A Plan for
SEPTA's
Regional Metrorail System

Report to
Southeastern Pennsylvania Transportation Authority

By
University of Pennsylvania
University of Delaware

Philadelphia
April 1993
A Plan for

SEPTA’s
Regional Metrorail System

Report for the
Southeastern Pennsylvania Transportation Authority

SEPTA
Final Report

Prepared by:

Prof. Vukan R. Vuchic, Ph.D.
Principal Investigator
Eric C. Bruun, Ph.D.
Nikola Krstanoski
Yong Eun Shin
Research Fellows
Department of Systems
University of Pennsylvania

Prof. Shinya Kikuchi, Ph.D.
Co-principal Investigator
Partha Chakroborty
Janki Parameswaran
Natasa Vukadinovic
Research Fellows
Department of Civil Engineering
University of Delaware

Philadelphia
April 1993

ACKNOWLEDGEMENT

The funds for this research were provided by a contract with SEPTA; in addition, the University of Pennsylvania team was partially supported by a grant from the U.S. Department of Transportation through the Regional University Transportation Centers Program and the Mid-Atlantic Universities Transportation Center. This support is gratefully acknowledged, but implies no endorsement of the results.
Executive Summary

A PLAN FOR SEPTA'S REGIONAL METRORAIL SYSTEM

Recent trends on SEPTA's Regional Rail (RGR) System have been very upsetting. Direct and indirect favoring of the private automobile use, insufficient and unpredictable transit funding, increasing operating deficit combined with limitations imposed by institutional problems and some obsolete operating practices have created a downward spiral of service reductions and ridership losses.

The Regional Rail System has a very extensive network: its lines and stations serve large areas in Philadelphia and its four surrounding counties, entering even two neighboring states, Delaware and New Jersey. Yet, the entire system carries now less than 90,000 weekday riders, down from 130,000 riders some 15 years ago, even before the Center City Tunnel was opened. High operating cost of trains with oversize crews lead to long headways, which put RGR service in a major disadvantage in its competition with the private automobile. Track sharing with Amtrak and often excessive requirements of FRA operating rules create delays and reduce service reliability. Virtual absence of marketing limits the System's ability to attract new riders.

Consequently, the RGR is presently an underfinanced, underperforming and, therefore, greatly underutilized Philadelphia Region's resource. This condition has created an urgent need for a careful evaluation and planning of actions that will stop and reverse the downward trend.

This report presents a plan for an investment, physical and operational upgrading of the RGR System. The intent of this plan should be creation of a modern Regional Metrorail System, more similar to such electrified regional rapid transit systems as the Washington Metrorail, Atlanta's MARTA and San Francisco's
BART than to diesel-powered commuter rail systems, such as the Chicago METRA or the new Los Angeles Metrolink.

Implementation of the recommended plan will result in better service, increased ridership, greater operating efficiency and improved public image. The modernized Regional Metrorail System will have a potential to increase the Region's mobility in an economically efficient and environmentally friendly manner.

* * *

Recommended Goals for SEPTA:

UPGRADE THE REGIONAL RAIL SYSTEM INTO A MODERN REGIONAL METRORAIL SYSTEM WHICH WILL HAVE A HIGHER ECONOMIC EFFICIENCY, STRONGER PASSENGER ATTRACTION AND PLAY A GREATER ROLE IN THE REGION'S ECONOMIC AND SOCIAL LIFE. THE POTENTIAL OF THE REGIONAL RAIL SYSTEM TO INTEGRATE THE CITY AND ITS SUBURBS, TO SHAPE LAND USE PATTERNS AND TO IMPROVE THE REGION'S ENVIRONMENT AND QUALITY OF LIFE SHOULD BE FULLY UTILIZED.

INCREASE WEEKDAY RIDERSHIP TO 200,000 TRIPS.

Recommended Policy for SEPTA:

UNDERTAKE A COORDINATED SET OF ACTIONS TO UPGRADE THE REGIONAL RAIL SYSTEM INTO A MODERN REGIONAL METRORAIL SYSTEM. IMPLEMENT THIS POLICY BY UNDERTAKING A SERIES OF ACTIONS CLASSIFIED AS: ORGANIZATIONAL/PROCEDURAL, INFRASTRUCTURE, ROLLING STOCK, OPERATIONS AND SERVICE, AND IMPLEMENTATION PROCEDURES.

Organizational/Procedural

1. Create a Regional Metrorail Planning Committee: a group of Departments' representatives which will be responsible for development of RGR goals, plans and
standards, and for coordination of different departments in the implementation of this Plan.

2. The Committee should consist of members from several Departments, such as Planning, Regional Rail Division, Facilities Engineering and Construction, Government Relations and Finance.

3. Specific goals should include the following ones:
   - Secure the investment funds necessary for upgrading the RGR into a modern Regional Metrorail system;
   - Improve RGR operating efficiency and integrate further its network and services with other transit modes;
   - Improve service quantity, quality and system image;
   - Focus on efforts aimed at achieving major increases in RGR ridership.

Infrastructure Changes

4. Solve the problem of car detection so that one-car trains can be operated;

5. Construct high-level platforms at all stations based on the design standards classified by their domains into:
   - Network standards;
   - Standards by line or by line segment;

   The standards should include platform lengths, widths, ramps, track crossings, etc.

   Estimated cost: $104M.

6. Review current design and construction standards and practices with the goal of cost reduction or increased cost effectiveness.

7. As a major problem in designing and financing feasibility, the ADA requirements should be analyzed to devise a rational solution; without such a solution the ADA requirements may render this Plan, or any other significant
improvements of the RGR System, financially and/or physically infeasible.

**Rolling Stock**

8. Design a new vehicle model for base services with the following features:
   - Two double-channel doors at quarter points of car length;
   - Engineer’s compartment with good working conditions and better contact with passengers (no vestibules);
   - Internal layout allowing easy boarding for passengers and for the handicapped, placement of ticket canceling (or ticket issuing) machines;
   - Improved internal and external aesthetics and image;
   - Weight considerably lower than Silverliner IV’s;
   - Technical innovations for reduced energy and maintenance costs;
   - Ability for the engineer to control doors and operate the public address (PA) system inside and outside the car;
   - Easy coupling/uncoupling;
   - Improved signing/information.

Estimated net cost for a fleet of 68 cars: $133M.

**Operations and Service**


   Estimated cost: $13M

10. Reduce crew sizes to an engineer and a conductor; later, on 1- and 2-car trains, engineer only.

11. Introduce a new policy (maximum) headway of 30 minutes on all lines at all times.

12. Improve system coverage/accessibility through better integration with other
transit modes, additional park-and-ride (P+R), pedestrian, and bicycle facilities.

13. Introduce special and promotional fares for round trips, students, intra-suburban travel, "Wednesday Special", etc.

14. Improve information, particularly for potential passengers.

Implementation Procedure

15. Improve the RGR System's economic efficiency and operational effectiveness through integration of components, cost-cutting measures and rational standards.

16. Introduce integrated upgrading of stations, rolling stock and operations line-by-line. Prepare prioritization of lines and determine the schedule of the implementation procedure.

17. Supplement these improvements by an image-building campaign for the Regional Rail System and SEPTA in general. Consider naming the upgraded system "Philadelphia Regional Metrorail".

18. Announce the plan for the Philadelphia Regional Metrorail with strong publicity to help obtain necessary investment funds and general public and political support.

* * *

Projected Results:

- Investment cost: Approximately $260-300M for the ultimate plan. The upgrading should be implemented in stages, line by line;

- Greatly improved:
  ● Service: frequency, speed, comfort and convenience;
  ● Operating ratio: lower cost per space-mile offered, increased passenger revenue;
  ● System image.

- Operating costs: Reduced by up to $8M per year.
- Significant ridership increase: off-peak 100%, peak 30%. (approximate estimate).

- Creation of a system more similar to the Washington Metro than to conventional Commuter Railroads; the Philadelphia Regional Metrorail would have twice the length of the Washington Metro, while the investments recommended here would amount to less than 5% of the capital costs Washington’s Metro will have required for its construction.

- Numerous "external" positive effects, such as:
  - Increased transit ridership on other modes;
  - Reduced traffic congestion;
  - Decreased air pollution;
  - Increased accessibility of downtown and suburban employment, retail and recreational areas;
  - A significant stimulus for better land use/transit coordination;
  - Greater unity of the City and surrounding counties;
  - Improved image and competitiveness of the Region.

Vukan R. Vuchic, Ph.D.                                      Shinya Kikuchi, Ph.D.
University of Pennsylvania                                       University of Delaware

Philadelphia
April 1993
TABLE OF CONTENTS

Executive summary: A PLAN FOR SEPTA'S REGIONAL METRORAIL SYSTEM i

LIST OF FIGURES 4

LIST OF TABLES 6

1. PROJECT PURPOSE AND SCOPE 1- 1
   1.1 The Need for System Integration, Policy and Standards 1- 2
   1.2 The Scope of the Project 1- 3
   1.3 Contents and Organization of This Report 1- 4

2. PRESENT CONDITIONS AND THEIR EVALUATION 2- 1
   2.1 Passenger Volumes and Characteristics 2- 1
      2.1.1 Station Usage 2- 1
      2.1.2 Passenger Load Profiles 2- 7
   2.2 Physical Condition of Stations 2-10
      2.2.1 Infrastructure 2-10
      2.2.2 Platform Heights 2-11
      2.2.3 Platform Lengths and Widths 2-13
   2.3 Rolling Stock and Its Characteristics 2-14
   2.4 Operational Aspects 2-16
      2.4.1 Schedules: Frequencies and Train Consists 2-16
      2.4.2 Fare Structure, Fare Types and Collection Methods 2-19
      2.4.3 Crew Sizes, Assignments and Duties 2-22
      2.4.4 Regulations and Other External Constraints 2-24
   2.5 Evaluation of Present Conditions 2-28

3. DEFINITION OF SYSTEM GOALS AND OBJECTIVES 3- 1
   3.1 SEPTA and Its Peers 3- 1
   3.2 Regional/Commuter vs. Regional/Metro Systems: a Comparison 3- 5
   3.3 Regional Rail System Goals 3-10

4. INTERRELATIONSHIPS AMONG SYSTEM ELEMENTS 4- 1
   4.1 Current Deficiencies Caused by Lack of System Integration 4- 1
4.2 Interdependence among Infrastructure, Rolling Stock and Operations

5. ANALYSIS OF INFRASTRUCTURE ELEMENTS

5.1 Platform Heights
   5.1.1 Platform Types by Elevation
      5.1.1.1 Low-Level Platforms
      5.1.1.2 Medium-Level Platforms
      5.1.1.3 High-Level Platforms
      5.1.1.4 Present SEPTA’s Station Platform Height
   5.1.2 Differences among the Three Platform Types
      5.1.2.1 Speeds of Passenger Boarding and Alighting
      5.1.2.2 Passenger Comfort and Safety
      5.1.2.3 Door Control and Train Dispatching
      5.1.2.4 Access and Pedestrian Track Crossings
      5.1.2.5 Geometric Feasibility and Constraints
      5.1.2.6 Investment Costs
      5.1.2.7 Operating Costs
   5.1.3 Selection of Platform Heights
      5.1.3.1 Evaluation of Low-Level Platforms
      5.1.3.2 Evaluation of Medium-Level Platforms
      5.1.3.3 Evaluation of High-Level Platforms
   5.1.4 Alternative Strategies for Upgrading of Stations
      5.1.4.1 Continuing Status Quo
      5.1.4.2 Gradual or Quick Upgrading to High-Level Platforms
   5.1.5 Uniformity of Platform Types along a Line

5.2 Platform Lengths and Widths
   5.2.1 Platform Lengths
   5.2.2 Platform Widths

5.3 Other Considerations in Platform Design
   5.3.1 The Types and Role of Design Standards
   5.3.2 Accommodations for the Disabled

6. ROLLING STOCK

6.1 Improvements of Individual Features

6.2 Cost Estimates

6.3 Conclusions

7. OPERATIONAL ELEMENTS

7.1 Fare Collection
   7.1.1 Analysis and Selection of the Fare Collection Method
   7.1.2 Options for Implementation of SSFC
### LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Passenger boardings and alightings by station - inbound directions</td>
<td>2-3</td>
</tr>
<tr>
<td>2.2</td>
<td>Passenger boardings and alightings by station - outbound directions</td>
<td>2-4</td>
</tr>
<tr>
<td>2.3</td>
<td>Passenger load profiles by line - inbound directions</td>
<td>2-8</td>
</tr>
<tr>
<td>2.4</td>
<td>Passenger load profiles by line - outbound directions</td>
<td>2-9</td>
</tr>
<tr>
<td>2.5</td>
<td>Regional Rail car cross section, platform levels and lateral clearances</td>
<td>2-12</td>
</tr>
<tr>
<td>2.6</td>
<td>Plan and profile - SEPTA's single-unit car Silverliner IV</td>
<td>2-15</td>
</tr>
<tr>
<td>2.7</td>
<td>Train departure times, consists, and train crew sizes on the R3 line (Center City to Elwyn)</td>
<td>2-17</td>
</tr>
<tr>
<td>2.8</td>
<td>Train departure times, consists, and train crew sizes on the R3 line (Elwyn to Center City)</td>
<td>2-18</td>
</tr>
<tr>
<td>2.9</td>
<td>Fare level and structure on Regional Rail and City Transit</td>
<td>2-20</td>
</tr>
<tr>
<td>2.10</td>
<td>Classification of types of fare by characteristic</td>
<td>2-21</td>
</tr>
<tr>
<td>2.11</td>
<td>Train crew sizes for different train consists</td>
<td>2-23</td>
</tr>
<tr>
<td>2.12</td>
<td>Relationship between actual work hours and paid hours of passenger attendants - weekdays</td>
<td>2-25</td>
</tr>
<tr>
<td>2.13</td>
<td>Relationship between actual work hours and paid hours of engineers and conductors - weekdays</td>
<td>2-26</td>
</tr>
<tr>
<td>3.1</td>
<td>Network lengths, daily ridership and passenger density on regional rail systems</td>
<td>3-4</td>
</tr>
<tr>
<td>3.2</td>
<td>Network lengths and number of stations of different regional rail systems</td>
<td>3-7</td>
</tr>
<tr>
<td>3.3</td>
<td>Comparison of headways - peak hour and midday operation</td>
<td>3-9</td>
</tr>
<tr>
<td>4.1</td>
<td>Basic interrelationships among possible improvements</td>
<td>4-6</td>
</tr>
<tr>
<td>4.2</td>
<td>Relationship of Regional Rail physical and operating elements</td>
<td>4-7</td>
</tr>
<tr>
<td>5.1</td>
<td>Present and recommended platform heights</td>
<td>5-2</td>
</tr>
<tr>
<td>5.2</td>
<td>Comparison of boarding and alighting rates for low- and high-level platforms</td>
<td>5-8</td>
</tr>
<tr>
<td>Section</td>
<td>Title</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>5.3</td>
<td>Different types of pedestrian track crossings</td>
<td>5-16</td>
</tr>
<tr>
<td>5.4</td>
<td>Derivation of platform length standards</td>
<td>5-27</td>
</tr>
<tr>
<td>5.5</td>
<td>Platform lengths for the Silverliner rolling stock</td>
<td>5-29</td>
</tr>
<tr>
<td>5.6</td>
<td>Platform lengths for the new rolling stock</td>
<td>5-30</td>
</tr>
<tr>
<td>5.7</td>
<td>Diagram of recommended platform lengths</td>
<td>5-31</td>
</tr>
<tr>
<td>5.8</td>
<td>Maximum train consists on individual line sections</td>
<td>5-32</td>
</tr>
<tr>
<td>6.1</td>
<td>Comparison of car door designs: car ends vs. quarter points</td>
<td>6- 3</td>
</tr>
<tr>
<td>6.2</td>
<td>Conceptual presentation of the passenger boarding process</td>
<td>6- 4</td>
</tr>
<tr>
<td></td>
<td>with present and recommended door configurations</td>
<td></td>
</tr>
<tr>
<td>6.3</td>
<td>Design details for doors with automatic steps</td>
<td>6- 5</td>
</tr>
<tr>
<td>6.4</td>
<td>Car-platform gap as a function of curve radius</td>
<td>6- 6</td>
</tr>
<tr>
<td></td>
<td>for different door locations</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td>Internal layout of the recommended car</td>
<td>6- 7</td>
</tr>
<tr>
<td>6.6</td>
<td>Regional rail rolling stock design</td>
<td>6-11</td>
</tr>
<tr>
<td>8.1</td>
<td>Recommended plan for upgrading SEPTA's Regional Rail System</td>
<td>8-16</td>
</tr>
<tr>
<td>8.2</td>
<td>Projected results of alternative plans</td>
<td>8-23</td>
</tr>
<tr>
<td>Table</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.1</td>
<td>SEPTA Regional Rail 1989 daily ridership by line and direction</td>
<td>2-2</td>
</tr>
<tr>
<td>3.1</td>
<td>Basic characteristics of regional/commuter and regional/metro rail systems</td>
<td>3-2</td>
</tr>
<tr>
<td>3.2</td>
<td>Upgrading regional/commuter into regional/metro rail systems</td>
<td>3-6</td>
</tr>
<tr>
<td>5.1</td>
<td>Average time required for boarding and alighting: comparison of low- and high-level platforms</td>
<td>5-9</td>
</tr>
<tr>
<td>5.2</td>
<td>Comparisons of different types of pedestrian crossings</td>
<td>5-12</td>
</tr>
<tr>
<td>5.3</td>
<td>Estimated station construction costs for high- and low-level platforms</td>
<td>5-20</td>
</tr>
<tr>
<td>5.4</td>
<td>Design train consists and recommended platform lengths by line</td>
<td>5-33</td>
</tr>
<tr>
<td>6.1</td>
<td>Important features of the new rolling stock</td>
<td>6-13</td>
</tr>
<tr>
<td>7.1</td>
<td>Present and future fare collection procedures</td>
<td>7-4</td>
</tr>
<tr>
<td>7.2</td>
<td>Present crew duties and their reassignments for 2- and 1-person crews</td>
<td>7-10</td>
</tr>
<tr>
<td>7.3</td>
<td>Present and future crew sizes for different train consists</td>
<td>7-15</td>
</tr>
<tr>
<td>8.1</td>
<td>Possible steps in upgrading Regional Rail System elements</td>
<td>8-14</td>
</tr>
<tr>
<td>8.2</td>
<td>Integration of individual upgraded elements into different system plans</td>
<td>8-17</td>
</tr>
<tr>
<td>8.3</td>
<td>Inclusion of individual components into different plans</td>
<td>8-19</td>
</tr>
<tr>
<td>8.4</td>
<td>Incremental costs and savings of alternative plans</td>
<td>8-22</td>
</tr>
<tr>
<td>8.5</td>
<td>Evaluation of alternative plans: costs, revenues and required additional ridership</td>
<td>8-26</td>
</tr>
</tbody>
</table>
Chapter 1

PROJECT PURPOSE AND SCOPE

The Philadelphia Regional Rail System, inherited in 1983 by SEPTA from sequential ownerships by different railroad companies, is extensive and complex. By its network length and area coverage, the Philadelphia Regional Rail network is similar to the networks in New York and Chicago, and far superior to the regional rail networks in other North American cities. On the other hand, the condition of the system presents serious problems. Inadequate funding and the lack of a clear public policy and organizational set-up had resulted in decades with no major improvements and modernization, or even adequate maintenance.

The two formerly independent systems, Penn-Central and Reading, operated by Conrail for some time, were connected physically and merged organizationally after SEPTA's takeover and the opening of the Center City Tunnel in 1984.

This study presents a proposal for a policy, guidelines and standards for improvements and upgrading of the Regional Rail System's services as these are affected by infrastructure and operational elements.

The network and service characteristics, as well as the pattern of usage of the SEPTA's Regional Rail System, are similar to those of other traditional commuter rail systems, such as New Jersey Transit, Long Island Rail Road and Chicago Metra. These systems differ considerably from the recently built Regional Metro (rapid transit) systems, such as the San Francisco BART and Washington Metro. Since these new, Regional Metro systems, which will be defined later in the text, are considerably more successful in attracting ridership and in their operating efficiency, a careful comparison of the features of these two types of rail systems will be useful; it should provide insights which may be
useful in formulating a corporate strategy for further improvements of SEPTA's Regional Rail System.

1.1 The Need for System Integration, Policy and Standards

SEPTA has made significant progress in improving its Regional Rail System's infrastructure and operations, but much of this effort had to be done as short-term projects without a basic system development policy and strategy.

Following the takeover and physical unification of the network via the Tunnel, SEPTA made a number of changes with the purpose of integration of the system's lines, as well as integration of the entire Regional Rail network with other transit services. Joint information, weekly and monthly passes with many transfer privileges among modes and introduction of some feeder bus lines are examples of such actions.

As much as limited funds permitted, SEPTA has also physically renovated and upgraded a number of Regional Rail stations, introduced a public address (PA) system and paid special attention to service reliability. However, being chronically underfinanced and under numerous short-term pressures and crises, SEPTA has not yet developed a coordinated plan and technical standards. Decisions about station platform designs, car design features and their impacts on operating efficiency, crew sizes and duties, methods for reducing operating costs and decreasing service headways have often been made individually, without full consideration of their interactions.

Having stabilized the basic operations of the system since the takeover nine years ago, the time has come for SEPTA to develop a comprehensive policy and technical standards which would allow a coordinated goal-targeted improvement program. Such a program should greatly increase the effectiveness of the limited investment resources and lead to improved operating efficiency and increased
quality of services.

In addition to the need for coordination of maintenance, overhaul and improvement of the existing system, a comprehensive review and formulation of a new policy is needed in order to create an integrated system and introduce some of the infrastructure design and operational innovations which have been developed and implemented by various regional rail systems in recent decades.

1.2 The Scope of the Project

With an overall goal of upgrading SEPTA's present Regional Rail System into an efficient transit network which utilizes the state-of-the-art operating concepts, this study encompasses design principles and standards for stations and rolling stock, as well as for various aspects of the System's operations. The study is intended to produce a set of policies, guidelines and standards which ensure a full coordination of the System's physical elements and operational procedures. For example, platform heights, door controls, train crew size and fare collection practices must all be planned and designed in a coordinated manner.

In addition to specific designs and operating procedures, the report provides guidelines for planning and selection of system elements for the entire network, for individual lines, or for specific stations. While the main objective of the report is to develop physical standards and planning guidelines for the "ultimate system", or long-range horizon, analyses and recommendations include a set of measures for implementation of the improvements in stages, as the planning process and financing capabilities permit. The objective has been to allow immediate initiation of steps toward a coordinated long range plan.
1.3 Contents and Organization of This Report

The initial part of this report, Chapter 2, is a systematic review and evaluation of the present system and its operations. This review yields a listing of the present physical deficiencies and obsolete procedures. The emphasis is on the lack of coordination among various components, such as the investment in automated fare collection without a corresponding reduction of train crew sizes. This is followed by the definition of goals and objectives which should be used for the Regional Rail System in its analysis and planning.

The major portion of the report consists of a detailed analysis of the Regional Rail System's elements, such as platform heights, car/door designs and duties of the crews, and development of improved designs and operations for them. This part, presented in Chapters 4 through 7, includes considerations of experiences and practices of various advanced regional rail systems in different cities and countries. Different designs for each system component are analyzed and several sets of alternative solutions are formulated. Each set is internally coordinated. A comparative evaluation of coordinated sets of elements is performed.

In Chapter 8, a cost model is presented and used for further evaluation of developed improved components. This is followed by the final Chapter, 9, which presents the recommended system standards, elements and implementation strategy, as well as the methodology for systematic development of alternate designs and procedures for future upgrading of the System.
Chapter 2

PRESENT CONDITIONS AND THEIR EVALUATION

This chapter presents the basic data and description of the Regional Rail System which are relevant to the formulation of the policy and standards. The present system is evaluated with respect to the efficiency of its operations and quality of service. The data and system description are aimed at the main goal of this project: how to increase ridership and achieve higher operating efficiency of the Regional Rail System.

2.1 Passenger Volumes and Characteristics

The dominant form of travel on the Regional Rail System continues to be radial commuting from suburbs into Center City Philadelphia. With the opening of the tunnel and the introduction of diametrical ("through") lines, there is some travel between suburbs, passing through the Center City. This type of travel is still a very small part of total travel, while "reverse commuting", i.e., travel by City residents to suburban locations, has been increasing rather significantly in recent years. Compared to regional rail systems in other U.S. cities, SEPTA's system provides more complete all-day service.

The heavy dominance of commuter trips results in very sharp passenger volume peaking, and makes it highly desirable to attract off-peak riders who would increase utilization and revenue at virtually zero marginal cost.

The distribution of passengers among the various Regional Rail lines is given in Table 2.1.

2.1.1 Station Usage

Daily passenger volumes for all stations except the three in Center City are presented in Figures 2.1 and 2.2. The characteristics of these volumes
Table 2.1  SEPTA Regional Rail 1989 daily ridership by line and direction

<table>
<thead>
<tr>
<th>Line</th>
<th>West of Center City (former Penn Central lines)</th>
<th>North of Center City (former Reading lines)</th>
<th>Total inbound</th>
<th>Total outbound</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inbound</td>
<td>Outbound</td>
<td>Inbound</td>
<td>Outbound</td>
</tr>
<tr>
<td>R1</td>
<td>826</td>
<td>1040</td>
<td>79</td>
<td>72</td>
</tr>
<tr>
<td>R2</td>
<td>3105</td>
<td>3263</td>
<td>2542</td>
<td>2357</td>
</tr>
<tr>
<td>R3</td>
<td>3808</td>
<td>3487</td>
<td>3318</td>
<td>3174</td>
</tr>
<tr>
<td>R5</td>
<td>10739</td>
<td>11102</td>
<td>5251</td>
<td>5165</td>
</tr>
<tr>
<td>R6</td>
<td>250</td>
<td>241</td>
<td>2119</td>
<td>2167</td>
</tr>
<tr>
<td>R7</td>
<td>3612</td>
<td>3699</td>
<td>2186</td>
<td>2482</td>
</tr>
<tr>
<td>R8</td>
<td>1959</td>
<td>2283</td>
<td>2059</td>
<td>2027</td>
</tr>
<tr>
<td></td>
<td>24299</td>
<td>25475</td>
<td>17554</td>
<td>17444</td>
</tr>
<tr>
<td>Total number of passengers (per day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figure 2.1 Passenger boardings and alightings by station - inbound directions

Source: SEPTA survey: R1, R2, and R5 on Dec 29, 1990; R6 and R7 on May 21, 1990; R8 on Dec 17, 1990.

#### Center City Stations

<table>
<thead>
<tr>
<th>Station</th>
<th>Boardings</th>
<th>Alightings</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPU</td>
<td>200</td>
<td>100</td>
</tr>
<tr>
<td>NBS</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>LON</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>TAB</td>
<td>50</td>
<td>75</td>
</tr>
<tr>
<td>FER</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>MEP</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>ELPI</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>JFK</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>GHQ</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>GLS</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>NBD</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>RYD</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MBK</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>BTH</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>PHN</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FHL</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SOM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TRV</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>NEF</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LNH</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WAI</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OLM</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>LMB</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CHI</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>YVR</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>FAC</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Per day**

- Number of passengers

---
Figure 2.2 Passenger boardings and alightings by station - outbound directions

Source: SEPTA surveys: R1, R2, R3, and R5 on Oct 1, 1986; R6 and R7 on May 21, 1986; R8 on Dec 17, 1986.
relevant to this project are that station usage varies considerably. The three Center City stations being utilized far more than all the other stations. The overall usage of stations, i.e., the average number of passengers per station, is considerably lower than on the Regional Rail Systems in other U.S. cities, which is the result of the extensive network and the large number of stations.

There have been several proposals in the past to close some of the closer-in stations due to their low usage. Although some of these stations have been physically maintained and they have regular services, there has been no concerted effort to attract additional riders and increase their utilization.

With the increasing residential population in the suburbs and services which offer high speed and comfort, the Philadelphia Regional Rail System recorded a significant increase in ridership in the 1960's and 1970's, reaching the record level of 130,000 passengers per day in 1979.

At that time, however, a number of changes detrimental to the System's ridership occurred. First, various maintenance and reconstruction projects were carried out without adequate protection for service reliability. Second, service frequencies were reduced on many lines. Third, several major fare increases were introduced over a short period of time. Fourth, some sections, particularly the outlying portions of the lines and all diesel services, were discontinued.

The most severe blow was a one-hundred day long strike at the time of SEPTA's takeover, which brought the ridership down to 65,000 daily passengers in 1984, i.e., only 50% of the ridership record achieved only five years earlier.

A significant improvement of services resulted from the opening of the tunnel. Integration of the two networks, former Penn-Central and Reading, improved public information, a limited amount of marketing, and improved physical condition of the stations and trains have resulted in an appreciable recovery of
ridership up to the level of 90-95,000 per weekday. This recovery is, however, still far below the potential which the region has for utilization of its extensive Regional Rail System. This inadequate utilization of the System’s potential can be assigned, generally speaking, to the following three major elements.

1. Development patterns and land uses have been changing, leading to increasing suburbanization and decreased relative importance of the Center City. Even more importantly, land use development is continuing with very little relationship to the transit network and services, or even to the capacity of the existing highway facilities. In other words, land use development is being planned on a piecemeal basis with a particularly serious neglect of transit systems considerations.

2. National transportation policies which influence urban passenger travel have been detrimental to transit use. SEPTA has suffered from serious decreases in funding, while highway funding has been increased. Moreover, the real price of gasoline in the United States has come to an all-time low point. Taking into account inflation, the present price of gasoline is lower than it has been at any time before except for a short period in the 1970’s. As a result of these national and regional trends, transit services have become much less competitive with respect to cost. At the same time, the quality of transit service has decreased relative to the increasing quality of automobile service, a result of extensive, but well hidden subsidies to highways.

3. The comfort, convenience and image of Regional Rail Services have remained high and have received a significant boost through the opening of the Center City Tunnel and the elegant Market East Station. However, this
system continues to attract mostly suburban commuters, while other travelers are not attracted to it because of its low frequency of service (all lines except two, R-1 and R-5, offer only hourly services in the off-peaks and every two hours services on Sundays) and by the very high cash fares. For example, an incidental rider typically faces a round trip fare of $5.00 to $7.00, even without counting the possible additional fare for the extra on-board payment of $1.50. A lack of adequate information and virtually no marketing are additional reasons for the low ridership.

2.1.2 Passenger Load Profiles

The profiles of the passenger load (the number of passengers on the trains between stations) on the Regional Rail lines are shown for inbound and outbound directions in Figures 2.3 and 2.4, respectively. As seen in the figures, passenger loading progressively increases toward Center City for the inbound train movements and decreases toward the suburbs for the outbound train movements.

The passenger flow pattern is not only radial but also uni-directional in each peak period. This typical radial travel pattern between Center City and the suburbs causes inefficient operations which are common to most commuter oriented transit systems. The requirements for fleet and crew are dictated by the need to serve only the maximum load section for only one direction in the peak period. As a result, cars and the crews are poorly utilized. In the a.m. peak, far more than the necessary number of crews and cars are allocated to the outlying section of the inbound trains and all outbound trains in the a.m. peak. In the p.m. peak, the crews and cars are underutilized in the outlying section of outbound trains and all inbound trains.

The passenger volumes entering the Center City stations from the former
Figure 2.3 Passenger load profiles by line - inbound directions

Source: R1, R2, R3 and R5 on Oct. 29, 1989; R6 and R7 on May 21, 1989; R8 on Dec. 17, 1989.
Figure 2.4 Passenger load profiles by line – outbound directions

Source: R1, R2, R3 and R5 on Oct. 29, 1989; R6 and R7 on May 21, 1989; R8 on Dec. 17, 1989.
Penn Central lines are shown greater than those of the former Reading lines. This creates an unbalanced requirement in the train consist because most trains are scheduled to serve inbound passengers from the two former lines in one peak period travel cycle. In the a.m. peak, the trains which arrive from the former Penn Central lines are required to have the cars and the crews which satisfy the requirements at the maximum load section, which is just before the 30th Street Station; however, the same cars and crew sizes are not required when the same train serves the inbound a.m. peak passengers on its return trip to Center City, after traveling outbound with virtually no passengers.

In order to improve the efficiency of operations, the need to increase the suburbs-to-suburbs passenger volume and the reverse travel during the peak period is obvious. While the Center City Tunnel has brought about the opportunities to provide services which promote the cross-town travel, a greater effort to market the reverse travel and suburbs-to-suburbs travel must be made, for example, with the higher service frequencies and attractive fare schemes during the off-peak period.

2.2 Physical Condition of Stations

The Philadelphia Regional Rail system was not designed and built as an integrated transit network. Its initial infrastructure was designed by several different railroad companies which were primarily oriented toward freight transportation. This diversity has been only partially overcome by the efforts to integrate the System in recent years.

2.2.1 Infrastructure

Adequacy of the present Regional Rail infrastructure can be analyzed through two aspects: first, its physical soundness; second, functional design and form of stations. Both of these aspects vary considerably among stations.
The physical condition has been improved considerably in recent years, but many stations are still in poor condition. Broken platform surfaces and edges, or situation where platforms gradually disappear, i.e., their dimensions are not clearly defined, are very common. Many access paths have been allowed to deteriorate over a long period without adequate maintenance and only a fraction of these has been rehabilitated in recent years.

The conditions of station buildings and shelters also vary greatly. Many station buildings are classical structures with considerable architectural beauty. Some of them have been renovated, while others are still in poor condition and require investment for rehabilitation and modernization. The poor condition of the infrastructure presents serious problems: first, they cause inconvenience and safety hazards to the riding public; second, their shabby appearance and the poor quality of service deter many potential riders; third, their maintenance costs are higher and less predictable than they should be; finally, there is a greater probability of accidents that could lead to injuries, compensation claims, and litigations.

2.2.2 Platform Heights

SEPTA presently has standards that define the basic dimensions of three types of platform by height. The "low-level platform" has an elevation equal to the top of rail (TOR); the "medium-level platform" is eight inches above the TOR, and the "high-level platform" is 48 inches above the TOR. Figure 2.5 shows the various platform levels and their relations to the TOR and the car body.

A great majority of stations in the Regional Rail System have low level platforms. High-level platforms exist at three Center City stations as well as at several outlying recently built stations, including the entire Airport Line. There are a few stations with platforms designated as "medium-level", but their
Figure 2.5 Regional Rail car cross-section, platform levels and lateral clearances
heights vary between TOR and the "medium-level platform" of eight inch elevation. As a matter of fact, there are a few stations at which the platform height is below TOR level, creating a step which exceeds 15 inches (38 cm), creating considerable inconvenience and hazard to the passengers.

In some cases, upgrading of stations has been used to replace low- by high-level platforms. However, since there has not been a coordinated plan for financing the upgrading of many stations, some Regional Rail lines have mixed low- and high-level platforms. This set-up not only slows down operations, but it requires extra work for the crew to select the appropriate setting of the traps on car doors and may necessitate employment of otherwise redundant crew members.

At a few stations, namely, those in the "high-level platform territory" and along AMTRAK and other rights-of-way with four or more tracks there are grade-separated track crossings, either over- or underpasses. At most low-level platform stations there are simple and convenient track crossings at grade. These crossings are simple and efficient. They also meet the needs of handicapped persons.

2.2.3 Platform Lengths and Widths

Platform lengths are even more diversified than platform heights. An unofficial standard for platform length is considered to be about 500 ft, or length sufficient for a six-car train. At the CBD stations, Market East, Suburban and 30th Street, platform lengths are considerably greater, allowing two short trains to stop behind each other simultaneously. Such stopping is used at Market East and Suburban stations for regular train stopping in two positions, Section A and Section B. This operation allows considerably higher line capacities and less confusion and crowding of platforms. On the other hand, most
outlying stations have station platform lengths varying from 120 to 900 feet, i.e., adequate to accommodate two- to nine-car trains.

Due to their poor conditions and inadequate maintenance, at many stations it is not possible to precisely determine how long individual platforms are.

Platform widths typically vary from 20 feet at the station buildings down to 4-5 feet at the extremities. Many platform edges are actually not well defined, so that the exact platform measures cannot be established in such cases.

2.3 Rolling Stock and Its Characteristics

Both major categories of Regional Rail rolling stock, the Silverliners and Bombardier (push-pull) trains, have the same functional layout of doors, cabs, aisles and seating. As can be seen in Figure 2.6, the layout is intended for maximum seating capacity, at the expense of internal passenger circulation.

Drivers' cabs, or vestibules, have an old-fashioned design, lacking the features for easy driving, control, and seating comfort. The cars also lack many modern features that would increase crew productivity, such as multiple locations for PA system microphones, and electronic signs for passengers.

All cars have single-channel doors from the driver's cabs or vestibules at both ends. The option to install double-channel doors at the center of the car, built into Silverliner IV cars, have never been exercised. The present layout of door, aisles and seating results in very slow alighting and boarding rates and very long standing times at both low- and high-level platform stations. When the cars are heavily loaded, the congestion results in an exponential increase of standing times. Moreover, utilization of car capacity is negatively affected by this layout; passengers worrying how they can get out of the car often stay near the doors, preventing utilization of the remote seats and standing areas. The doors are train-lined when the traps are down, i.e., at high-level platform stations.
stations. At all other stations, conductors must supervise them nearly at all times, because the doors cannot be closed unless door traps are down.

2.4 Operational Aspects

Since SEPTA's takeover of the Regional Rail System in 1984, a number of changes have been introduced to upgrade the System from its traditional railroad-type of operation with long trains, large crews and long headways, to an upgraded regional rail system with operation resembling rail rapid transit. However, some of the traditional features which cause low level of labor productivity and slow operating speeds still remain.

2.4.1 Schedules: Frequencies and Train Consists

Train departure times, number of cars per train (train consists) and train crew sizes on one of the lines, R-3, are presented in Figures 2.7 and 2.8. Corresponding diagrams for R-2 and R-5 lines, but without crew sizes, are shown in the Appendix Figs. A2.1 - A2.8. These diagrams show that most off-peak schedules are regular, with 60-min. headways. More frequent service, with 30-min. headways, is provided only on R-1 and R-5 lines. In some cases, such as on most lines on Sundays and on a few lines (e.g., R-2 to/from Wilmington) during off-peaks, 2-hour headways are used.

During the peak hours considerably shorter headways are used. The R-5 line west of Center City has an average of 6-8 min. headways during the peak hours. However, this schedule includes zonal trains, most of which stop only at stations of single zones, so that they do not serve other stations. This type of schedule therefore results in approximately double headways at most stations. Stations on the lines which operate 20-min. headways during the peak hours have even lower service quality; most of their stations are served by every other train, offering headways as long as 40 minutes.
on the R3 Line (center city to Bryn)

Figure 2.7 Train departure times, consist, and train crew sizes


Legend:
- Non-revenue service from Center City to Secane
- Revenue service from Center City to Secane
- Revenue service from Center City to Bryn/Media

(5) Conductor and engineer (on the train)

The number above each bar represents the crew size.
Two other characteristics of the services on R-3 line should be pointed out. First, the shortest train consists on this line is 2-car, while the longest consists, 5-car trains, are used only for one or two train pairs per day. This fact will be significant in analyzing the platform length standards.

The second observation refers to crew sizes. As Figures 2.7 and 2.8 show, 2-person crews are used on very few trains, except in the evening hours; during the off-peak mid-day hours, when train headways are determined by frequency rather than capacity, most lines are served by 2-car trains with 3-person crews. This point is explained in more detail in section 2.4.3.

2.4.2 Fare Structure, Fare Types and Collection Methods

To achieve such different goals as collection of maximum revenue, stimulate off-peak riding, take into account different passengers and satisfy various legal requirements, SEPTA has developed a very elaborate fare schedule. Therefore, SEPTA's fares are very diversified.

The basic fare structure is radial-zonal graduated fare. The fare levels with respect to the numbers of zones traveled are shown in Figure 2.9. The advantage for a passenger of using a TrailPass is clearly seen in the figure: the difference between the cash fare during peak the period and the TrailPass fare (computed based on 44 trips per month) vary from $1.20 to $2.25. The dashed lines in the figure show fares if a Media Trolley is used in combination with different City Transit fares.

The diversity in actual amount, duration, form of payment type of trip, etc., further depends on several categories of factors, as shown in Figure 2.10. The factors include location of purchase, form of ticket, duration of validity, passenger type and travel direction and distance. According to the Figure, numerous permutations of different factors and consequently fare level are
Figure 2.9 Fare level and structure on Regional Rail and City Transit

Assumptions: 1992 fare
- TransPass: $58/month
- 44 trips/month
<table>
<thead>
<tr>
<th>LOCATION OF PURCHASE</th>
<th>FORM OF TICKET</th>
<th>DURATION OF VALIDITY</th>
<th>PASSENGER TYPE</th>
<th>TRAVEL DIRECTION AND DISTANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agent</td>
<td>Ticket</td>
<td>Peak only</td>
<td>Adult</td>
<td>To/from CBD</td>
</tr>
<tr>
<td>Machine</td>
<td>Pass</td>
<td>Off-peak only</td>
<td>Child</td>
<td>Intra-suburban</td>
</tr>
<tr>
<td>On-board</td>
<td>Coupon</td>
<td>All day</td>
<td>Family</td>
<td>Within City limits</td>
</tr>
<tr>
<td>Employer</td>
<td>Voucher</td>
<td>1 week</td>
<td>Group</td>
<td>Within CBD</td>
</tr>
<tr>
<td></td>
<td>Employee ID</td>
<td>1 month</td>
<td>Senior citizen</td>
<td>Inter-suburban</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indefinite</td>
<td>Handicapped</td>
<td>Via NJT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conrail employee</td>
<td>Single zone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SEPTA &amp; AMTRAK Police</td>
<td>Multi zone</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Traffic checker</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.10 Classification of types of fare by characteristic
possible.

The present Regional Rail fare system is very sophisticated and achieves the basic goals effectively. However, the diversity and complexity of the fares also causes some problems. Fare types and amounts are difficult to memorize and handle. A particularly serious problem is that, in spite of recent innovations leading to decreased on-board fare collection, conductors still spend considerable time for fare supervision and collection. Another problem is that due to the limited possibility of purchasing tickets off-board (particularly at non-CBD stations and during off-peak hours), many passengers must pay higher on-board fares and increase the workload of the conductors. In addition, incidental riders, whom the system should spend effort to attract, are those most commonly subjected to the higher fares.

2.4.3. Crew Sizes, Assignments and Duties

Despite changed labor contracts at the time of SEPTA's takeover of the Regional Rail System, and of subsequent technical changes which have stimulated increased off-board fare payment, fare collection remains one of the basic reasons for large train crews (2 to 4 persons per train). Other major functions which require presence of conductors and passenger attendants include handling door traps, supervision of boarding and alighting, train departure control, assisting the engineer in any problems, etc.

As a result, the Regional Rail System is the most labor-intensive mode of rail transit; most of SEPTA's trains have, in addition to the engineer, two crew members. Some trains have three, while some off-peak trains have only one additional person (conductor). The number of cases that each combination of train consist and crew size take place on weekday trains of the R-3 line are shown in Figure 2.11. The largest number of cases is the 2-car trains with 3 or
Crew size is the total of engineer, conductors, and passenger attendants.

Notes: The number above each bar represents the number of crew members for SEPTA R3 (Elwyn-CBD) daily runs (total inbound and outbound number of runs on a weekday)

Source: SEPTA General Picking Notice, effective October 28, 1990

Figure 2.11 Train crew sizes for different train consists
4 crew members.

The labor intensiveness of the train operations is the basic reason for long headways, as well as for the low operating ratio of the Regional Rail System. Very sharp peaking of passenger volumes, long lines and consequent long cycle times, make "tailoring" of crew sizes to train operations rather difficult and schedules inefficient. As the diagrams in Figures 2.12 and 2.13 show, the ratios of paid hours to actual work hours for conductors, engineers, and passenger attendants vary greatly; in many cases paid hours exceed substantially the hours of work. This characteristic of the Regional Rail System exacerbates the problem of low labor efficiency and increases its negative impacts on the service and its operating cost.

2.4.4. Regulations and Other External Constraints

Design and operation of SEPTA's Regional Rail System are influenced considerably and to some extent dictated by the standards of the Federal Railroad Administration. Another set of constraints is imposed by SEPTA's track sharing with AMTRAK and Conrail. The FRA regulations represent national standards for all railroads which are very important for safety of operations and for coordination among railroad systems which have joint tracks and facilities. In SEPTA's case the benefits from these regulations are reflected in the compatibility of its equipment with the operations of AMTRAK and Conrail trains. At the same time, these regulations and sharing of facilities impose considerable constraints on the SEPTA system. These constraints are caused by the following factors:

1. Many regulations were developed primarily for long distance and freight, rather than for urban/regional passenger transportation. For example, track layout at many stations and signal system developed for freight trains running at long headways presently cannot handle frequent passenger train
Figure 2.12 Relationship between actual work hours and paid hours of passenger attendants—weekdays.

Source: SEPTA General Picking Notice effective on October 28, 1990.
Work Hours

Source: SEPTA General Picking Notice effective on October 28, 1990.

Figure 2.13 Relationship between actual work hours and paid hours of engineers and conductors – weekdays
operations. Thus, track layout at the Jenkintown Junction does not allow convenient turning back of trains coming from the City (for a detailed analysis of this Junction see the report by the University of Pennsylvania and University of Delaware to SEPTA dated May 1987).

2. Some of the operating rules that are still enforced have been made obsolete by the development of modern technology. An example of this is the requirement for the brake test which requires two persons and takes several minutes. The corresponding operation is performed in other countries by the engineer, performing the test of less than one minute in his/her cabin.

Another example of obsolete rules is the requirements that all trains with locomotives, including the push-pull ones, must ring the bell while entering each station. This requirement originates from the time when only some of the cars in the train had brakes; it should not be applied to modern equipment in which all axles on the train are brake equipped.

3. The structure of federal rules is in some respect not logical; while trackage, signal system and rolling stock are subject to many federal regulations, station platform design and condition are not regulated in any way.

4. Some of the federal requirements, particularly those relating to accessibility for the handicapped, are unrealistic and virtually punitive; many required modifications and new facilities involve major expenses, but the funds for their implementation are not made available to SEPTA by any government. Consequently, mobility of the handicapped, which is the problem of the entire society, is being paid for only by the transit users. Moreover, in many cases, provision of accessibility for the handicapped on existing transit systems is physically infeasible or extremely costly.

In the absence of federal standards for station design, it is incumbent on
SEPTA to develop such standards in much greater detail than it has done so far. Actually, this lack of federal standards for stations represents a good opportunity for SEPTA to develop standards and create operational procedures which are optimal for its system and for the specific conditions of this region.

2.5 Evaluation of Present Conditions

As this review of the present conditions on the Regional Rail System shows, upgrading and adjustment of this System to passenger transit has been pursued by SEPTA since its takeover from Conrail. However, the modifications have been done separately, without a coordinated design policy and standards for individual system components, such as fare collection, platform heights, and train dispatching. Even upgrading of individual components was not always consistent. For example, some stations in the middle of the line were reconstructed with high-level platforms. This has, in turn, increased the duties of train crews and slowed down train operations instead of speeding them up.

The main underlying reason for this type of development has been the lack of a coordinated policy toward the Regional Rail System. Such a policy should be utilized to develop a corporate strategy, which should then be translated into specific technical standards.
Chapter 3
DEFINITION OF SYSTEM GOALS AND OBJECTIVES

The description of the present Regional Rail System and its operation in the preceding two chapters shows that a number of improvements of this system have been made in recent years, but in many cases upgrading of some elements was not fully coordinated with the functioning of the entire System. There is obviously a need for a careful formulation of an overall, integrated policy and definition of objectives for further modernization of this system. To develop such a policy, it is useful to briefly review characteristics of SEPTA’s Regional Rail and compare it with similar systems in other metropolitan areas.

3.1 SEPTA and Its Peers

Regional Rail Systems in major U.S. metropolitan areas can be grouped into two major categories. The first category represents the regional/commuter systems, i.e. traditional commuter railroad lines. Although most of these systems have been upgraded in various ways, they retain basic characteristics of commuter-oriented railroad operations serving extensive radial networks. The second category consists of the recently built rapid transit systems, which have transit-type operations and serve not only cities, but also extensive suburban areas. Since these transit networks play a similar role to that of the regional/commuter systems, they are referred to as regional/metro systems. They consist of fewer lines with large park-and-ride lots in the suburbs and somewhat better distribution in central cities. They are much more intensively used.

The basic characteristics of several major regional rail systems in North America, grouped into these two categories, is presented in Table 3.1. The table shows the characteristics mentioned above: the regional/commuter systems have
Table 3.1 Basic characteristics of regional/commuter and regional/metro rail systems

<table>
<thead>
<tr>
<th>City/System</th>
<th>Network length (mi)</th>
<th>No. of stations</th>
<th>Passenger/weekday</th>
<th>Operating ratio</th>
<th>Weekday pass/mi</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regional/Commuter Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LI</td>
<td>325</td>
<td>140</td>
<td>292,000</td>
<td>46</td>
<td>898</td>
</tr>
<tr>
<td>NJ</td>
<td>394</td>
<td>154</td>
<td>170,000</td>
<td>53</td>
<td>431</td>
</tr>
<tr>
<td>MN</td>
<td>327</td>
<td>117</td>
<td>200,000</td>
<td>53</td>
<td>612</td>
</tr>
<tr>
<td>CH</td>
<td>495</td>
<td>230</td>
<td>275,000</td>
<td>55</td>
<td>556</td>
</tr>
<tr>
<td>PH</td>
<td>180</td>
<td>156</td>
<td>90,000</td>
<td>38</td>
<td>500</td>
</tr>
<tr>
<td><strong>Regional/Metro Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>72</td>
<td>34</td>
<td>250,000</td>
<td>44</td>
<td>3,472</td>
</tr>
<tr>
<td>WA</td>
<td>78</td>
<td>70</td>
<td>520,000</td>
<td>70</td>
<td>6,667</td>
</tr>
<tr>
<td>AT</td>
<td>32</td>
<td>29</td>
<td>192,000</td>
<td>37</td>
<td>6,621</td>
</tr>
<tr>
<td>LL</td>
<td>14</td>
<td>13</td>
<td>41,000</td>
<td>82</td>
<td>2,929</td>
</tr>
</tbody>
</table>
much greater network lengths and numbers of stations than the regional/metro systems. The passenger attraction of the second group is, however, much greater: the weighted average density of passengers for the four regional/metro systems varies between 2,900 and 6,700 weekday passengers per mile, while the corresponding numbers for the regional/commuter systems are only between 400 and 900 weekday passengers per mile. These differences are also obvious in Fig. 3.1, which depicts riderships and network lengths for individual systems.

The operating ratios are not distinctly different between the two groups because they depend mostly on the policy of fare level versus operating financial assistance. However, it is significant to note that the two systems with the highest operating ratios are new ones, i.e., PATCO and WMATA.

This comparison does not by any means imply that the older regional rail systems are inferior to the new ones. The differences in their passenger attraction are logical when one takes into account the fact that all the new systems have been designed recently and adapted to the present urban form, travel patterns in metropolitan areas, as well as modern rail transit system operations. Thus, for example, the new systems have much more extensive park-and-ride facilities, they have more stations in downtown areas, and they offer much higher service frequencies. This is possible with one-person crews and streamlined operations typical for modern rapid transit systems.

The main reason for these differences is that in all cases the investments made for the new systems have been several times greater than the investments allocated for upgrading and modernization of the older regional/commuter rail systems.

The main purpose of this comparison is to analyze the differences in the features of the two system categories and to discover which physical/operational
Figure 3.1 Network lengths, daily ridership and passenger density on regional rail systems
components contribute mostly to the stronger passenger attraction by the new systems.

3.2 Regional/Commuter vs. Regional/Metro Systems: a Comparison

Table 3.2 lists the main system characteristics typical for the traditional regional/commuter systems (in the first column), and for the regional/metro systems (in the last column). Comparing these two columns, one can see the following basic differences, as listed in the second column.

Rights-of-way are different only with respect to their ownership and control: most traditional systems share some or all of their trackage with other railroad companies (freight and/or Amtrak), while the regional/metro systems have exclusive control over their rights-of-way. This element is important in the cases where other rail operations are frequent and cause delays to regional rail trains. Yet, most of the traditional systems have high reliability of service, indicating that this difference is not highly significant.

The differences in the types of stations and platforms are very significant. The high platforms and more attractive design of regional/metro stations not only facilitate boarding/alighting of passengers, but they also contribute to the much stronger public image of these systems. Furthermore, although train crew size and productivity do not affect the ridership directly, greater labor productivity of the new systems makes a much higher service frequency feasible.

The differences between the two categories with respect to their physical (network) characteristics and operational features which are most significant for greater passenger attraction of the regional/metro systems are the following:

- The regional/commuter systems have much longer networks and greater numbers of stations, as Fig. 3.2 illustrates. This is a great advantage over
Table 3.2 Upgrading regional/commuter into regional/metro rail systems

<table>
<thead>
<tr>
<th>Traditional regional/commuter</th>
<th>Characteristics</th>
<th>Modern regional/commuter</th>
<th>Regional/metro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exclusive, with crossings</td>
<td>Right-of-way</td>
<td>Exclusive, with crossings</td>
<td>Exclusive</td>
</tr>
<tr>
<td>RR company</td>
<td>- Type</td>
<td>Transit agency</td>
<td>Transit agency</td>
</tr>
<tr>
<td></td>
<td>- Ownership</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open, low (high)</td>
<td>Stations, platforms</td>
<td>Open, high</td>
<td>Controlled, high</td>
</tr>
<tr>
<td>60 (30)</td>
<td>Headways (min.)</td>
<td>30</td>
<td>10-12</td>
</tr>
<tr>
<td>30 (20)</td>
<td>- Base</td>
<td>10 (20)</td>
<td>3-8</td>
</tr>
<tr>
<td></td>
<td>- Peak</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Train crew productivity</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>High</td>
<td>Fares</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td></td>
<td>Service integration</td>
<td>Integrated</td>
<td>Integrated</td>
</tr>
<tr>
<td>Very limited</td>
<td>- Other transit</td>
<td>Expanded</td>
<td>Extensive</td>
</tr>
<tr>
<td>Limited</td>
<td>- Auto: P+R, K+R</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>Public image</td>
<td>Modern, attractive</td>
<td>Modern, attractive</td>
</tr>
<tr>
<td>Mostly commuter to CBD</td>
<td>System's role</td>
<td>Regional transit</td>
<td>Regional transit</td>
</tr>
</tbody>
</table>


Figure 3.2 Network lengths and number of stations of different regional rail systems
regional/metro systems. However, the latter systems more than compensate this
disadvantage by the following design and operational features.

- Much shorter headways, as illustrated in Fig. 3.3. This gives the
  regional/metro systems a significantly higher competitiveness with the automobile
  and thus a greater ability to attract passengers.

- Lower fares, made possible by more efficient design and operation of the
  new systems and by greater public support for the transit systems in these
  cities; this greater support is perpetuated by the higher system image.

- Better integration with other transit, park-and-rides and kiss-and-ride
  access modes, is found on regional/metro rail systems.

- While the new systems are considered not only as integral components, but
  as the basic "spines" of the transit systems in their regions, the traditional
  regional/commuter systems are still operated predominantly with independent
  schedules and no transfer privileges, with some exceptions (SEPTA's Trailpasses
  are valid on all other transit lines).

- The overall public image of the two regional rail system groups vary
  considerably. Although the regional/commuter systems provide a much greater are
  coverage and serve many old, established areas and suburban towns, the
  regional/metro systems have a much greater overall attractiveness due to their
  modern station designs, integration with other modes more complete information,
  marketing, and more innovative features.

- As a consequence of these features, particularly short headways
  throughout the day and full integration with other transit, the regional/metro
  systems have a role of regular transit, while the regional/commuter rail systems
  are predominantly and sometimes nearly exclusively commuter transit systems.
Headways During Peak Hour Operation

Headways During Midday Operation

Figure 3.3 Comparison of headways - peak hour and midday operation
3.3 Regional Rail System Goals

Extensive analysis of these differences in features, and specific characteristics of SEPTA’s Regional Rail System, have led to the formulation of the system characteristics to which the SEPTA’s system could be upgraded in order to significantly increase its ridership. These upgraded characteristics, which would make SEPTA’s Regional Rail as similar to the regional/metro systems as local conditions permit, are listed in the third column of Table 3.2. Yet, even after these changes, the Regional Rail System could still retain some of its advantages over the new systems (such as much greater area coverage, simpler and less expensive technology, historic charm, etc.).

Consequently, the main objective of upgrading SEPTA’s Regional Rail System is to make its features similar to those of regional/metro systems, while retaining its inherent advantages. That objective will lead to the overall goal that the Regional Rail System provides services which are:

- Attractive to passengers (high level-of-service);
- Competitive with automobile travel;
- Economical to operate (high operating ratio).

The major constraint for the upgrading of the system is that it fits within realistic funding levels. With respect to passenger attraction, the goal considered to be realistic for the Philadelphia Region and the potential of its Regional Rail System is to reach a weekday ridership of at least 200,000 persons.
While most transit lines and modes are designed for a specific type of operation and service, commuter/regional rail systems have traditionally originated as long-distance railroad network services adapted for local travel within metropolitan regions. Thus, SEPTA’s Regional Rail System came into being as specialized local services of two major railroad companies, the Pennsylvania and Reading. Through the years, a number of adaptations were made, including truncations and extensions of lines, electrification, construction of high-level platforms at some stations, were undertaken at different times in the past.

In recent years improvements included some progress in signing of trains for their lines and destinations, partial fare integration with other transit services (Trailpasses), automatic ticket-issuing machines, etc. However, various elements of the system’s infrastructure, rolling stock, equipment and operating procedures (such as fare collection) have never been thoroughly examined as an integrated system.

To illustrate this deficiency, several examples of inefficient operations and missed opportunities to introduce improvement measures are described here. This description of problems is followed by a definition of relationships among system elements which will represent the basis for formulating the plan for upgrading of the Regional Rail System.

4.1 Current Deficiencies Caused by Lack of System Integration

Many elements of the Regional Rail System have remained traditional, without contemporary innovations which have been introduced in many transit systems in recent decades. For example, platforms at most stations are very low
(at TOR or even lower); car doors are narrow, (appropriate for intercity travel, rather than for fast passenger exchanges); engineer’s cab and equipment have the same design as those typical for rolling stock from the 1920s; train crews perform their duties in a way similar to that of several decades ago: they step down and up the stairs at each station, perform visual/manual checking of fares for each passenger, once for each zone, make station announcements mostly by voice because of an inconvenient location for the PA microphone, etc.

A number of improvements of the Regional Rail System have been introduced in recent years, particularly since SEPTA’s takeover in 1983. Fare collection has been greatly simplified through the promotion of monthly and weekly Trailpasses and installation of ticket issuing machines (later discontinued due to vandalism problems); information for the public in cases of delays has been improved; station signs have been erected; lines have been designated as R-1, R-2, etc. Some stations have been reconstructed and others are planned for similar improvements.

While each one of these measures has been useful, their introduction has often been done without coordination with other elements, which has prevented achievement of the maximum effectiveness of each investment. As a matter of fact, in some cases lack of coordination among improvements has resulted in increased rather than decreased operating costs and/or travel times. Several examples will illustrate the problem of the lack of coordination among system elements.

The following examples illustrate activities which have had mixed, sometimes even negative results because they were done without functional coordination with other system elements.

1. Introduction of a Self-Service Fare Collection (SSFC) system, a
necessary element of system upgrading, has the main purpose and economic justification if it is accompanied by crew size reductions which reduce operating costs and allow introduction of more frequent services. Thus, the required investment in purchase, installation and maintenance of such machines is more than offset by decreased operating costs and/or increased services, new ridership and, ultimately, increased revenues.

SEPTA introduced in 1987 the Autelca ticket issuing machines at a number of stations. The cost was about $40,000 per machine. The main benefit from these machines should have been to make possible pre-purchase of tickets, thus reduce the work of train crews and allow deployment of smaller crews. Thus, ultimately, operating costs would have been reduced. The problem has been that because of other duties (changing traps, supervising the doors, etc.), crew sizes could not be reduced; thus, there were no savings through crew reductions or any other productivity increases due to the installation of these expensive machines. The investment in them actually resulted in an increase rather than decrease of operating costs.

2. Some stations have been rebuilt in recent years with high-level platforms. The decision which stations should be rebuilt has been made on the basis of local requirements such as the number of daily passengers, available land, condition of the station, etc. However, operating requirements have not been fully considered. Some such stations have been built between stations with low platforms, so that train crews must now lower the traps prior to that station and lift them after it; thus, the crew duties have been even increased because this infrastructure improvement was not coordinated with operating procedures.

3. In some cases track reconstruction was not coordinated with station layout and design standards. For example, reconstruction of tracks was so
designed that their elevation was increased. In station areas this track elevation created platforms that are now below top of rail, with discomfort and safety problems for the passengers. The task of the crew to supervise passenger boarding/alighting was thus made more difficult. Consequently, the lack of coordination among upgrading measures has resulted in wasted efforts and even in counterproductive changes.

4. Lack of standards regarding platform lengths also creates problems. At many stations platforms are not exactly defined, nor have they been precisely constructed: some platforms tend to "fade out" into areas which used to be platforms, but are now not maintained. Passenger discomfort, safety hazards and crew duties are thus increased.

There are still debates in SEPTA about the standards for platform lengths. The system-wide 6-car platform length standard, was in the past promoted by SEPTA. This standard represented a serious obstacle to station renovations and resulted in wasted investments and increased operating costs. Although this length is not an official standard any more, one still encounters opinions that all new, and even reconstructed stations should have lengths for 6-car trains. Since most lines are not likely to ever need 6-car trains, this standard would be counterproductive.

These are only selected examples of the problems which exist due to the lack of a coordinated policy and design standards for the Regional Rail System.

4.2 Interdependence among Infrastructure, Rolling Stock and Operations

The Regional Rail System is a very complex one in which infrastructure, rolling stock, operating personnel and working practices interact mutually. To ensure full utilization of the investments and efforts into upgrading of one or
several components, the relationships among various system elements must be clearly understood. This section identifies the critical elements and their relationships which must be understood in order to achieve an integrated, efficiently operating system.

Figure 4.1 shows the basic interrelationships among elements and consequences of their changes. The flow diagram encompasses only the major elements influencing operating ratio of the system.

As the flow chart shows, platform heights and track crossings influence passenger comfort, operating speed and crew sizes; the crew size, which is at the same time influenced by the fare structure and fare collection method, is the critical element affecting operating costs, because regional rail is the most labor-intensive transit mode. The reduction of operating cost per train is the key objective in achieving increased operating ratio.

A more detailed and complete presentation of the system elements and their relationships is shown in Figure 4.2. The diagram is self-explanatory, but some relationships deserve highlighting. On the "supply side" (upper left corner), the System's physical elements (platform heights and rolling stock) and fare collection procedure influence the crew size, the main factor affecting operating cost per train (upper center). This cost is critical for train frequencies, particularly during off-peak hours, which in turn has a major impact on passenger attraction (lower right) and thus on revenues and operating ratio.

Note that crew size is influenced by several factors, so that its reduction requires a coordinated set of improvements of all these factors, rather than in only one, as was the case on SEPTA's system with Autelca machines.

The main "demand" element, peak hour ridership (lower left box), is interdependent with peak hour train sizes and frequencies, which further interact
Figure 4.1 Basic interrelationships among possible improvements
Figure 4.2  Relationship of Regional Rail physical and operating elements
with platform lengths and heights, as well as with crew sizes and operating costs.

In addition to this "demand-supply-demand loop", another group of factors influences passenger attraction: quality of services and treatment of passengers (the three boxes in the bottom of the diagram). These factors may be considered as an "outside" influence, rather than elements of the closed loop, but they do have a major impact on passenger attraction (both peak and off-peak).

Many transit systems tend to underestimate this potential impact. SEPTA has demonstrated awareness of the importance of these factors and has achieved significant improvements in service reliability and, to some extent, integration of services. However, passenger information and marketing are still grossly inadequate and their improvements hold a great potential for ridership increases.

It is obvious that a development policy with technical standards for the Regional Rail System should be developed. This policy must be based on coordination of infrastructure, rolling stock and operational elements. For that purpose, the next three chapters, 5, 6 and 7, analyze all reasonable alternatives for improvements of, respectively, individual infrastructure, rolling stock and operating elements. In Chapter 8, a cost model is developed and used to evaluate several alternative integrated plans which consist of different combinations of system element improvements.

The analyses of Regional Rail System elements that should be upgraded. Particularly, their interdependences and formulation of integrated plans in Chapter 8, will be based on the conceptual flow charts, Figures 4.1 and 4.2. Based on the evaluation of alternative plans, recommendations with respect to the selected plan and strategy for its implementation are presented in Chapter 8.
Chapter 5

ANALYSIS OF INFRASTRUCTURE ELEMENTS

This chapter analyzes all infrastructure elements which directly affect train operating procedures and thus influence the quality of service and operating costs.

5.1 Platform Heights

Heights of station platforms influence passenger speed, comfort and safety of passenger boarding/alighting, as well as most operating elements (crew duties, dispatching process, operating speed and car design). Since platform heights represent one of the basic infrastructure elements, they have been given particular attention in this study.

5.1.1 Platform Types by Elevation

Based on their elevations relative to the top of rail (TOR), platforms can be classified into three types: low, medium and high. Figure 5.1 shows these platform levels in relation to the car cross-section and its steps; detailed dimensions of the platforms and steps are given in Figure 5.1, which also presents the present SEPTA platform height standards and those recommended in this report. The definitions and characteristics of the three platform heights are given here.

5.1.1.1 Low-Level Platforms. Platforms without a special structure, i.e. those with elevations between TOR and 8" (20 cm) above it, are referred to as low-level. The platforms with 8" (20 cm) elevations will be designated as standard low level; they reduce the first step from the highest rise of 15" (38 cm) to the smallest rise of 7" (18 cm).

Low-level platforms at TOR elevation are the simplest type, requiring
Figure 5.1 Present and recommended platform heights
little or no investment. They can usually be constructed with the fewest geometric constraints; sometimes, at stations located over street crossings of the tracks, street surfaces are used as TOR low-level platforms.

With respect to operations, low-level platforms involve ascending and descending over four steps with rises between 11" (28 cm) and as high as 15" (38 cm) when the platform is at TOR elevation. Therefore passenger movements are relatively slow, they require certain effort and may represent a safety problem. For older passengers or those with luggage, crew assistance is often needed.

The doors on SEPTA’s rolling stock cannot be closed until the trap is placed for high-level boarding. This is done manually by a crew member. Furthermore, an attendant is usually also required to supervise and assist in boarding and alighting at each pair of two adjacent stairways. Consequently, low-level platforms represent one of the main reasons for the present large crew sizes; train operation with low-level platforms is labor-intensive.

5.1.1.2 Medium-Level Platforms. These are platforms with elevations between 8" (20 cm) and 15" (38 cm) above TOR, i.e. between the standard low-level and the lowest step of the stairway on the Silverliner fleet.

Medium-level platforms represent a compromise between the simplicity and low investment cost of the low-level platform and the time and effort advantages for boarding and alighting with the high-level platform.

5.1.1.3 High-Level Platforms. These platforms have elevations equal to the car floor height, which is for SEPTA 48" (1.22 m) above TOR. Exceptionally, elevations down to one-step below the floor level, i.e., between 48" (1.22 m) and 40" (1.02 m), may be used.

High-level platforms, providing the highest operating performance and level of service for passengers, are standard on all rapid transit systems. Initially,
they were seldom used on regional rail systems because these were sharing most
lines and stations with long distance trains. With modernization of regional
rail systems and their gradual separation from long distance railroads, and in
some cases from freight train operations, high-level platforms are being
increasingly introduced. Several traditional commuter rail systems, such as New
Jersey Transit, Metro North and Long Island Rail Road, have upgraded many of
their stations, particularly on their heavily patronized lines, to high-level
platforms over the last 25 years.

High-level platforms are far superior to medium- and low-level types with
respect to operations (speed, boarding/alighting supervision and control),
passenger comfort and safety, accommodation of the handicapped, etc. Their
construction does, however, involve the highest investment, and in some cases it
must solve various physical constraints. The design must include provision of
stairways and ramps in addition to platforms themselves and, sometimes it
requires adaptations or reconstruction of station buildings or acquisition of
additional land; moreover, they cannot be built on street grade crossings. The
required investment thus depends not only on the size of the platforms and
station, but even more so on the local conditions and constraints.

Another problem with high platforms is mixed operation of regional rail and
freight cars: high-level platforms may intrude into the clearance envelope of
freight cars. There have been some recent design innovations that allow high-
level platform construction with dimensions that were previously considered
infeasible. Several solutions to this problem can be used:

i. Build platform edge far enough to allow freight car clearances. A gap
approximately 12" (30 cm) wide can be negotiated by passengers with care, but it
is not recommended for safety/liability reasons. (The platforms in the Airport
stations in Philadelphia have such large gaps. This was an error in the design because freight cars never operate on that line).

ii. Build solid platforms at the freight car clearance distance and add either folding or break-away (styrofoam) extension (overhang). Break-away edges are such that if an oversize freight car strikes them, the car suffers no damage and the edges can be replaced inexpensively. This design can permit the construction of platform edges closer than the current standard of 5'7" (1.70 m) from the center line of the track. It also permits deviation from the current standard which requires an additional 1" (2.5 cm) of clearance for every one degree of track curvature. (The design with folding edges has been used at the new Fern Rock station).

iii. Construct close solid platforms (concrete or wood) for good passenger safety and accommodation of the handicapped and prohibit on that line the passage of freight cars exceeding a strictly defined profile.

For the trackage shared with Conrail, the constraint may be oversize freight rolling stock which occasionally utilizes these lines. The trackage rights agreement between SEPTA and Conrail states that if SEPTA desires to build high-level platforms, "...Conrail will cooperate by reducing its standard clearances to whatever level is possible without causing a safety hazard or an unreasonable detriment to freight service, or a violation of existing governmental laws and regulations...". If any alterations or adjustments to the clearance profile are necessary, they must be performed at SEPTA's expense.

Construction of ramps for the handicapped is usually easier with high-level than with low-level platforms, because addition of such a ramp to a high-level platform has a lower marginal cost than the cost of an exclusive ramp. Consequently, the requirement that ramps for the handicapped must be built at
every station is a factor favoring construction of high-level platforms. The main factors are, however, the great benefits in the speed of boarding/alighting, door control, lower labor requirements and increased safety.

5.1.1.4 Present SEPTA's Station Platform Heights. As mentioned in Chapter 2, a vast majority of SEPTA's stations have low-level platforms with different elevations, some of them even below TOR. Presently, renovated stations are built at standard low level, i.e., 8" (20 cm) above TOR (sometimes referred to in SEPTA as "medium-level"), while new stations are usually built with high-level platforms. Only about a dozen stations, including the three major Center City stations and three Airport stations, presently have high-level platforms. Medium-level platforms are not used.

5.1.2 Differences Among the Three Platform Types

For a policy decision about the types of platform heights, it is important to carefully analyze the differences in their characteristics. They are presented and analyzed here.

5.1.2.1 Speeds of Passenger Boarding and Alighting. In order to estimate the benefits of high- as compared to low-level platforms with respect to station standing times, several field surveys were made in which boarding and alighting rates were measured. The surveys included stations with high- and low-level platforms during peak and off-peak hours. In addition, results of similar surveys performed by the Delaware Valley Association of Railroad Passengers (DVARP) were obtained and used for the analysis of standing times.

The survey measured the net boarding and alighting times, not including train standing time when no passengers were boarding or alighting. This was done in order to estimate the impact of platform heights specifically, because the time lost for opening and closing the doors may not be directly affected by the
platform height.

The results of these surveys are presented in Figures 5.2a and 5.2b and in Table 5.1. The first diagram is for predominantly boarding and the second for predominantly alighting process. The simple regression analyses gave the average time rates per person for boarding and for alighting as the slopes of the straight lines. The rates shown here are very similar to those obtained in the survey conducted by DVARP.

The boarding and alighting rates are generally higher for high-level platforms than for low-level platforms at moderate to heavy passenger volumes. The results indicate that high-level platforms result in a 19% decrease in boarding times and 37% decrease in alighting times. However, since there are fixed lost times due to door opening, uneven distribution to different doors and train dispatching, actual savings in standing times would be lower than the reported differences in net boarding and alighting times. The DVARP survey confirms this: it found smaller total train standing time savings than the observed net rates would indicate.

When there is a significant volume of both boarding and alighting passengers, the boarding times tend to be higher due to "friction" between the boarding and alighting "streams" of passengers. This is inherent in the design of the Silverliners, because the boarding passengers cannot see if there are people moving towards the doors to alight.

As the passenger volumes get higher, the boarding rate for high-level platforms tends to still follow a linear relationship. On the other hand, the rate for low-level platforms tends to be much more widely scattered and unpredictable already at relatively moderate volumes (beyond approximately 10 passengers per door). However, the average rate is approximately the same as for
Figure 5.2 Comparison of boarding and alighting rates for low- and high-level platforms
Table 5.1 Average time required for boarding and alighting: Comparison of low-and high-level platforms

<table>
<thead>
<tr>
<th></th>
<th>Low-level platform</th>
<th>High-level platform</th>
<th>Percent improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boarding time (sec.)</td>
<td>2.30&quot;/person</td>
<td>1.85&quot;/person</td>
<td>19.3 %</td>
</tr>
<tr>
<td>Alighting time (sec.)</td>
<td>2.34&quot;/person</td>
<td>1.48&quot;/person</td>
<td>36.6 %</td>
</tr>
<tr>
<td>Difference Between</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boarding and</td>
<td>-0.05&quot;/person</td>
<td>0.38&quot;/person</td>
<td></td>
</tr>
<tr>
<td>Alighting</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes:

(1) Data on low level platform are obtained from surveys conducted at Overbrook and Jenkintown on March 27, April 4 and 24, 1991.

(2) Data on high level platform are obtained from surveys conducted at Suburban Station on March 27, April, 1991.

(3) Average boarding and alighting times shown above are computed based on the observed relationships between the number of boarding and alighting activities (not the total standing time) For the boarding time, the cases with predominantly boarding activity (a.m. inbound trains) are used. For the alighting time, the cases with predominantly alighting activity (p.m. inbound trains) are used.
high-level passengers, at least for peak period riding populations. Thus, it is
easier to predict dwell times with high-level platforms. It should also be noted
that although there is scatter in rates for low-level platforms, the lowest
boarding rates (which were not factored into the regression analysis) represent
the cases when tickets are collected from passengers as they board.

The overall percentage of time saving cannot be expressed as a single
number for any given line, because this saving would vary greatly not only with
the number of boarding/alighting passengers, but also with the conditions of
departure control at every station. Generally, during off-peak times, when few
passengers board and alight, fixed time loss dominates and the amount of time
saving may not be very significant. However, during the peaks, when passenger
volumes are very high, and train standing times reach at certain stations 60, 90
or even 120 seconds, the increase in boarding rate due to high-level platforms
could be in the order of 15-25%. This magnitude of saving is very significant
for increasing travel speeds on the lines.

In conclusion, overall benefits which upgrading to high-level platforms
would bring with respect to station standing times would be significant during
the peak hours: train operating speeds could increase by approximately 5-15%'
along a given line, depending on the number of stations and lengths of
interstation spacings. During off-peak hours, time savings would be smaller, but
random delays due to slow boarders, such as children, elderly and persons with
luggage, would be decreased significantly. Thus, even when operating speed may
not be greatly increased, service reliability would become greater, which again
translates into speed increases through reduction of reserve times in schedules.
In some cases, a decrease in scheduled fleet requirements may be possible.

5.1.2.2 Passenger Comfort and Safety. Similar to the speed of
boarding/alighting, passenger comfort and safety are the highest for high-level platforms, and they decrease with the increasing elevation passengers have to negotiate.

With respect to SEPTA's Regional Rail System and operations, low-level platforms involve ascending and descending of passengers over four steps with rises from 11" (28 cm) to 15" (38 cm), depending upon a specific platform height. The first step is usually the highest. Therefore, passenger movements are relatively slow, they require certain effort and may represent a safety problem, particularly when the platform is slippery, if the train is not fully stopped, or when passengers carry luggage.

From a safety standpoint, the high-level platform is superior to low-level platforms, because most opportunities for mishaps on stairs are eliminated. A negative element may be if the gap between the car and the platform is excessive.

There is another very important element of safety to be considered. With the required ramps for the handicapped, there would be an increasing number of stations at which trains with raised traps and open doors pass by these ramps - a situation which has already caused fatalities. With high-level platforms this hazard is eliminated, because trains travel with closed doors.

5.1.2.3 Door Control and Train Dispatching. Operation with high-level platforms has fundamentally different door control and train dispatching than medium- or low-level platforms. High-level operation allows better visibility and trainlined control of doors along the entire train. With one person being able to open, supervise and close all doors, time is saved, safety is increased and the need for supervision of each pair of doors by a crew member is eliminated.

5.1.2.4 Access and Pedestrian Track Crossings. Pedestrian track crossings
and station access paths are essential elements for passenger attraction. Achieving safety, convenience and economy in provision of pedestrian track crossings is the subject of much discussion when reviewing the present conditions at Regional Rail stations.

There are three types of track crossings: at-grade crossings, overpasses, and underpasses. Table 5.2 shows both pros and cons of these three types of crossings.

Table 5.2 Comparisons of different types of pedestrian crossings

<table>
<thead>
<tr>
<th>Type of Crossing</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>At-grade crossings compared with grade-separated crossings:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ Require much lower investment cost;</td>
<td>+ Provide high pedestrian safety;</td>
<td>+ Provide high pedestrian safety;</td>
</tr>
<tr>
<td>+ Require the lowest maintenance cost;</td>
<td>- Involve high investment and maintenance costs;</td>
<td>- Involve very high investment and maintenance costs;</td>
</tr>
<tr>
<td>+ Involve much shorter path of travel;</td>
<td>- Have extremely long walking path;</td>
<td>- Level change and steps, although less than overpass;</td>
</tr>
<tr>
<td>+ No level change for climbing, no steps;</td>
<td>- Level change may be excessive for some people;</td>
<td>- Security, lighting and drainage problems;</td>
</tr>
<tr>
<td>+ Hence, the simplest crossing for the disabled;</td>
<td>- Elevator for the disabled required;</td>
<td>- Elevator or long ramps for the disabled required.</td>
</tr>
<tr>
<td>- Lower safety: there is a possibility of train-pedestrian accidents.</td>
<td>- There is a potential security problem.</td>
<td></td>
</tr>
</tbody>
</table>

These comparisons show that at-grade crossings are far more convenient and economical than grade-separated ones; virtually the only, but most important single factor favoring grade-separated crossings, is pedestrian safety. Thus,
wherever safety of grade crossings is adequate, grade separations should not be built.

Most of SEPTA's Regional Rail facilities are not fenced off to prevent pedestrian access and crossings; there are also numerous street grade crossings. Under such conditions grade-separated crossings are not only illogical to provide, but they would be simply ignored by passengers as well as by other people crossing tracks.

There are several conditions which affect safety and may influence the decisions which type of track crossings to provide. They are listed and discussed here.

a. Number of tracks: lines which have more than two tracks may represent a much higher safety hazard than 2-track lines because of the possibility that a crossing person gets caught in the "scissors" between two or more trains.

b. Train frequency and speeds: very frequent train passings make grade separated crossings more desirable. Even more so, high-speed intercity trains, such as Amtrak’s trains which may go at more than 60 mph (95 km/h), and even as high as 125 mph (200 km/h), cannot tolerate any grade crossings, street or pedestrian.

c. Passenger volume: large passenger volume is a contributing factor for grade separation of track crossings; however, it is usually not a sufficient factor: if train frequency is low, crossing at grade convenient, and visibility good, grade separation may not be justified even if passenger volumes are high, because most passengers would not use it.

d. Visibility and audibility: sharp curves and various factors which may prevent passengers from seeing or hearing approaching trains may increase the need for grade separated crossings.
e. Platform heights: low- and medium-level platforms make pedestrian crossings possible at nearly any location. High-level platforms can have pedestrian crossings only at the ends of platforms; their specific locations and design should be carefully determined for each station based on local conditions.

Depending upon the prior existence of tunnels or overpasses, conversion of low-level platforms to high-level may force the construction of these as well, as it will no longer be possible for passengers to simply walk across the tracks. In most cases the least expensive, yet adequate solution will be to provide grade crossing consisting of boards outside the ends of the platforms. On the other hand, if at-grade crossing is to be eliminated, the elevated platforms can facilitate enforcement of that prohibition.

f. Locations and number of crossings: Since the crossings are important links for pedestrian access through the station, the locations of crossings should be designed to avoid an excessively long path of travel. In order to minimize the travel distance, care must be taken to ensure the strategic placement of crossings, such as adjacent to the passenger loading zone, accessible parking spaces, or access platforms. At stations with heavy passenger volumes, more than one track crossing should be considered.

In conclusion, standards and criteria for different types of track pedestrian crossings will continue to vary among Regional Rail lines, their sections and individual stations. The three Amtrak corridors - Wilmington, Paoli-Downingtown and Trenton - are already grade separated and any pedestrian crossings at grade should be prevented. Along other lines, grade separations are necessary if one or several of the above factors justify them. If not, i.e., at most stations along typical 2-track lines in suburban areas, grade-separated crossings should be provided where terrain is conducive, and there are street
over- or underpasses. If such crossings are convenient, a fence between the tracks should be built to prevent pedestrian movements across the tracks (Swarthmore). In other locations, where none of the above safety problems exist, grade-separated crossings may not be justified not only because of their very high cost, but because the obviously unnecessary inconvenience they impose on passengers prevents their usage.

Incorrect decisions about pedestrian crossings have often been costly: an elaborate overpass requiring a climb and descent for a 20-ft (6.1 m) high bridge has resulted in major investments without any results: such facilities are often not used by anybody (e.g., the new overpass at Wallingford Station). Thus, they would not be justified even if unlimited funds were available.

Figure 5.3 presents the basic layouts of different pedestrian crossings recommended for various combinations of platform heights, train speeds, and passenger volumes.

5.1.2.5 Geometric Feasibility and Constraints. Reconstruction of the present low-level platforms to medium- or, particularly, high-level platforms requires careful analyses of potential geometric problems and constraints. Major aspects of this problem are discussed here.

The car body profile which determines the body clearance standard specified by SEPTA for its own vehicles is shown in Figure 2.5. This profile requires that edges of high-level platforms should be 5'7" (1.70 m) from the center line of the track, while the platform edges for medium- and low-level platforms can be only 5'1" (1.55 m) from the center line. The dynamic envelope of the current rolling stock used by any operator that shares trackage within the SEPTA system on its own tracks is within these dimensions.

At several stations existing physical conditions (station layout,
<table>
<thead>
<tr>
<th>Platform level</th>
<th>Passenger volume</th>
<th>Train speed</th>
<th>Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low &amp; medium</td>
<td>Light</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>Low or medium</td>
<td>Heavy</td>
<td>Medium</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>Moderate or heavy</td>
<td>Medium or high</td>
<td></td>
</tr>
<tr>
<td>Low, medium or high</td>
<td>Heavy</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.3 Different types of pedestrian track crossing
buildings, street crossings, etc.) would make construction of a high-level platform very difficult and expensive. In Jenkintown station, for example, platforms are in close proximity to a rather expensive building that would require major revision, or perhaps demolition, in order to permit high-level platform construction. There are numerous other older stations that would probably have to be reconstructed or demolished. Some of these are in poor condition and in need of major renovation, so that their demolition would represent a minimal loss. However, there are also many stations of considerable architectural, historic, and aesthetic value. Some of them could be easily adapted to high-level platforms, because they are elevated from tracks; others would require major changes.

5.1.2.6 Investment Costs. The best estimates of investment costs that could be obtained from several sources in SEPTA have been based on the data from recent station renovation and upgrading projects. Estimated and actual costs for high-level platforms experienced not only by SEPTA, but also by New Jersey Transit and ConnDOT for Metro North lines have been obtained.

In spite of considerable efforts to develop accurate cost estimates for different platform types, the assumed unit cost figures cannot be considered as highly reliable for several reasons. First, the obtained data are based on a limited number of construction projects, most of which do not include construction of high-level platforms; second, platform design, particularly length and width, as well as physical constraints, are rather site specific, affecting both unit and total cost values; and third, the estimates do not include any economies of scale (particularly prefabricated construction of high-level platforms), which would be used if entire rail lines were upgraded in a single, coordinated project.
For the purposes of this project, the estimated investment costs have been expressed as a sum of two different categories of items:

a. Costs of station upgrading required regardless of platform height and length, such as canopies, ramps for the handicapped, lighting, signing, railings (usually also needed for the standard low platforms), etc. The ramps for the handicapped have been assumed to have for a 4-foot (1.20 m) rise at 1:12 slope, resulting in one 48-foot (14.40 m) long ramp per platform. These costs were estimated to be $355,000 per station.

This amount includes rather high estimates for some items, so that many stations would actually require a considerably lower fixed cost than these numbers would indicate; the high estimates were adopted for the average values to compensate for the cases where physical conditions are restrictive, station building must be modified, or additional land must be required, all of which may involve higher than average investments.

b. Costs required for construction of a low- or high-level platform, which is expressed on a per-linear foot of platform length basis. This assumes that the central half of platform length, along the station building, is 10 ft (3.00 m) wide, while both outer quarter lengths are tapered to 6 ft (1.80 m). Thus, an average width of 8 ft (2.40 m) is adopted for the entire platform length.

The per-unit-length construction cost is estimated at $500/foot ($1,640/meter) for high level, and 20% lower, of $400/foot ($1,310/meter) for low-level platforms. Thus, the cost expressions for the upgrading costs of a station, including both platforms, are as follows.

For high-level platforms with length L [ft] or [m]:

\[ C \text{ [$/station]} = 355,000 + 1,000L \text{ [ft]} = 355,000 + 3,280L \text{ [m]} \]

For the standard low-level platforms:

5-18
\[ C [\$/\text{station}] = 355,000 + 800L \text{ [ft]} = 355,000 + 2,620L \text{ [m]} \].

These costs and some of their components are given in Table 5.3.

For a "typical" station with platforms for 4-car trains, assuming new cars (see section 5.2.1 for the derivation of standard platform lengths), the length is 345 feet (105 m), so that the total upgrading cost would be $700,000 for high- and $630,000 for low-level platforms.

Several decisions could influence the average station upgrading costs. First, instead of adopting a "network standard platform", dimensions of platforms should be determined for each line separately. It does not make sense to build 6-car long platforms at stations along the R-6 line because R-5 needs trains of that size. Some lines may need only 5, 4 or even 3 or even 2-car trains. This standard must be determined through an analysis of the present schedules and their possible adjustments. For example, if the line has only one pair of 5-car trains per day, it may be possible to change the schedule and increase frequency so that 5-car trains are replaced by more frequent 4-car trains. Future growth must, however, be anticipated and the new schedule must have sufficient reserve capacity to accommodate possible significant ridership growth. If the investment funds are extremely limited, it may be possible to build shorter high-level platforms along outlying sections of some lines.

Other possibilities for reducing costs of station upgrading include precast station platforms instead of locally poured ones; narrower platform widths; considerably shorter (minimum 2-car) platforms at lightly used stations: this would require announcements on the trains that passengers destined at these stations should be in, for example, the first two cars of the train; finally, wooden platforms would involve considerably lower costs than concrete ones.

Since platform lengths will vary among lines and even among stations along
Table 5.3 Estimated station construction costs for high- and low-level platforms

<table>
<thead>
<tr>
<th>Items</th>
<th>Cost ($)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signing, canopy, benches</td>
<td>$105,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Local extras</td>
<td>$150,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Handicapped ramps (1:12 slope)</td>
<td>$100,000</td>
<td>Per station</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$355,000</td>
<td>Per station</td>
</tr>
<tr>
<td><strong>Variable cost</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precast construction demolition, railings</td>
<td>Low-level: $400</td>
<td>Per foot of 8' wide platform</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-level: $500</td>
</tr>
</tbody>
</table>
some lines, costs will have to be estimated for each line, and they will be considerably lower than if the entire network would be designed with standard platform length, e.g., for 5- or 6-car train lengths.

5.1.2.7 Operating Costs. Regardless of platform type, operating costs of stations are very low because all of the components and structures are stationary. Those tasks that must be performed periodically, such as painting, preservation, and repairing of concrete, are largely independent of the platform type, particularly if platforms are designed specifically for low maintenance.

Consequently, operating costs should not represent a major element in comparative analysis of different platform types.

5.1.3 Selection of Platform Heights

It is obvious from the preceding analysis that platform heights represent the main infrastructure element which influences virtually all other elements: rolling stock design, efficiency of operations (door control and train dispatching), station dwell times and passenger comfort, as well as investment and operating costs. This element was therefore analyzed extensively.

5.1.3.1 Evaluation of Low-Level Platforms. Platforms at the TOR level or a few inches higher, prevalent on the system today, are unsatisfactory in many respects and their upgrading should be planned. The stations presently being reconstructed to 8" (20 cm) above TOR, referred to as standard low-level platforms, represent a significant improvement. The largest step of 15" (38 cm) is reduced to a 7" (18 cm) high step, which is even less than the heights of remaining steps. Operation of doors and traps remains the same as now.

5.1.3.2 Evaluation of Medium-Level Platforms. Considerable attention has been given in this project to construction of medium-level platforms, which would be 15" (38 cm) above TOR, i.e., flush with the lowest step on the cars.
Initially, it appeared that medium-level platforms could represent the optimal solution for some lines as a design which improves boarding/alighting over the present TOR-level platforms, but avoids the high investment and complexity of high-level platform construction.

A detailed analysis showed considerable potential for the usage of medium-level platforms as compared to the present TOR-level platforms (some stations even have elevations below TOR!). However, compared to the standard low level platform (8"/20 cm above TOR), medium-level platforms did not show significant advantages (the 15" step is eliminated in each case, but medium-level involves higher cost without bringing the significant advantages of high-level platforms. Consequently, medium-level platforms have been eliminated from further considerations.

5.1.3.3 Evaluation of High-Level Platforms. Comparisons of high-level with medium- and low-level platforms, respectively, are given here.

| The high- compared to medium-level platform has the following advantages (+) and disadvantages (-): |
| + Easier, faster and safer boarding/alighting; |
| + Provides access for the handicapped; |
| + Easier door supervision - reduces crew duties; |
| + Train dispatching becomes metro-type, so that it can be done by the engineer alone; |
| + Rolling stock is less complicated, lower cost; |
| - Requires somewhat higher investment; |
| + Involves more design/geometric difficulties to be solved. |
The features of the high-level compared to those of low-level platform can be summarized as follows:

+ Eliminates steps on the cars, resulting in:
  - more comfortable boarding/alighting - thus greater attractiveness for passengers
  - faster boarding and alighting rates
  - handicapped access to train from platform is immediately available
  - highest safety while boarding and alighting;
  + Deters track crossing where it is unsafe or undesirable;
  + Allows positive, train-lined door control;
  + Easier to reduce crew size;
  + Conducive to metro-type operation;
  + If new rolling stock is used, simplifies car design;
  - Investment cost is much higher compared to present platforms; somewhat higher than newly built low-level platforms;
  - May meet with expensive or construction difficulties with existing infrastructure or clearance requirements;
  - May limit platform length possible if a road crossing is in the vicinity;
  - Prevents track crossing where it is safe or desirable.

Briefly summarized, high-level platforms require a considerable investment, although not much higher than reconstruction to the standard low, 8" (20 cm) high platforms. They involve more complicated design, sometimes necessitate additional adaptations of buildings, accesses, or even some land acquisition. However, their operating advantages are very significant. Higher passenger comfort and safety represent advantages, but not sufficient to justify the additional investment. Faster boarding/alighting is desirable and under certain conditions a very significant factor. Moreover, an extremely important benefit
is the safer train dispatching and ability to handle all station procedures by one person for the entire train. Train travel with closed doors is another valuable feature.

To reach the final policy decision on platform standards, these advantages must be weighed against the additional investment costs. The estimated average investment costs for upgrading stations and construction of the standard low-level and high-level platforms of $630,000 and $700,000, respectively, will be used in further comparative analyses of alternative plans.

5.1.4 Alternative Strategies for Upgrading of Stations

There are several possible strategies for upgrading stations, particularly raising platform levels. These may be categorized as:

i. Status quo: continue with limited gradual upgrading to standard low- and, sometimes, to high-level platforms;

ii. Gradual replacement of low-level with high-level platforms;

iii. Quick replacement of low-level platforms with high-level platforms;

Each one of these strategies will be briefly analyzed.

5.1.4.1 Continuing Status Quo. Retaining the present station designs and only renovating them, usually with old designs, is the least cost option (and therefore may be considered by some as "the most realistic"). However, that option is not a solution to many present Regional Rail System's shortcomings and inefficiencies. As long as low-level platforms are kept, it will be impossible to improve passenger boarding/alighting processes, to reduce crew duties, to make more frequent services economically feasible, etc. It should also be mentioned that the ADA requirements have increased the costs of the "Status quo" option and thus somewhat reduced the additional costs needed by the high-level platform options.

5.1.4.2 Gradual or Quick Upgrading to High-level Platforms. Although quick
replacement would result in sooner realization of benefits from such upgrading, there are several reasons for gradual implementation. First, it requires a more gradual flow of investment expenditures. Second, planning, design, construction and management capacity can be deployed more efficiently in an effort that takes 2-5 years, rather than if it is forced as a single short-term effort. And third, gradual implementation allows upgrading line by line and introduction of the new type of operation on individual lines. Thus, experimentation and experience from construction and new operation would be obtained for later lines, while investment into any one line could be immediately utilized.

It is therefore logical that station upgrading be implemented in a line-by-line sequence.

5.1.5 Uniformity of Platform Types along a Line

With the existing rolling stock, a combination of any platform heights can be used on any line, although every change between low- and high-level platforms requires manual change of the trap plate by a crew member. Therefore changes of platform heights along any line should be minimized. Actually, construction of a high-platform at a station between other low-level platform stations creates two additional operations by the crew; this labor-intensive operation should always be avoided.

In order to prevent this problem, the logical manner for conversion is to either convert several contiguous stations to the same platform height simultaneously, or to gradually convert stations that are at the end of a chain of stations with the same heights. For example, on the western leg of R-5 Overbrook Station would be the logical one to convert first to high-level platform, because it is next to the three Center City high-level platform stations; high-level platform construction should then follow at Wynnewood,
Narberth, and subsequent stations.

If a new rolling stock is used that is suitable only for one type of platform, then it is necessary that the entire line be converted at once with the introduction of the new rolling stock.

5.2 Platform Lengths and Widths

SEPTA's Regional Rail, like most older regional rail systems, has many outlying stations with platforms of variable lengths and widths, many times without clear delineations: they sometimes "fade out" toward their ends. Upgraded stations, regardless of platform heights used, should have clearly defined dimensions - lengths and widths. Therefore, standards for these dimensions will be developed here.

5.2.1 Platform Lengths

Platform lengths depend on the maximum length of trains which operate on the given line, length of cars and positions of doors. Thus, standards must be adopted for all train lengths from 1 to 6 cars. Platforms for single car trains will be used only exceptionally, but the values from 2 to 6 cars may be applicable to different lines or their segments.

Platform lengths are defined for two different types of rolling stock: the present (Silverliners and Bombardier) and recommended with quarter-point doors (see Chapter 6). Computation of lengths for each type are shown in Fig. 5.4. For each vehicle type the maximum length between the farthest used doors is taken and an additional distance for train stopping tolerance is assumed. This distance is 30 ft (10 m) for 1- and 2-car trains, and 45 ft (15 m) for longer trains.

It can be seen in the Figure that for the existing rolling stock two different dimensions are established: minimum, which assumes that the last door
Desirable Minimum

a. Silverliner rolling stock

b. New rolling stock (quarter-point doors)

Figure 5.4 Derivation of platform length standards
on the train is not used (which is a frequent practice), and desirable, when all
doors except the first, at the engineer's vestibule, are used. These two
standards for all train lengths of the present cars are shown in Figure 5.5.

With the new rolling stock all doors will be used, and the same stopping
tolerance distances are used. Platform lengths for all train lengths of new
stock are shown in Figure 5.6.

If the values in these two figures are compared, one can see that the new
rolling stock requires somewhat greater platform lengths than the present stock.
The relationship between the dimensions for the present and new rolling stock,
shown in Figure 5.7, is such that if the dimension for an n-car train of new
stock is adopted, it could also accommodate (n+1)-car long train of present
rolling stock.

To apply these standards to individual Regional Rail lines, the longest
trains have been found for each line section and direction, as well as the number
of such trains per day. This information, plotted in Figure 5.8, is used as the
basis for adoption of recommended platform lengths for all lines. In adopting
the "design train consists", the present maximum values are used, except for the
lines on which there is only 1 or 2 trains with maximum consists; in these cases
one car shorter consists are used because it is recommended that the longest 1-2
trains be shortened and additional capacity be provided through schedule
adjustments.

Table 5.4 presents a summary of recommended platform lengths for each
Regional Rail line, R-1 to R-8. The recommended standards do not provide for
possible increase in maximum train consists because it is recommended that
additional capacity, when needed, should be provided by headway reductions,
rather than by consist increases. Only in the cases of three lines, R-3, R-4 and
Figure 5.5 Platform lengths for the Silverliner rolling stock
Figure 5.6 Platform lengths for the new rolling stock
Figure 5.7 Diagram of recommended platform lengths

5-31
Figure 5.8 Maximum train consists on individual line sections.

Schedule effective October 29, 1990.
Table 5.4 Design train consists and recommended platform lengths by line

<table>
<thead>
<tr>
<th>Line</th>
<th>Current maximum train consist</th>
<th>Number of max. train consists/direction</th>
<th>Design train consist</th>
<th>Recommended platform lengths</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>2</td>
<td>All</td>
<td>2</td>
<td>160 ft. (50 m.)</td>
</tr>
<tr>
<td>R2</td>
<td>4</td>
<td>1/3</td>
<td>4</td>
<td>345 ft. (105 m.)</td>
</tr>
<tr>
<td>R3</td>
<td>5</td>
<td>2/2</td>
<td>4 (5)*</td>
<td>345 ft.* (105 m.)</td>
</tr>
<tr>
<td>R5</td>
<td>5</td>
<td>7/6</td>
<td>5 (6)*</td>
<td>430 ft.* (131 m.)</td>
</tr>
<tr>
<td>R6</td>
<td>4</td>
<td>2/1</td>
<td>3 (4)*</td>
<td>260 ft.* (80 m.)</td>
</tr>
<tr>
<td>R7</td>
<td>5</td>
<td>3/4</td>
<td>5</td>
<td>430 ft. (131 m.)</td>
</tr>
<tr>
<td>R8</td>
<td>4</td>
<td>5/5</td>
<td>4</td>
<td>345 ft. (105 m.)</td>
</tr>
</tbody>
</table>

* Additional ("ultimate") length of 85 ft. (26 m.) can be constructed in order to meet increased projected demand in the future.

** The platform lengths that correspond to the number of cars per train is shown in Figure 5.6.
R-5, it is recommended that, if possible, one car length should be added, or at least, land for possible future platform extension, be reserved.

These somewhat "frugal" standards are recommended because of the need to achieve the greatest possible effectiveness for investment funds which are yet to be obtained. It is considered much more important to reach the upgraded system operation as soon as possible, than to delay it by providing designs for an "ultimate size" system.

Another option for minimizing the required investment for construction of high platforms, as mentioned in section 5.1.3.3, is to provide shorter lengths on some outlying line sections and use only the first 2-3 cars of the trains on those sections; this practice, although not ideal, is used on some lines now without major problems. Through signing and announcements passengers on outbound trains are informed that for outlying stations they should use only the first 2 cars, for example. On the inbound trains no such announcements are necessary.

5.2.2 Platform Widths

Platform width, together with its length, determines total area for passenger access, waiting, circulation and departure, and hence it must be designed mostly for passenger safety and convenience, as well as with consideration for emergency evacuation. At least, platforms should be wide enough for a person with children or strollers, or in a wheelchair, to await a train without causing an obstruction for other passengers.

Generally, two types of criteria may govern determination of station widths. First, if passenger volumes are low, the minimum dimensions providing for passenger movements and safety govern. This is achieved by 6-foot (1.80 m) wide platforms, or, at extremely restricted locations, 5-foot (1.50 m) wide platforms. And second, where passenger volumes are substantial, the central part
of the platform may be widened to 8 or 10 feet (2.50 or 3.00 m). If there are stairways, ramps or other major fixed objects, they should be outside of this dimension.

For stations expected to have very large passenger volumes, special design analysis must be made to determine platform dimensions.

In addition to these factors, availability of the land, location of supporting facilities, such as stairs, pedestrian crossings, P+R areas and station accesses should also be taken into account. Cost analysis related to the width was discussed in section 5.1.2.6.

5.3 Other Considerations in Platform Design

Several general comments about the role of standards, platform design procedure and strategy are in order here.

5.3.1 The Types and Role of Design Standards

Standards with respect to platform dimensions could be set at several levels:

a. Network-wide standards, valid for all stations. These standards are typically used for new systems planned as total coordinated networks, such as BART. In the case of SEPTA's Regional Rail System, such standards apply to rolling stock dimensions and clearances, various operating rules and practices, etc. However, with respect to station dimensions, particularly station lengths, adoption of a single standard for the entire network would be irrational and highly wasteful.

b. Standards by line should be the most logical ones for station platform designs. The reason is simple: each line is served by the same sizes and maximum consists of trains. Standards may vary considerably among lines (platform lengths may be from 2 to 6 cars).
c. Standards by track direction (inbound/outbound) is a very common design practice on regional rail systems due to the high directional imbalance of their passenger flows. The lines are already designed with distinct differences between the "inbound" and "outbound" platforms: the former is larger, with station building, more extensive information, etc., because it serves large volume of waiting passengers starting their daily trips; the latter must accommodate mostly departing passengers who need only minimal facilities.

d. Standards by line section; differences in design standards on different sections of individual lines are usually not desirable because they tend to involve changes in operations at certain points along a line (shortening of trains, blocking of cars). Yet, SEPTA has on the Ex-Reading side a typical trunk/branch network on which some station standards may differ; for example, longer platforms may be needed from Center City to Jenkintown then on some of the three branches beyond that station.

e. Standards for individual stations actually do not represent standards, but imply considerations of local conditions at each station and individual, custom design. Many items at stations must be treated on this basis. This is particularly the case in designing high-platforms which may consider preservation or modification of historic station buildings, environmental aspects and other local neighborhood considerations.

5.3.2 Accommodations for the Disabled

Careful considerations must be given to the accommodations of the disabled (handicapped) in the designs of all stations. Some basic elements have been included in this project, as they affected the standards, costs and other decisions. Major ones are as follows.

- Ramps for the disabled must be built from TOR to the car floor level,
i.e., a grade change of 48" (1.20 m), at a 1:12 slope; thus, the ramps should be about 50 feet (16 m) long.

- Special ramps for the disabled with miniplatforms, which exist at several stations, have proven to be highly hazardous with the present low-platform operations; there have been several fatalities of conductors who were standing on train steps. High-level platforms will eliminate this hazard.

- High-level platforms will in most cases involve lower incremental costs for the disabled accommodations than the present miniplatforms do because only the ramps will be required; moreover, the requirement that the train stops precisely at the miniplatform will be eliminated, reducing time losses for trains. Therefore, the ADA requirements represent another significant element favoring construction of high-level platforms.

- In determining platform widths, special consideration for the handicapped includes the requirement that a person using a wheelchair needs at least a 36 inch wide path to be able to pass between two fixed objects, such as structural columns or benches. Platform slope can be potentially hazardous to a person using a wheelchair. It should therefore be as flat as possible, preferably not exceeding 2% slope.

Details of standards for the handicapped exist in government manuals. Yet, upgrading of the Regional Rail System faces some potentially very serious problems which demand careful attention. The problem is the provision for major track crossings. At stations with two tracks a carefully designed pedestrian at-grade crossing made of wooden boards is adequate for the handicapped. However, for crossings of high-speed and multitrack lines, such as the three Amtrak corridors (R-2 west, R-5 west and R-7 west) this solution is not feasible.

Construction of elevators for the handicapped has been mentioned as a
possible solution at these stations. This is actually not feasible at nearly any station for several reasons. First, the investment cost of such elevators (going to elevations above the lines’ catenaries) would be so exorbitant, that their inclusion in the upgrading plan could easily make the entire plan infeasible for financial reasons. Second, operation of such elevators would be extremely costly. And third, unlike rapid transit systems with enclosed stations, the Regional Rail is an open system without positive control of stations; operation and protection of facilities such as escalators in the open would be completely out of character with the system’s setup, operations and control.

Fortunately, stations along the Amtrak’s corridors already have grade separated crossings, mostly underpasses. The solution for the handicapped will thus in most cases be to provide the needed ramps to those underpasses.

It is pointed out that meeting the ADA requirements on the Regional Rail System may be not only expensive and wasteful, but actually destructive for the entire project, as has already been the case at 30th Street Station where the special pedestrian connection between Amtrak and SEPTA’S subway station was prevented due to unreasonable interpretation of the ADA requirements. If rational solutions are not found, Regional Rail System upgrading may be prevented and the System may be doomed to retain its present inefficiencies and underutilization of its potential role in the Philadelphia Region.

It is therefore recommended that a special project be undertaken to reach policy decisions and develop further design guidelines for the ADA requirements, so that the potential damage to the entire Regional Rail System upgrading plan is prevented.
This section summarizes the characteristics of rolling stock directly relevant to the design and operational features of stations and of the RGR System in general. Based on the evaluation of the present rolling stock in section 2.3, the features of the stock that need improvements are defined and general features of a new EMU car that would meet the requirements of an upgraded regional metro system are defined. Finally, some cost estimates for the new stock are presented.

6.1 Improvements of Individual Features

Some features of the present stock - the Silverliners and Bombardier cars - will have to be changed if the RGR System is to be upgraded to the regional metro type of operation. The major features related to the upgrading of platforms, fare collection and other operational elements are described here.

Doors and steps used at present represent the slowest possible method of boarding and alighting passengers. Single-channel doors at car ends, doors to the vestibules and four high steps very often cause long standing times which defeat the superb dynamic characteristics of the Silverliners. Consequently, the next generation of vehicles must have a drastically different design of doors and loading areas.

The future cars should have two double-channel doors located at quarter points of the car length. This will increase door capacity by a factor of 2 and sometimes 4 (when only one door on a Silverliner is used). Moreover, convenience and speed of entry/exit will increase because of far better collection/distribution of passengers inside the vehicle. As the diagram and expressions
in Figure 6.1 show, the longest distance passengers have to pass from the doors is now equal to the interior car length, \( L \); in the new design that would be decreased to \( L/4 \).

The benefits from the new door design and arrangement is illustrated in Figure 6.2. The same number of passengers has shorter access distances to doors and boards much faster with the new than with the present door setup, so that standing times can be substantially decreased.

Another problem with the present doors is that they cannot be centrally controlled nor closed when the train serves low-platform stations (which is a great majority of the RGR network). If station platforms are retained as they are now, the new cars should have movable steps which are automatically lowered or raised, depending on the type of station. This type of mechanism, shown in Figure 6.3, exists on many light rail transit systems (e.g., the San Francisco Muni), but it is complex, prone to operational problems and it involves higher purchase and operating costs of vehicles.

By far the best solution for this problem will be if high-level platforms are constructed, so that steps are not required at all. The doors are then much simpler, their control is easily centralized and trains travel always with closed doors.

The diagram and sketches in Figure 6.4 show the gap between the car door edge and high platform edge as a function of curvature (radius or degree) for three door locations: at car center, at its ends, and at quarter points. It shows that quarter-point doors have medium values between the center and end doors and are less critical when both platforms, in inside and outside curves, are considered.

*Internal layout* for the future cars is shown in Figure 6.5. A major change

6-2
<table>
<thead>
<tr>
<th>Rolling stock</th>
<th>No. of channels</th>
<th>Seats/2 cars</th>
<th>Max walk</th>
<th>Layout</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td>3</td>
<td>60 - 120</td>
<td>$L, L/2$</td>
<td><img src="image" alt="Diagram for Present" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3 channels</td>
</tr>
<tr>
<td>Recommended</td>
<td>8</td>
<td>30</td>
<td>$L/4$</td>
<td><img src="image" alt="Diagram for Recommended" /></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8 channels</td>
</tr>
</tbody>
</table>

Figure 6.1 Comparison of car door designs: car ends vs. quarter points
Train arrives

Passengers board

Train departs

a. The present cars: 8 to 10 persons per door channel, standing time 40s.

Train arrives

Passengers board

Train departs

b. Recommended cars: 2 to 3 persons per door channel, standing time 20s.

Figure 6.2 Conceptual presentation of the passenger boarding process with present and recommended door configurations
a. Possible vestibule design at quarter point doors with movable steps

b. The mechanism for automatically movable steps

Figure 6.3 Design details for doors with automatic steps
Figure 6.4 Car-platform gap as a function of curve radius for different door locations.
For high platforms only

No steps

Ticket cancelling machine

For different platform heights

Movable steps

Option:
*Facing seats at ends

Alternative 2:
*Open driver's seat
(Lindenwold line)

Alternative 1:
*Folding door cabin
(Broad Street Subway)

Figure 6.5 Internal layout of the recommended car
should be that instead of the present vestibules, which take considerable area, require doors and separate the engineer from passengers, the entire interior should be open. Engineer’s position should be in the front right corner without full separation, similar to that on PATCO cars. Should a separation for the engineer be required, it could be designed as a folding wall, similar to that in the Broad Street Subway cars.

Replacement of the vestibule by a seat within the overall passenger compartment would greatly contribute to the feeling by passengers of the presence of a crew member. This would be a significant step to train size crew reduction. Experiences from other transit systems show that such an arrangement is not only feasible, but also very effective for train operation, door control and contacts with passengers.

Areas around the doors at quarter points can be vestibules that allows luggage, strollers, etc., to be more conveniently loaded and stored; short distance riders can stand without obstructing the flow. Such a design would entail foregoing one or two rows of seats, but would still provide the same or more capacity, only that some of it would be for standees. If the end vestibule is eliminated, that area can be used for seating, compensating for the loss at quarter-point vestibules. This would be in keeping with practice at virtually all modern regional rail systems, except those running at very high seated loads (using double-decker cars for long-distance commuting, for example).

The entrance vestibules should also allow positioning of small ticket-canceling machines, so that passengers may easily use them upon entry.

The entrance area, as well as the aisles, should have vertical stanchions, allowing short distance passengers to stand comfortably with that support. One of the reasons most passengers now resent standing is that there are no
stanchions which they could use for stability, comfort and safety.

**Passenger information**, including signing of train destination on the front and at all train doors, should be an important innovation which is presently virtually non-existent. Inside the cars there should be a network display (as it is now), and a detailed diagram of the respective line. Forthcoming station should be regularly either announced or displayed.

**Car aesthetics** should also be improved considerably. The Silverliners are distinctive by their purely functional design, i.e., by their total lack of any distinction! These vehicles are basically unattractive aesthetically and thus a poor marketing tool and image maker. All RGR vehicles except the push-pull locomotives have a "face-less" front end, very small windows, and totally inadequate destination signing.

The new cars should have larger windows, better car end designs (without hanging chains), some color schemes or other features that are attractive and give the cars a strong image.

**Car couplers** should allow easy and highly reliable coupling/uncoupling with remote controls.

**Propulsion, various equipment and body construction** of the new cars should be considerably improved over Silverliner IVs, which have extra weight due to the unused equipment for dual propulsion. Actually, the Silverliner IV is (along with the Cosmopolitan design in service with the MTA with which it shares some common components) among the heaviest regional rail EMU rolling stock per unit floor area in the world. Heavy weight results in consumption of relatively large amounts of electricity to achieve the high rate of acceleration required for the frequent stopping regime in which the car operates.

In the new cars contemporary propulsion technology, most likely AC type,
would be used to reduce maintenance effort required. More efficient aggregates would be used, such as static inverters instead of rotating machinery for generation, to reduce stationary energy consumption.

Simpler propulsion equipment, absence of steps and many recent innovations in electric propulsion, such as AC drive, static inverters, diagnostics, etc., should make the cars considerably more efficient.

Figure 6.6 shows the Silverliner IV and another RGR type of car as an illustration of the proposed door arrangements (other features of the shown car may not be relevant to this discussion).

6.2 Cost Estimates

Based on recent purchase prices for similar rail cars, it is estimated that the new cars with automatically movable steps would cost about $2.4M, while those without steps would cost 2.2M per vehicle.

It is estimated that lower weight and improved propulsion should result in energy and maintenance costs amounting to approximately 70% of the Silverliners' costs.

If new cars are not purchased, there will be a need to perform general overhaul of Silverliner IVs in the near future. The overhaul is estimated to cost between $600,000 and $1,500,000 per car, depending on the scope of car rebuilding and retrofitting; the specific rebuilding program would also determine whether it would have a significant impact on later car operating and maintenance costs. For the computations in the system cost model, a value of $800,000 will be used for car overhaul.

6.3 Conclusions

For a convenient review, a summary of the recommended features for the new
a. Silverliner IV

b. An example of regional rail cars (Helsinki) with some proposed features

Figure 6.6  Regional rail rolling stock design
rolling stock and comparison of new cars' estimated capacity is presented in Table 6.1.

There are strong arguments that a set of new cars should be purchased to provide off-peak services. The main reason is that a number of features needed for upgrading the entire RGR System's operation would be obtained through the new rolling stock. Such features as increased door capacity, centralized control, placing the engineer closer to passengers, provision of space for canceling tickets, etc., cannot be obtained with the existing stock, unless it would be extensively rebuilt and retrofitted.

Naturally, the main problem with purchasing new cars would be the question of funding. However, the fact is that while the new cars would require a significant investment, they would result in a very significant reduction of operating expenses. Analyses that are presented in Chapter 8 indicate that over a period of some 15 years purchasing new rolling stock results in a saving which under many conditions would cover the initial investments.

Consequently, the option of purchasing new cars for off-peak services is an important component of the plan to upgrade the Regional Rail System and its financial evaluation is quite favorable when the initial high investment is considered together with the savings in operations which would be accrued over a period of 15 years.
Table 6.1 Important features of the new rolling stock

* Doors - 2 x 2 channels, located at quarter points;
* Doors - automatic, self-service opening, trainlined for closing;
* Driver’s cab with passage, or Washington Metro-type with folding wall; no end vestibule;
* Space for ticket cancelling machines;
* Better aesthetics, bigger front-end and side windows;
* Amtrak and REA standards compatibility;
* New couplers
* Option: automatic movable steps with three positions: for high, medium and low platform;
* Performance assumptions over a 15-year life:
  - 70% of Silverliner’s energy consumption - lighter vehicle, AC drive, and better engineering;
  - 70% of Silverliner’s maintenance costs - AC drive, static inverters, diagnostics, but more complicated doors and stairs;

<table>
<thead>
<tr>
<th>Item</th>
<th>Silverliner IV</th>
<th>New cars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seats</td>
<td>120</td>
<td>SU: 104; MP: 110</td>
</tr>
<tr>
<td>Total Passengers</td>
<td>180</td>
<td>SU: 180; MP: 200</td>
</tr>
<tr>
<td>Door Channels</td>
<td>2 (1)</td>
<td>4</td>
</tr>
<tr>
<td>Seats/Channel</td>
<td>60 (120)</td>
<td>SU: 26; MP: 27</td>
</tr>
<tr>
<td>Spaces/Channel</td>
<td>90 (180)</td>
<td>SU: 45; MP: 50</td>
</tr>
</tbody>
</table>
Chapter 7

OPERATIONAL ELEMENTS

This chapter covers two major operational elements of the proposed upgrading of the Regional Rail System: fare collection and crew sizes. The two are mutually interdependent, and their efficiency can be greatly increased when the proposed infrastructure and rolling stock upgrading is implemented.

7.1 Fare Collection

In recent years SEPTA has introduced a number of changes in fare collection procedures, most of them aimed at reduction of duties for crews. Prepaid tickets and, particularly, monthly and weekly passes, have simplified the supervision of fare payments. Higher fares for on-board payments have further induced passengers to prepurchase tickets.

Yet, fare control and collection still remains one of the most important and most time-consuming duties the crews must perform. Thus, fare collection often dictates the sizes of crews and prevents their reduction. Consequently, the present fare collection procedure must be changed if the crew sizes are to be reduced; without this measure, labor cost per train-mile (-kilometer) remains very high and makes operation with very long headways necessary for cost reasons.

7.1.1 Analysis and Selection of the Fare Collection Method

To develop a more efficient method of fare collection, it is useful to make a systematic analysis of the fare structure, requirements for fare collection and control, and practical possibilities for their implementation.

The fare structure on SEPTA's Regional Rail System has been simplified in recent years (fewer zones, all fares in multiples of 25 cents). However, this simplification has probably reached its maximum. Because of the extensiveness of the Regional Rail network, the fares must remain graduated. That type of
fares requires a more complicated control than flat fare. Each passenger must be checked twice to ensure that he/she has paid the correct amount.

The best way to control graduated fares is therefore to have a "closed" system, where each passenger is checked entering and exiting the station gates. A second possibility, when the system is not physically closed and fully controlled, is that the control is made twice during the travel. This increases the work of the crew.

The third possibility is self-service fare collection (SSFC), which eliminates the need for double and even for a single control, thus virtually eliminating this duty from the crew. SSFC replaces positive control (manual/visual inspection of each passenger's payment) by a random ("spot-check") control.

The spot-check control is performed by one or two controllers who enter a train at random times, check all passengers' tickets and issue penalties if any passenger does not have a valid ticket. Frequency of control varies with circumstance, but they usually cover 3-8% of the trips.

Transit operators in most U.S. cities were extremely skeptical about introduction of SSFC. Although this type of fare collection has been successfully used in many European cities for over 20 years, U.S. transit managers tended to believe that cheating on fare payments would be out of control in our cities.

After careful planning, SSFC was introduced in several U.S. cities and has now been in use for over 10 years. Most light rail and some bus systems use SSFC. Introduction of SSFC requires some preparations: ticket issuing and validation usually has to be modified; public education must be performed; several controllers must be employed; finally, certain cheating does exist.
Yet, the experiences from all cities which have used SSFC have shown that this method is not only feasible, but it has many advantages over the conventional fare collection and control methods. Revenue losses due to cheating are far lower than initially feared, particularly when one considers that some revenue losses exist also today. Control function requires additional employees, but their costs are far lower than the savings achieved by reduction of crew members. Elimination of delays caused by fare collection is an additional benefit.

The character of the Regional Rail lines is such that SSFC introduction represents a very logical innovation: these lines have no overcrowding, the public could be easily introduced to the system, and the savings due to crew reductions (assuming other upgrading measures are also introduced) would be substantial.

7.1.2 Options for Implementation of SSFC

Presently there are three types of fare payments:

- **Pass** (weekly or monthly), which is purchased at station or off the transit system (by mail, through payroll, etc.). Passes allow unlimited travel within their specified term of validity; thus, they are inspected visually, but require no validation or cancellation.

- **Ticket**, purchased at station (booth or vending machine), which the conductor (or PA) cancels and collects.

- **Cash** payment on board train, collected by the conductor, who issues a canceled receipt.

These present procedures of fare payments, validations and inspection are presented according to the place of each activity (at stations or on-board trains) in tabular form in the upper part of Table 7.1.
Table 7.1 Present and future fare collection procedures

<table>
<thead>
<tr>
<th></th>
<th>At station</th>
<th>On-board</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Present:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass:</td>
<td>Purchase</td>
<td>Inspect</td>
</tr>
<tr>
<td>Ticket:</td>
<td>Purchase</td>
<td>Cancel (manual)</td>
</tr>
<tr>
<td>Cash:</td>
<td></td>
<td>Purchase, Cancel</td>
</tr>
<tr>
<td><strong>Future:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pass:</td>
<td>Purchase</td>
<td>Spot-check</td>
</tr>
<tr>
<td>Ticket:</td>
<td>Purchase</td>
<td>Spot-check</td>
</tr>
<tr>
<td>Timed-ticket</td>
<td>Validate (machine)</td>
<td>Spot-check</td>
</tr>
<tr>
<td>Purchase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash:</td>
<td></td>
<td>Purchase</td>
</tr>
<tr>
<td>Timed-ticket (machine)</td>
<td>Spot-check</td>
<td></td>
</tr>
</tbody>
</table>
All of these fare payments are checked by the conductor not only once; because the fares are in different amounts (according to the zone(s) travelled), the conductor should check them for each zone. Since this is impractical, the inspection is not done rigorously and it is not fool-proof. Fare evasion or underpayments are not frequent, however, because of the travel patterns: on most lines the cumulative travel allows easy control of the vast majority of passengers in the first zone, and only a quick inspection in outer zones.

For SSFC, passes can be handled in the same way as now, only their inspection will be on a spot-check basis, rather than as regular control. For the tickets there are two basic options involving two different procedures for payment and validation.

The first option is that the tickets, which are purchased at stations, at booths or from vending machines, are timed: their time of purchase is printed on the ticket and they are valid for, say, 90 or 120 minutes after that purchase. Whether they are checked by the controller or not, their validity expires after that ride or after the prescribed length of time.

The second option is that tickets are purchased without any time cancellation. They are valid for use at any time during the following 3 or 6 months, as is the case with SEPTA’s tickets now. However, for the trip when the ticket should be used, it must be canceled or validated for that particular period of time. The validation is usually done in a small machine aboard the train by the passengers when they board. Again, the tickets may then be checked by the controller or not, but after that period their validity expires.

The cash fare on-board trains will be possible only if vending machines are provided on the train. The tickets purchased would either be timed, or they would have to be canceled in a validating machine, also on-board the train.
These fare collection procedures and different options of ticket sales and validation are presented in the lower part of Table 7.1.

Naturally, further analyses and planning of these fare collection procedures will be necessary. However, it is obvious that either one of these systems is physically and operationally feasible. Regardless of which procedure is adopted, the change from the present positive checking of all fares to only a spot-check type control will greatly diminish the duties of the crews and allow significant reductions of crew sizes, as is further explained in the following section.

7.2 Crew Duties and Crew Sizes

The required crew sizes on the Regional Rail trains are mostly dictated by the features of the infrastructure (especially platform height and length), the rolling stock, as well as by fare collection and other operating practices. The present crew sizes and their duty assignments will be reviewed here, focusing on the possibilities to reduce the sizes as different steps of system upgrading are implemented.

The main reason for reducing crew sizes is to achieve lower operating costs per train-hour, so that increased frequency of service, crucial for generation of additional ridership (and revenues) can be introduced with only moderate cost increases.

7.2.1 Present Crews and Their Duties

The on-board Regional Rail train crews consist of a minimum of two persons, the engineer and the conductor. As the consist gets longer, additional crew members - passenger attendants (PA's) - are assigned to provide assistance to the conductor. The conductor trains and supervises the attendants, and has overall responsibility and authority aboard a train. In addition, there are station,
terminal and yard employees who are supposed to help the on-board crew members.

For analysis of possible crew reductions, all the functions which different crew members must perform are defined here.

1. **Driving**: This is strictly the engineer's responsibility.

2. **Train inspection and brake test**: Trains are mostly tested by the yard personnel before the train departure, but engineers and conductors are also required to assist in performing regular brake tests at terminals and to observe car performance if any problems arise on the line. Moreover, it is the conductor's responsibility to ensure that end doors, bars, and chains are in position on end cars for the protection of the passengers.

3. **Couple/uncouple cars**: This duty is performed by yard personnel, or by engineers and conductors in the yard or on the lines.

4. **Communications with Control Center**: Engineer and conductor can communicate by radio with the Control Center.

5. **Make announcements**: The conductor or any crew-member designated by him makes the announcements. These are required for each station and at any time that a service disruption or significant delay occurs. Exceptionally, the engineer can also make announcements.

6. **Position traps**: A trap is moved by the crew member who controls the door. The doors and traps are often left open between two adjacent stations with low-level platforms, while they are left closed between adjacent high-level platform stations. Thus they do not require movement at every station stop, but they must be moved where there is a transition between platform heights.

7. **Open doors**: At high-level platforms, the doors are trainlined and the conductor controls them. At low-level platform stations, the conductor controls two adjacent doors and assigns other doors to passenger attendants.
8. **Supervise and close doors**: The doors are trainlined and closed by the conductor at high-level platform stations. At low-level stations, the attendant or conductor monitoring that door is responsible for it at departures. As already mentioned, in practice the doors remain open and traps raised until the train approaches a station with high platform and the traps must be lowered.

9. **Signal departure**: The conductor is responsible for the timely movement of the train and signals the engineer when it is time to depart.

10. **Set destination signs**: The signs are set by the conductor and yard personnel. The conductor is responsible to ascertain that the train has the proper signing for destination, short-run (intermediate terminals) and express/local running. In the case of insufficient signs to properly designate the entire train, certain positions get priority. The conductor is also responsible for the proper storage of and the reporting of incomplete sign sets.

11. **Information for passengers**: At stations where (and when) there are attendants in the ticket offices, they assist in providing information; otherwise, it is the responsibility of the conductor and attendants to provide passenger information.

12. **Fare collection and control**: The conductor and passenger attendants perform fare collection/control: they must verify a valid pass, collect and cancel tickets, or sell tickets to all persons that do not have them. This may be a significant portion of passengers in the case of off-peak trains, but it is usually a very small minority during peak-hour operations. The crews spend the largest amount of time for fare collection duties.

13. **Change seats**: The conductor and/or PA must change directions of seats on the cars which have that feature.

14. **Safety and Security**: The safety and security of passengers are
provided by all crew members.

15. **Operate switches and signals:** The engineer and conductor are responsible to operate manual switches and signals, or to perform manual train protection at crossings. These duties are performed only in exceptional situations, not in regular operation.

16. **Trouble-shooting:** All the on-board crew members have responsibilities for either rectifying or reporting minor problems.

17. **Emergencies:** Interventions in emergency events are responsibility mainly of the engineer and conductor.

18. **Reporting:** All the on-board crew members are responsible for reporting at the end of their work any incidents that occurred during the operation.

A summary of the present distribution of duties among different crew members on the SEPTA Regional Rail System is presented in the first column of Table 7.2.

### 7.2.2 Current Practice of Crew Assignments

According to the current guidelines for assignment of revenue collection personnel, in addition to the engineer, crew size for each train depends primarily on the train consist, i.e., the number of cars per train. The guidelines state that each train consists of a conductor and so many PA's, that each crew member handles a maximum of two cars. Exceptionally, it is stated that the crew size varies by ridership statistics and Revenue Collection Department studies. For example, excessively heavily loaded trains with a large number of intermediate riders may receive additional crew members (PA's), mainly because of the heavy duty of fare collection.

Further, PA's may be assigned to off-peak trains in order to "fill out" their work day where such assignment does not conflict with break periods.
Table 7.2 Present crew duties and their reassignments for 2- and 1-person crews

<table>
<thead>
<tr>
<th>Duty</th>
<th>Present</th>
<th>2-person</th>
<th>1-person</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Inspection/brake test</td>
<td>E, C, A, Y</td>
<td>E, C, Y</td>
<td>E, Y</td>
</tr>
<tr>
<td>Couple/uncouple cars</td>
<td>E, C, Y</td>
<td>E, C, Y</td>
<td>E, Y</td>
</tr>
<tr>
<td>Comm. w/control ctr</td>
<td>E, C</td>
<td>E, C</td>
<td>E</td>
</tr>
<tr>
<td>Announcements</td>
<td>C, A, E</td>
<td>C, E</td>
<td>E, T</td>
</tr>
<tr>
<td>Position traps</td>
<td>C, A</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Open doors</td>
<td>C, A</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>Supervise &amp; close doors</td>
<td>C, A</td>
<td>E, C</td>
<td>E</td>
</tr>
<tr>
<td>Signal departure</td>
<td>C</td>
<td>C</td>
<td>--</td>
</tr>
<tr>
<td>Signage</td>
<td>C, A, Y</td>
<td>C, Y</td>
<td>E, Y</td>
</tr>
<tr>
<td>Information</td>
<td>C, A, S</td>
<td>E, C, T</td>
<td>E, T</td>
</tr>
<tr>
<td>Fare collection/control</td>
<td>C, A</td>
<td>C</td>
<td>Spot check</td>
</tr>
<tr>
<td>Change seats</td>
<td>C, A</td>
<td>C</td>
<td>E</td>
</tr>
<tr>
<td>Safety and security</td>
<td>C, A, S</td>
<td>C, S</td>
<td>E, S, T</td>
</tr>
<tr>
<td>Switch operation</td>
<td>T (C, Y)</td>
<td>T (C, Y)</td>
<td>T (Y)</td>
</tr>
<tr>
<td>Trouble shooting</td>
<td>E, C</td>
<td>E, C, T</td>
<td>E, T</td>
</tr>
<tr>
<td>Emergencies</td>
<td>E, C</td>
<td>E, C, T</td>
<td>E, T</td>
</tr>
<tr>
<td>Reporting</td>
<td>E, C, A</td>
<td>E, C</td>
<td>E</td>
</tr>
</tbody>
</table>

required under the Federal Hours of Service Law and incurs no additional pay hour costs. Thus, the rules for crew sizes stipulate the minimum crew sizes, but allow variations with passenger volumes and availability of otherwise unused person-hours of work.

In actual practice the crew sizes on many trains exceed the minimum numbers stipulated by the Guidelines. This often results in excessively labor-intensive operations and higher operating costs.

7.2.3 Plan for Reassignment of Duties and Reduction of Crew Sizes

The functional analysis of the Regional Rail System in Chapter 4 has shown that train crew sizes have a critical role in the nature of the entire system. The current operating practices and crew sizes represent the key differences between the regional/commuter and regional/metro systems. The diagrams in Figures 4.1 and 4.2 clearly show that crew size reductions play the critical role in the proposed upgrading of the Regional Rail System.

Most of the actions for upgrading the Regional Rail System have a direct bearing on crew sizes:

- High platforms will greatly facilitate boarding/alighting and eliminate the need for crews to supervise steps;
- New rolling stock will allow centralized supervision and closing of doors by one person, conductor or engineer;
- Self-service fare collection, which can be gradually introduced, will reduce the major duty of the crews: checking, canceling and selling of fares on-board. In the final stage, when the complete SSFC is in operation, the entire duty will be transferred to several roving controllers for the entire network.

With the implementation of these upgrading measures, the most time-
consuming duties of the crews will be eliminated. All other duties, defined in Section 7.2.1, can then be performed by the engineer and conductor, with somewhat increased assistance by the Control Center. The new assignments of duties to different operating members is presented in the second column of Table 7.2.

Actually, one further step in increasing operating efficiency will be possible. When all upgrading measures will have been implemented and new operational procedures are "broken in" and become routine, it will be possible to go to the "final stage" - one-person crews. Assignment of individual duties to the only crew member (the engineer), and other supporting personnel (control center, station and yard personnel) is listed in the last column of Table 7.2.

There will certainly be questions and doubts that Regional Rail trains of all sizes can be operated by 2-person crews; even more so, there are opinions that "railroad" trains can never be operated by the engineer only. The arguments are that the system is very complicated, trains are large, rail rights-of-way are not fully controlled, and railroad rules are restrictive; therefore, the present crew sizes cannot be reduced significantly; persons with this view may criticize the proposal for crew reductions, submitted here, as naive and unrealistic.

This skeptical view can be challenged on several grounds. First, the analyses presented here show how crew duties can be drastically reduced; second, the pressures for provision of higher service frequencies without major increases in operating costs create great pressures for innovations in operating practices and for modifying some railroad rules that are obsolete and not applicable to transit-type operations which SEPTA's Regional Rail System basically is. The traditional railroad practices, such as the brake test requirements, certain personnel activities, etc., should be examined and retained only where they are justified for safety reasons. And third, the skeptical views can be challenged
by numerous experiences with similar rail transit systems in other cities.

Operating practices with small crews on several similar rail systems can be mentioned. First, no rapid transit or light rail transit system in a developed country has more than 2-person crews; most have one only. Only regional/commuter systems still employ larger crews.

One-person train operation is found on many transit lines with fully controlled rights-of-way not only in subways (Broad Street), but also in suburban areas, such as single cars on the Norristown High-Speed Line, 6-car trains on the PATCO Line, and 10-car trains on the BART system. Single-person crews are also used on the lines without full control of rights-of-way, such as LRT lines in San Diego and Calgary with 3-car trains and total capacities of 570 spaces per train. Finally, there are regional rail trains in many European cities consisting of up to 6 cars (Frankfurt, Munich), or even 9 cars (Copenhagen) which operate at speeds of up to 120 km/h (75 mph), which have one-person crews.

Consequently, it is recommended that train crew sizes be reduced in two stages. First, as soon as several upgrading measures are introduced, trains should be operated with 2-person crews, engineer and conductor only. These crews will be fully adequate for trains with up to 3 or 4 cars. For longer consists, when they carry heavy passenger volumes, it may be useful to have an additional crew member (PA) to provide various types of assistance to the public, information, or more frequent spot-checks of fare payments.

In the second and final stage, when all the recommended upgrading measures are implemented, trains with one and two cars can be operated by one-person crews. Longer trains may be given a conductor for the same reasons that long trains in the first stage are given the third crew member.
The recommended crew sizes for different train lengths are given in Table 7.3 for the present, first and second stages of upgrading (labeled as "Future I" and "Future II", respectively). The "Future I" will be feasible as soon as the upgrading recommended in this report is introduced; "Future II" may require some additional operational changes.
Table 7.3 Present and future crew sizes for different train consists

Scenarios:

- Present: Engineer + Conductor + n * Pass. Attendant
- Future I: Engineer + Conductor (+ PA?)
- Future II: Engineer (+ Conductor)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Present</th>
<th>Future I</th>
<th>Future II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2 (3)</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>2-3</td>
<td>1-2</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>2-3</td>
<td>1-2</td>
</tr>
<tr>
<td>Off-peak hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2-3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2-3</td>
<td>2</td>
<td>1-2</td>
</tr>
<tr>
<td>4</td>
<td>2-4</td>
<td>2</td>
<td>1-2</td>
</tr>
</tbody>
</table>
Chapter 8

ALTERNATIVE PLANS, THEIR ANALYSIS AND SYSTEM INTEGRATION

The Regional Rail System’s efficiency and its ability to attract additional passengers depend on the quality of its components (infrastructure and rolling stock) and the type of service it offers. In the preceding three chapters, 5-7, the basic physical and operational elements of the Regional Rail System which directly affect services have been analyzed with respect to their present form, efficiency and possible upgrading.

To determine the most effective use of investment funds, however large or limited they may be, it is necessary to examine various combinations of improvements of individual system components. Each combination will have a different set of benefits and costs. A comparison of such combinations will be performed in order to select the recommended plan for the Regional Rail System upgrading.

For the comparative analysis of different combinations of components it was necessary to develop a cost model for estimating capital and operating costs. In this Chapter the cost model for the Regional Rail System is presented. This is followed by a formulation of alternative sets of improvements, their comparative analysis and, finally, selection of the recommended plan.

8.1 The Regional Rail System Cost Model

This chapter investigates the financial implications from investment in infrastructure and rolling stock suitable for providing the Regional Rail base service. The first section defines the objectives of the model. The second section discusses the important factors that must be incorporated in a cost analysis. The next section develops the model. The penultimate section
discusses some of the assumptions that are implicit in the analysis approach. The last section uses this basic model to analyze a variety of different operational and investment scenarios.

8.1.1 Objectives of the Model

The main objectives of developing the cost model are to provide a tool for:

- Estimation of costs for upgrading individual elements;

- Examination of sensitivities of system costs to changes of individual system elements;

- Analysis of costs of changes in combinations of different elements;

- Examination of the relationships between system cost and revenues from the attracted ridership.

8.1.2 Important Factors that Impact Costs and Revenues

Investment in infrastructure is a vital element for the future of the Regional Rail System. Station investment would involve new platforms either of a standardized low height at 8" (20 cm) over the top-of-rail, or high platforms at 48" (1.22 m) over top-of-rail, plus handicapped access ramps, new railings, canopies, passenger information systems, and possibly ticketing machines.

The other possible large capital investment is in rolling stock. Presently, many Silverliner IVs are due for an overhaul. Thus, the avoidable overhaul cost if new rolling stock is purchased also needs to be considered.

The operating costs are influenced by the performance and crew requirements of the rolling stock. The three primary inputs to be considered are energy, maintenance, and crew labor. Because we are only interested in the differences in costs imposed on the Regional Rail Division (RRD) due to additional investment and changes in operational performance, the relevant cost factors are those that are variable with respect to the proposed changes. In other words, many costs are fixed or a function of the peak fleet size required and would not be
influenced much by a change in stations or rolling stock performance. Thus, it will be necessary to use care to separate these fixed costs from the variable costs. The rationale for the unit costs which are to represent the variable cost component for each of the three primary resource inputs used in this model are given below.

**Energy** consumption is presumed to be primarily a variable cost that is a function of car-miles (car-km) travelled, so that the unit cost factor, $c_e$, is in terms of dollars/car-mile. The value used in 1990 dollars is $1.15/car-mile. This number is calculated by dividing the total annual energy bill by the total annual car-miles driven. This is therefore an averaged figure. The actual computation of energy consumption is exceedingly difficult to perform based on the price charged because the pricing formula is based on peaking factor, time of day and other criteria.

Furthermore, the consumption per vehicle is not based strictly on the energy required while in service, but it is also a function of how many hours per day the vehicle is on standby and being heated or cooled. Since the analysis concerns only less than one-third of the total fleet, i.e., the cars required for base service which involves little standby time, there should be little change in the ratio of driving time to standing time with new rolling stock. The energy consumption unit cost for new rolling stock for base service would then be only a constant percentage of the unit cost factor for existing rolling stock. This percentage is set at a default value of 70% as a reasonable estimate for the improvement possible with new technology and much lower vehicle weight.

**Maintenance** consists of significant fixed and variable cost components. The average cost as a function of car-miles (car-km) can be calculated as the total annual maintenance cost (exclusive of infrastructure and building heating
expenses, etc.) divided by the total car-miles operated per year. The resulting 1990 average cost figure was $1.50/car-mile. Inspection labor hours are largely dictated by the peak fleet size and the number of consists to be formed each day that are subject to FRA inspection regulations. Cleaning labor is also dictated by the peak fleet size in service each day. Only the remaining percentage of the maintenance cost can be influenced by changes in maintenance routines or in-service repairs.

A conservative estimate of the portion of the unit cost that is variable, i.e. that can be affected by reductions in required maintenance and repairs, is 40%. This gives a rolling-stock maintenance unit variable cost, $c_v$, of 0.40 x ($1.50) = $0.60/car-mile. The unit variable cost factor for new rolling stock would then be a constant percentage of the unit variable cost factor for the existing rolling stock. This percentage has a default value of 70% in this analysis as a reasonable estimate of the improvement possible using new technology.

The crews on-board the trains represent a labor cost that is roughly proportional to the train-hours operated. In this case, the unit cost factor is simply the sum of the hourly rates of the all members on a train. Although all inputs otherwise use 1990 dollar values, the ratios of full labor cost to paid wage is increased by using the current ratio of about 1.60 to reflect the increased overhead that is likely to remain in the near future. Thus, the rate for an operator is $c_{op}$ = 1.60 x ($13.30) = $21.28/train-hour, for a conductor, $c_c$ = 1.60 x ($12.53) = $20.05/train-hour, and for a passenger attendant of $c_{pa}$ = 1.60 x ($10.64) = $17.02/train-hour.

The model must also allow for revenues to change as the level of service changes or passenger attractiveness increases as a result of investment. The
number of passengers this would entail can be found only indirectly by making.
assumptions about the distribution of fares paid or the use of an average fare.

8.1.3 The Model

The model is a Net Present Value (NPV) formulation based on capital investment in year zero followed by operating costs or savings of uniform nominal amount for the next 15 years. (Taxes and the related depreciation allowances are ignored since SEPTA is a public agency.) The NPV of investing in infrastructure and rolling stock is the difference between the cash flow stream from the present situation (base) and the cash flow stream envisioned after additional investment (new):

\[
\text{NPV} = -(\text{Additional Capital Investment}) + \frac{(\text{Annual Operating Savings})}{(A/P, i, N)}
\]  

where \((A/P, i, N)\) is the Capital Recovery Factor, or CRF, that discounts the stream of operating savings back to the year zero, assuming a minimum allowable rate of return (MARR) of \(i\%\) and a planning horizon of \(N\) years:

\[
(A/P, i, n) = CRF = \frac{i(1+i)^N}{i(1+i)^{N-1}}
\]

The Additional Capital Investment term can be broken down into the sum of rolling stock investment and the station investment:

\[
\text{Add. Cap. Investment} = (\text{NP-MV})\text{FLTSIZE} + (\text{TFSC+TVSC}) + \text{OTHIC}
\]

where related to the rolling stock, NP is the purchase price of the new rolling stock, MV is the Market Value of the existing rolling stock, and FLTSIZE is the number of new units purchased.

For the purposes of replacement investment analysis, the Avoidable Cost of overhaul must be added to Salvage Value to give a pseudo market value. The cost of new rolling stock minus the pseudo market value gives the net Additional
Capital Investment per unit of rolling stock, NP-MV, over the base situation. (Because of the need for overhaul, as well as obsolete design, the Silverliner IVs are assumed to have negligible resale value).

Related to infrastructure investment, TFSC is the total investment in stations that is "fixed" or independent of station size; it includes such elements as canopies, passenger information systems, and handicapped access ramps, while TVSC is the total station investment that is a function of platform length for such items as railings and platform construction. In the subsequent section on operating scenarios a detailed breakdown of the assumed station construction costs is given.

Besides these items, the model includes some other additional investment costs, namely, signal adjustments to prevent the possibility of not detecting single-car trains, ticket-vending and/or ticket-canceling machines. These investments are taken into consideration through the term OTHIC in Equation 3.

The Annual Operating Savings term is based on the difference between the current or base operating costs and the operating costs with new rolling stock:

\[ \text{Annual Operating Savings} = (TC_{CR} + C_e + C_m)_{\text{base}} - (TC_{CR} + C_e + C_m)_{\text{new}} \]  (4)

where \( TC_{CR} \) is the Total Annual Crew Cost:

\[ TC_{CR} = K_2 \sum_{j} C_{CRj} - K_2 \sum_{j} \sum_{k} (C_{op} + C_e + n_{pa} C_{pa})_k (\text{Revenue Train-hours})_k \]  (5)

\( C_{CRj} \) is the total annual crew cost on route \( j \) of the seven different Regional Rail lines, and \( k \) is an aggregation for each different type of run that uses the same consist size, crew size, and terminals. There may be several different types of runs even during base services; for example, the R-5 has 4 different types of runs on Saturday. \( K_2 \) is a correction factor which converts Total Revenue Train-hours into Total Train-hours including deadheading.
$C_e$ is the Total Annual Energy Cost:

$$C_e = c_e (\text{Total car-miles}) = c_e K_j \sum_{j} \sum_{k} N_{avgk} (\text{Revenue Car-miles})_k, \quad (6)$$

where $j$ and $k$ have the same meaning as before, $N_{avgk}$ is the average consist size used on run type $k$, and $K_j$ is a correction factor used to convert Total Revenue Car-miles into Total Car-miles including deadheading.

Similarly, $C_m$ is the Total Variable Annual Maintenance Cost:

$$C_m = c_m (\text{Total Car-miles}) = c_m K_j \sum_{j} \sum_{k} N_{avgk} (\text{Revenue Car-miles})_k, \quad (7)$$

where $j$, $k$, and $K_j$ have the same meanings as before.

In this model, revenues will be considered as an extra term called Annual Revenues, or AR, that can be used to set the Net Present Value (NPV) of the investment and Operating Savings (or operating increases) stream to zero:

$$NPV = 0 = -(\text{Add. Cap. Invst}) + (\text{Ann. Ops. Savings.})/(A/P, i, N)$$

$$+ (\text{Annual Revenue})/(A/P, i, N) \quad (8)$$

This extra term can be interpreted as the additional annual revenue required to offset the Additional Capital Investment after any Annual Operating Savings (or operating increases). A negative value for this required Additional Revenue means that operating savings alone cover the capital investment. Solving for this Annual Revenue to break-even gives:

$$\text{Annual Revenue} = (\text{Add. Cap. Cost})/(A/P, i, N) - \text{Ann. Oper. Sav.} \quad (9)$$

Below is a summary of important default input values for the analysis.

8.1.4 Summary of Default Input Values

The values used for determining the Capital Recovery Factor are:

$$i = \text{Minimum Allowable Rate of Return} = 10\%$$
\( N = \) analysis time horizon = 15 years

\( \text{CRF} = \text{Capital Recovery Factor} = (A/P, i, N) = \frac{i(1+i)^N}{((1+i)^N-1)} = 0.1315. \)

The deadhead correction factors are based on the ratio of total-miles to revenue-miles and total-hours to revenue-hours from FTA Section 15 Reports:

\( K_1 = \) deadhead miles correction factor = \( \frac{43,700}{41,000} = 1.07 \)

\( K_2 = \) deadhead hours correction factor = \( \frac{1633}{1537} = 1.06 \)

The operating resource input costs that can be influenced by performance of the rolling stock are based on discussion with SEPTA staff in the Regional Rail Division and Finance:

\( c_{eb} = \) average energy rate = \$1.15/car-mile

\( c_{vb} = \) average variable maintenance rate = \$0.60/car-mile, based on 40% of average maintenance rate of \$1.50/car-mile

The new rolling stock is assumed to require only 70% percent as much energy consumption and 70% as much maintenance effort as the present stock:

\( c_{e\text{ new}} = 0.70 \ c_{e\text{ base}}; \quad \ c_{v\text{ new}} = 0.70 \ c_{v\text{ base}}. \)

The 1990 wage rates are multiplied by 1.60 to reflect the trend towards higher fringe rates that will probably pertain in future operations:

\( c_{op} = \) operator wage rate = \$21.28/hr

\( c_{c} = \) conductor wage rate = \$20.05/hr

\( c_{pa} = \) passenger attendant wage rate = \$17.02/hr

There is always assumed to be one operator and one conductor by default. Removal of the conductor can be simulated by setting the wage to zero. The number of passenger attendants depends on the route and the number of cars in the consist:

\( n_{pa} = \) number of passenger attendants = 1 for some 2-car consists, 1 for all 3-car consists

\( MV = \) estimated market value of used Silverliner IV, or instead, for purposes of comparison with new rolling stock, the avoidable cost of overhaul
plus scrap value.

\[ \text{Estimate} = \$800,000 + 100,000 = \$900,000 \]

\[ \text{NP} = \$2,400,000 \text{ or } \$2,200,000 \text{ with and without movable steps, respectively.} \]

\[ \text{FLTSIZE} = 48 \text{ for present headways on all routes and 15\% reserves; } = 68 \text{ for 30-min. headways on all routes and 15\% reserves (one-car operation, except on R-5).} \]

**Base line.** In order to compute the scheduling elements for the type of operation as defined above, SEPTA's timetables (valid as of 27 October 1991) for off-peak periods were used and assumed to be operated during all hours of operation. This schedule is defined as **Base line service.** The additional peak-period trains are viewed as a largely independent operation that can be served by the remaining existing rolling stock. From the number of trains in operation and their frequency, the cycle time were computed for each line. Appropriate adjustments were made for the cases where a variety of services were offered, such as extended service for a longer line, express service, etc.

As previously mentioned, there are different types of runs or services for each basic line. This did not affect the computation of train-hours and train-miles because the latest were found directly from timetables by adding miles and hours of each train in operation (extra peak trains were excluded). However, the number of trains was computed indirectly based on headways and cycle times of the different types of runs.

The assumed values of train consists represent the average numbers of cars per train, computed from current SEPTA's data.

**Double frequency** service is defined as operation with 30 min. headways on all lines on weekdays and Saturdays. Sunday service does not differ from the previous case. Lines R-1 and R-5 already have 30 minute headways, so no changes were made on these two lines. For all other lines, the number of trains has been
approximately doubled (in the case of the R-3, the current 5 trains increase to only 9), and the number of cycles per day per train was recomputed.

These numbers have been multiplied by the cycle times and round-trip lengths of the lines in order to estimate train-hours and train-miles, respectively.

8.1.5 Implicit Assumptions of the Cost Model

The primary assumption is that the cost of providing the extra trains during the peaks can be computed separately and added to the cost computed by this model; the full cost of operation is a sum of the costs for the baseline operation and the extra cost during the peak periods.

The fact that many costs are a function more of the peak fleet size and not of providing service is implicit in the model and is not the major source of concern for creating error. Rather, it is assumed that base service continues through the peak periods as well, and that the incremental peak demand is handled entirely by adding trains rather than lengthening of the base trains.

Thus, new costs may be imposed for providing peak service by requiring longer consists for the extra peak trains to supply the capacity which has to be added to that of the base service trains. However, the magnitude of this error is likely to be well within the margin of error the model already has due to the uncertainty of construction and other cost estimates.

8.1.6 Reliability of the Cost Model

It is important that analysts using this model and those interpreting its computations have a correct understanding of its validity and its limitations.

The basic relationships included in the model are logical and correct. Although, as in every model, the relationships in it are considerably simplified from the real world conditions, this is not a serious problem because the model
is used for evaluation and ranking of alternative plans. As long as the analyst
is aware of all model assumptions and interprets its outputs accordingly, the
model’s results will be valid and useful.

A major problem in securing reliability of the model’s results has been
estimation of the construction data. Great efforts have been made to obtain
actual cost information about SEPTA Regional Rail upgrading projects, as well as
the costs of similar projects on a few other systems, including NJT and ConnDOT.
However, these data have varied greatly because of the great diversity of
conditions and types of projects SEPTA has performed so far.

The cost data used in the model represent the best set which could be
obtained, including a number of data sources and this team’s estimations and
judgment. Bearing this in mind, the results presented in this report should not
be considered as a reliable basis for specific stations or projects. They do,
however, give reliable relative costs for different alternative plans, and they
represent adequate cost estimates for the policy purposes of this stage of
Regional Rail System planning.

8.2 Classification of Upgraded System Elements

To formulate possible alternate plans for the Regional Rail System
upgrading, all major components considered in the preceding chapters are listed
and for each one of them, all major steps of upgrading are defined. To avoid
unnecessary complexity, some simplifications have to be made. For example, among
the numerous design features considered for new rolling stock, only those most
relevant to other system components are considered: steps, door locations,
dimensions and control have been assumed as three different types, including the
set from the present fleet. Driver’s position and relation to the passenger
compartment have been defined for alternatives with new stock. These elements
interact with others, such as platform height and crew sizes.

For each one of the major elements, several alternative steps of upgrading have been selected as realistic alternatives. For all components the "Base case" is the present condition, and it is designated by the symbol "α". Subsequent improvements are designated sequentially as "β" and "γ". These designations are used for convenient reference in formulating improvement plans which consist of different sets of element improvements. The improvement steps for the six basic elements and their designations are presented in Table 8.1 and briefly described here.

**Platform Heights** have the following alternatives:

- **α** - Present platforms, i.e. mostly at TOR level or slightly higher, and a few high platform stations;
- **β** - Upgrading to standard low level (8" = 20 cm) and equipping stations with railings, shelters, PA system, etc.;
- **γ** - Construction of high-level platforms (48" = 1.22 m). Railings, shelters and other equipment are the same as in the preceding case.

**Rolling Stock** also has two possible improvements. The alternatives are:

- **α** - Present cars;
- **β** - A fleet of new cars with two quarter-point double-channel doors and movable steps which can be automatically set to either low- or high-platform levels; the fleet requires 48 cars for present headways, 68 for 30-minute headways;
- **γ** - New cars, the same as above, except that the movable steps are not provided because the cars will operate only at high-level platform stations.

**Crew Size** options are again classified into three categories:

- **α** - Present crew sizes;
- **β** - Two-person crews, i.e., engineer and conductor only;
- **γ** - One-person crew, i.e., the engineer driving train with all functions automated and self-service fare collection (SSFC) introduced, so that fares are controlled on spot-check basis.

**Fare Collection** is considered in two major alternatives:
α - Present fare collection procedures;

β - Installation of ticket issuing machines and other equipment and introduction of a self-service fare collection (SSFC).

Headways - only two options are considered for headways:

α - Present headways;

β - Introduction of 30-minute headways on all lines during off-peak hours (1 hour headways on Sundays, except R-1 and R-5, which remain with 30-minute headways).

Minimum Train Consists also have two options only:

α - Present operation with minimum consists of two cars;

β - Operation of single cars as the minimum train consist.

The listing of these six categories of improvement options in Table 8.1 will now be used to formulate alternative plans for system improvements.

In addition to the upgrading of above six system elements, the Regional Rail System should be improved through a number of basic operational changes and marketing activities. These are briefly summarized here.

Service Quality Improvements include the following actions:

- Increased park-and-ride (P+R) capacity and attractiveness.

- Integration of Regional Rail with feeder transit; this would include such actions as expansion of joint fares from TrailPasses to other forms of tickets, increased convenience of transferring, improved physical integration at transfer stations, schedule coordination, etc.

- Introduction of innovative fares such as lower intrasuburban, and student fares, group fares, "Wednesday Special", etc.

- Introduction of considerably improved passenger information;

- Marketing of Regional Rail services (particularly the Airport and Trenton/New York lines), creation of an improved system image.

The listed operational/promotional improvements are assumed to be included in all alternative plans.
Table 8.1 Possible steps in upgrading Regional Rail System elements

<table>
<thead>
<tr>
<th>Level of action taken</th>
<th>Platform height</th>
<th>Rolling stock</th>
<th>Crew size</th>
<th>Fare collection</th>
<th>Headway</th>
<th>Minimum train consist</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
<td>Present</td>
</tr>
<tr>
<td>β</td>
<td>Construct 8&quot; (20 cm) platform</td>
<td>New rolling stock (high/low steps)</td>
<td>Operator plus conductor</td>
<td>Self-service fare collection</td>
<td>30 min. headway</td>
<td>One-car trains</td>
</tr>
<tr>
<td>γ</td>
<td>Construct 48&quot; (122 cm) platform</td>
<td>New rolling stock (no steps)</td>
<td>One-person crew</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
8.3 System Integration: Formulation of Alternative Plans

The relationships among the above discussed physical and operating elements are presented in the form of a flow chart in Figure 8.1. The chart shows how upgrading of individual elements leads (and is necessary) to achievement of the main goals of system upgrading: attraction of additional passengers, reduction of operating costs and, thus, improvement of the operating ratio.

Returning to Table 8.1, alternative system upgrading plans are formulated as different combinations of upgrading steps in the six categories. Using the present situation as the base case, subsequent plans are formulated by upgrading different sets of elements, as shown in Table 8.2. Most plans are obtained by upgrading one element from the preceding case. This allows derivation of the incremental cost and other impacts for each individual element improvement. In that manner six alternative plans have been defined, in addition to the Base ("Do nothing") case, designated as Plan 1.

The composition of individual plans in Table 8.2 can be followed easily by referring to Table 8.1. The stage of improvement of each element is designated by the respective symbols from that table: α, β or γ.

Plan 1 consists of α conditions for all elements: none of the analyzed system elements, such as platforms, rolling stock or fare collection, would be changed. Thus, Plan 1 represents the present situation or "Do nothing" in comparison to all subsequent plans.

Plan 2 assumes the ability to operate single-car trains and, consequently, has fewer operated car-miles. This would allow later reduction of train crews to two persons on all minimum-consist trains (which will be effected in Plan 5). Overhaul of the existing cars is assumed.

Plan 3 assumes the construction of standard low-level platforms, but
Figure 8.1 Recommended plan for upgrading SEPTA's Regional Rail System
Table 8.2 Integration of individual upgraded elements into different system plans
(For definition of individual steps of upgrading refer to Table 8.1)

<table>
<thead>
<tr>
<th>Plans and their incremental improvements</th>
<th>Platform height</th>
<th>Rolling stock</th>
<th>Crew size</th>
<th>Fare collect.</th>
<th>Headway</th>
<th>Train consist</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Present situation</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
</tr>
<tr>
<td>2. One-car operation</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>3. 8&quot; platform construct. one-car operation</td>
<td>β</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>4. 8&quot; platforms, new rolling stock (movable steps)</td>
<td>β</td>
<td>β</td>
<td>α</td>
<td>α</td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>5. 48&quot; platforms, old rolling stock, reduced crew, SSFC</td>
<td>γ</td>
<td>α</td>
<td>β</td>
<td>β</td>
<td>α</td>
<td>β</td>
</tr>
<tr>
<td>6. New rolling stock (no steps), 48&quot; platform, 30 min. headways</td>
<td>γ</td>
<td>γ</td>
<td>β</td>
<td>β</td>
<td>β</td>
<td>β</td>
</tr>
<tr>
<td>7. 48&quot; platforms, new roll. stock w/o steps, SSFC, 30 min headways, one-car trains, one person crew</td>
<td>γ</td>
<td>γ</td>
<td>γ</td>
<td>β</td>
<td>β</td>
<td>β</td>
</tr>
</tbody>
</table>

* Present rolling stock overhauled
retention of the present rolling stock, and no changes in other elements, except
car overhaul.

Plan 4 introduces new rolling stock, but no changes in other elements from
Plan 3. However, since most platforms are low, the new stock must have movable
steps.

Plan 5 brings a number of interdependent changes. High-level platforms are
constructed; rolling stock "returns" to the base case - the Silverliner fleet
(to examine the minimum amount of changes). The high-level platforms represent
the basic element for further crew reduction, i.e., two-person crews on all
trains, not only on the minimum-consist ones. However, for that reduction, SSFC
must also be introduced. Thus, Plan 5 represents a major system evolution: it
incorporates logically related changes in four elements from Plan 4 (but only
three from Plan 3).

Plan 6 introduces new rolling stock, but at somewhat lower cost than the
stock in Plan 4, because no steps are required on it. Since the new stock will
have considerably lower operating costs than the present stock in Plan 5 due to
technological innovations, shorter headways will become more economically
feasible. Headways of 30 min. are therefore introduced on all lines during off-
peak periods.

Plan 7 represents the "ultimate" solution, in which all elements are
upgraded to their respective maximum degrees, $\beta$ or $\gamma$. The Regional Rail System
in this condition becomes very close to the Regional/Metro systems, as discussed
in Chapter 3 and specified in Table 3.2.

A simple, clear overview of the components included in different plans is
given in Table 8.3.
Table 8.3 Inclusion of individual components into different plans

<table>
<thead>
<tr>
<th>Action</th>
<th>Included in Plans</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Single-car trains</td>
<td>2, 3, 4, 5, 5, 7</td>
</tr>
<tr>
<td>2. Overhaul</td>
<td>2, 3, 5</td>
</tr>
<tr>
<td>3. Standard low-level platforms</td>
<td>3, 4</td>
</tr>
<tr>
<td>4. New cars with steps</td>
<td>4</td>
</tr>
<tr>
<td>5. High-level platforms</td>
<td>5, 6, 7</td>
</tr>
<tr>
<td>6. SSFC</td>
<td>5, 6, 7</td>
</tr>
<tr>
<td>7. Crew reduction to 2 members</td>
<td>5, 6</td>
</tr>
<tr>
<td>8. Short headways</td>
<td>6, 7</td>
</tr>
<tr>
<td>9. New cars without steps</td>
<td>6, 7</td>
</tr>
<tr>
<td>10. Crew reduction to 1 member</td>
<td>7</td>
</tr>
</tbody>
</table>

The operational/promotional improvement measures, described at the end of the preceding section, 8.2, are included in all of these plans. However, their costs are not included in further analyses. Thus, further analysis here considers only the incremental costs and ridership increases of Plans 2-7 over Plan 1 (not over the respective preceding plan), assuming that any costs and gains (passenger increases) due to service quality improvements would be additional to the analyzed upgrading measures and would not significantly change the relative merits of different plans.

Consequently, the exclusion of the operational/promotional improvements from this analysis is made to clarify the significance of different upgrading measures and their mutual relationships. It does not imply by any means low significance of these measures. To the contrary, it is well known that access to regional rail systems through integration of regional and local transit...
services, improvements of pedestrian and bicycle paths in station access areas and provision of park-and-ride facilities has a major influence on passenger attraction of the Regional Rail lines. Very high cost-effectiveness of many passenger information, promotional and marketing actions is also known.

The cost-effectiveness of many operational/promotional service improvement measures makes their introduction logical with any effort to improve the Regional Rail System, and therefore with any one of the alternative plans.

8.4 Evaluation of Alternative Plans

The above defined alternative plans should be evaluated and compared on the basis of three criteria which most directly reflect achievement of the main objectives of the Regional Rail System: investment cost, changes in operating cost (in most cases savings) and potential for attracting new passengers. A number of other aspects, such as safety, convenience, image, positive impacts on other SEPTA's services, short- and long-range positive impacts on urban environment and land use development, etc., should also be considered, but most of them are indirectly included in the three basic criteria. For example, passenger attraction depends on headways, platform heights, attractiveness of rolling stock, which influence such service quality elements as travel time, speed, reliability and system image.

8.4.1 Comparison of Investment Costs, Operating Costs and Newly Attracted Passengers

The six upgrading Plans, 2-7, will be evaluated comparing them with the present state - Plan 1 - as the basis. Financial aspects will be computed as incremental costs required for each plan, i.e., the costs in excess of the present system cost. Newly attracted passengers and revenues they would generate in excess of the present conditions are also included.
Table 8.4 presents the best estimates of the three criteria for each of the alternative plans that could be developed as a result of collection of various data on past operating/passenger attraction experiences on SEPTA's Regional Rail System, on several peer systems in other cities, discussions with SEPTA personnel and extensive analyses by the project team.

Column 2 in Table 8.4 lists for each plan its major components; their estimated investment costs for the network are listed and summed up in the column 3. Column 4 presents items which affect operating costs and/or have impacts on passenger attraction. The estimated changes in operating costs are given in column 5, while column 6 presents a projection of newly attracted passengers. Since the analysis is based on base services, this passenger attraction increase is expressed as percent of the present off-peak ridership.

Complex interdependence among the components must be considered in interpreting the estimates in Table 8.4. For example, investment cost and impact of car overhaul on the operating costs of the fleet will depend not only on the type or extent of overhaul, but also on the number of cars that are overhauled, which, in turn, depends on adopted headways and minimum train consists; the consists depend on signal improvements which would exclude the possibility of non-detection of single-car trains.

To facilitate understanding of these three characteristics of each plan, the values from Table 8.4 have been graphically presented on a diagram in Figure 8.2. The projected ridership increases and changes (mostly reductions) of operating costs are plotted as bars. Investment costs of the plans are marked on the abscissa, but not to scale.

The incremental passenger increases have been estimated as results of the specific improvements, as well as of the impacts of the enhanced convenience.
<table>
<thead>
<tr>
<th>Plan</th>
<th>Investment item</th>
<th>Investment cost ($10^6)</th>
<th>Operating item</th>
<th>Op. cost savings ($10^6/year)</th>
<th>Off-peak passenger increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Item</td>
<td>Item</td>
<td>Total</td>
<td>Item</td>
<td>Item</td>
</tr>
<tr>
<td>2</td>
<td>Overhaul</td>
<td>39</td>
<td>5</td>
<td>44</td>
<td>Overhaul</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td></td>
<td></td>
<td></td>
<td>1-car train</td>
</tr>
<tr>
<td>3</td>
<td>Overhaul</td>
<td>39</td>
<td>93</td>
<td>137</td>
<td>Overhaul</td>
</tr>
<tr>
<td></td>
<td>St. low platform</td>
<td></td>
<td></td>
<td></td>
<td>St. low platform</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td>5</td>
<td>137</td>
<td></td>
<td>1-car train</td>
</tr>
<tr>
<td>4</td>
<td>St. low platform</td>
<td>93</td>
<td></td>
<td></td>
<td>St. low platform</td>
</tr>
<tr>
<td></td>
<td>48 new cars I minus salvage</td>
<td>103</td>
<td>5</td>
<td>201</td>
<td>New cars</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td></td>
<td></td>
<td></td>
<td>1-car train</td>
</tr>
<tr>
<td>5</td>
<td>Overhaul</td>
<td>39</td>
<td>104</td>
<td>161</td>
<td>Overhaul</td>
</tr>
<tr>
<td></td>
<td>High-level platform</td>
<td>13</td>
<td>4.1</td>
<td>-35</td>
<td>High-level plat.</td>
</tr>
<tr>
<td></td>
<td>SSFC</td>
<td></td>
<td></td>
<td></td>
<td>Crew reduc.</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td>5</td>
<td>161</td>
<td></td>
<td>1-car train</td>
</tr>
<tr>
<td>6</td>
<td>High-level platform</td>
<td>104</td>
<td>133</td>
<td>255</td>
<td>High-level plat.</td>
</tr>
<tr>
<td></td>
<td>68 new cars II minus salvage</td>
<td>133</td>
<td>5</td>
<td>255</td>
<td>New cars</td>
</tr>
<tr>
<td></td>
<td>SSFC</td>
<td></td>
<td></td>
<td></td>
<td>Crew reduc.</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td>5</td>
<td>255</td>
<td></td>
<td>Shorter headway</td>
</tr>
<tr>
<td>7</td>
<td>High-level platform</td>
<td>104</td>
<td>133</td>
<td>255</td>
<td>High-level plat.</td>
</tr>
<tr>
<td></td>
<td>68 new cars II minus salvage</td>
<td>133</td>
<td>5</td>
<td>255</td>
<td>New cars</td>
</tr>
<tr>
<td></td>
<td>SSFC</td>
<td></td>
<td></td>
<td></td>
<td>Crew reduc. II</td>
</tr>
<tr>
<td></td>
<td>1-car train</td>
<td>5</td>
<td>255</td>
<td></td>
<td>Shorter headway</td>
</tr>
</tbody>
</table>

Table 8.4 Incremental costs and savings of alternative plans
Figure 8.2 Projected results of alternative plans
image, and other qualitative characteristics of service which respective system upgradings bring; however, some other synergistic impacts of different improvements have not been evaluated due to the scarcity of data on experiences with such complex system improvements in a coordinated way.

### 8.4.2 Joint Evaluation of Costs and Additional Passengers

A review of characteristics of the seven Plans in Table 8.4 and in Figure 8.2 leads to the following comparative evaluations of their characteristics and results.

**Plan 1**, as the "status quo" plan, does not include any major investment nor change of served passengers. Although the "do nothing" policy would necessarily involve some investments into maintenance and renovations of facilities and rolling stock, these are excluded from the comparative analysis. Actually, the most likely variations to the present status could be achieved by the service/promotional improvements, discussed previously.

**Plan 2** consists of overhaul of existing cars and improvements of signals to enable full use of single-car trains. A relatively modest investment of $44M would result in basically maintaining the present rolling stock and decreasing operating costs by $2.2M per year. Since most of the improvements would be aimed at decrease of operating costs which do not affect passengers directly, the impact on ridership is expected to be very small, only about a 5% increase.

**Plan 3** consists of the same improvements as Plan 2, plus station improvements: improved appearance and equipment and construction of standard low platforms. Its investment of $137M would result in the same operating cost saving as Plan 2 ($2.2M per year), but a greater passenger attraction - an increase of 20%.

**Plan 4** introduces new rolling stock instead of the overhaul of existing
stock in Plan 3. This requires a higher investment - $201M, increases annual savings to $5.1 and attracts 45% higher ridership over the present one.

Plan 5, with introduction of high platforms and SSFC makes crew reductions possible. Since the existing cars are retained, the investment of $161M is lower than for Plan 4; annual operating cost reduction is $4.1M and ridership increase is somewhat lower than in Plan 4 - 35% vs. 45%.

Plan 6 resumes new cars, as Plan 4, introduces shorter headways which involve higher operating costs, but generate greater passenger ridership. The investment is increased to $255M, annual operating costs increase by $0.5M, and the ridership is expected to double from the present volume.

Plan 7 has the same investments as Plan 6, but it takes full advantage of high platforms, new stock and SSFC by reducing train crews to one person - a "metro-type operation" - which reduces annual operating costs by $5.9M compared to the present.

It should be noted that a highly significant improvement of service - reduction of headways from 60 to 30 min - results in a rather moderate cost increase (about $7.5M per year).

With the same investment as Plan 6, the same passenger increase, but much lower operating costs, Plan 7 is obviously preferred to Plan 6.

The computations of these costs have been made utilizing the cost model developed for this project (see Section 8.1). The results of the computations are presented in Table 8.5. The columns in the table present the plan number, followed, in sequence, by the annualized total, capital only and operating only costs. It is noted that for all plans investment costs are algebraically positive, while the operating costs, with exception of Plan 6, are algebraically negative. This means that the investment will result in reduced operating costs,
Table 8.5 Evaluation of alternative plans: costs, revenues and required additional ridership

<table>
<thead>
<tr>
<th>Plan</th>
<th>Annualized capital and operating costs ($)</th>
<th>Annualized capital costs ($)</th>
<th>Annualized operating costs ($)</th>
<th>Add. wkday pass. req’d to offset cap. + op. costs</th>
<th>Add. wkday pass. req’d to offset op. costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>3,500,000</td>
<td>5,700,000</td>
<td>-2,200,000</td>
<td>5,200</td>
<td>- 3,300</td>
</tr>
<tr>
<td>3</td>
<td>15,700,000</td>
<td>17,900,000</td>
<td>-2,200,000</td>
<td>23,500</td>
<td>- 3,300</td>
</tr>
<tr>
<td>4</td>
<td>22,100,000</td>
<td>27,800,000</td>
<td>-5,100,000</td>
<td>33,000</td>
<td>- 7,600</td>
</tr>
<tr>
<td>4*</td>
<td>17,300,000</td>
<td>22,400,000</td>
<td>-5,100,000</td>
<td>26,000</td>
<td>- 7,600</td>
</tr>
<tr>
<td>5</td>
<td>17,000,000</td>
<td>21,000,000</td>
<td>-4,100,000</td>
<td>25,500</td>
<td>- 6,100</td>
</tr>
<tr>
<td>6</td>
<td>35,300,000</td>
<td>34,800,000</td>
<td>500,000</td>
<td>53,000</td>
<td>750</td>
</tr>
<tr>
<td>6*</td>
<td>28,200,000</td>
<td>27,700,000</td>
<td>500,000</td>
<td>42,000</td>
<td>750</td>
</tr>
<tr>
<td>7</td>
<td>40,800,000</td>
<td>46,700,000</td>
<td>-5,900,000</td>
<td>61,000</td>
<td>- 8,800</td>
</tr>
<tr>
<td>7*</td>
<td>33,500,000</td>
<td>39,400,000</td>
<td>-5,900,000</td>
<td>50,000</td>
<td>- 8,800</td>
</tr>
</tbody>
</table>

* These plans include savings achieved by avoiding overhaul costs.

Negative signs indicate "negative costs", or saving with respect to present costs.
i.e., that the system's operating efficiency will be increased.

The fifth column represents the number of additional weekday passengers needed to fully cover annualized total cost of the system (column 2), assuming the present average fare of $2.57. The last column presents the number of passengers needed to cover only the change in the operating costs. The values in this column are negative (except for Plan 6), because operating costs will be reduced compared to the present. This means that a smaller number of passengers than at present would achieve the same coverage of operating costs as today. Since it is expected that the ridership would increase, it is obvious that the operating ratio of the system would be improved significantly.

8.5 The Recommended Plan for the Future Regional Rail System

The preceding analysis shows that Plan 7 clearly meets best the goals for upgrading the Regional Rail System into a Regional Metro. It greatly increases the ridership and significantly decreases the system's operating costs.

The investment cost for Plan 7, estimated at $255M, is very moderate bearing in mind the results: modernization of a large Regional Rail network and a very significant increase of its role in the region.

As discussed above, most of the cost estimates are on the conservative side. However, due to uncertainty of many estimates, one must also anticipate the possibility that the total cost may turn out to be too low. Looking at the System in perspective, however, even if the investment cost turns out to be twice greater than estimated here, an investment of some $500M to obtain a modern Regional Metro is many times lower than what peer cities have invested in much smaller networks and achieved excellent results (see Chapter 4). The Atlanta MARTA system has cost over $2 billion for a network of only two lines, which now carry about twice greater ridership than SEPTA's Regional Rail; the Washington
Metro will cost well in excess of $10 billion when the network of about 100 miles is completed, and its ridership will be at least six times greater than SEPTA's, and BART is presently investing over $2 billion into several extensions in the Bay Area suburbs.

Once it is decided that Plan 7 should be implemented, Plans 2, 3 and 4 should be disregarded because they contain elements which do not lead to Plan 7: overhaul of the existing vehicles, construction of the standard low-level platforms and purchase of new cars with steps for low platforms would represent a wasted effort and expenditure because these elements would not be usable for Plan 7 implementation.

Implementation of Plan 7 should be staged over time in the following way. Upgrading of components can be made by the use of Plan 5 (single car trains, high-level platforms, SSFC and crew reduction to two members) with the exception that overhaul of the existing cars be delayed until new cars are purchased. Later, when the new cars are purchased, further reduction to one-person crew would become feasible. This innovation would make the short (30 min) headways economically feasible. Thus, implementation of Plan 7 would be completed.

This upgrading can be implemented in stages, line-by-line. One line would be selected and upgraded with all recommended changes, in the sequence described above. The experience obtained and results achieved on one line would be used in preparing upgrading projects for other lines.

The R-5 line, as the busiest on the system, would be most desirable to upgrade first; however, it is extremely long and it would face many physical constraints (four track stations on the Paoli section, mixing with Amtrak trains, etc.). Lines R-3 or R-8, operating exclusively on SEPTA's rights-of-way, may be the most logical choices for the first stage of upgrading implementation.
Chapter 9

FINDINGS, CONCLUSIONS AND RECOMMENDED STANDARDS

The description and overview of SEPTA’s Regional Rail System in this report has shown that the potential of this System with respect to both ridership attraction and efficiency of operations is presently very much underutilized. The main causes of the present inefficiencies are the chronic underfunding and the failure to modernize the System for decades prior to SEPTA’s takeover, and only partial improvements since that time.

With respect to its physical components (infrastructure, rolling stock) and operating characteristics (scheduling, fare collection, crew duties), the Regional Rail System has not yet been fully integrated into a coordinated and efficient system. Moreover, coordination of Regional Rail lines with other modes has not been fully implemented either.

To realize the great potential which the existing large network of high-speed lines has, it is necessary to implement a complete functional integration of its physical and operating components into an optimally coordinated system. This study has therefore undertaken a comprehensive analysis of the system components and functions. Alternative improvements of individual components have been analyzed, and those alternatives which would lead to the greatest improvement when deployed in coordination with other system elements have been selected. This chapter summarizes the analyses and recommendations for improvements. It defines the integrated system which can be implemented either in a short period of time as a single major project, or gradually in stages of upgrading line by line.
9.1 Goals, Policies and Strategies

As stated in earlier chapters, SEPTA's Regional Rail System should be upgraded into a system with operation similar to that of metro systems. Such a "Regional Metro" will have a much higher passenger-attracting ability and greater operating efficiency than the present system.

9.1.1 Specific System Goals

Based on the general goals outlined in Chapter 3 and subsequent analyses of the present and improved features of the Regional Rail System, the following specific goals for its development are defined here.

1. Weekday ridership on the network should be increased to at least 200,000 passenger trips.

2. Level-of-service should be increased by providing on most lines off-peak headways of 30 minutes and peak hour headways of 10 to 20 minutes. Speeds should be increased wherever possible by reducing station standing times, and by performing track and signal modernization to eliminate speed restrictions which were introduced during various transitional developments in the past, but are not necessary today, or may be made superfluous when tracks and signals are upgraded (e.g., between Market East, Suburban and 30th Street Stations).

3. The stations which are used by very small numbers of passengers should be eliminated. However, any decision to close a station should be made only after all reasonable efforts to increase ridership on the system (or at particular station) have been tried without significant results. The number of passengers justifying a station is not constant: it depends on the station location along the line, potential for developments in its vicinity, and several other factors.

4. Operating cost per train-mile (-kilometer) should be decreased,
primarily through reduction of train crews, operation of shorter train consists, and purchase of new rolling stock with state-of-the-art design features which involve lower energy consumption and operating costs. Simplification of terminal procedures (brake test, setting of door traps and changing the signage) would also decrease operating costs.

5. Reduced job positions resulting from smaller crews should be reassigned to the new job positions created by increased service frequency.

6. Image and passenger attraction of the Regional Rail System should be greatly increased through public education and marketing and, particularly, through provision of high-quality services more competitive with the automobile, not only by speed and reliability, but also by frequency.

7. Efforts to stimulate intensive land use developments around Regional Rail stations and thereby increase their accessibility, should be continued and SEPTA's cooperation with planning agencies and townships should be intensified. The potential of Regional Rail to ensure more efficient land uses than those typical for automobile-based developments, and to contribute to an improved urban environment and quality of life, should thus be better utilized.

9.1.2 Policy and Strategy for Development

The presently predominant practice of station reconstruction by rebuilding existing facilities, i.e., reconstruction limited to physical replacement of elements with the same layout and design, should be replaced by systematic and coordinated upgrading of individual facilities on the basis of the comprehensive plan and program presented here. Moreover, in spite of numerous improvements in coordination among planning, construction and operations activities in recent years, many individual actions are still made without their logical coordination with an overall development policy.
It should be SEPTA's policy that any changes in and improvements of the Regional Rail System should be carefully examined as to their coordination with other system components. This planning and coordination should be the responsibility of one specific department or a specially designated task force in SEPTA. The long-range planning is the domain of the Department of Operations Planning and Development; setting of functional and construction standards should be based on the long-range system plan and implemented by the Regional Rail Division. It is important that functional and operational factors dictate planning and design of physical system components.

The basis for upgrading of the Regional Rail System should be Plan 7, described in Chapter 8. This plan is found to be most cost-effective of all alternative plans, and it will result in evolution of the present regional/commuter into a regional/metro system. The investment of $255 million, although a large amount of funds, is very small compared to investments made by our peer cities into much smaller transit systems. The amount is also justified by the expected increased operating efficiency, newly attracted ridership, and greatly increased role of the System in the mobility and viability of the Philadelphia Region.

The changes and improvements recommended in Plan 7 should be further analyzed and planned, particularly with respect to their investment and operating costs. They should then be classified into development stages which would consist of network sections or individual lines. The plans for individual stages should then be used for estimation of the required stream of investments and sequence of individual actions for system upgrading.

9.2 Recommended Standards for System Elements

The Plan 7 for the SEPTA's Regional Rail System, developed in Chapter 8
consists of a number of system components; these are presented in the following sections in three groups: stations and infrastructure (analyzed in Chapter 5), rolling stock (Chapter 6), and operations (Chapter 7). Implementation of an integrated plan is summarized in Section 9.3.

9.2.1. Station Elements

Upgrading of station elements represents an effort that requires considerable investment, but it will bring the most fundamental improvements to the service quality and operating efficiency in the history of the Regional Rail System. These elements are classified here in four subcategories: platform heights, platform lengths and other elements.

**Platform Heights**

- All stations which are being renovated should be built with 48" (1.20 m) high platforms.
- The ultimate goal should be to have only high-level (48"/1.20 m) platforms on the entire system.
- High-level platforms should be built progressively along individual lines from Center City outward. There should be no line with more than one change between low and high platform in each direction of travel.

**Platform Lengths**

- The standard for the platform lengths should be selected for each line separately, as a function of maximum train size for the line. Platform lengths should have the following dimensions:

<table>
<thead>
<tr>
<th>Design train length (no. of cars)</th>
<th>Platform length (feet/meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>160 / 50</td>
</tr>
<tr>
<td>3</td>
<td>260 / 80</td>
</tr>
<tr>
<td>4</td>
<td>345 / 105</td>
</tr>
<tr>
<td>5</td>
<td>430 / 131</td>
</tr>
<tr>
<td>6</td>
<td>515 / 157</td>
</tr>
</tbody>
</table>

- On some lines, where outer sections may be served by shorter trains than the inner sections (e.g., Doylestown-Lansdale vs. Lansdale-Center City), different platform length standards may be used for different line sections, avoiding unnecessary investment costs.
- Exceptionally, at locations of severe physical constraints, such as street grade crossing in the station area, even individual stations may have shorter platforms than the standard adopted for the line. Although these exceptions are not desirable, they may be applied at individual stations which are lightly used and physically constrained.

Other Station Elements

- Station platform widths should be determined as a function of design passenger volume, considering also the likely distribution of passengers along the train and the locations of platform access points. The minimum platform width, typically at its extremities, should be 6.0 ft. (1.80 m).

- Access for the handicapped persons, as specified by federally required ADA design standards, should be included in the platform designs.

- On lines with two tracks at stations with good visibility, track crossings for pedestrians should be provided at grade. At stations with low-level platforms they are usually located as close to the station building as practical. When high-level platforms are constructed, the crossings must be relocated to one or both ends of the platforms.

- Grade separated track crossings for pedestrians are justified only at stations with more than two tracks, at locations with restricted visibility, and/or where high speed trains pass the station without stopping. This is generally the case along the three Amtrak corridors (portions of R-2, R-5 and R-7).

- In designing high-level platforms, the following factors should be carefully considered:
  - Access to the station buildings/passenger shelters;
  - Provision of one ramp for wheelchairs to each platform;
  - Preservation of historic station buildings;
  - Aesthetic and environmental impact on the surroundings;
  - Land availability and possible restrictions due to street crossing of tracks.

9.2.2 Rolling Stock

It is recommended that a new type of rolling stock be purchased with the design that will allow full utilization of the new system features with respect to platform design, fare collection, crew duties and sizes, etc. Specifically, the new car should incorporate the following features:
- Two double-channel doors located at quarter points of the car length;
- Streamlined control of doors;
- Doors should be equipped with push-buttons for individual opening by passengers, as well as warning bells (or buzzers) for centralized closing by the engineer.
- PA system should be normally operated by the engineer and include options for in-car (train) announcements, outside announcements, and both simultaneously.
- The cars must have built-in centrally-controlled signing devices for line and destination designations and other information.
- Only high-level platform boarding/alighting should be provided for. The feature of the present cars - steps with traps for both high- and low-level platform boardings - will not be needed. This will necessitate that the new cars be introduced at the time when each individual line is converted to high-level platforms only;
- The engineer (driver) should have good operating environment, including a comfortable seat and convenient contact with passengers in the vehicle;
- There should be some stanchions in the car for standees. Although at most times there are no standees, the incidental ones must be offered comfortable and safe standing. Some passengers prefer to stand for short trips;
- Vehicle interior and exterior should be aesthetically pleasing;
- Vehicle should have couplers designed for easy, fast and safe coupling and uncoupling operations;

9.2.3 Operational Elements

Recommendations in this group fall into two sequentially related improvements: fare collection and reduction of crew sizes, which has two steps.

Fare Collection

There are three major steps of improvement in fare collection which can be introduced in sequence.

- Introduce electronic ticket issuing machines. These hand gadgets are relatively cheap, easy to carry, and they can greatly facilitate manual on-board sale of tickets by crew members.
- Introduce ticket canceling machines on-board trains which would reduce the volume of checking and ticket collection which the conductor must presently perform.

- Introduce simple ticket issuing machine on-board trains and change to full self-service fare collection system. The functions presently performed by the conductor and passenger attendants can then be replaced by spot-checking by an inspector.

**Crew Size**

- With the increased fare collection efficiency suggested in the preceding recommendation, it will be possible to immediately reduce crew sizes on trains of one- and two-car lengths to two persons, engineer and conductor.

- When high platforms are constructed and SSFC is introduced, it will be possible to operate all trains with two-person crews (engineer and conductor).

- With the introduction of new rolling stock, which will place the engineer in direct contact with passengers, and with high platforms which allow door control by a single person, it will be possible to further reduce train crews to engineer only for all train lengths.

- The general policy should be that the suggested crew reductions per train be used to increase frequency of service, so that no job losses will result from these changes.

**Other Elements**

- Immediate effort should be initiated to modify the signal system so that one-car train operation will become feasible again. Very significant savings in operating cost and/or attraction of new passengers through increased service frequency will easily justify the effort this improvement may involve.

- Service headways on most lines should be reduced to 30 minutes during off-peak hours and 10-20 minutes during peak-hours.

### 9.3 Implementation Planning and Strategy

The goals for the Regional Rail System presented in Chapter 3 have been the basis for selection of recommended improvements for different infrastructure, rolling stock and operational elements.

Implementation of this plan for upgrading of the Regional Rail System will require careful planning and strategy development. Major steps in this process...
are outlined here.

**Step 1:** Using this report, elaborate recommendations for each system component to the operational level and investment cost estimates. This work may be organized in the following topics:

a. Stations: layout, platforms and other elements;
b. New rolling stock;
c. Fare collection equipment and procedures;
d. Operations: crew duties, train control, etc.
e. Service quality improvements: better information for the public, improved access to stations by different modes (walking, bicycles, feeder buses, park-and-ride), marketing, etc.

**Step 2:** Coordination and integration of the work in Step 1 and development of investment cost estimates for the entire project.

**Step 3:** Search for funding of the plan. Local, state and federal funds should be obtained. With the projected high cost-effectiveness of this plan, a strong attempt should be made to include it in the projects eligible for ISTEA funding for this Region.

**Step 4:** Prepare a strategic plan for implementation of the suggested upgrading measures on one line, to test various concepts, integration methods and cost estimates. For example, station reconstructions and various changes in fare collection can be tested on one line even before new rolling stock is purchased.

The lines that may be most convenient for testing and demonstration of the new facilities and concepts are R-3 and R-8. They do not use Amtrak's trackage, they are well utilized, but perform below their potential. Due to their latent passenger demand, impacts of individual
innovations on attraction of additional passengers will be interesting to test and analyze.

**Step 5:** Demonstrate a coordinated set of improvements on one line and analyze it;

**Step 6:** Finalize plans and implement upgrading of the entire network as a coordinated effort which should be implemented in a period of approximately two years.
REFERENCES


Trackage Rights Agreement between Southeastern Pennsylvania Transportation Authority and Consolidated Rail Corporation; October 1, 1990.


APPENDIX

Investment Costs Estimation

Investment costs in the report were estimated through the numerous discussion with SEPTA departments and persons who take in charge of related fields. Assumptions were also made based on the results of the discussion. Followings explain each item of investment costs in some details with the assumptions for those items.

1. Overhaul costs: $39 million

If SEPTA make a decision not to purchase new rolling stock, the present rolling stock requires overhaul.

Costs per car: $800,000
number of cars needs overhaul: 48 cars

2. 1-car train operation: $5 million

Present cab signal problem prevents SEPTA from operating 1-car train. It is assumed that $5 million would be spent in order to fix the problem.

3. Platform construction costs:

Number of stations that need construction (low level or no platforms): 143 stations

Lengths of platform varies among lines:

<table>
<thead>
<tr>
<th>Route</th>
<th>Number of stations that need construction</th>
<th>Platform length</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>R2</td>
<td>27</td>
<td>345</td>
</tr>
<tr>
<td>R3</td>
<td>26</td>
<td>345</td>
</tr>
<tr>
<td>R5</td>
<td>38</td>
<td>430</td>
</tr>
<tr>
<td>R6</td>
<td>15</td>
<td>260</td>
</tr>
<tr>
<td>R7</td>
<td>22</td>
<td>430</td>
</tr>
<tr>
<td>R8</td>
<td>15</td>
<td>345</td>
</tr>
</tbody>
</table>

Total 143
Allocation of station costs per items:

<table>
<thead>
<tr>
<th>Items</th>
<th>Cost ($)</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signing, canopy, benches</td>
<td>$ 105,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Local extras</td>
<td>$ 150,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Handicapped ramps (1:12 slope)</td>
<td>$ 100,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Total</td>
<td>$ 355,000</td>
<td>Per station</td>
</tr>
<tr>
<td>Variable cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precast construction demolition, railings</td>
<td>Low-level: $400</td>
<td>Per foot of 8' wide platform</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-level: $500</td>
</tr>
</tbody>
</table>

4. New Cars

Costs per cars:
- with movable steps: 2.4 million
- without movable steps: 2.2 million

Number of cars needed: 1-car operation: 48 => 103 mil
2-car operation: 68 => 133 mil

5. Salvage value for older rolling stock: $ 100,000 per car is assumed.

6. SSFC: $13 million ($14.5 million)

Cost per ticketing machine: $ 42,000
Outbound stations plus both platforms on R3, R5, R7 lines: 210 machines X $42,000 = $9 million

Cost per cancelling machine: $ 40,000
Two machines per cars: 96 ticketing machines for 48 cars: 4 million
or: 136 ticketing machines for 68 cars: 5.5 million
Operating saving estimation

1. 1-car train operation during off-peak hours: 2.2 million

2. New cars:
   energy saving &
   maintenance saving:  2.9 million

3. Crew Reduction I (no passenger attendants): 1.9 million
   Crew reduction II (no conductor and attendants => one-man
   operation):  8.3 million

4. Shorter headway (30 minutes headways on all lines except R1 and
   R5 which already have had shorter headways): -7.5 million