, but it would involve extremely complex operations and require so many maneuvers, that extended terminal time might necessitate an increase in the number of trains. Overall, this arrangement is therefore considered unacceptable.

- **Construction of additional track crossovers.** Several of the proposed alternative track modifications at Jenkintown described in section 1 would make turning Airport trains back at Jenkintown quite simple. Any one of the several
track modification alternatives represents a better solution than the preceding
two, except that required construction would involve certain cost and time for
implementation.

3.3 EVALUATION AND SELECTION OF ALTERNATIVE IMPROVEMENTS

3.3.1 Comparative Evaluation

Based on the analysis described in the preceding sections, all considered
alternative improvements have been analyzed with respect to their various
quantitative indicators and qualitative characteristics. Four alternative
improvements have been selected as feasible ones and worth of serious consider-
ation:

1. Introduction of the "floating reserve trains" on the existing
   line.

2. Extension of the Airport Line to Jenkintown with two subalterna-
   tives:

   a. Departure from northbound platform (implementable immediately);

   b. Construction of a crossover for turnback maneuver;

   For both turnback alternatives there are two possibilities: peak
   hours and all day operations.

3. Pairing with Norristown Line, with a subalternative of cutting
   alternate trains back at Wissahickon.

4. Shortening the Airport Line to Suburban Station.

All significant schedule elements of these alternative improvements are
presented in Table 3.2. Since they have been discussed in the descriptions of
these alternatives, this table is self-explanatory.

A summary of major evaluation factors for the analyzed alternatives is
## Table 3.2 Schedule elements of alternative improvements

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Train movement direction</td>
<td>NB</td>
<td>SB</td>
<td>NB</td>
<td>SB</td>
<td>NB</td>
<td>SB</td>
<td>NB</td>
<td>SB</td>
</tr>
<tr>
<td>Operating time $T_o = T'_o + T''_o$</td>
<td>43</td>
<td>42</td>
<td>41</td>
<td>41</td>
<td>50</td>
<td>49</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Terminal time $T_t = T'_t + T''_t$</td>
<td>17</td>
<td>18</td>
<td>34</td>
<td>34</td>
<td>15</td>
<td>6</td>
<td>36</td>
<td>48</td>
</tr>
<tr>
<td>Cycle time $T$</td>
<td>120</td>
<td>150</td>
<td>120</td>
<td>180</td>
<td>180</td>
<td>210</td>
<td>180</td>
<td>210</td>
</tr>
<tr>
<td>Useful run time $T_r = T'_r + T''_r$</td>
<td>30</td>
<td>27</td>
<td>28</td>
<td>26</td>
<td>50</td>
<td>49</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td>Headway $h$</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Fleet size $N$</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Reserves $R$</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Useful running time ratio $\alpha_2 = \frac{N T_r}{(N+R)T}$</td>
<td>0.32</td>
<td>0.45</td>
<td>0.55</td>
<td>0.53</td>
<td>0.60</td>
<td>0.68</td>
<td>0.60</td>
<td>0.68</td>
</tr>
<tr>
<td>Utilization ratio $\alpha_1 = \frac{N T_o}{(N+R)T}$</td>
<td>0.47</td>
<td>0.54</td>
<td>0.55</td>
<td>0.53</td>
<td>0.60</td>
<td>0.68</td>
<td>0.60</td>
<td>0.68</td>
</tr>
</tbody>
</table>
presented in Table 3.3. This summary also has the present operation as the basis for comparison for the alternatives. Major assumptions and explanations for the table are listed under it.

3.3.2 Recommendations

As a conclusion of this extensive study of Airport Line improvement alternatives, the following recommendations are made:

1. "Floating reserve train" concept is recommended for immediate introduction. It only requires a refinement of terminal maneuver at the Newtown Junction and derivation of required terminal times at each end of the line. If successfully introduced, this modification will result in a saving of one car and approximately 2.5 train crews.

2. Extend Airport Line to Jenkintown with departures from the northbound platform. This modification requires very limited preparations and it should also utilize the same scheduling concept as recommended under 1.

3. Construct one of alternative track modifications at Jenkintown which will facilitate turnback movements.

4. Pairing of Airport Line with Norristown Line should be carefully considered as a potential improvement and a possibility of introducing such a link on an experimental basis should be explored.

5. Shortening Airport Line to Suburban Station should only be considered as an emergency measure, and an alternative superior to the closure of the line, should an extraordinary crisis occur.

6. The Airport Line should be given designation R1. This designation would be valid regardless where the northern terminal of
### Table 3.3 Overall evaluation of alternative improvements

<table>
<thead>
<tr>
<th>Alternative line</th>
<th>APT - NTJ &quot;Sitting&quot; All-day</th>
<th>APT - NTJ &quot;Float&quot; All-day</th>
<th>APT - JKT &quot;Float&quot; Peak only</th>
<th>APT - NTE &quot;Float&quot; All-day</th>
<th>APT - SUB &quot;Float&quot; All-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserve type</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line length (miles)</td>
<td>15.8</td>
<td>15.8</td>
<td>20.7</td>
<td>20.7</td>
<td>28.0(4)</td>
</tr>
<tr>
<td>Cycle time (min)</td>
<td>120</td>
<td>150</td>
<td>150/180(1)</td>
<td>180</td>
<td>210</td>
</tr>
<tr>
<td>No. of cars (trains)</td>
<td>4 + 2</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Daily car-miles</td>
<td>1169</td>
<td>1169</td>
<td>1532</td>
<td>1267</td>
<td>2072</td>
</tr>
<tr>
<td>Difference from present operations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Car requirements</td>
<td>0</td>
<td>-1</td>
<td>-6(2)</td>
<td>-6(2)</td>
<td>-3(5)</td>
</tr>
<tr>
<td>- Train requirements</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0(3)</td>
<td>-2</td>
</tr>
<tr>
<td>- Daily car-miles</td>
<td>0</td>
<td>0</td>
<td>-956(3)</td>
<td>-734(3)</td>
<td>-63</td>
</tr>
<tr>
<td>- Daily Train-miles</td>
<td>0</td>
<td>0</td>
<td>+82(4)</td>
<td>+304(4)</td>
<td>+204(6)</td>
</tr>
</tbody>
</table>

(1) 150 min. during off-peak (APT-NTJ); 180 min. during peak period (APT-JKT).
(2) Car reduction due to train size reduction of R1, R2 and R5 trains during peak period.
(3) Car-miles reduction due to car trip reduction of R1, R2 and R5 trains during peak period.
(4) Train-miles increase due to longer line length for the Airport Line.
(5) Car and car-miles reduction due to the eliminations of the present NTE-NBS section operation and NBS-NTJ section operation.
(6) Additional train-miles are incurred due to frequent operation on Norristown Line.
the line is, at North Broad, Jenkintown or Norristown. If R1 goes to Norristown, the truncated Ivy Ridge Line should remain R6, keeping the logical clockwise sequence of line numbers. West Trenton Line should remain paired with Elwyn and, consequently, given designation R3.