An Analysis of Fare Collection Costs on Heavy Rail and Bus Systems in the U.S.

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ABSTRACT

In this research, an effort is made to analyze the costs of fare collection on heavy rail and motorbus systems in the U.S. Since existing ticketing and fare collection (TFC) systems are major elements of transit infrastructure and there are several new alternative TFC technologies available on the market, the need to evaluate the performance of existing TFC systems arises. However, very little research has been done, so far, to assess impacts of TFC technologies on capital and operating expenses in public transit. The two objectives of this research are: (1) to formulate a conceptual evaluation framework and a plan to assess the operating costs of existing TFC systems in transit and (2) to analyze the operating expenses associated with existing TFC systems on heavy rail and motorbus transit in the U.S. with the aid of the evaluation framework and plan.

This research begins with a review of the current state of knowledge in the areas of transit TFC evaluation, the economics of public transit operations, and fare collection practices and technologies. It helps to determine the scope of work related to assessment of TFC operating costs on public transit and provides the basis for the development of a conceptual evaluation framework and an evaluation plan. Next, this research presents a systematic approach to define and describe alternative TFC systems and suggests that the major TFC system determinants are payment media, fare media, TFC equipment, and transit technology (mode). Following this is the development of measures of effectiveness to evaluate alternative TFC systems. These measures assess cost-effectiveness and labor-intensiveness of TFC operations. The development of TFC System Technology Index follows. This Index recognizes the fact that TFC systems may consist of different sets of TFC technologies both traditional and innovative. Finally, this research presents statistical results that support the hypothesis that TFC operating costs are related to transit demand, transit technology (mode) and TFC technologies. These results further suggest that: (1) TFC operating costs per unlinked passenger trip on heavy rail systems are higher than on motorbus systems and (2) TFC operating costs per unlinked passenger trip tend to increase as the use of non-electronic fare media increases. Actions for further research are also recommended.

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LIST OF ACRONYMS

ADA	Americans with Disabilities Act
APTS	Advanced Public Transportation System
ASCII	American Standard Code for Information Interchange
BART	Bay Area Rapid Transit
CMM	change making machines
EEPROM	electrically erasable programmable ROM
EPROM	erasable programmable ROM
EPS	electronic payment systems
EQ	(TFC) equipment
EWH	employee work hours
FM	fare media
FT	Federal Transportation (Act)
FTA	Federal Transit Administration
HR	heavy rail
IC	integrated circuit
MB	motorbus
MS	Magnetic stripe
NTD	National Transit Database
OC	operating costs
PFR	passenger fare revenues
PM	payment media
PROM	programmable ROM
RAM	random access memory

RF	radio frequency
ROM	read only memory
TCRP	Transit Cooperative Research Program
TFC	ticketing and fare collection
TFCEWH	TFC employee work hours
TFCOC	TFC operating costs
TFCSTI	TFC System Technology Index
TVM	ticket vending machines
UPT	unlinked passenger trips
USOA	Uniform System of Accounts
WMATA	Washington Metropolitan Area Transit Authority

CHAPTER 1: INTRODUCTION

This chapter introduces the background of the research, defines the real world problem that led to this research, states the objectives of the research, outlines the scope of the research, and describes the report structure. Section 1.1 includes a brief overview of the developments and challenges surrounding transit operations with respect to ticketing and fare collection (TFC) activities. Section 1.2 defines the problem that many transit operators face in attempting to evaluate and select the most suitable TFC system for their needs. Section 1.3 links the real world problem discussed in Section 1.2 with the objectives of this research. Finally, Section 1.4 outlines the scope of the research and Section 1.5 describes the structure of this report.

1.1 BACKGROUND

Activities associated with ticketing and fare collection are a distinctive part of transit operations and can be traced back to the very beginning of the transit industry in the second quarter of the 19^{th} century. Although the TFC part of transit operations has undergone significant changes over the last 150 years, some of its key functions and concepts have remained intact and their description can be useful in getting a better understanding of processes, requirements, and challenges associated with TFC.

Generally, the key concepts of ticketing and fare collection are the concepts of payment media and fare media, their distribution, validation, collection, and processing. During the early years of the transit industry in the U.S. there was no distinction between payment media and fare media since transit fares were on the order of several cents and were paid for low denomination coins, i.e., pennies and nickels. However, over the following decades a concept of fare media has evolved due to various reasons including, for example, concern over safety and security of transit vehicle operators, fare theft, and introduction of time-based and distance-based fares.

The term “fare media” can be defined as an instrument accepted by a transit operator as a proof of payment for its services. Prior to the introduction of electronic fare media, the major forms of fare media included cash (coins and bills), tokens, punch cards, paper tickets (stored-value media), and paper passes (stored-time media).

Alternatively, the term “payment media” describes financial instruments that can be used to purchase fare media from a particular transit operator. Prior to the introduction of electronic payment media, the major forms of payment media included cash (coins and bills) and negotiable instruments (personal and organization checks, money orders, and other).

Although the introduction of fare media, as instruments to facilitate the collection of payment for transit services, has helped transit operators address several problems (briefly mentioned above), it also led to the development of another activity in transit operations that was not originally included in public transit. This activity has become known as ticketing and fare collection and encompasses the following three major activities: fare media preparation and distribution; fare media validation and collection;

and, payment and fare media processing and depositing. As a result, transit operators are required to apportion some of their financial and labor resources to conduct the ticketing and fare collection activity. Furthermore, the amount of labor and financial resources that a particular transit operator spends on TFC may depend on a number of factors including the transit operator's fare policy, labor rules, transit demand and supply, TFC technology used, and mode of transit.

Beginning in the 1970s and continuing today, the practice of TFC has been affected by a number of new organizational, policy, and technology developments and challenges. Primarily, these developments and challenges have been ignited by a rapid growth in computer and telecommunication technologies. In addition, the practice of TFC has been significantly impacted by innovations in electronic payment and fare media, and new types of automated fare distribution, validation, collection, and processing equipment. Technology growth, together with several transit industry trends such as decline in transit ridership (see figure 1-1), decline in transit operating ratio (see figure 1-2), and greater emphasis on transit convenience and equity, has brought new challenges to the transit industry's agenda. Some of the most frequently-mentioned challenges in transit today include: integrating transit operations into a seamless and convenient regional transit service; increasing efficiency and effectiveness of transit operations; handling increased complexity of fare structure; and managing new data collection requirements for policy and operations planning.

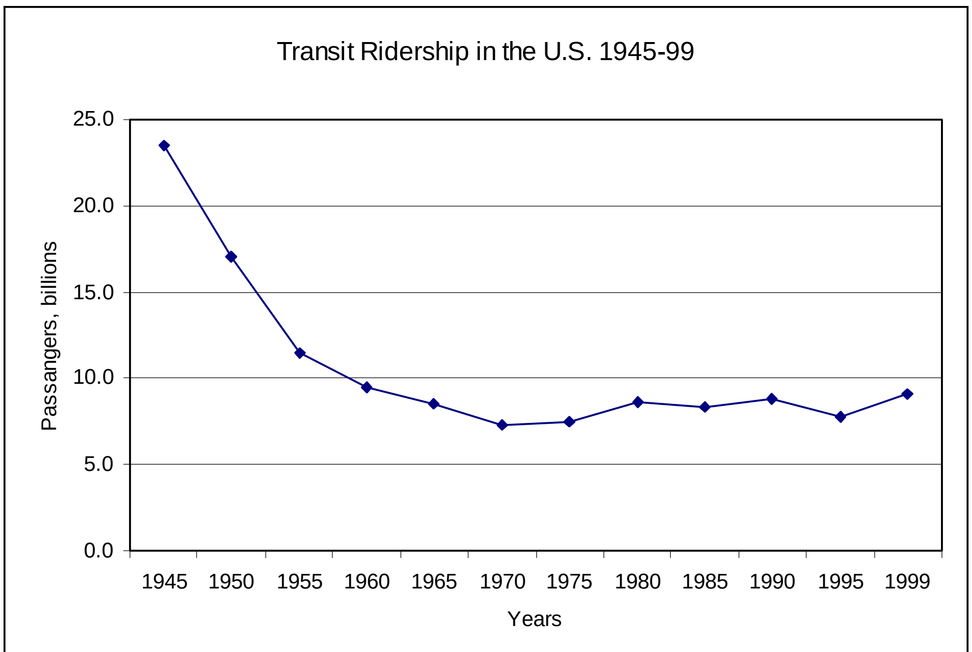

Figure 1-1. Transit ridership in the U.S. 1945-99 (APTA, 2001).

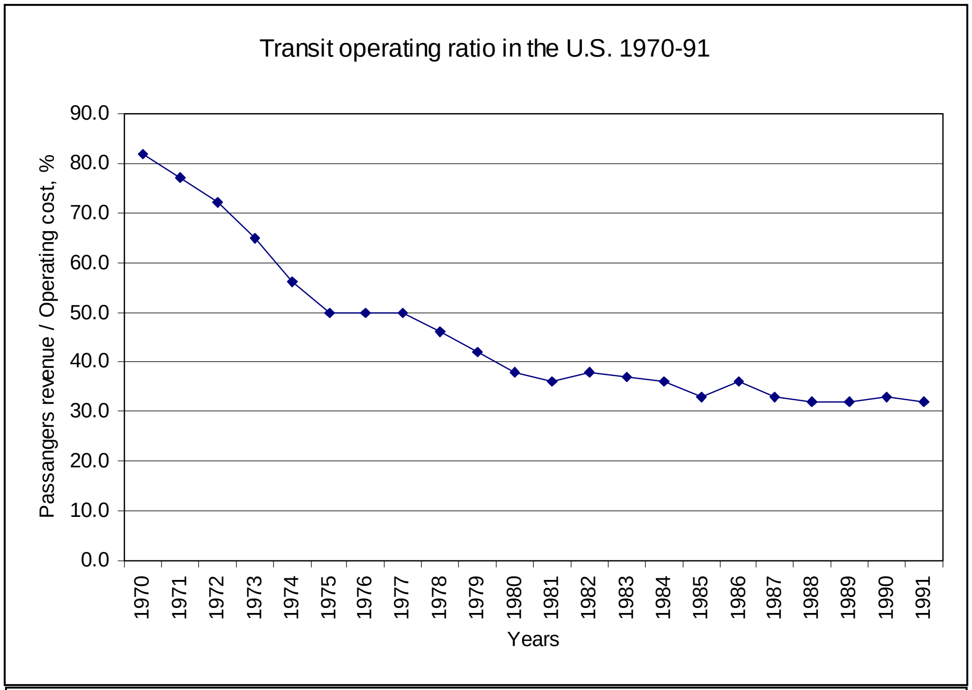

Figure 1-2. Transit operating ratio in the U.S. 1970-91 (APTA, 2001).

1.2 Problem Statement

Cyclically, transit operators need to repair, upgrade, or replace their vehicle fleets and other physical infrastructure assets. At the same time, the majority of transit operators in the U.S. face pressure to maximize their operating efficiencies, increase revenues, and expand their ridership. As one of the major elements of transit infrastructure, TFC systems need to be efficient and effective. Since there are several alternative TFC technologies available on the market, the need to evaluate their performance arises. One of the main dimensions of TFC system performance that transit agencies try to minimize is operating costs. However, very little research has been done, so far, to assess the impacts of alternative public transit TFC technologies on capital and operating expenses.

1.3 Objectives of the Research

Two main objectives of this research follow directly from the problem statement outlined above. The first objective is to formulate a conceptual evaluation framework and a plan to assess the operating costs of alternative TFC technologies in transit. The second objective is to analyze the operating costs associated with alternative TFC systems on heavy rail and motorbus transit in the U.S. with the aid of the evaluation framework and plan.

1.4 SCOPE OF THE RESEARCH

To achieve the above objectives, this research consists of eight main tasks: (1) literature review (2) formulation of the TFC system evaluation framework, (3) design of the research methodology, (4) development of the TFC system evaluation plan, (5) preparation of data for the analysis, (6) data analysis, (7) discussion of the results obtained, and (8) conclusions and recommendations for future research.

Task 1—literature review—involves a review of the current state of knowledge in the areas of: (a) transit evaluation; (b) economics of public transit operations; and (c) fare collection practices, functions, and technologies on public transit in the U.S.

Task 2—formulation of the evaluation framework—includes the following steps: (a) discussion of issues associated with fare collection on transit; (b) discussion of objectives for TFC system selection; and (c) identification and description of alternative TFC systems currently employed by transit operators in the U.S.

Task 3—design of the research methodology—presents the general theory regarding the performance of transit TFC systems and a set of hypotheses that are tested on the following stages of the research.

Task 4—development of the evaluation plan—involves the following steps: (a) identification, design, and selection of TFC system performance measures; (b) selection of analytical methods and techniques to examine performance of alternative TFC systems in terms of selected measures; (c) determination of data requirements to utilize the selected measures; and (d) identification of available data sources and selection of a principal data source(s) to examine performance of alternative TFC systems in terms of selected measures.

Task 5—preparation of data for the analysis—includes the following steps: (a) preliminary selection of transit systems to include into the analysis; (b) assembling, filtering, and editing of the data from the identified primary data source(s); and (c) preparation of the final database and design of a verification questionnaire to supplement and/or verify the data from the principal data source(s).

Task 6—data analysis—involves preliminary statistical analyses of the data and testing of the hypotheses formulated in Task 3. The preliminary data analyses may include examination of scatter diagrams, box plots, histograms, and correlation matrices. The hypothesis testing is based on regression analyses and may involve assessment of t-statistics, coefficient of determination, and the effect of outliers and influential observations.

Task 7—discussion of the results—presents findings and results of the research.

Task 8—conclusions and recommendations—includes the following steps: (a) summary of the research; (b) discussion of the research limitations; (c) overall evaluation of the results and conclusions; and (d) recommendations for further research.

1.5 REPORT STRUCTURE

This report consists of six chapters.

Chapter 1—Introduction—serves as an introduction and provides background of the research.

Chapter 2—Literature Review—presents a review of literature related to the research and describes the present state of knowledge in the areas of TFC system evaluation, economics of public transit operations, and fare collection practices and technologies (Task 1 of the research).

Chapter 3—Research Methodology—covers the formulation of the evaluation framework (Task 2 of the research), design of the research methodology (Task 3 of the research), and development of the evaluation plan (Task 4 of the research).

Chapter 4—Data Analyses—describes the preparation of data for the analysis (Task 5 of the research), hypotheses testing, and other statistical analyses of the data (Task 6 of the research).

Chapter 5—Findings and Results—presents major findings and results of the research (Task 7 of the research).

Chapter 6—Summary and Conclusions—presents summary and conclusions of this research and outlines recommendations for further research (Task 8 of the research).

References are included following Chapter 6 and provide the reader with a list of the literature used to conduct the research and prepare this report.

CHAPTER 2: LITERATURE REVIEW

This chapter provides a review of recently published literature related to the subject of the research and consists of three sections. Section 2.1 describes the current state of knowledge in the area of TFC system evaluation in public transit. Section 2.2 discusses the economics of public transit operations with the focus on operating expenses associated with the provision of heavy rail and motorbus services. Finally, Section 2.3 provides background on the current fare collection practices, functions, and technologies on public transit in the U.S.

2.1 EVALUATION APPROACHES

In this part of the literature review, the current state of knowledge in the area of TFC system evaluation in public transit is discussed. Section 2.1.1 describes one of the earliest attempts to develop an evaluation framework and methodology to assess merits of electronic fare collection media such as smart cards as well as other advanced public transportation technologies, undertaken by Collura (1992). Next, Advanced Public Transportation System (APTS) Evaluation Guidelines prepared by Casey and Collura (1994) and sponsored by the Federal Transit Administration (FTA) are discussed in Section 2.1.2. Section 2.1.3 presents an effort by Collura and Plotnikov (2000) to address the need for a "business case" to answer questions surrounding the assessment of advanced fare collection technologies. In Section 2.1.4, the discussion of issues addressed by Collura and Plotnikov in EPS Business Case (2000) is continued and a broad conceptual framework and detailed evaluation plan to be used in the assessment of alternative fare collection systems on public transit services is presented (Collura and Plotnikov 2001). Finally, Section 2.1.5 presents a comprehensive review of fare policies, strategies, structures, and TFC technologies and systems in the U.S. conducted by Fleishman et al. (1996) under the sponsorship of Transit Cooperative Research Program (TCRP).

2.1.1 Evaluating the use of smart card systems

An early attempt to develop a conceptual framework and evaluation methodology to assist in the assessment of advanced fare collection technologies (e.g. smart cards) was undertaken by Collura in 1992. Collura (1992) argues that since the major purpose of an APTS application, such as a smart card system, is to improve overall transit system performance, APTS evaluations should focus on how APTS applications affect transit system efficiency and effectiveness.

2.1.1.1 Conceptual Framework

To facilitate the conduct of an APTS evaluation, Collura (1992) presented a framework (see figure 2-1) the major components of which include transit system management, transit system performance, and impacts. As a guide in the development of the framework and the evaluation methodology, Collura used a number of demonstration project evaluations and transit system performance assessments. Collura stressed that the

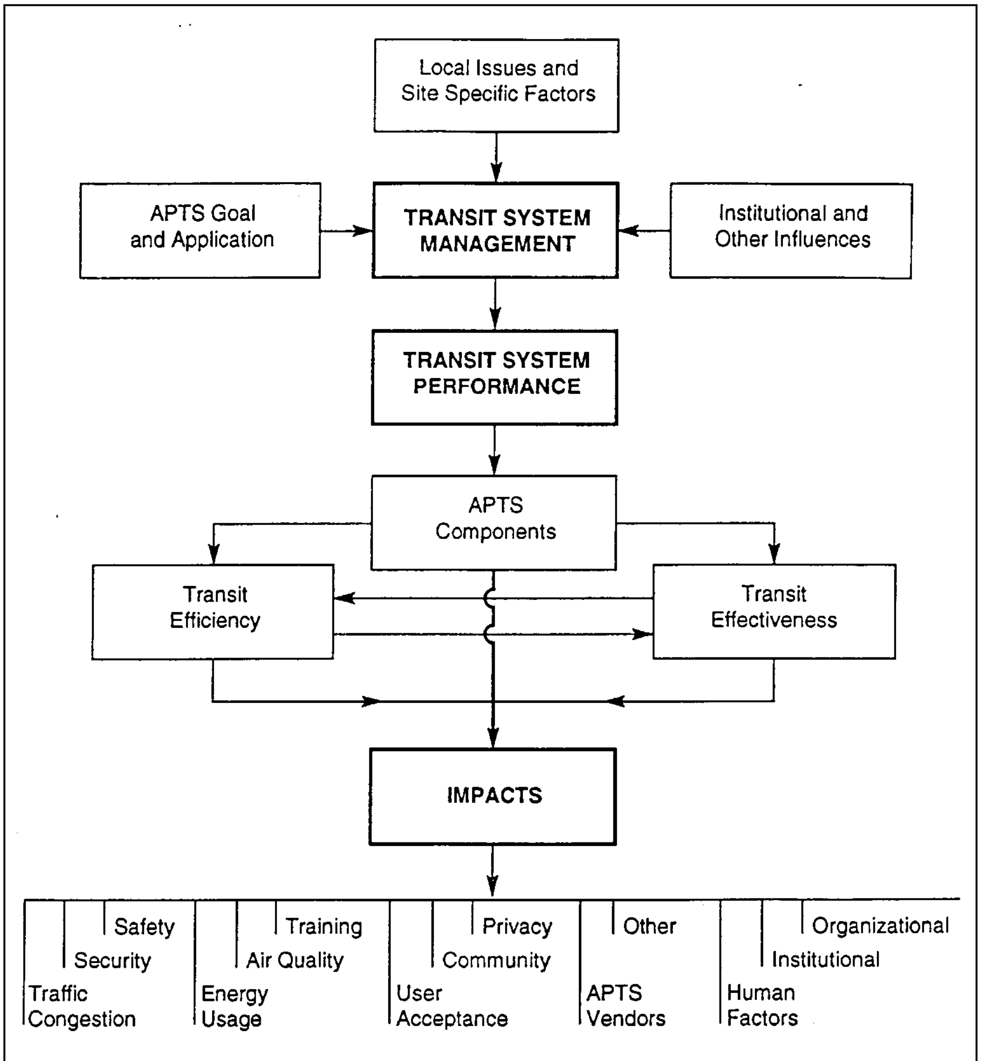

Figure 2-1. APTS evaluation framework (Collura, 1992).

evaluation framework developed was conceptual and suitable to assess various APTS applications including smart cards.

The first element of the evaluation framework developed by Collura (1992) is transit system management that includes the organizations and individuals responsible for local transit policy-making, administration, and operations. Furthermore, Collura (1992) points out that management decisions are shaped by local issues and site-specific factors, institutional and other external influences, and available technology.

According to Collura (1992), transit system performance can be influenced by a myriad of variables and can be viewed in terms of efficiency and effectiveness. Efficiency is related to the extent to which system inputs are employed to produce outputs whereas effectiveness concerns the users and actual demand for service.

The third element of Collura's evaluation framework is impacts. Collura (1992) mentions that some impacts can relate to the transit agency, its organizational structure, and administrative procedures while others deal with environmental, social, energy and other national and local concerns.

2.1.1.2 Evaluation Methodology

The evaluation methodology proposed by Collura (1992) consists of identifying appropriate criteria, determining data requirements, designing and administering necessary surveys, and conducting analyses.

Collura (1992) stresses that the selection of criteria is a critical element in a project evaluation. Properly selected criteria should help to: examine the APTS components in terms of functional and cost characteristics, determine efficiency and effectiveness of alternative systems, and assess the nature and extent of other impacts. These criteria can be both quantitative and qualitative and should incorporate measures of costs and benefits. Table 2-1 presents selected examples of criteria to evaluate various impacts of smart cards (Collura 1992).

Finally, Collura suggests that a variety of data collection methods might be employed and that data analysis techniques, ranging from simple "before and after" analysis to more sophisticated multiple regression analysis, might be used during the evaluation process.

2.1.2 Advanced Public Transportation System Evaluation Guidelines

The evaluation framework presented by Collura (1992) was further developed in research sponsored by the FTA and conducted by Casey and Collura (1994). The results of this research were documented to provide evaluation guidelines for use by contractors responsible for evaluating APTS operational tests sponsored by the FTA. In this document, particular emphasis was placed on the formulation of measures to facilitate the assessment of APTS Program objectives. Also, the authors suggested that potential applicability of the evaluation guidelines extended beyond the evaluation of APTS operational tests to the evaluation of advanced technologies in public transportation in general.

The evaluation process developed by Casey and Collura (1994) consists of four major modules: the evaluation frame of reference, evaluation planning, evaluation implementation, and potential evaluation spin-offs (see figure 2-2). The rest of this section describes the first two modules of the evaluation process developed by Casey and Collura (1994) since these two modules are related to the research undertaken in this dissertation. First, the evaluation frame of reference is discussed. Then, issues of data requirements and sources are covered. Next, an approach toward the development of evaluation measures is presented. Finally, issues relating to data collection and analysis are discussed.

COSTS	**CRITERIA**
• FIXED	• COSTS OF CARDS, SCANNERS, AND OTHER EQUIPMENT
• VARIABLE	• COSTS OF PERSONNEL INVOLVED IN ADMINISTRATION, SALES, AND MARKETING
FUNCTIONAL CHARACTERISTICS	
• EASE OF USE	• HOURS OF TRAINING REQUIRED
	• PERCEPTIONS OF USERS (E.G., DRIVERS / SMART CARD SYSTEM; DISPATCHER / ACCURACY OF AVL VEHICLE SYSTEM
EFFICIENCY	**CRITERIA**
• ENHANCE PRODUCTIVE USE OF VEHICLES	• CHANGES IN BOARDING AND ALIGHTING TIMES
• INSURE RELIABILITY OF EQUIPMENT	• HOURS (OR USES) BETWEEN FAILURES OR SHOP REPAIRS
• IMPROVE DRIVER PERFORMANCE	• DRIVER PERCEPTIONS
• REDUCE BILLING AND ACCOUNTING COSTS	• BILLING AND ACCOUNTING COSTS AS PERCENTAGE OF OPERATING COSTS
	• OPERATING COSTS PER VEHICLE MILE
EFFECTIVENESS	**CRITERIA**
• INCREASE RIDERSHIP	• TOTAL PASSENGERS • PASSENGER/VEH. MI. • PASSENGER/VEH. HR.
• INSURE THAT USE OF SMART CARD IS COST-EFFECTIVE	• OPERATING COST/SMART CARD PASS TRIP
• INCREASE REVENUE	• SMART CARD REVENUES AS PART OF TOTAL REVENUES • REVENUES AS PERCENT OF OPERATING COSTS • NUMBER OF EVADERS/VIOLATERS

Table 2-1. Selected APTS evaluation criteria (Collura, 1992).

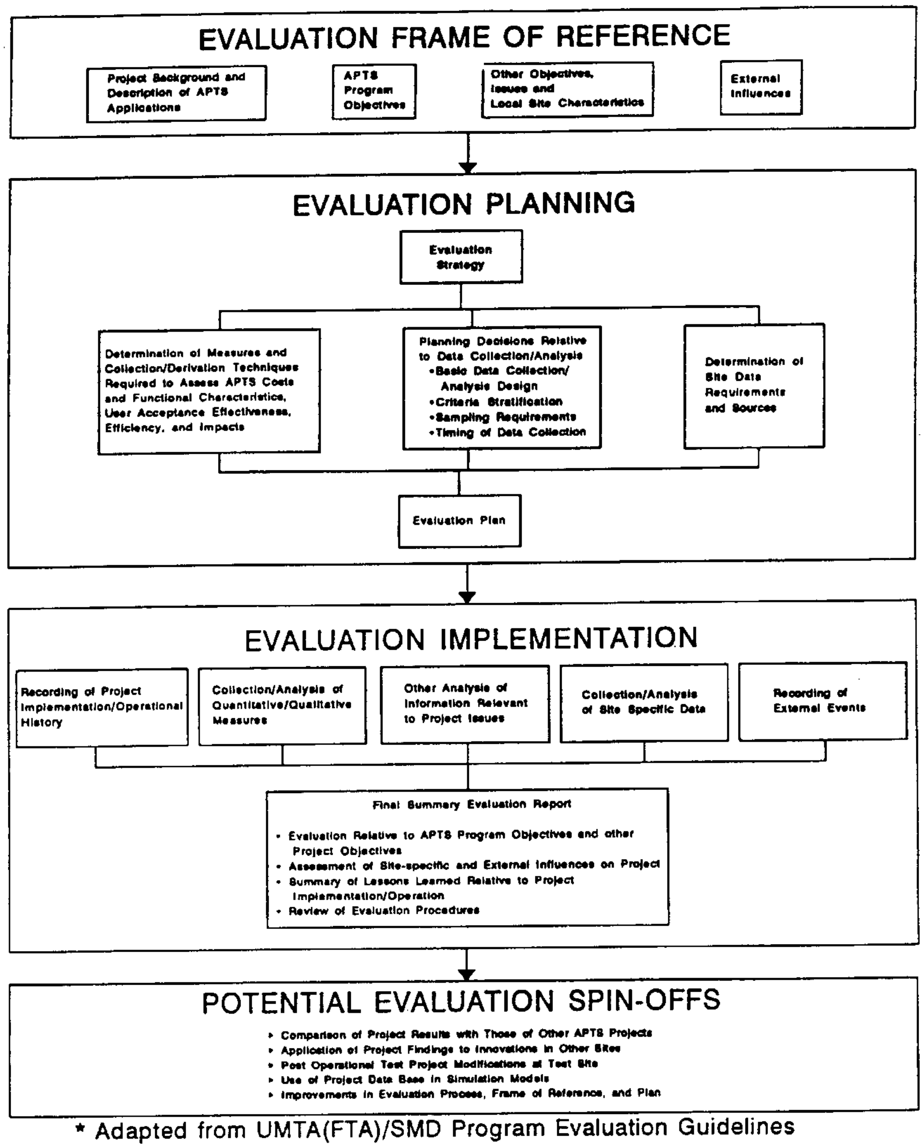

Figure 2-2. Modules of an APTS evaluation process (Casey and Collura, 1994).

2.1.2.1 Evaluation Frame of Reference

As viewed by Casey and Collura (1994), the evaluation frame of reference consists of four elements: the operational test application; APTS Program objectives; external influences; and local issues, objectives, and site characteristics. As the authors point out, an APTS operation test can consist of one or more technological applications, one of which might be the use of smart cards to facilitate automatic fare collection.

The objectives of an APTS operational test are derived from the two major goals of the APTS Program: 1) to enhance the ability of public transportation to satisfy customer needs, and 2) to contribute to broader community goals by providing information on innovative applications of available technologies) and can be grouped in four general categories as depicted in table 2-2. The authors also emphasize that there may be objectives other then those of the APTS program, namely state and local objectives.

Furthermore, since the operational test site can range from a corridor in a city to a group of cities, an understanding of the unique socio-economic, geographic, and transportation characteristics of the site is important and necessary. Casey and Collura (1994) recommend that to the maximum extent possible, external influences on the project should be identified and appropriate strategies to reduce the likelihood of such influences should be designed.

2.1.2.2 Site Data Requirements and Sources

According to the guidelines, the purpose of the site data is to provide an in-depth understanding of the site-specific characteristics that may influence the outcome of the project or the interpretation of project results. Also, site data might be necessary to enhance the comparability and transferability of APTS project findings. Table 2-3 illustrates a basic set of data requirements developed for use in APTS operational test projects.

The authors anticipate that the data sets and descriptive information shown in table 2-3 should be available from secondary sources and should not involve specialized data collection activities. Typical sources for various categories of site-specific data are listed in table 2-4.

2.1.2.3 Evaluation Measures

Once a set of project objectives and issues is finalized, a set of measures should be associated with these objectives and suitable techniques to derive each measure and to collect necessary data should be identified. Casey and Collura (1994) suggest six categories of measures: costs, functional characteristics, user acceptance, transit system efficiency, transit system effectiveness, and impacts.

Table 2-2. Objectives of an APTS operational test (Casey and Collura, 1994).

Objective #1: Enhance the Quality of On-Street Service to Customers

- Improve the quality, timeliness, and availability of customer information,
- Increase the convenience of fare payments within and between modes,
- Improve safety and security,
- Reduce passenger travel times, and
- Enhance opportunities for customer feedback.

Objective #2: Improve System Productivity and Job Satisfaction

- Reduce transit system costs,
- Improve schedule adherence and incident response,
- Increase the timeliness and accuracy of operating data for service planning and scheduling,
- Enhance the response to vehicle and facility failures,
- Provide integrated information management systems and better management practices, and
- Reduce worker stress and increase job satisfaction.

Objective #3: Enhance the Contribution of Public Transportation Systems to Overall Community Goals

- Facilitate the ability to provide discounted fares to special user groups (e.g., disabled persons or employees eligible for tax-free employer subsidies),
- Improve communication with users having disabilities (e.g., visual or hearing impairments),
- Enhance the mobility of users with ambulatory disabilities,
- Increase the extent, scope, and effectiveness of Transportation Demand Management
- Increase the utilization of high occupancy vehicles, with an emphasis on reducing the use of single occupant vehicles, and
- Assist in achieving regional air quality goals and mandates established in the Clean Air Act Amendments of the Intermodal Surface Transportation Efficiency Act (ISTEA).

Objective #4: Expand the Knowledge Base of Professionals Concerned with APTS Innovations

- Conduct thorough evaluations of operational tests,
- Develop an effective information dissemination process,
- Showcase successful APTS innovations in model operational tests, and
- Assist system design and integration.

Table 2-3. APTS evaluation basic data requirements (Casey and Collura, 1994).

1. Population
2. Square miles
3. Population density, persons per square mile
4. Number of persons in the labor force
5. Number of households, by type
6. Age, sex, education, occupation, income distributions
7. Household auto ownership
8. Number of persons with no drivers license
9. Modal split, by trip purpose or time of day if available
10. Existing (Pre-operational test) transit service characteristics
    - Organizational arrangements
    - Route miles (fixed route systems)
    - Tour area (non-fixed route systems)
    - In-service vehicles per square mile of service area (non-fixed route system)
    - In-service vehicles per hour within service area
    - Time of service operation throughout day
    - Days of service operation throughout year
    - Service frequency (fixed route systems)
    - Fare schedule
11. Description of para-transit service characteristics
    - Data on taxi operations
    - Information on carpool promotion/matching programs
12. Map of the site showing:
    - The APTS project service area - note that this might be a contiguous area served throughout by the APTS transit system, or it might be two or more non-contiguous areas linked by the APTS service through a travel corridor
    - The existing transportation network - major highways, transit lines, commuter rail lines
    - Air quality attainment and non-attainment areas
    - Major topographical features such as rivers
    - The central business district
    - Any other important activity centers
13. Description of relevant site features such as:
    - Weather conditions
    - Seasonal population variations
    - Institutional/political climate
    - Economic conditions
    - Cost indices (e.g., cost of living index, prevailing transit wage rates)
    - Population/employment growth rate, land use development patterns
    - Residential mobility
    - Air quality conditions concerning ozone, lead, carbon monoxide, PM10, and other environmental concerns

Table 2-4. APTS evaluation data sources (Casey and Collura, 1994).

DATA NEEDED	TYPICAL SOURCES
Demographic	U.S. Bureau of the Census City or County Clerk State Department of Labor State Department of Internal Revenue City or County Planning Board
Air Quality	Environmental Protection Agency
Land Use Characteristics	City Directories Local, Regional and State Planning Agencies Tax Assessor's Records Planning Studies
Motor Vehicle Travel	State Highway Department (or State DOT) U.S. Census (Journey-to-Work) Local Traffic Department Earlier Travel Surveys State Registration Records Gasoline Tax Collection Records
Public Transportation Travel	Private Transit-Paratransit Companies Transit Authorities State Highway Department (or State DOT) Local Planning Agency U.S. Census (Journey-to-Work) Earlier Travel Surveys
Travel by Intercity Modes (air, rail, bus)	Federal Agencies such as: Federal Aviation Administration Interstate Commerce Commission Federal Railroad Administration Department of Commerce State Regulatory Agencies Earlier Travel Surveys Private Carriers

Since the performance of an APTS system and its individual components is central to an operational test evaluation, questions surrounding the costs and functional characteristics should be addressed and overall operational test objectives should be examined. The extent to which various APTS applications are utilized would also be an important dimension of performance in each operational test. Therefore, quantitative and qualitative measures of user acceptance should be developed for each test. Since transit system efficiency and effectiveness may also be affected by the use of the APTS application, some measures to assess these dimensions of performance are necessary too. Efficiency is related to the extent to which system inputs are employed to produce outputs while effectiveness concerns the users and actual demand for service and could relate to revenue, cost effectiveness, service utilization, quality, convenience, reliability and other aspects. Finally, other impact measures might be required to assess internal activities and administrative procedures of a transit agency, human factors, privacy, equity, air quality, institutional and political concerns, and other factors.

Casey and Collura (1994) also believe that the six categories of measures discussed are not exhaustive, but should provide guidance in the selection of measures to evaluate the APTS objectives shown in table 2-1 above. The authors further illustrate the point by linking individual APTS program objectives with examples of corresponding evaluation measures (see table 2-5).

2.1.2.4 Data Collection/Analysis Techniques

The next step after the relevant measures for project evaluation are determined is to identify appropriate data collection and derivation techniques. Casey and Collura (1994)

Table 2-5. Selected APTS evaluation measures (Casey and Collura, 1994).

Subobjective / Category of Measure	Improve Timeliness and Availability of Customer Information	Increase Convenience of Fare Payments	Improve Safety and Security	Reduce Passenger Travel Time	Enhance Opportunities for Customer Feedback
APTS User Acceptance	• No. and type of information inquiries • No. using information to change their usual mode • No. of information outlets or sources • Changes in available information • Perceptions on customer information services	• No. using new payment option • Perception of riders on convenience of options	• Perceptions of riders on safety and security	• Perceptions of riders on travel time changes	• No. and type providing feedback
APTS Functional Characteristics	• Field measurements of information accuracy			• Actual measurements of travel time	
Transit System Efficiency			• Changes in vehicle down-time		
Transit System Effectiveness	• Time to answer telephone inquiries	• Changes in transfer wait time, in-vehicle time, and no. of passengers transferring	• Response time • Accident rate • Incident rate • Perceptions of drivers on safety and security	• Actual travel time changes • On-time performance	• No. of suggestions, complaints re improvements
Impacts		• Ease of use, by riders, of new fare payment options • Ease of use by drivers and other staff			

suggest the following four basic data collection methods: by measurements, by counts or observations, by surveys or interviews, and by searching records.

The authors warn that the evaluator should apply sound judgment in determining whether the anticipated cost of using a particular technique is justifiable in terms of the contribution to the overall project evaluation. The total project expenditure for data collection should be allocated among individual measures, taking into account each measure's contribution to the project evaluation. Also, the accuracy of a particular technique should be consistent with the accuracy requirement for the measure, which is dependent on the relative importance of the measure.

Once the measures and data requirements are determined, measure stratification should be performed. According to the authors, measure stratification is the categorization of individual measures for collection/derivation and/or analysis purposes. Stratification can take the following forms: categorization of a measure into additive components; categorization of a measure according to target market, operational, geographic, or time categories; and grouping of raw values of a measure into class intervals. For example, transit operating cost data reported in the National Transit Database (NTD) illustrates categorization of a measure into additive components.

2.1.3 EPS Business Case

Responding to the need for a "business case" to answer questions surrounding the potential investment in advanced fare collection technologies (termed as electronic payment systems (EPS) in the transit community), Collura and Plotnikov (2000) reviewed the possible structure and scope of an EPS business case.

Collura and Plotnikov (2000) acknowledge that in recent years many transit agencies across the U.S. have considered the use of electronic media, including magnetic stripe and smart cards, for fare collection. To address issues and questions regarding the merits of EPS in transit, representatives from transit agencies, financial institutions, systems integrators, and technology providers have expressed the need for an EPS "business case." Some authors suggest that an EPS business case should be limited primarily to the analysis of financial impacts, whereas others argue that a more comprehensive analysis is needed.

One approach stems from the concept of a "business case," as it is known in the private sector (Schmidt, 1997). According to this approach, the emphasis is put on the assessment of financial impacts associated with an EPS investment. Non-financial issues are also considered under this approach, but it is suggested that they play a marginal role in decision-making.

The other approach, outlined by Dinning (1997), calls for a thorough assessment of "all information necessary to "make the case" for smart card implementation." Dinning (1997) suggests that in addition to financial and operational issues associated with an EPS implementation, institutional, technological, and customer acceptance issues should also be taken into account. In other words, the EPS business case should include a comprehensive assessment of all issues and factors related to an EPS implementation (Dinning, 1997).

Collura and Plotnikov (2000) argue that the two approaches differ primarily with regard to the scope of coverage and relative importance of various issues and factors related to an EPS implementation. However, the general structures of the business case descriptions by Dinning (1997) and Schmidt (1997) appear to be very similar, in that there will be a need to make and clarify assumptions, construct cost and benefit models, analyze results of these models, perform sensitivity and scenario analyses, and make recommendations regarding project implementation.

Collura and Plotnikov (2000) conclude that while various non-financial EPS impacts can be of significant importance for a transit agency and travelers, an adequate tool to assess these impacts in monetary or some other uniform terms should be found.

2.1.4 Evaluating Electronic Payment Systems in Public Transit

Building upon the research discussed in EPS Business Case (2000), Collura and Plotnikov (2001) prepared a broad conceptual framework and detailed evaluation plan to be used in the evaluation of alternative fare collection systems on public transit services.

2.1.4.1 Framework for EPS Evaluation

As suggested by Collura and Plotnikov (2001), a framework should consist of at least three elements: 1) an articulation of the EPS-related issues as perceived by major participants and other stakeholders in the EPS implementation and a definition of the problems the EPS is designed to address; 2) a review of the fare collection procedures, policies, and technologies including the existing and proposed fare collection systems; and, 3) a clear statement of the intended EPS objectives.

According to Collura and Plotnikov (2001), the implementation of an EPS may intend to address one or more issues and problems. Such issues and problems might be viewed from the perspective of a transportation agency/provider, the customer, or some other stakeholder. For example, from a provider's perspective these issues and problems might include relatively high costs of collecting bills and coins, lack of reliable data on transit usage, inadequate inter-modal coordination, and high levels of fare evasion and fraud. From a customer's perspective an EPS perhaps should be directed at improving service quality and convenience, facilitating transfer between transit modes and operators, providing discount fares, and simplifying financial transactions in general.

The authors observe that the existing and proposed fare collection systems may involve the use of media such as tokens, dollar bills, coins, flash passes, magnetic stripe tickets, or smart cards. Some of the media might be used on a flat fare basis while others on a distance-based basis. In addition, some media require the use of electronic readers either at turnstiles or on board vehicles and on-line or off-line information processing. Finally, it should be noted that electronic media vary in terms of capital and operating cost, memory function and capacity, security, and other performance characteristics and that the selection of a fare medium with certain performance characteristics should be linked to the intended EPS objectives.

EPS objectives need to be established with input and guidance from all project participants and stakeholders. Objectives might include, for example, reduction of fare collection costs, increase of transit cost efficiency and effectiveness, improvement in data collection, reduction of revenue loss due to fraud and fare evasion, provision of seamless transit travel, and improvement in customer convenience and satisfaction.

2.1.4.2 EPS Evaluation Plan

The second component of the approach proposed by Collura and Plotnikov (2001) is a detailed evaluation plan including suggested measures and analytical techniques, data requirements and sources, and data collection procedures. The measures can be either qualitative or quantitative, and may be used to determine the extent to which the EPS achieves its objectives. To facilitate evaluation it is suggested that EPS measures be grouped into three general categories related to: system performance, user acceptance, and other impacts.

System performance measures focus on impacts relating to transit system operations. System performance measures may be either financial or non-financial. Generally, the non-financial measures relate to security, reliability, and other functional and technical aspects of the EPS technology.

User acceptance measures capture aspects of EPS performance related to the rider such as the number and proportion of transit riders who choose to use the EPS vis-à-vis other fare collection systems, if available. In addition, the convenience associated with the EPS as perceived by the rider would also be viewed as an important dimension of user acceptance and might be measured using rider perception measures.

Other impacts such as institutional and organizational impacts might be evaluated quantitatively and qualitatively in terms of, for example, equity, the extent to which coordination among two or more transit providers or agencies is required, and the level of participation required of a third party (e.g. clearinghouse) for billing, accounting, and reconciliation purposes.

Finally, the authors note that the data required to employ these measures and the necessary analytical techniques would be collected by transit staff and other EPS implementation participants. Special attention should be given to use sampling methods and automated data collection procedures. Interviews and focus group discussions involving participants and other stakeholders should also be considered.

2.1.5 <u>TCRP Report 10: Fare Policies, Structures, and Technologies</u>

Perhaps the most recent comprehensive research on fare policies, strategies, structures, and TFC technologies and systems in the U.S. was conducted under the sponsorship of TCRP between 1993 and 1995. This research, identified as TCRP Project A-1, was undertaken by a team headed by Daniel Fleishman of Multisystems, Inc. to evaluate alternative fare structures, review current and emerging fare collection technologies, and develop evaluation guidelines for fare policies, structures, and technologies. The information collected under TCRP Project A-1 was updated at the end of 1995 and published in 1996 as TCRP Report 10: Fare Policies, Structures, and Technologies (Fleishman et al. 1996).

Although this comprehensive report covers a wide spectrum of issues ranging from overall fare policy development to selection and procurement of new TFC technology, one of its major themes is the development of an evaluation tool (referred to as fare decision-making guidelines in the report) to assess different aspects of ticketing and fare collection process.

This section of the literature review discusses the parts of TCRP Report 10 that describe the overall structure of the fare decision-making guidelines and address specific issues relating to the assessment of operating costs associated with different TFC technologies and systems. First, the fare decision parameters, defined in TCRP Report 10, are described. Then, the major issues that usually lead to fare-related changes are outlined. Subsequently, the fare decision-making process developed in TCRP Report 10 is presented. Finally, the factors influencing selection of new TFC technology are discussed.

2.1.5.1 Fare Decision Parameters

According to Fleishman et al. (1996), there are five fundamental parameters related to fare decisions: fare policy, fare strategy, fare structure, fare payment technology, and fare collection system.

The term “fare policy” is defined as “the principles, goals, objectives, and constraints that guide and restrict the management of a transit agency with respect to setting and collecting fares”.

The term “fare strategy” is defined as “a general fare collection/payment structural approach” such as flat fare, differential pricing, market-based pricing, and transfer pricing.

The term “fare structure” is defined as “the combination of one or more fare strategies with specific fare levels”.

The term “payment technology” is defined as “the type of fare payment media and equipment used for fare collection and sale/distribution of media”.

Finally, the term “fare collection system” is defined as “the basic fare collection and distribution approach (such as barrier, payment on entry, and proof of payment), as well as the specific equipment and payment media”.

Fleishman et al. (1996) suggest that, in the long term, a transit agency will need to make decisions about each of these parameters. He argues that fare decision parameters are interrelated and a decision regarding one of them ultimately affects decisions regarding the others despite the fact that each parameter is often evaluated separately. For example, a decision concerning fare policy typically precedes and delineates fare strategy and fare structure options while the payment technology selected could also affect fare structure options.

2.1.5.2 Decision-making scenarios

Although transit agencies employ different approaches in making decisions about fare structures and systems depending on such factors as the type of change being made, the nature of the agency, and the status of the existing fare structure and fare system, ideally, these decisions should derive from the agency's fare policy. A transit agency's fare policy sets the principles and goals behind the fare-related decisions and may include general long-term goals, such as maximization of ridership, revenue, or social equity, as well as more specific short-term objectives such as achieving a certain fare recovery ratio or meeting a certain ridership or revenue target (Fleishman et al. 1996).

However, Fleishman et al. (1996) point out that while some agencies maintain ongoing fare policies that guide fare-related changes, most agencies make fare decisions on an as-needed basis. Usually, a specific problem, such as a greater than expected decrease in ridership or a fare theft scandal, leads to fare-related changes.

Another dimension of the fare system decision-making process relates to the major factors that influence the selection of a particular decision-making approach. According to Fleishman et al. (1996), changes in a transit agency's policy, adoption of new technology, or introduction of a new mode or service are the three common factors affecting the selection of a particular decision-making approach.

When a transit agency establishes a new set of goals and objectives, changes to fare structure and fare payment technology are usually warranted. New goals can be short-term, such as improving budgetary situation, or long-term such as fostering public mobility. Table 2-6 illustrates a policy-driven decision-making scenario (Fleishman et al. 1996).

In a technology-driven scenario, the fare-related changes are triggered by the adoption of a new fare payment technology. A new fare structure may be developed to take advantage of the capabilities of the new technology. Table 2-7 presents the attributes of a technology-driven decision-making scenario (Fleishman et al. 1996).

Finally, the introduction of a new mode or service can lead to changes in fare payment technology and fare structure for the transit agency. Table 2-8 shows examples of the issues associated with the service-driven decision-making scenario (Fleishman et al. 1996).

Table 2-6. Policy-driven fare decision-making scenario (Fleishman et al., 1996).

SCENARIO 1: POLICY-DRIVEN DECISION-MAKING

Transit agency seeks new technology (e.g., MBTA - 1993) and/or new fare structure (e.g., CTA - 1989/90) to meet specific local policy goals.

Technology decision areas:

- fare collection/control strategy (e.g., proof-of-payment vs. barrier)
- level of automation (e.g., magnetic cards vs. smart cards); type of equipment/technology
- same technology on all modes, or change only on rail (or only on bus)
- type of media distribution strategy/equipment (e.g., TVM's vs TOM'S, use of ATM'S, credit cards)
- phase in new technology or implement all at once

Fare structure decision areas:

- retain existing basic structure, introduce additional fare options (e.g., peak/off-peak differential, deep discounting), or totally revamp existing structure (e.g., introduce -- or, conversely, eliminate -- distance-based pricing)
- change pricing (e.g., base fare, passes), or leave as is
- introduce fare structure revisions before technology modifications, or at same time

Table 2-7. Technology-driven fare decision-making scenario (Fleishman et al., 1996).

SCENARIO 2: TECHNOLOGY-DRIVEN DECISION-MAKING

Transit agency has selected new technology, and develops new fare structure to take advantage of capabilities of new technology (e.g., NYMTA - 1992/3).

Policy decision areas:

- relative importance of major policy goals (e.g., which is more important, maximize ridership or maximize revenue – or balance both)

Fare structure decision areas:

- introduce additional fare options, or totally revamp existing structure
- change pricing (e.g., base fare, passes), or leave as is
- introduce fare structure revisions before technology modifications, or at same time

Table 2-8. Service-driven fare decision-making scenario (Fleishman et al., 1996).

SCENARIO 3: SERVICE-DRIVEN DECISION-MAKING

A) Existing transit agency is introducing new mode (e.g., rail service), and needs technology and/or new structure (e.g., Bi-State in St. Louis - 1992/3).

B) Agency is new, and needs to develop fare policy and structure, as well as to select technology (e.g., SCRRA/Metrolink - 1992/3).

Policy decision areas:

- develop policy goals for new mode and for overall system (e.g., maximize ease of use of new mode, maximize integration of modes)

Technology decision areas:

- fare collection/control strategy
- level of automation; type of equipment/technology
- same technology as on existing mode(s), or new technology; alternatively, new technology on whole system
- type of media distribution strategy/equipment

Fare structure decision areas:

- extend existing fare structure (if applicable) to new mode, introduce new structure for new mode, or introduce new structure for entire system
- extend existing pricing to new mode, change pricing for new mode only, or change pricing for system

In addition, Fleishman et al. (1996) acknowledge that the above three scenarios are general in nature and that the decision-making process may differ substantially from one agency to another depending on the size and complexity of the system, the existing fare structure and fare system, the institutional settings, the organizational environment, and the nature of external influences.

2.1.5.3 Fare-related decision-making process

As seen by Fleishman et al. (1996), the steps of an "idealized" decision-making process generally follow the policy-driven or service-driven planning approaches (see figure 2-3). However, the authors recognize that not every fare-related decision needs to follow every step of this process. Presumably, in a technology-driven scenario, the transit agency would complete the steps between "evaluate fare system options" and "select fare system" prior to deciding upon the technology to adapt. The other steps would also need to be completed, but they would only apply to the fare strategy and structure issues.

The fare policy, structure, and technology decision-making process developed by Fleishman et al. (1996) addresses all steps that an agency is likely to follow and fare-

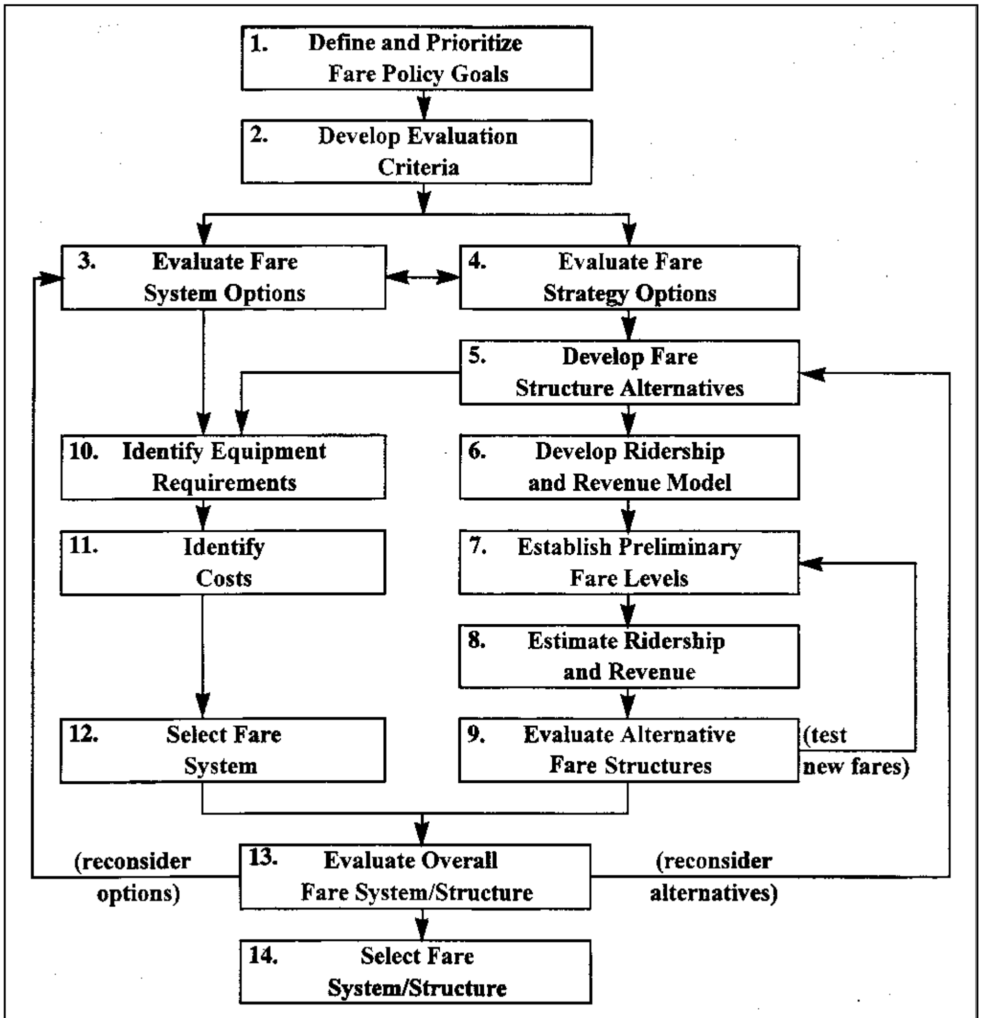

Figure 2-3. Fare-related decision-making process (Fleishman et al., 1996).

related decisions it is likely to be faced with. Nonetheless, the authors concede that an agency may choose to pursue only selected steps of an "idealized" decision-making process and not necessarily in the order suggested. They stress that the procedures and requirements of the individual steps and their interrelationships are of greater importance then the particular order in which they are undertaken.

The first two steps of the developed decision-making process—"define and prioritize fare policy goals" and "develop evaluation criteria"—are considered of special importance by the authors, so these steps are discussed thoroughly in the TCRP Report 10.

Fleishman et al. (1996) developed a set of common fare policy goals and grouped them into four basic categories: customer-related, financial, management-related, and political. Customer-related goals reflect the perception of the fare structure and system by riders and the effect of fare structure and system on the transit system use. Financial goals capture the effect of fare structure and system on costs and revenues. Management-related goals address the effect of fare structure and system on the agency's operations and management. Finally, political goals relate to the political and legal viability of the fare structure and system. Table 2-9 lists a set of common policy goals and applicability of individual goals to strategy or technology issues or to both.

The second step of the fare-related decision-making process is the development of evaluation criteria. The purpose of these criteria is to assess the relative merit of alternatives being considered. Fleishman et al. (1996) caution that appropriate evaluation criteria could vary from one agency to another since agencies might have different financial, operational, political, and legal constraints as well as different fare-related goals. Also, a single set of criteria will not necessarily be appropriate for all fare system elements. Table 2-10 shows a set of criteria that Fleishman et al. (1996) suggested for consideration. These criteria are separated into fare strategy-related and fare technology-related and each criterion is linked to a respective policy goal it designed to assess.

The authors give a detailed description of each criterion as well as suggest possible measures for each criterion. They reiterate that not every criterion would be appropriate for every agency or in every evaluation and that many agencies using these criteria in evaluating options might want to make adjustments to reflect their specific situations.

2.1.5.4 Selection and Evaluation of New Technology

According to Fleishman et al. (1996), the approach toward evaluation of new fare collection and distribution technologies or specific types of equipment varies form one agency to the next, depending on the availability of funds, the general decision-making process, and the magnitude and complexity of the change, including total cost and disruption to operations. Other major factors affecting decision process include the type of equipment or technology being considered, the size of the agency, and the number of units required.

Typically, the evaluation of new technology falls into two basic decision-making scenarios: (1) purchase of a specific piece of equipment (the decision is based on identification of costs and benefits of purchasing versus not purchasing) and (2) procurement of a new fare collection system (the decision is based on identification of fare collection needs and goals and evaluation of costs and benefits of alternative technologies and configurations).

The next step in the evaluation of new technology involves the assessment of fare media and equipment capabilities, costs, and benefits. The authors point out that the agency needs to identify the full range of anticipated costs and benefits associated with a new fare technology in order to perform a meaningful in-depth analysis. In addition, the authors note the absence of cost-benefit analysis with respect to newer fare collection technologies, particularly smart cards.

Table 2-9. Fare policy goals (Fleishman et al., 1996).

Policy Goal	Goal Applies to	
	Strategy	System/Technology
Customer-related		
increase ridership/ minimize revenue loss	X	
maximize social equity	X	
increase ease of use (i.e., convenience)	X	X
increase fare options	X	X
reduce complexity	X	X
Financial		
increase revenue/ minimize ridership loss	X	
reduce fare abuse and evasion	X	X
improve revenue control		X
reduce fare collection costs (administrative/operating)	X	X
increase prepayment/ reduce use of cash	X	X
Management-related		
improve data collection		X
improve modal integration	X	X
increase pricing flexibility	X	X
maximize ease of implementation	X	X
improve fleet/demand management	X	X
improve reliability of fare equipment		X
improve operations (i.e., maximize throughput)	X	X
Political		
maximize political acceptability	X	
achieve recovery ratio goal/requirement	X	

Table 2-10. Evaluation criteria (Fleishman et al., 1996).

Policy Goal	Evaluation Criteria: Strategy	Evaluation Criteria: System/Technology
Customer-related		
increase ridership/ minimize revenue loss	impact on ridership	
maximize social equity	impact on equity	
increase ease of use (i.e., convenience)	convenience/ ease of use	convenience/ ease of use
increase fare options	range of options	
reduce complexity	complexity/ease of understanding	
Financial		
increase revenue/ minimize ridership loss	impact on fare revenue	
reduce fare abuse and evasion	impact on fare abuse/evasion	security (re duplication, impact on abuse)
improve revenue control		accountability (re revenue control)
reduce fare collection costs (administrative/operating)	impact on fare collection costs	cost of media, equipment, facilities
increase prepayment/ reduce use of cash	impact on prepayment	
Management-related		
improve data collection		1
improve modal integration	2	
increase pricing flexibility		flexibility (re adding options)
maximize ease of implementation	ease of implementation	
improve fleet/demand management	impact on fleet/ demand mgmt.	
improve reliability of fare equipment		reliability of technology
improve operations (i.e., maximize throughput)		operations impact (on throughput)
Political		
maximize political acceptability	political acceptability	
achieve recovery ratio goal/requirement	3	

notes:
1 - any tech. improvement will likely improve data collection
2 - related to actual pricing of options and transfer policy
3 - related to actual pricing of options

According to TCRP Report 10, the financial implications of particular fare technologies are usually the most important decision factor. The two basic categories of cost to be considered are capital costs and operating and maintenance costs. In addition, potential cost savings and additional revenues associated with implementing a new fare collection system are the important aspect in estimating financial impacts of different technologies.

Capital costs are one-time expenditures for hardware and software purchase, installation, and support services. Fleishman et al. (1996) list the following factors that may affect capital costs: the amount of customization required for a product; the quantities of the particular equipment being ordered; the extent of integration with existing equipment; the nature of the vendor selection and negotiation process; the extent of refinement of the technology; growth potential; warranty terms; documentation requirements; software requirements; facility modification; Americans with Disabilities Act (ADA) requirements; and other factors.

The second basic category of cost is ongoing operating and maintenance expenses that include production and distribution of fare media, equipment servicing and repair, and fare collection and accounting labor. These costs vary depending primarily on the type of fare collection system and technology selected, whether the service is contracted out or performed in-house, and the hourly wage rates for labor at each agency.

Finally, other potential financial benefits associated with technological improvements to a fare collection system can be generated through the reduction of fare abuse and fraud as well as increased ridership deriving from improved convenience for the riders.

In conclusion, Fleishman et al. (1996) present a general approach for evaluating fare technology and system options. They suggest that the fare collection and payment system has three basic qualifiers: type of fare collection system (e.g. proof of payment, payment on entry, or barrier), fare media technology, and fare equipment. Table 2-11 illustrates the criteria suggested for evaluation of fare media technologies along with the resulting ratings. The authors suggest that these criteria would be similar to those used to evaluate different fare collection systems and fare equipment.

2.2 ECONOMICS OF PUBLIC TRANSIT OPERATIONS

This section of the literature review discusses economics of public transit operations with the focus on operating costs (OC) associated with provision of heavy rail and motorbus services. First, Section 2.2.1 discusses the sources of transit cost information available to researchers. Then, Section 2.2.2 describes the capital structure of a typical transit agency in terms of assets and liabilities. Next, Section 2.2.3 talks about long-term financing and capital budgeting. A classification of expenditures on long-lived assets is discussed. Finally, Section 2.2.4 presents a review of short-term financing and cash budgeting. The sources and structure of short-term cash inflows and outflows in the transit environment are discussed.

Table 2-11. Example of fare technology evaluation (Fleishman et al., 1996).

Evaluation Criteria	Weight	Relative Impact of Payment Media					
		Cash	Token	Paper Ticket	Magnetic Ticket	Contact Card	Contactless Card
convenience (ease of use)	1	1	2	2	2	2	3
security (ability to prevent duplication)	1	2	1	1	2	3	3
accountability (impact on revenue control)	1	1	2	2	3	3	3
cost of purchase or production of media	1	3	3	3	3	1	1
cost of equipment	1	3	2	3	1	1	1
flexibility (re changing or adding fare options)	1	2	1	2	3	3	3
operations impact (e.g., on throughput)	1	1	2	1	2	2	3
reliability of technology	1	1	2	2	2	3	3
Total Score		14	15	16	18	18	20

Rating Key: 3=High, 2=Medium, 1=Low

2.2.1 Sources of Transit Cost Information

As evident from the research on transit evaluation approaches (Collura 1992, Casey and Collura 1994, Fleishman et al. 1996, Collura and Plotnikov 2001), capital and operating costs of a transit system and its individual components are important measures (criteria) in assessing transit investment alternatives. Furthermore, Collura 1992, Casey and Collura 1994, and Collura and Plotnikov 2001 argue that the identification of data sources and the collection of data for selected measures are key elements of any successful evaluation.

To facilitate the overall transit planning process as well as the development of transit cost models and transit evaluation measures, the FTA sponsored the preparation of a report on the estimation of transit costs. The report, titled "Estimation of Operating and Maintenance Costs for Transit Systems" and prepared by KPMG in 1992, presents a broad review of issues associated with transit cost modeling, sources of transit cost information, and a description of the Section 15 database (the National Transit Database [NTD]).

According to the report (KPMG 1992), transit cost models and evaluations should be based, to the greatest extent possible, on readily available information in order to facilitate the overall budgeting process applied by management and to enable the FTA and other reviewers to easily confirm the sources of information used in the cost model or evaluation.

The report (KPMG 1992) states that the key sources of transit cost information available to transit planners, evaluators, and researchers include transit property budgets, Section 15 (NTD) data and APTA peer property data, and peer property cost models. In the following three subsections, major advantages and limitations of the aforementioned data sources are discussed.

2.2.1.1 Transit Property Budgets

As reported by KPMG (1992), transit property budgets can provide important information for both the existing transit system and for proposed new technologies (e.g., labor unit costs). The major advantages of using budgets as data sources include a fine level of detail, identification of contracting, clear documentation of assumptions, and internal acceptability to management.

The report states that budgets can provide important information regarding staffing throughout the organization and allocation of staff by mode. Coupled with the information on the level of service provided, this information can yield labor productivity values. Budgets can also identify the level of contracting helping to further explain staffing structure and labor productivity values. Furthermore, budget documents may provide a concise source of information regarding assumptions of future financial conditions such as inflation, work rule changes, levels of service, absenteeism and other labor productivity factors, and major maintenance campaigns. Also important is that budget documents are accepted as the authoritative source of financial information in a transit agency. For a variety of reasons, other cost information sources may not be accepted by management as complete or accurate (KPMG 1992).

The two major limitations on the applicability of budgets as the source of information for structuring cost models and cost evaluations include difficulties associated with peer property comparisons and application of historical trends to future forecasts. The former limitation results from the fact that most transit properties compose their operating budgets according to their internal organizational structure, which can differ substantially from one agency to another. The latter limitation reflects the possibility that future conditions will be different than in the past (e.g., new union contracts, aging fleet, new vehicles), resulting in changes in labor productivity and unit costs (KPMG 1992).

2.2.1.2 Section 15 (NTD) and APTA Data

Another major source of transit cost information is Section 15 (NTD) and APTA data. The National Transit Database is produced by the FTA and was designed to provide transit financial and operating data for public transit operators, Federal, state, and local governments, and the public. Today, the National Transit Database serves as an essential resource for public transit management, planning, policy-making, and other analytical applications (FTA, Office of Program Guidance and Support, 1997).

The beginnings of the National Transit Database can be traced back to the joint effort by the government and industry to standardize transit information and provide a source of data for various applications. In 1972, the American Transit Association and the Institute for Rapid Transit (predecessors of APTA) started a project to design a uniform transit industry reporting system. This project, known as Project FARE (Uniform Financial Accounting and Reporting Elements), was funded by the FTA and led to the development of a system of accounts and records to provide the scope, uniformity, consistency, and accuracy required by the broad spectrum of data users (FTA, Office of Program Guidance and Support, 1997).

In 1974, the Federal Transportation (FT) Act of 1964 was amended to include a uniform system of accounts and records and a uniform reporting system. Also, the program that provides for the National Transit Database was established under Section 15 of the FT Act. Specifically, Section 15 prohibits the Secretary of Transportation from making any grants under Section 9 of the FT Act unless all grant applicants and beneficiaries are subject to the reporting system and uniform system of accounts. The National Transit Database prescribes a basic financial accounting system and a set of definitions and procedures for recording operating data to ensure that over 500 participating public and private transit operators apply a uniform approach to data collection. The Section 15 reporting system was first applied to data from operators' fiscal years ending between July 1, 1978 and June 30, 1979 (FTA, Office of Program Guidance and Support, 1997).

In 1990, the FTA considered many fundamental questions about the objectives of the National Transit Database and assessed its strengths and weaknesses. Two years later, the FTA carried out significant structural changes to the program and database. These changes applied for the 1992 report year reflected the FTA's effort to balance the benefits of the data to a broad range of constituent groups, against the costs to operators of reporting the data and to the FTA of developing annual databases (FTA, Office of Program Guidance and Support, 1997).

To assure that the data submitted to the National Transit Database are accurate, uniform in definition, consistent, and timely, the FTA undertakes the following actions:

- The data to be provided is defined by the FTA in a user's guide.
- the FTA trains transit property employees responsible for preparing the reports.
- Independent certified public accountants review the submissions.
- Contractors to the FTA review the data for reasonableness, based on an analysis of trends over time and comparisons to industry standards.

The two most important advantages of using the NTD data are the standardized reporting and fine level of detail for some of the largest transit properties in the country and those that have received the FTA grants for information management systems. The common reporting format provides basis for making accurate comparisons and computing industry averages. At the same time, the level of detail required in some NTD cost reports is frequently more detailed than the information found in operating budgets (KPMG 1992).

Despite the advantages mentioned above, the NTD data has several shortcomings that limit its usefulness for purposes of transit evaluation and transit cost modeling. First, the National Transit Database does not provide for much detail in the classification of employees. Second, the NTD expense forms separate labor costs for each function into only two object classes: “operators’ wages” and “other salaries and wages.” As a result, except for operators, there is no distinction between costs for management, supervisory, administrative, support, and labor personnel. Third, the NTD data does not report local cost factors that are likely to vary from one transit agency to another, such as wage rates, fringe benefits, and other specific work rule provisions. Fourth, the NTD data does not describe the physical differences between otherwise similar transit properties, such as technology, age of the system components, climate, passenger loading, and type of fare collection equipment. Finally, the NTD data is prone to errors in data definitions and reporting, despite the rigorous control of the quality of the data conducted by the FTA (KPMG 1992).

Another source of transit fiscal information are the Transit Operating and Financial Statistics published annually by the APTA. The statistics published by the APTA are based on NTD reports but they are provided directly by the transit properties, not by the FTA. These statistics have two primary advantages over NTD data, namely prompt and concise reporting. APTA releases the data much sooner than the FTA due to less intensive review and verification of the data. Also, these data are presented by transit property, rather than by type of expense or revenue category. The major disadvantage of APTA’s statistics is that these data are less reliable and may not be consistent with NTD reports because they are not a subject to the same level of review as NTD data (KPMG 1992).

2.2.1.3 Peer Property Operating Cost Models

A third major source of transit cost information is operating and maintenance cost models developed for peer transit properties. These models are usually based on a carefully researched and reasoned set of assumptions (KPMG 1992).

When comparing transit service proposals, the FTA requires that all the fully allocated costs of public agencies be counted. In accordance with this policy, the use of fully allocated costs to compare service proposals treats public agencies as if they were required to recover their cost of production (Price Waterhouse, 1987).

The underlying principle of a fully allocated costing analysis is that all costs incurred in delivering a specific service should be attributed to that service. The fully allocated cost of a specific service includes both the direct costs of the labor, capital, and material recourses used exclusively in the delivery of the service and a portion of the shared costs of the labor, capital, and material recourses used in the delivery of the range of services produced by a transit agency. Also, a fully allocated costing analysis represents a complete accounting of all fixed costs (costs that do not vary with small changes in the level of transit service) and all variable costs (costs that vary with the level of transit service provided). By contrast, a marginal cost analysis deals only with the variable costs of a particular service (Price Waterhouse, 1987).

The most commonly-used type of a fully allocated cost model in the transit environment is the three-variable unit cost model. It is, however, just one of many acceptable ways to develop a fully allocated cost estimate for a particular transit service. Figure 2-4 provides a summary of the cost allocation process using a three-variable, fully allocated, unit cost model. Table 2-12 shows an example of assigning transit expense classes to the allocation variables with which they are most closely associated. Typically, transportation–related costs are allocated to vehicle hours since these costs are a function of the number of vehicle hours operated. Vehicle maintenance and fuel costs are allocated to vehicle miles because vehicles' wear and fuel consumption are a function of the number of miles operated. Finally, administrative and capital costs are largely a function of the transit system size, so they are allocated to peak vehicles (Price Waterhouse, 1987).

In addition to vehicle hours, vehicle miles, and peak vehicles there are several other allocation variables widely used for developing fully allocated cost models. These allocation variables include revenue hours, revenue miles, total vehicles, number of employees and ridership. Moreover, any variable or measure that can be related to the services provided and is logically related to the rate of consumption of an expense element is an acceptable basis for allocation (Price Waterhouse, 1987).

The major advantages of using previously developed operating cost models as a source of transit cost information include: 1) provision of additional data that may be valid for similar transit systems and 2) provision of an upper and lower bound of key labor productivity and unit cost values that could be useful in conducting sensitivity analyses and reasonableness tests.

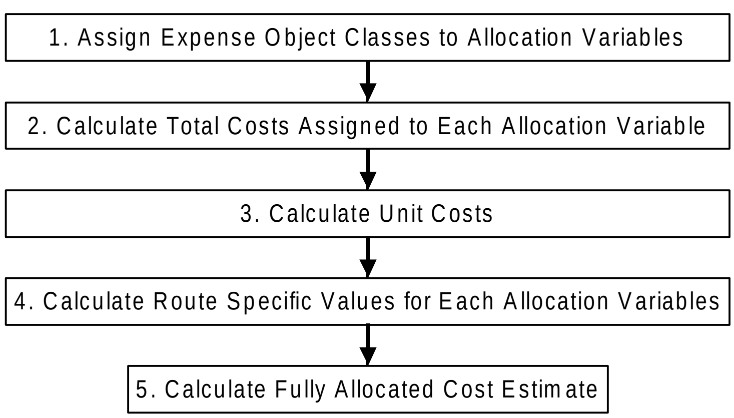

Figure 2-4. Cost allocation process (Price Waterhouse, 1987).

Table 2-12. Association between transit expenses and allocation variables (Price Waterhouse, 1987).

EXPENSE OBJECT CLASS	VEHICLE HOURS	VEHICLE MILES	PEAK VEHICLES
LABOR			
Operator Salaries	X		
Maint Salaries		X	
Other Salaries			X
FRINGE BENEFITS			
Operator	X		
Maintenance		X	
Other			X
SERVICES			
Professional & Tech			X
Contract Maintenance		X	
Security Services			X
Other Services			X
MATERIALS & SUPPLIES			
Fuel & Lubricants		X	
Tires & Tubes		X	
Other Materials			X
UTILITIES			
Utilities			X
CASUALTY & LIABILITY			
Premiums for Damage		X	
Recoveries of Losses			X
Payouts for Uninsured			X
TAXES			
Vehicle Registration			X
Fuel & Lubricant		X	
Other Taxes			X
MISCELLANEOUS EXPENSES			
Dues & Subscriptions			X
Travel & Meetings			X
Bridges, Tunnel Tolls		X	
Advertising Media			X
Other Misc Expense			X
RECONCILING ITEMS			
Interest Expense			X
Leases & Rentals		X	
DEPRECIATION			
Vehicles			X
Other			X

On the other hand, the limitations of using data acquired from previously developed operating cost models include their low level of detail and case-specific sets of assumptions used in the development of the cost models.

2.2.2 Capital Structure

In general, the capital structure of a transit property is similar to the capital structure of a typical firm, and is defined in terms of assets and liabilities (see figure 2-5) (Ross, Westerfield, and Jaffe, 1996).

The assets represent various valuables that the firm owns. Two types of assets are usually recognized—current assets and fixed assets. Fixed assets are the relatively long-lasting property of the firm. Fixed assets can be tangible and intangible. Tangible fixed assets include land, buildings, machinery, equipment, and other physical things. Intangible fixed assets may include patents, trademarks, and the quality of management. The other category of assets—current assets—includes firm's cash and equivalents, inventories, accounts receivable, and other valuables that the firm may expend in a relatively short period of time (Ross, Westerfield, and Jaffe, 1996).

Prior to obtaining an asset, a firm needs to secure financing to pay for the asset. A firm's liabilities are the contractual obligations of the firm to its owners (shareholders) that invest money into the firm and lenders (bondholders) that loan money to the firm. Short-term liabilities represent loans and other obligations that must be repaid within one year. Long-term liabilities are the debt that can be paid off in more than one year. Finally,

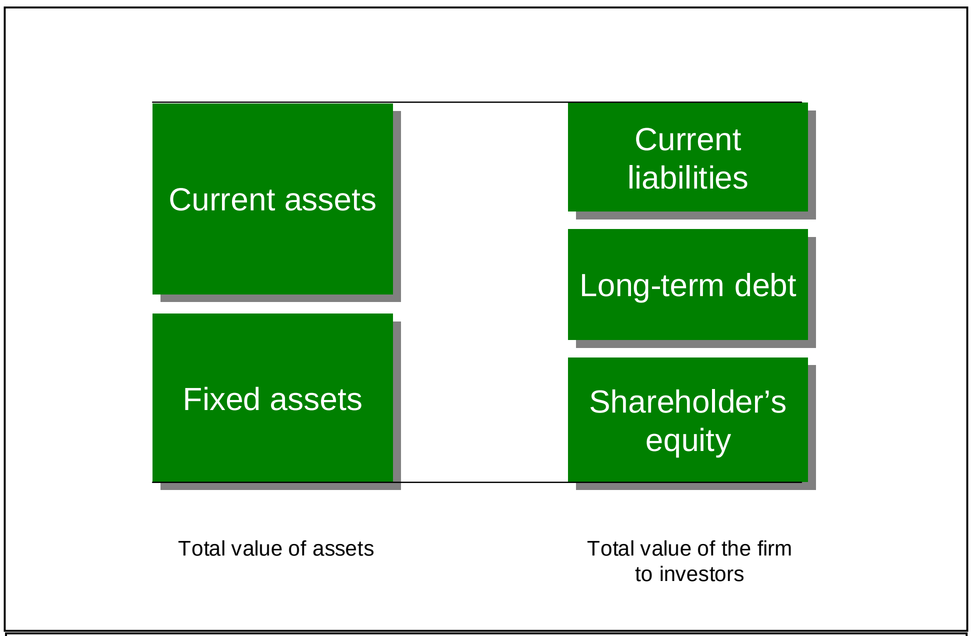

Figure 2-5. Capital structure of a firm (Ross, Westerfield, and Jaffe, 1996).

shareholder's equity is the difference between the value of the assets and the debt of the firm and can be thought of as a residual claim on the firm's assets (Ross, Westerfield, and Jaffe, 1996). However, since most of transit agencies in the U.S. are the property of public authorities, they do not sell equity as a source of financing but secure funding through Federal, State, and local subsidies.

In the following two subsections, the structure of typical transit property's assets and liabilities, as categorized by the the FTA and APTA, is presented.

2.2.3 Transit Agency Assets

As classified in the Uniform System of Accounts (USOA), the basic accounting document developed by the FTA and the APTA, there are eleven categories of transit agency assets: (101) Cash and Cash Items; (102) Receivables; (103) Materials and Supplies Inventory; (104) Other Current Assets; (105) Work in Progress; (111) Tangible Transit Operating Property; (112) Tangible Property Other Than for Transit Operations; (121) Intangible Assets; (131) Investments; (141) Special Funds; and (151) Other Assts (see figure 2-6) (FTA, 1998).

The Cash and Cash Items (101) category covers cash on hand and in banks available for the liquidation of transit agency liabilities. This category also includes the book cost of investments such as US Treasury bills, marketable securities and other similar investments acquired for the purpose of temporarily investing cash. The Receivables (102) category represents amounts owed to the transit agency by other parties. This category covers: the amounts due from others for materials and supplies furnished, and services rendered; the book cost of all collectible obligations; the amount of current interest accrued to the date on commercial paper owned, loans made, bank deposits, etc.; amounts receivable from Federal, state and local governments or other parties; and other

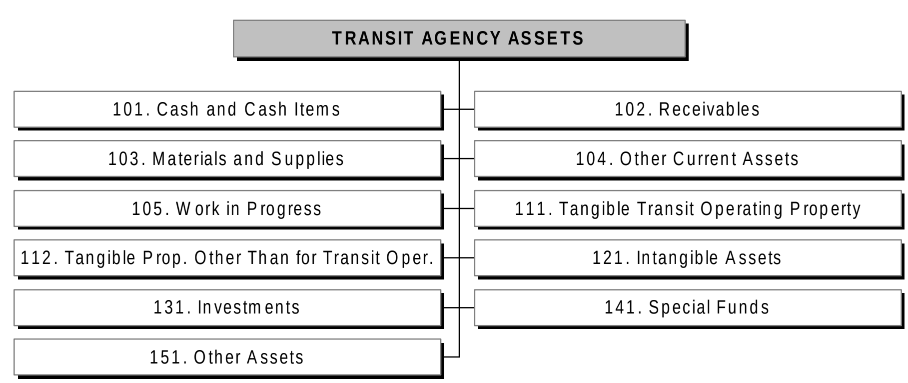

Figure 2-6. Transit agency assets (FTA, 1998).

receivables. The Materials and Supplies Inventory (103) category includes the cost of all unapplied materials and supplies including tools, repair parts, fuel, etc. The Other Current Assets (104) category covers the amount of all assets of a current nature (i.e. convertible to cash within one year of the balance sheet date) not included in any of the current asset accounts 101 through 103 (FTA, 1998).

The Work in Process (105) category covers labor, material, and overhead amounts applied to projects not yet completed or placed in service. The Tangible Transit Operating Property (111) category covers transit operating property owned by the transit agency and having an expected life in service of more than one year at the time of installation. It includes the rolling stock, maintenance facilities, general administration buildings, equipment, etc. that are used to support the provision of transit services. The Tangible Property Other Than for Transit Operations (112) category includes tangible property owned by the transit agency but not used in transit operations. The Intangible Assets (121) category covers the intangible rights and benefits accruing to the transit agency with a value enduring through a period longer than one year. The Investments (131) category includes investments of transit funds in the operation of other entities for purposes other than the temporary investment of surplus cash. The Special Funds (141) category covers cash and near cash items whose use is restricted to satisfying a specific class of transit agency long-term obligations. It includes sinking funds, capital asset funds, insurance reserve funds, pension funds, and other special funds. Finally, the Other Assets (151) category covers the assets not included in categories 101 through 141 (FTA, 1998).

2.2.3.1 Transit Agency Liabilities

According to USOA classification, there are nine categories of transit agency liabilities. They are: (201) Trade Payables; (202) Accrued Payroll Liabilities; (203) Accrued Tax Liabilities; (204) Short-Term Debt; (205) Other Current Liabilities; (211) Advances Payable; (221) Long-Term Debt; (231) Estimated Liabilities; and (241) Deferred Credits (see figure 2-7) (FTA, 1998).

The Trade payables (201) category covers the amounts payable to others for materials and services received, amounts due to public authorities, current accounts with officers and employees, and other similar items. The Accrued Payroll Liabilities (202) category includes obligations to pay for the labor services rendered by employees of the transit agency, deductions from employees' wages for Social Security, income taxes, and other similar items. The Accrued Tax Liabilities (203) category covers obligations to pay taxes that have accrued during the accounting period. The Short-Term Debt (204) category covers obligations to repay borrowings for periods of less than one year and current maturities of longer term financing transactions. The Other Current Liabilities (205) category includes miscellaneous obligations of the transit agency due within one year of the current period ending date and not covered in categories 201 through 204 (FTA, 1998).

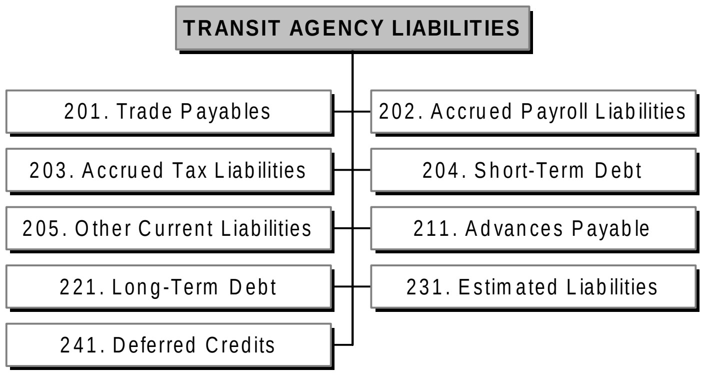

Figure 2-7. Transit agency liabilities (FTA, 1998).

The Advances Payable (211) category includes longer term obligations of the transit agency evidenced by open accounts and notes rather than by more conventional long-term debt instruments, such as equipment obligations, bonds, etc. The Long-Term Debt (221) category covers obligations of the transit agency due after one year from the current period ending date and evidenced by formal long-term debt instruments such as equipment obligations, bonds, etc. The Estimated Liabilities (231) category includes amounts, which have been established and segregated as estimates of future liabilities. Finally, the Deferred credits (241) category covers credit balances in suspense accounts that cannot be entirely cleared and disposed of until additional information is received, and other items of a deferred nature (FTA, 1998).

2.2.4 Long-Term Financing

The process of making and managing expenditures on long-lived assets is often referred to as capital budgeting or long-term financing (Ross, Westerfield, and Jaffe, 1996).

As defined in the Uniform System of Accounts, transit capital costs are the expenses related to purchasing capital equipment and financing capital projects. Capital costs are non-annually recurring expenditures that have long-term impact on the transit agency and are depreciated over a number of years. All transit capital expenses fall into one of the following major categories: Rolling Stock, Facilities, and Other (FTA, 1998).

The Rolling Stock category of capital costs contains all funds spent on rolling stock for replacement or for fleet expansion, rehabilitation or remanufacture of revenue service vehicles, acquisition of major components for inventory, and acquisition of major components for use in the rehabilitation or remanufacture of revenue vehicles (FTA, 1998).

The Facilities category of capital costs contains all funds spent on the transit right-of-way facilities (e.g., buildings, tunnels, bridges, elevated structures, track, bus loops), passenger stations, passenger parking facilities, operating yards and stations, power generation and distribution facilities, vehicle maintenance shops and garages, central/overhaul maintenance facilities, light maintenance facilities, equipment for any of the aforementioned items, and land. This category of capital costs also includes funds spent for maintenance or improvements that are not made annually or with more than an annual frequency (FTA, 1998).

The Other category of capital costs contains of funds spent on any item not included into the Rolling Stock or Facilities categories and includes expenses on general administration facilities and equipment, revenue vehicle movement control equipment, revenue collection and processing equipment, data processing equipment, communication equipment, and office equipment and furnishings (FTA, 1998).

As mentioned above, expenditures on revenue collection and processing equipment fall into the Other category of capital costs. The revenue collection and processing equipment includes the installed and portable machinery and equipment for selling, collecting, and counting passenger fares that are located in passenger stations, on revenue vehicles, at operating yards and stations, and in general administration buildings (FTA, 1998).

Since most transit agencies in the U.S. are the property of public authorities, financing of capital projects usually comes from Federal, state, or local budgets.

2.2.5 Short-Term Financing

As opposed to capital budgeting, cash budgeting relates to short-term financial needs of a firm (Ross, Westerfield, and Jaffe, 1996). The sources and structure of short-term cash inflows and outflows in a transit environment, as classified by the APTA and the FTA, are discussed in the following two subsections.

2.2.5.1 Short-Term Financing: Revenues

This section presents the classification of transit revenues under the Uniform System of Accounts. The USOA classifies the origin of revenues using some 18 categories as depicted in figure 2-8.

The Passenger Fares for Directly-Operated Transit Service (401) category includes revenues earned from carrying passengers along regularly scheduled and demand responsive routes. This category of revenues includes the base fare, zone premiums, express service premiums, and transfers and discounts applicable to the passenger’s ride. There are eight types of passenger fares that fall into this category. These are: full adult fares, senior citizen fares, student fares, child fares, disabled rider fares, park-and-ride fees, special ride fares, and other primary fares. A detailed description of these fares can be found in the USOA manual (FTA, 1998).

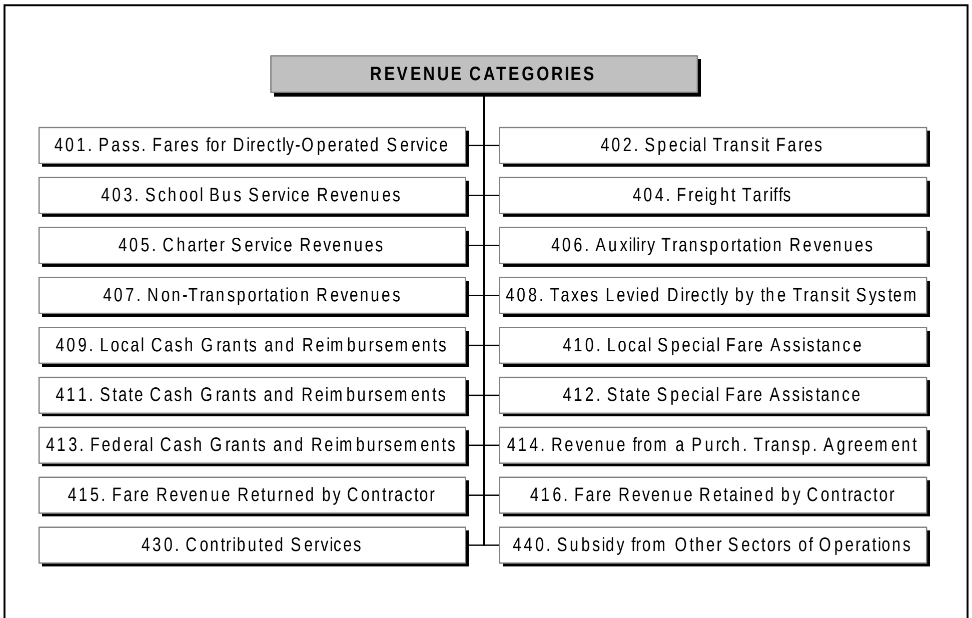

Figure 2-8. Transit revenue categories (FTA, 1998).

The Special Transit Fares (402) category includes revenues earned for rides given in regular transit service but paid for by some organization other than by the rider. Special transit fares may include contract fares for postal workers and police officers, state and local government fares, and non-contract special service fares such as those for sporting events. This category also includes funds for rides given along special routes (e.g. sightseeing) for which funds may be guaranteed by a beneficiary of the service (FTA, 1998).

The School Bus Service Revenues (403) category includes funds earned from operating vehicles under school bus contracts. The Freight Tariffs (404) category includes revenues earned from carrying freight on runs whose primary purpose is passenger operations. The Charter Service Revenues (405) category includes revenues earned from operating vehicles under charter contracts. The Auxiliary Transportation Revenues (406) category cover revenues received from station and vehicle concessions, advertising services, automotive vehicle ferriage, and other revenues received from property owned, leased, or operated by the transit system (FTA, 1998).

The Non-Transportation Revenues (407) category covers revenues earned from sales of maintenance services, rental of revenue vehicles, rental of buildings and other property, investment income, parking facilities revenues, and other non-transportation revenues. The Taxes (408) category includes tax revenues from property taxes, sales taxes, income taxes, payroll taxes, utility taxes, gasoline taxes, and other revenues earned by taxation on some basis other than those specified above when the taxing authority is the transit agency (FTA, 1998).

The Local Cash Grants and Reimbursements (409), State Cash Grants and Reimbursements (411), Federal Cash Grants and Reimbursements (413) categories include revenues obtained from the local, state, and Federal governments correspondingly to assist in paying the cost of operating transit services. The Local Special Fare Assistance (410) and State Special Fare Assistance (412) categories represent funds from local and state governments correspondingly to assist in paying the cost of operating transit services (FTA, 1998).

The Revenue Accrued Through a Purchased Transportation Agreement (414) category covers funds obtained from the revenue accrued by the transit agency as a seller of transportation services through purchased transportation agreements. The Fare Revenue Returned by Seller (415) and Fare Revenue Retained by Seller categories cover revenues returned and retained correspondingly by sellers through purchase transportation agreements. The Contributed Services (430) category covers the receipt of services from another entity where such services benefit transit operations and the transit operator is under no obligation to pay for the services. Finally, the Subsidy from Other Sectors of Operations (440) category includes subsidies from utility rates, bridge and tunnel tolls, and subsidies from other sectors of transit operations to help cover the cost of providing transit service (FTA, 1998).

2.2.5.2 Short-Term Financing: Expenses

According to the the FTA and APTA classification, the short-term transit expenses, also referred to as operating and maintenance costs, can be grouped in two ways depending on the purpose of the analysis at hand: by expense object classes or by expense functions (FTA, 1998).

As defined in the Uniform System of Accounts, an expense object class contains the expenses for an article or service obtained. Object class expenses are grouped based on the types of goods or services purchased and include salaries and wages, fringe benefits, services, materials and supplies, and other expenses (see figure 2-9) (FTA, 1998).

Expenses in the Labor (501) object class include pay and allowances owed to employees in exchange for the services provided to the transit agency. This class covers payments to employees arising from the performance of a piece of work as opposed to the allowances covered in the Fringe Benefits object class. The Labor object class is subdivided into two categories: operators’ salaries and wages and other salaries and wages. The first category covers wages for performing revenue vehicle operations, servicing, control, inspection, and maintenance whereas the second category covers the labor of employees who are not classified as revenue vehicle operators or crewmembers (FTA, 1998).

The Fringe Benefits (502) object class includes all payments and accruals on behalf of employees of the transit agency. These payments are a part of the employment contract but are over and above the labor costs. The Services (503) object class includes the labor and other work provided by outside organizations for fees and related expenses. These services are usually procured as a substitute for in-house employee labor because the skills offered by the outside organization are needed for only a short period or are better

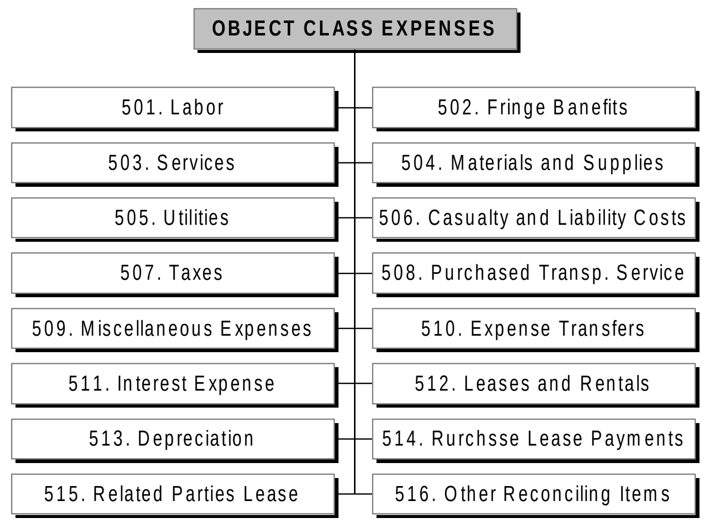

Figure 2-9. Object class expenses (FTA, 1998).

than internally available skills. The Materials and Supplies (504) object class includes products obtained from outside suppliers or those produced internally and are recorded under fuel and lubricants, tires and tubes, and other materials and supplies subcategories (FTA, 1998).

The Utilities (505) object class covers payments made to utility companies for use of electricity, gas, water, communications, and other resources. The Casualty and Liability Costs (506) object class includes costs for the protection of the transit agency from loss through insurance programs, compensation of others for their losses due to incidents for which the transit agency is liable, and other miscellaneous corporate losses. The Taxes (507) object class includes taxes levied against the transit agency by Federal, state, and local governments (FTA, 1998).

The Purchased Transportation (508) object class covers payments to providers, fare revenues retained by the provider, and other expenses incurred by the transit agency for items such as contract administration, services, and materials. The Miscellaneous Expenses (509) object class includes expenses that cannot be attributed to any of the other major expense categories defined above (FTA, 1998).

The Expense Transfers (510) objects class is used for reporting adjustments and reclassification of expenses previously recorded. The Interest Expenses (511) covers charges for the use of capital borrowed by the transit agency. The Leases and Rentals (512) object class includes payments for the use of capital assets not owned by the transit agency. The Depreciation (513) object class describes the depletion of the cost of the capital purchases. The Purchase Lease Payments (514) object class covers payments involving leasing that ultimately leads to the purchase of an asset by the transit agency.

The Related Parties Lease Agreement (515) object class includes payments when the lessor and lessee are related organizations. Finally, the Other Reconciling Items (516) object class captures any costs that cannot be classified in the other categories (FTA, 1998).

As distinguished from the expense object classes, expense functions are categories that record the costs to produce the results obtained by using the article or service. The USOA classification of expense functions includes four major categories Vehicle Operations, Vehicle Maintenance, Non-Vehicle Maintenance, and General Administration. Transit agencies are required to report expense data on either basic, optional, or informational levels. While there are four basic expense functions that all transit agencies have to report data on to the FTA, the Uniform System of Accounts specifies over 40 other expense functions arranged in a hierarchical order (see figure 2-10). Since the breakdown of these expense functions may be significantly different from the accounting schemes adopted by individual transit agencies, the reporting of these expense functions is optional (FTA, 1998).

Most of the activities associated with ticketing and fare collection on transit are included in the Ticketing and Fare Collection (151) expense function under the USOA (FTA, 1998). The component activities and object classes associated with the Ticketing and Fare Collection expense function are presented in figure 2-11 while a complete list of

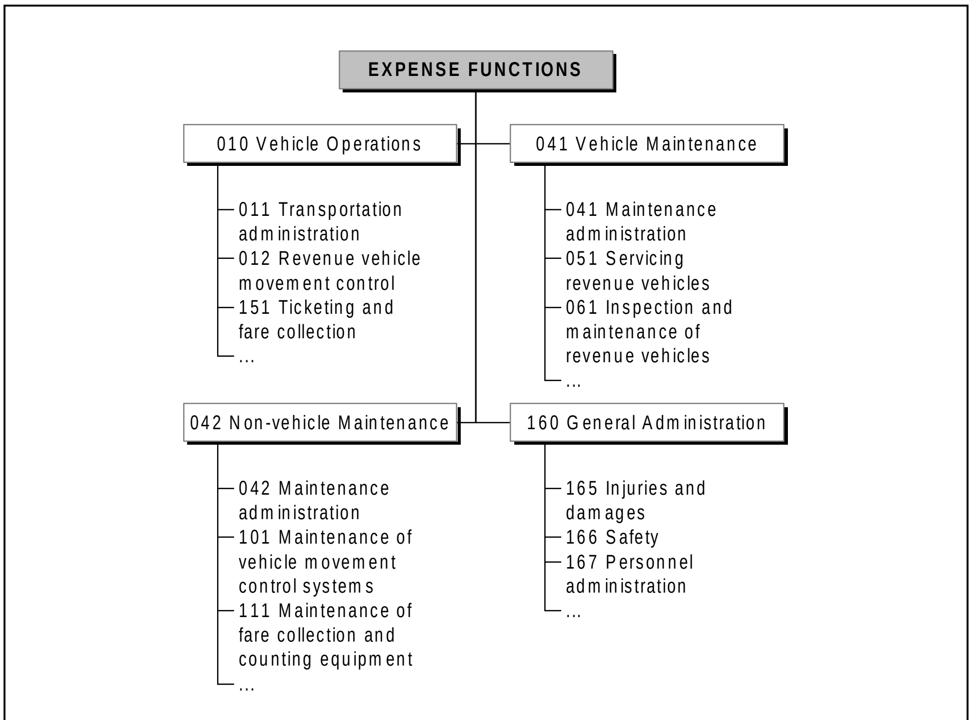

Figure 2-10. Transit expense functions (FTA, 1998).

activities and object classes associated with other expense functions can be found in the USOA manual.

2.3 FARE COLLECTION CONCEPTS AND TECHNOLOGIES

Activities associated with ticketing and fare collection are a distinctive part of transit operations and can be tracked back to the beginning stages of the transit industry. Although the ticketing and fare collection practice on transit has undergone significant changes over the years, some of its key concepts have remained intact, and their description is important in getting better understanding of processes, requirements, and business needs associated with fare collection in transit.

Generally, the key concepts of fare collection in transit are the concepts of payment media (PM) and fare media (FM), their distribution, validation, collection, and processing. In the following sections of this chapter, these concepts are addressed in detail. Section 2.3.1 defines the concept of payment media in the transit environment and describes the different types of payment media accepted by transit operators in the U.S. Section 2.3.2 defines the concept of transit fare media and describes the different types of fare media used by transit operators in the U.S. Section 2.3.3 classifies and discusses major TFC activities and functions associated with the use of non-electronic and electronic payment and fare media. Finally, Section 2.3.4 outlines the major components

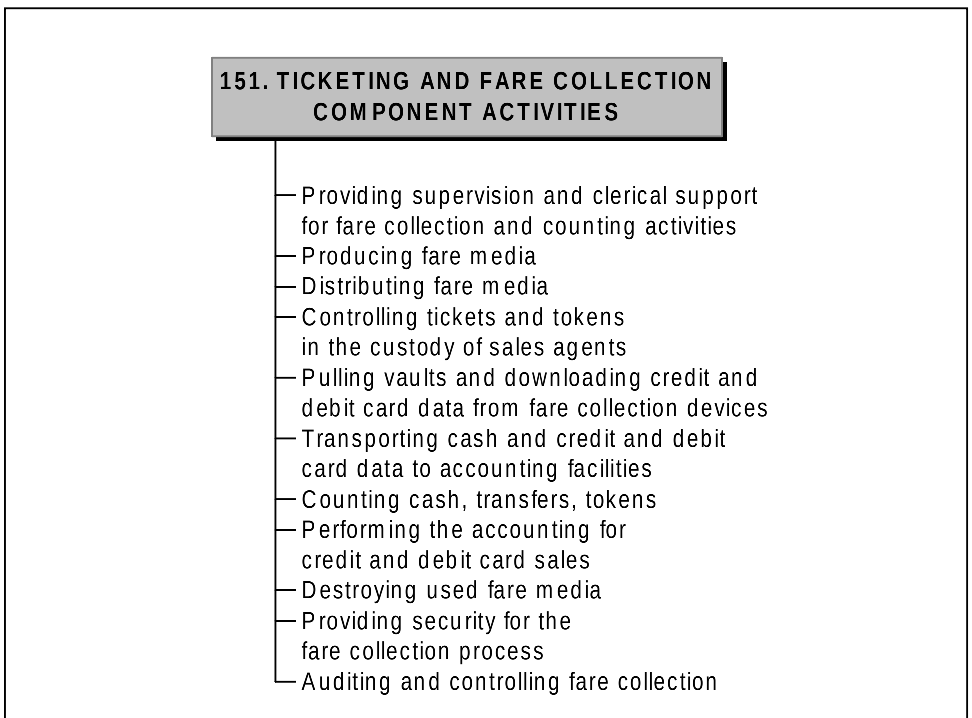

Figure 2-11. TFC component activities (FTA, 1998).

of a TFC system and types of TFC equipment employed by transit operators in the U.S.

2.3.1 Payment Media

As the term suggests, a "payment medium" is a financial instrument utilized to pay for a particular service or product. In respect to transit, this term describes financial instruments that a transit operator accepts as payment for its services (Gilcrease 2000).

2.3.1.1 Payment Media: Cash

Historically, the primary payment media that practically all transit operators accepted in return for their services have been coins and currency (Saltzman 1992, Fleishman 1996, Gilcrease 2000). Prior to the introduction of electronic banking operations, cash had served as a predominant payment instrument for most of retail purchases and services in the economy (O'Mahony 1997). Due to its almost universal use and acceptance, cash has also been a convenient payment medium for all categories of transit users as well as transit operators. However, the use of cash as the primary financial instrument has been on the decline during the second half of the 20th century due to the introduction of new forms of negotiable payment instruments and the emergence of magnetic cards (O'Mahony 1997).

Although the role of cash as a payment instrument in retail commerce and consumer services has diminished significantly over the last forty years, and the value of cash transactions was only about 0.3% of all U.S. payments in 1997, the volume of cash transactions accounted for nearly 86% of all payments in the U.S. (McEntee 1999). Some of the reasons why new payment instruments have emerged and the use of cash in the economy continues to diminish include high costs associated with handling and processing cash, risk of its theft and loss, and difficulties with cash payment tracking and accountability (Fleishman, 1996).

2.3.1.2 Payment Media: Negotiable Instruments

Another group of payment media that many transit operators accept in return for their services is negotiable payment instruments (APTA 1999). A negotiable payment instrument is a financial obligation that one party presents to another in return for particular products or services. The difference between cash and negotiable payment instruments is that the latter only suggest but do not guaranty the actual payment. This quality of negotiable instruments has its advantages as well as drawbacks (O'Mahony 1997).

The main advantage of negotiable instruments is that they significantly reduce the risk of theft and loss. Since negotiable instruments usually explicitly state the payer and payee, while the actual payment occurs only between their respective bank accounts, the correct payment may still be processed even in case of an instrument's theft or loss. For the same reason, negotiable instruments facilitate a high level of accountability and transaction tracking. Figure 2-12 depicts activities associated with processing a negotiable instrument (O'Mahony 1997).

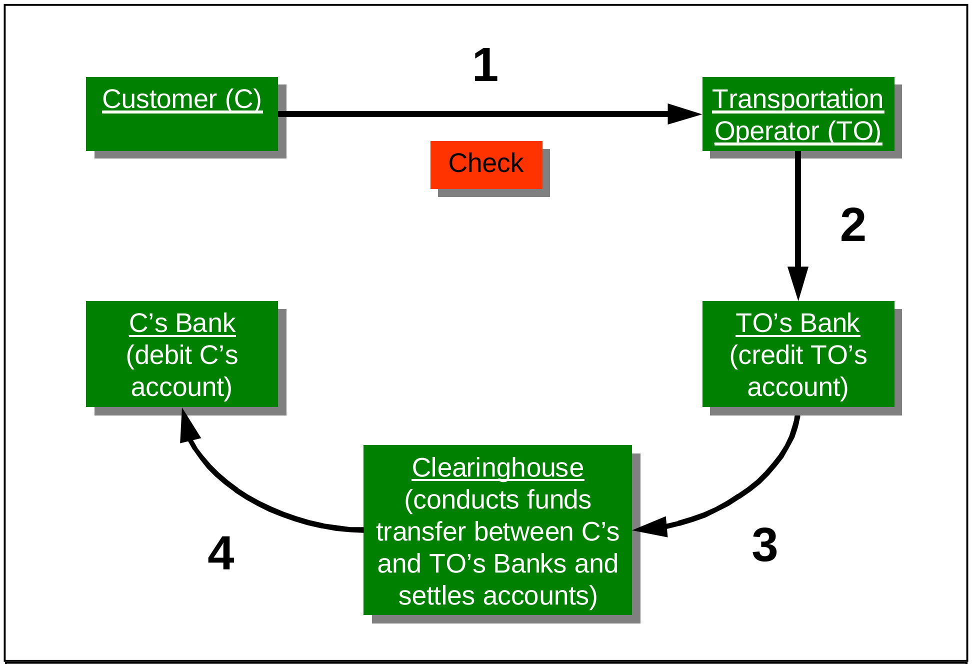

Figure 2-12. Check processing activities (O'Mahony 1997).

The drawbacks associated with negotiable instruments are also based on the fact that the actual payment for a product or service is postponed until after the product or service has been consumed. The party that accepts negotiable instruments bears the risk that the payer may default on his obligations. In addition, since a negotiable instrument is not an actual payment but only an obligation for payment, its security features are simpler than those of cash and the risks of counterfeiting or fraud are higher (O'Mahony 1997). The most common types of negotiable instruments accepted by transportation operators include personal checks, organization checks, cashier checks, traveler's checks, and money orders (APTA 1999).

2.3.1.3 Payment Media: Financial Institution Magnetic Cards

Finally, the third group of payment media accepted by transit operators is magnetic stripe cards issued by banks and other financial institutions. Although there are several electronic payment arrangements associated with magnetic stripe cards, these cards share a common technology and employ similar payment procedures. Conceptually, a magnetic stripe card is a physical medium that bears a reference to the cardholder's bank account or credit line in an electronic as well as visually readable form. Usually, three main pieces of information—the cardholder's name, card number, and card expiration date—are encoded on a stripe of magnetic tape bonded to the back of the card as well as embossed on the plastic body of the card (Hendry 1997, O'Mahony 1997). As a result, a person or a magnetic stripe reading device (reader) can easily read/scan this information, input it into the telecommunication network and pass it to the automated clearinghouse that processes the payment transaction and makes appropriate changes between the payer and payee accounts.

As briefly mentioned before, there are several electronic payment arrangements that utilize a magnetic stripe card technology. The most common forms of electronic payment used in the U.S. include credit, debit, and automated teller machine (ATM) card payments (O'Mahony 1997, HSN Consultants, Inc., 2000).

The ATM card is the simplest of electronic payment arrangements. This arrangement requires the use of a particular bank's electronic network outlet as a point of sale where the payer can initiate a payment using his or her ATM card. After authenticating the cardholder, the bank processes the payment order and transfers funds from the payer's to payee's account.

However, the most popular electronic payment arrangement in the U.S. is a credit card (HSN Consultants, Inc., 2000). This electronic payment arrangement is usually administered by an association of member banks that runs a common automated clearinghouse and licenses the right to issue cards bearing its logo. VISA and MasterCard are the largest and most well-known card associations operating worldwide (O'Mahony 1997). A cardholder can make a payment by presenting a card or providing the cardholder information over the telephone or the Internet to any of the merchants registered with the particular card association. A bank licensed to issue cards of a particular card association can provide its customers with either credit or debit cards. A credit card suggests that the bank opens a line of credit to its customer whereas a debit card is linked to the customer's regular account. Figure 2-13 depicts activities associated with processing a credit card payment in detail (O'Mahony 1997).

The major advantage of accepting magnetic cards as payment media for transit operators is that it significantly simplifies fare collection activities, eliminates some of the security concerns associated with these activities, and reduces the risks of theft and fraud. In addition, transit operators that accept magnetic cards can attract additional customers (as well as better satisfy existing customers) who use magnetic cards as a preferred payment media (Shock 2000).

The disadvantages of accepting magnetic cards as a payment media for transit operators include the need to pay processing and transaction fees (on the order of $0.10—$0.20 per transaction) to credit card associations and the need for a customer to have a particular card (in case cash and other payment media are not accepted) (Shock 2000). Table 2-13 illustrates that processing rates and transaction fees (Gilcrease 2000) can significantly reduce transportation operator's revenues, especially when the revenue stream consists of low-value transactions.

In conclusion, figure 2-14 summarizes the payment media options available to transit operators and users in the U.S.

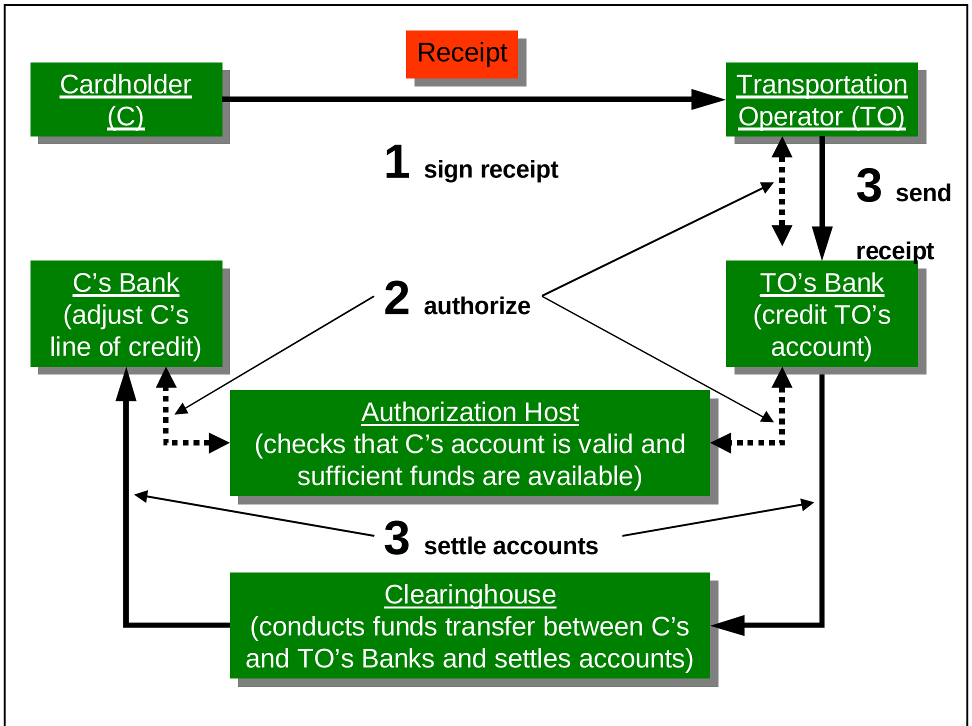

Figure 2-13. Credit card processing activities (O'Mahony 1997).

2.3.2 Fare Media

In the early years of transit industry in the U.S. there was no distinction between payment and fare media since transit fares were on the order of several cents and could only be paid with low denomination coins, i.e. pennies and nickels (Smerk, 1992, Saltzman, 1992). However, over the following decades a concept of fare media has evolved due to various reasons including concern over safety and security of transit employees, fare revenue theft, introduction of variable (time-based and distance-based) fares, and other reasons.

The term "fare medium" can be defined as an instrument accepted by a transit operator as a proof of payment for the transit operator's services. Before the introduction of electronic fare media, the major forms of fare media included cash (coins and bills), tokens, paper tickets ("stored-value" media), and flash passes ("stored-time" media). Pioneered in 1960s and further developed during 1970s, –80s, and –90s, today, electronic fare media come in the form of magnetic stripe tickets ("stored-value" media) and passes ("stored-time" media), and integrated circuit ("smart") cards (Fleishman 1998).

2.3.2.1 Fare Media: Cash

From the inception of the transit industry in the second quarter of 19^{th} century and until the third quarter of 20^{th} century, coins served as the predominant payment and fare

Table 2-13. Credit card transaction processing costs (Gilcrease 2000).

Annual Sales Volume	Discount rate for merchants where a physical card is present: Less than 50% of the time	Discount rate for merchants where a physical card is present: 50% or more of the time
$ - - $ 99,999	2.75%	1.99%
$ 100,000 - $ 199,999	2.65%	1.95%
$ 200,000 - $ 599,999	2.50%	1.85%
$ 600,000 - $ 1,199,999	2.40%	1.75%
$ 1,200,000 - $ 2,999,999	2.35%	1.70%
$ 3,000,000 - +	2.30%	1.65%
Fees		
Visa transaction fee	$ 0.18	$ 0.13
MasterCard transaction fee	$ 0.18	$ 0.18
Visa/MasterCard authorization fee	$ 0.07	$ 0.07
Amex authorization fee	$ 0.10	$ 0.10
Novus/Discover authorization fee	$ 0.10	$ 0.10
Merchant application fee	$ 150.00	$ 150.00
Monthly per location fee	$ 5.00	$ 5.00
Minimum monthly processing charge	$ 15.00	$ 15.00
Voice/touch tone authorization fee	$ 0.54	$ 0.54
Chargeback fee	$ 10.00	$ 10.00
Returned item fee	$ 15.00	$ 15.00

medium for transit services in the U.S. (Fleishman 1996, Gilcrease 2000). Since most transit fares in the U.S. were on the order of a nickel for almost a century, the use of coins was convenient for both transit users and operators (Saltzman, 1992). Later, when transit fares began to increase rapidly, transit operators started to accept bills in addition to coins.

The major benefit of using cash as a fare medium is that cash also serves as a major payment medium in the national economy and has universal availability and acceptance. As a result, a transit agency utilizing cash as a fare medium can limit its revenue collection activities to collecting, processing, and depositing of cash, and stay away from issues related to production, distribution, validation, collection, and disposing/recirculation of its own fare media (Fleishman 1996). Transit customers using cash as a fare medium are also benefited, since cash is readily obtainable and does not require a special purchase arrangement.

Although the use of cash as a fare medium has significant benefits, it also has inherent drawbacks. As transit fares increased beyond 25 cents and became differentiated on the basis of distance traveled, time-of-day, and type-of-rider (adult, senior, student, disabled), the issues of fare collection costs, complexity of fare structure, fare theft and fraud, and inconvenience of cash payment for riders have emerged and led to the introduction of

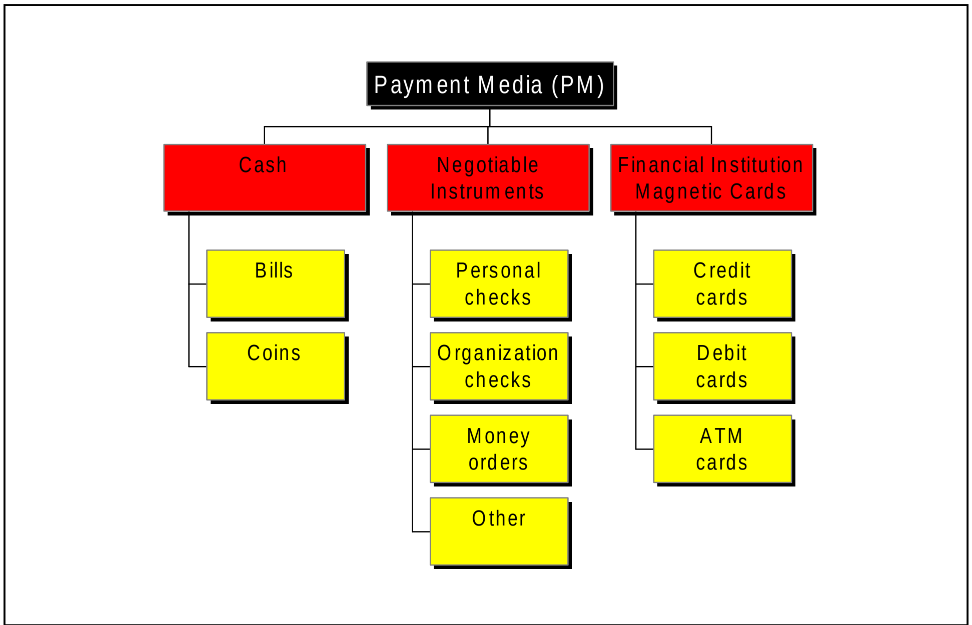

Figure 2-14. Transit payment media options.

fare media that were different from cash (Fleishman 1996, Diamond 2000). By introducing new fare media, transit agencies have primarily tried to reduce the costs of fare collection, increase customer convenience, reduce revenue theft and fraud, and increase flexibility in fare pricing.

2.3.2.2 Fare Media: Tokens

One of the earliest and most popular forms of fare media that came to replace cash was the token. Tokens are produced in a variety of shapes and sizes and can be made of different materials, usually, metal or plastic (Diamond 2000, Gilcrease 2000). For transit operators and users, the major benefits of using tokens as a fare medium instead of cash are the following:

a) Tokens allow for prepayment of transit services and can reduce fare theft and costs of fare collection depending on the mode, size, and other characteristics of the transit service;

b) Tokens can accommodate for volume discounts, thus encouraging the use of transit services (Fleishman 1996);

c) A single token can be used for a trip, thus increasing customer convenience (Diamond 2000).

The major drawbacks of using tokens as a transit fare medium instead of cash for transit operators and users are the following:

a) A transit operator needs to conduct additional revenue collection activities: produce, distribute, validate, collect, and recirculate tokens (Gilcrease 2000).

b) Transit users need to purchase an operator-specific fare medium whose use is limited.

c) The use of tokens as transit fare media may increase fare fraud since tokens are relatively easy to counterfeit (Fleishman 1996, Diamond, 2000).

2.3.2.3 Fare Media: Paper Tickets

Another popular form of fare media is a paper ticket. Very similar to tokens in their concept, paper tickets also come in a variety of shapes and sizes (Fleishman 1996, Gilcrease 2000). The major difference between tokens and paper tickets stems from the material they are made of. Since tickets are made of paper (or cardboard) they are easier and cheaper to produce, store, and distribute then tokens. For the same reason, tickets can be easily invalidated, removed from circulation, disposed, and reprinted. Typically, paper tickets do not require validation or processing by a collection device such as a fare gate (Fleishman 1996, Gilcrease 2000). The benefits of using paper tickets as transit fare media instead of cash include those mentioned for tokens plus the following:

a) Paper tickets are cheaper and easier to produce, store, distribute, dispose, and reprint than tokens.

b) Paper tickets can accommodate for distance-based fares, and different types of discounts, thus increasing fare structure equity and encouraging the use of transit services.

c) Paper tickets may increase (to a certain degree) user convenience since paper tickets can be easier to handle (i.e. carry, file reimbursement, etc.) than coins and tokens.

The major drawbacks of using paper tickets as fare media instead of cash include those mentioned for tokens plus the fact that they are prone to counterfeiting and fraud to a greater degree than cash and tokens.

2.3.2.4 Fare Media: Flash Passes

Another class of traditional (non-electronic) transit fare media is the flash pass. While a regular paper ticket entitles its holder for a single trip using a particular transit service, the flash pass gives its holder the right to use a particular transit service within a specified period. For this reason flash passes are sometimes referred to as period passes or “stored-time” fare media (APTA 1999). Since the flash pass is supposed to be used for more than a single occasion, it is usually made of cardboard or has a plastic coating. Flash passes can be designed to be valid for different periods ranging usually from one day to several months. Flash passes can also be issued (often with a discount) to particular groups of users such as students, seniors, and disabled and require their holders to have an ID to validate the pass (APTA 1999). The benefits of using flash passes as a fare medium instead of cash include those mentioned for tokens and paper tickets plus the following:

a) Flash passes can accommodate for time-based and type-of-rider (adult, senior, student, disabled) fares, and different types of discounts, thus increasing equity and encouraging the use of transit services (APTA 1999).

b) Flash passes can provide a transit agency with stable ridership and a significant part of the fare revenue being prepaid (Fleishman 1996).

The drawbacks of using flash passes as fare media instead of cash include those mentioned for tokens and paper tickets plus the following:

a) The use of flash passes may result in an unacceptable level of the fare media counterfeiting and fraud.

b) In case a rigorous fare validation policy is adopted, the use of flash passes can lead to an increase in the transit vehicle boarding time since flash passes are validated by visual inspection.

c) Flash passes may require a substantial prepayment on the part of a transit user and the value of a stolen or lost flash pass often cannot be recovered.

2.3.2.5 Fare Media: Magnetic Stripe Tickets and Passes

Magnetic stripe (MS) tickets and passes, as fare media for transit payment applications, debuted in the 1960s (Fleishman 1996). The concept of using cards carrying magnetically encoded data came to transit from the banking industry which adopted this technology for payment purposes in the early 1950s (Fleishman 1996, O'Mahony 1997). Since in the beginning the magnetic stripe technology was expensive, only large rapid rail operators such as the London Underground, London, U.K.; Bay Area Rapid Transit (BART), San Francisco, CA; and the Washington Metropolitan Area Transit Authority (WMATA), Washington, DC have been able to pioneer and justify this technology (Fleishman 1996).

The underlying concept behind magnetic stripe technology is to use the quality of magnetic material to retain polarization of individual magnetic particles after the application of a magnetic field. By altering the encoding current, sectors with opposing polarization of magnetic particles can be created on a stripe of magnetic material. Later, when the magnetic stripe is moved against a coil-wound magnetic head, pulses of current are generated in the head (see figure 2-15). These pulses can represent digital data and be encoded and decoded as needed. When encoding data, the strength of pulses will depend on the magnetic material used and the strength of the encoding current. When decoding, the speed at which the magnetic stripe is moved along the reading head and the consistency of speed determine the strength of pulses (Hendry 1997).

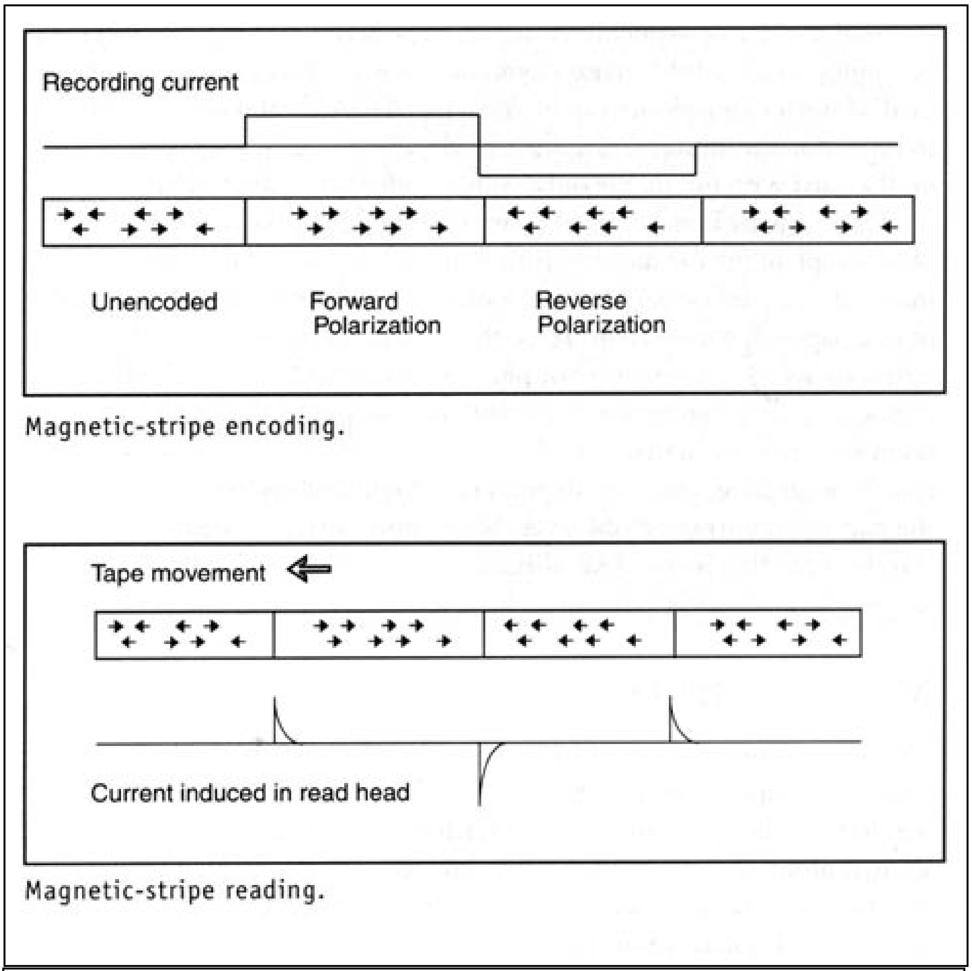

Figure 2-15. Magnetic-stripe encoding and reading (Hendry 1997).

Magnetic stripe media come in a variety of shapes and sizes and have two major elements—the carrier and a layer of magnetic material. The carrier is usually made of paper or plastic and can vary in its flexibility. The magnetic material can be bonded to the carrier in different places and usually forms a stripe (Hendry 1997).

Generally, two types of magnetic material—called low-coercivity and high-coercivity—are used in manufacturing MS media. Standard, low-coercivity MS media can be erased or corrupted by relatively weak magnetic fields such as those found in close proximity to audio speakers and other common appliances. High-coercivity MS media are more resistant to stray magnetic fields and would not be affected by most permanent magnets (Fleishman 1996, Hendry 1997).

The data storage capacity of magnetic stripe media depends on the type of magnetic material used and the size of magnetic stripe. Usually, several hundred bytes of data can be stored on a regular credit-card-size magnetic stripe media. Although the qualities of high-coercivity magnetic material permit the data to be erased from and rewritten on the card up to several hundred times, the costs of high-coercivity encoders often limit the application of this material to read-only swipe passes. On the other hand, most MS tickets used in transit feature low-coercivity magnetic material. These tickets are usually designed to be used with motorized readers and can endure some 50-100 read-write cycles (Fleishman 1996, Hendry 1997).

One of the most important and difficult issues that MS fare media helps to address in transit relates to fare policy and fare structure equity. Traditional, non-electronic fare collection media have intrinsic limitations in implementing and administering a flexible, efficient, and equitable fare policy. Although many transit operators have developed elaborate fare policies sensitive to the distance traveled, time of day, day of week, type of user, frequency of travel, etc. without using electronic fare media, the expenses associated with administering such policies tend to be very high. Alternatively, magnetic stripe fare media (as well as smart cards, discussed later) provide a capability of supporting a complex fare policy while keeping the costs of administering such a policy low. Depending on the specific technology used, MS fare media can provide the following capabilities in respect to fare policy and fare structure equity:

a) A "stored-value" MS ticket can be used for a particular number of trips based on the distance traveled, time of day, day of week, or other parameters. Generally, an MS ticket holds either a particular number of trips or some dollar value. Trip-based MS tickets can be pre-encoded and sold by machine or manually. Transit agencies usually sell single-trip, 2-trip, 5-trip, 10-trip, 20-trip, and/or 40-trip pre-encoded electronic tickets, although other multiple-trip arrangements can be easily accommodated. While MS tickets can be encoded for a multiple-trip flat fare payment, they can also be encoded for a particular dollar value. When a value-based MS ticket is used, the dollar value decremented from the ticket can depend on several factors, including distance-traveled, time-of-day, day-of-week, etc. This arrangement provides capabilities to administer graduated fares (Fleishman 1996, 1998).

b) The use of MS passes can encourage the use of the transit service and increase the prepaid portion of the passenger fare revenue without disadvantages of using flash passes. Sharing the same technology as MS tickets, MS passes are "stored-time" fare media. They can be encoded for either an unlimited or capped number of trips during a specified period. Unlike flash passes, the MS pass can be purchased in advance and activated later. Once activated on its first use, the MS pass "rolls" for the encoded time-period. Technically, any period ranging from several hours to several months can be encoded and purchased. Time intervals of 1-, 2-, 7-, 14-, and 28-days are usually used. MS passes can also address the issue of illegal pass sharing and reduce revenue loss due to abnormally high usage of a pass by putting a cap on the maximum number of trips allowed with a particular MS pass (Fleishman 1996, 1998). Since the encoding and validation of MS passes are automated, the major drawbacks of traditional flash passes, namely a high level of fraud and slow validation process, can be significantly reduced.

c) MS fare media has the capability of providing various discounts and bonus options to transit users. An initial purchase bonus can be given to customers who prepay a particular amount of transit service. Many transit operators give a 10 percent discount for a purchase equivalent to 10 base fares, which often translates to an additional free trip per 10 trips purchased if flat fare is administered. To encourage the long use of an electronic ticket, an add-value bonus can be given. By providing this bonus to customers, a transit operator can potentially recover some of its revenue loss through reduction in ticket preparation and distribution costs. Also, to encourage the use of transit services, MS fare media can accommodate a discount based on the number of trips traveled. Similarly, an off-peak discount would encourage off-peak use of transit, thus reducing the load on the transit system during the busiest hours of the day. To discourage the use of non-electronic fare media, a discount on purchase of MS fare media can be given. Also, the activities related to issuing and validating transfers as well as provision of transfer discounts could be simplified and better administered through MS fare media (Fleishman 1996).

d) MS fare media can assist in better policy planning through improved data collection on transit ridership and traveler behavior. Statistical data collected with MS fare media can accurately depict spatial and temporal load on the system, traveler response to changes in fare policy, customer preferences in terms of specific payment and fare media options, etc. MS fare media can also facilitate accurate transaction tracking and accountability (Fleishman 1996).

e) MS fare media have advantages over non-electronic fare media with regard to better security and capacity to reduce fare evasion, theft, and fraud (Echelon Industries 1992, Fleishman 1996, 1998).

f) MS fare media have the potential to bring down the operating costs of revenue collection because of lower labor requirements and a higher level of automation. In addition, a transit operator can collect a greater portion of passenger fare revenues through prepayment (Fleishman 1996).

The major barriers that hinder widespread acceptance of MS fare media in transit pertain to high capital costs, complexity of the MS fare collection system, and the need for skilled repair and maintenance personnel (Fleishman 1996). Only recently, the capital costs associated with MS fare collection systems have decreased to the level of traditional fare collection system costs (Booz-Allen, & Hamilton, Inc., 2000). Also, some MS fare collection systems may incur higher maintenance costs since some of these systems extensively employ electronic equipment with moving parts (Fleishman 1996).

2.3.2.6 Fare Media: Smart Cards

The advent of integrated circuit (IC) cards (primarily referred to as smart cards in North America) is the latest development in transit fare media. Developed in early 1970s and extensively used in Europe and Japan for telecommunications and financial applications, smart cards are also gaining widespread acceptance among transit operators and users throughout the world (Fleishman 1996, 1998, Hendry 1997, O'Mahony 1997). As of today, the majority of large metropolitan transit operators in Europe and Asia-Pacific offer smart cards as either a primary or supplementary fare media option on their systems.

Physically, the smart card is similar to a conventional credit card that utilizes magnetic stripe technology. A typical smart card consists of a plastic carrier, IC chip, and some type of data input/output (I/O) interface. Presently, most general-purpose smart cards (including transit smart cards) follow the standards specified by the International Standard Organization (ISO) with regard to the shape and size of the plastic carrier (Hendry 1997, Everett 1999). However, the other two key parameters of smart cards (namely the type of I/O interface, data transfer rate, type of microprocessor, and memory capacity) can vary significantly depending on the card's application and other factors.

With respect to the card interface, there are three major categories of smart cards: contact, contactless, and combi or dual-interface. A contact smart card features several metal contacts (whose shape, size, and location on the card are specified by an ISO standard (see figure 2-16)) to exchange data between the card and a card-accepting device such as a cash dispenser, vending machine, or pay phone (Hendry 1997, Everett 1999). Since a contact smart card has to be physically inserted into the card-reading device and its contacts must be properly aligned with the contacts of the card-reading device during the data exchange session, which could take up to several seconds, this type of smart cards is

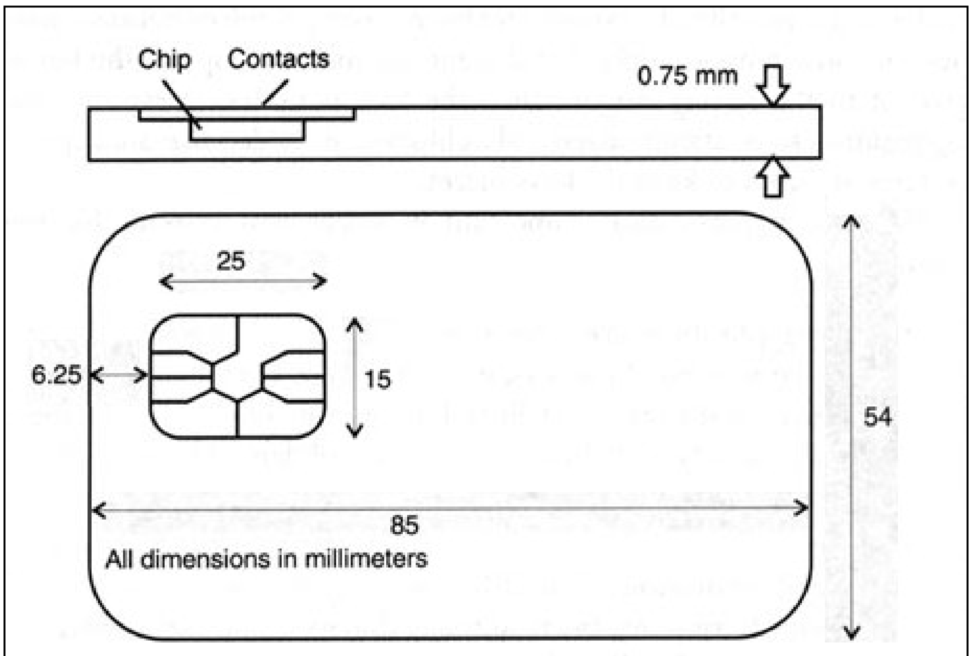

Figure 2-16. Contact smart card (Hendry 1997).

not well suited for transit applications where transaction time is a critical parameter (Fleishman 1996, 1998).

Unlike contact smart cards, contactless smart cards do not require a physical contact with a card-reading device during the data exchange session. These cards feature portable antennas embedded into the plastic carrier and communicate with a card-reading device via radio frequency (RF). Although some of the earlier models of contactless smart cards utilized portable batteries to power up the card, modern cards draw power from the electro-magnetic field generated by a card-reading device. Typically, contactless smart cards designed for transit applications require the card to be waived within up to 5 inches to the card reader. The data transmission rates of modern contactless smart cards exceed 100 kbps, which allows completing a fare payment transaction in less then 0.1 second (Fleishman 1998).

The combi or dual-interface smart card features both metal contacts and embedded antenna (see figure 2-17) and can communicate with a card-reading device via either a contact or contactless interface (Hendry 1997). A special category of dual-interface cards is a hybrid card that has two IC chips, each communicating via its own interface—contact and contactless. A hybrid card (as well as contact, contactless, and combi cards) can also bear a magnetic stripe, barcode, embossing, and/or other features (Hendry 1997, Alles 2000).

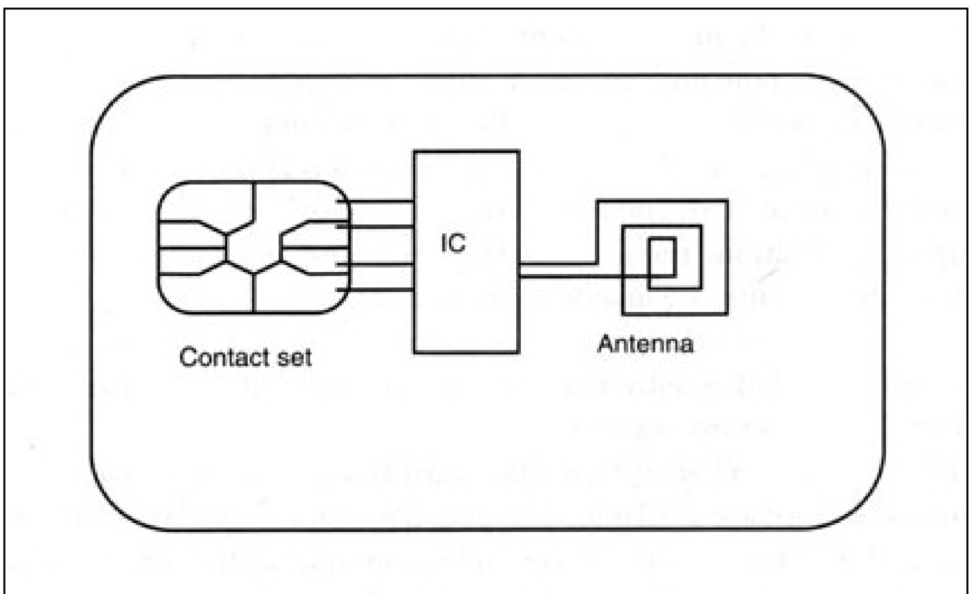

Figure 2-17. Dual-interface smart card (Hendry 1997).

The second major parameter that differentiates smart card capabilities and functions is the type and capacity of the card's on-board IC chip. Generally, there are two types of smart cards with respect to on-board circuitry—memory and microprocessor cards. Memory cards have integrated circuitry that is composed of one or more memory modules and may include the following: read only memory (ROM), programmable ROM (PROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), and random access memory (RAM). Typical memory cards can hold up to several kilobytes of data and often feature some sort of security logic (Hendry 1997, Everett 1999).

In addition to memory modules common to memory cards, microprocessor cards include a central processing unit (CPU). The card CPU is, usually, an 8-bit processor running at a speed of up to 5 MHz (Hendry 1997). The advantage of having a CPU on the card is that it is capable of running its own cryptographic algorithms and handling of multiple applications on a single card (Everett 1999).

Because of their computing and secure data storage capabilities, smart cards can be effectively used to integrate ticketing and fare collection activities of different transit operators (as well as other transportation and non-transportation applications) and facilitate building a seamless transportation system in a region. In addition to the benefits and capabilities of MS tickets and passes discussed in the previous section, smart cards have the following advantages over the non-electronic fare media:

a) The capital and operating costs of contactless smart card reading and revaluing devices are lower than the capital and operating costs of comparable equipment of non-electronic or MS media since most contactless smart card reading and revaluing devices involve no moving parts (Fleishman 1998).

b) Smart cards can be superior to traditional fare media in durability and, on average, have a much longer usable life cycle than traditional fare media (Hendry 1997).

c) Smart cards have a potential to improve operational performance of transit. Since transit vehicle boarding times depend largely on the length of fare payment and validation processes and because the electronic payment by a smart card can be as fast as 1/10 of a second, a significant improvement in boarding times on transit can be achieved.

d) Smart cards provide superior customer convenience it in terms of fare purchase, storage, and handling. With a contactless smart card, a transit customer only needs to touch a target on a card-reading device in order to make a fare payment.

e) In addition to many traditional purchasing and revaluing options, smart cards can be automatically replenished from a linked credit card account. A post-payment option is another potential benefit for customers using smart cards. When arranged, this option allows transit customers to be billed based on the transit services consumed at the end of a specified period in a fashion similar to credit card billing (Fleishman 1996, 1998).

f) Fare theft, counterfeiting, and fraud can be minimized or eliminated with the use of smart cards (Echelon Industries 1992, Fleishman 1996, 1998).

Although the benefits of smart cards for ticketing and fare collection are numerous, there are also several barriers to implementing smart cards on transit; they include:

a) High cost of smart card system integration and the cost of smart card fare media.

b) Smart cards are not well suited to occasional and infrequent transit riders.

c) Smart card technology is not standardized. There are only few smart card equipment vendors on the market and their products are not interoperable.

d) There is a concern over the use of personal travel data collected with the aid of smart cards.

Figure 2-18 summarizes the fare media options available to transit operators and users in the U.S.

2.3.3 <u>TFC Activities and Functions</u>

Although the introduction of new payment and fare media, as instruments facilitating fare collection activities, has helped transportation operators solve some of their fare

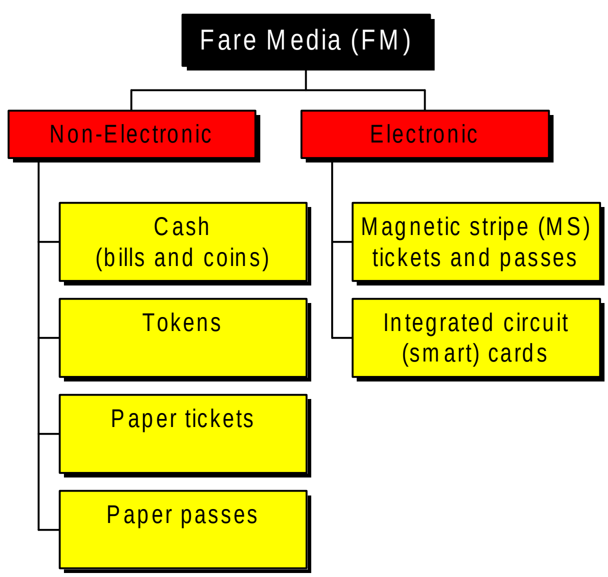

Figure 2-18. Transit fare media options.

collection problems, it also led to the development of a distinctive set of tasks that were not directly related to transit. This set of tasks is known as fare collection activities and encompasses the following six major functions: (1) fare media preparation; (2) fare media distribution; (3) fare media validation; (4) payment and fare media collection; (5) payment and fare media processing; and (6) payment and fare media depositing and recirculating. The following sections describe fare collection activities associated with the use of non-electronic and electronic payment and fare media.

2.3.3.1 TFC Activities and Functions: Non-electronic Media

The first function of the non-electronic TFC process is fare media preparation. This function applies only to those transit operators that use fare media other than cash, and may involve inspection of the fare media for factory defects, personalization of special fare media, and packaging and containerization of fare media for transporting to distribution outlets (Gilcrease, 2000).

The second function is fare media distribution. This function may include transporting fare media to distribution outlets and distribution of fare media to transit users (Gilcrease, 2000). Transit fare media distribution outlets may include transportation terminals, transit headquarters and divisions, transit vehicles, commercial or service outlets, information centers, parking and other outdoor sites, government offices, and non-government employment sites (APTA, 1999).

The third function of the fare collection process is fare media validation (Gilcrease, 2000). This activity can be conducted by a transit vehicle operator, conductor, or station attendant, or can be automated with the aid of electronic fareboxes and faregates.

The fourth function of the fare collection process is collection of payment and fare media. This activity involves collection of coins, bills, and checks from fare media distribution outlets; vaulting of ticket vending machines, fareboxes, and turnstiles; and collection of unused but expired fare media from fare media distribution outlets (Gilcrease, 2000).

The fifth function—payment and fare media processing—takes place at the transit agency money room. This activity involves consolidation, sorting, counting, and packaging of collected payment and fare media for subsequent bank deposit or recirculation into the fare media distribution system (Gilcrease, 2000).

Finally, the sixth activity of the fare collection process—payment media depositing and fare media recirculation/disposing—involves transporting processed revenue to the bank, and recirculating change and tokens back into the fare media distribution system (Gilcrease, 2000).

In summary, figure 2-19 depicts TFC functions and activities associated with the use of non-electronic payment and fare media on transit.

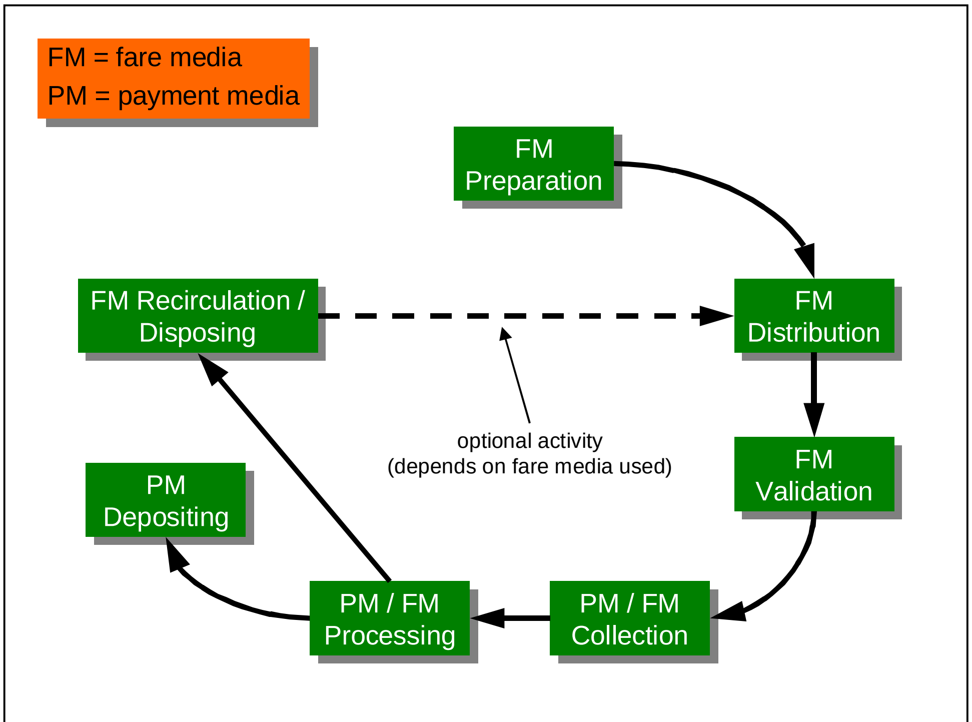

Figure 2-19. TFC activities and functions: non-electronic media.

2.3.3.2 TFC Activities and Functions: Electronic Media

The use of electronic payment media (i.e. credit, debit, and ATM cards) and electronic fare media (MS tickets and passes and smart cards) significantly affects the way that TFC activities are conducted on transit. Although some of the core TFC functions are similar regardless of the type of payment and fare media used, the use of electronic payment and fare media shifts the focus of TFC activities from handling and processing physical media to processing electronic data. Because a large part of electronic data processing takes place in the transit operator's headquarters, it is often referred to as TFC "back office" activities.

The first function of the electronic TFC process deals with fare media preparation. This function may include electronic fare media procurement, inventory control, initialization, personalization (if required), and issuance (Benton International 1995, IBI Group, 1998).

The second function of the electronic TFC process is the electronic fare media distribution. This function includes: transporting fare media to distribution outlets, distribution of fare media to transit users, loading fare media with value, revaluing fare media, and replacement of lost, stolen, and malfunctioning fare media. Electronic fare media is usually distributed through automated kiosks, transit operator's customer service offices, participating retail outlets, via mail, and other distribution outlets. Electronic fare media revaluing locations may include customer service offices, vending machines, automated revaluing kiosks and retail outlets. Electronic fare media can also be revalued through the Internet, telephone, via mail, or automatically on a periodic or on an as-needed basis (Benton International 1995, IBI Group, 1998).

The third function of the electronic TFC process is transaction processing. This function involves upload and receipt of fare media transactions, posting transactions to appropriate accounts, reconciling transactions received to transactions posted, downloading a "blocked" fare media file and other administrative orders to all fare media accepting devices (Benton International 1995, IBI Group, 1998).

The fourth major function of the electronic TFC process involves customer account maintenance and revenue management and settlement. Customer account maintenance activities, typically, include establishing fare media holder accounts, maintaining payment media balances, maintaining account receivable balances, maintaining account personalizing and status information, and invoicing accounts based on usage or automatic depletion. The revenue management and settlement function typically encompasses management of prepaid funds and other revenues, fee and funds settlement, and settlement reporting. At the end of each fund settlement cycle, all transaction records can be processed to determine settlement and funds positions for the entire transit system (Benton International 1995, IBI Group, 1998).

Figure 2-20 summarizes schematically TFC functions and activities associated with the use of electronic payment and fare media on transit.

Finally, it is worth repeating that the concepts of fare and payment media for transit applications have evolved over the years due to several reasons including concerns over safety and security of transportation employees, impact of payment process on operational efficiency of transportation services, revenue theft, introduction of variable (time-based and distance-based) fares, and other. While new fare and payment media have helped to solve many of the initial fare collection problems and created new payment opportunities, they also led to the development of a distinctive set of tasks that were not directly related to transit. Recent developments in microelectronics may help to address many of today's TFC needs and lead to the development of a common fare media to be used for different transit and non-transit applications. Ultimately, a single electronic payment media may evolve, thereby eliminating the distinction between payment and fare media as depicted in figure 2-21.

2.3.4 Components of a TFC System

By definition, a system is a group of related components or parts that function together as a whole. Similarly, a TFC system is a group of special equipment components that facilitate collection and processing of fares and ridership data on transit. Individual pieces of TFC equipment can be grouped into several broad categories based on their functional purposes and attributes. In general, a TFC system consists of the following major components: fare media; fare media preparation facilities and equipment; fare media distribution facilities and equipment; fare media validation and collection facilities and

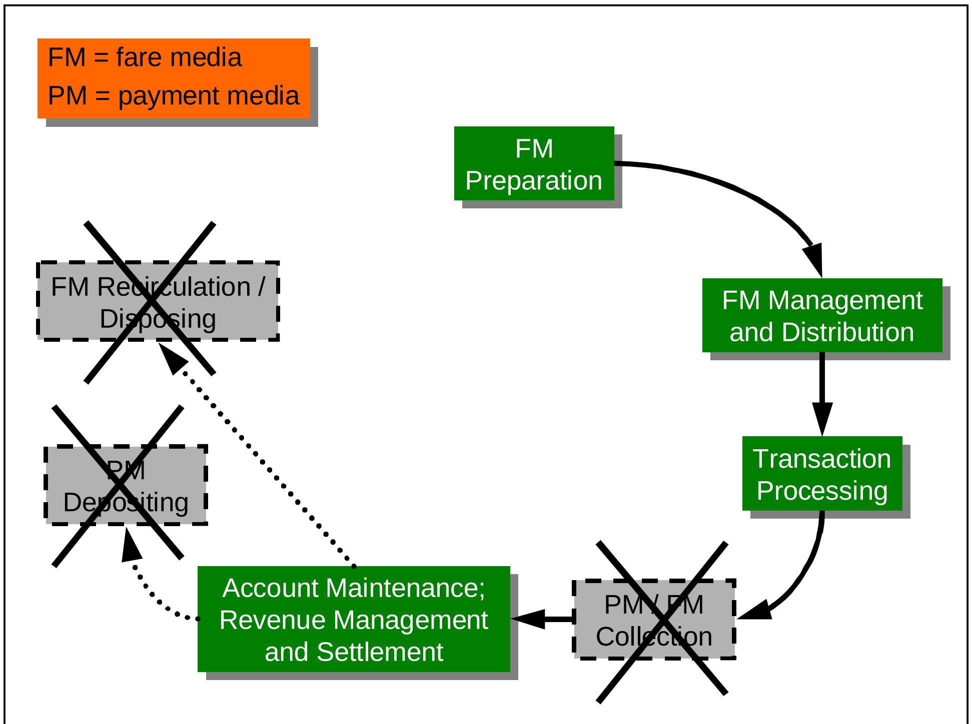

Figure 2-20. TFC activities and functions: electronic media.

equipment; communication, transportation, and data collection facilities and equipment; and back office facilities and equipment.

The type of fare medium or media used by a particular transit operator defines, to a large degree, the specific configuration of other components of a TFC system. However, the general functions of TFC system components usually remain similar independent of the fare media used.

Fare media preparation equipment and facilities generally include premises where the procured fare media is stored, inspected, packaged, initialized, and personalization (if necessary). These premises may house secure vaults, fare media counting machines, MS ticket and smart card encoders, special fare media printers, computer and other equipment.

Fare media distribution facilities and equipment typically include premises dedicated for fare media distribution or designed to serve other transit related purposes (such as rail station halls and platforms). These premises may house ticket vending machines (TVM), change making machines (CMM), customer service and sales offices, automated revaluing kiosks, electronic fare media readers, and other equipment (APTA 1998, Fleishman 1996).

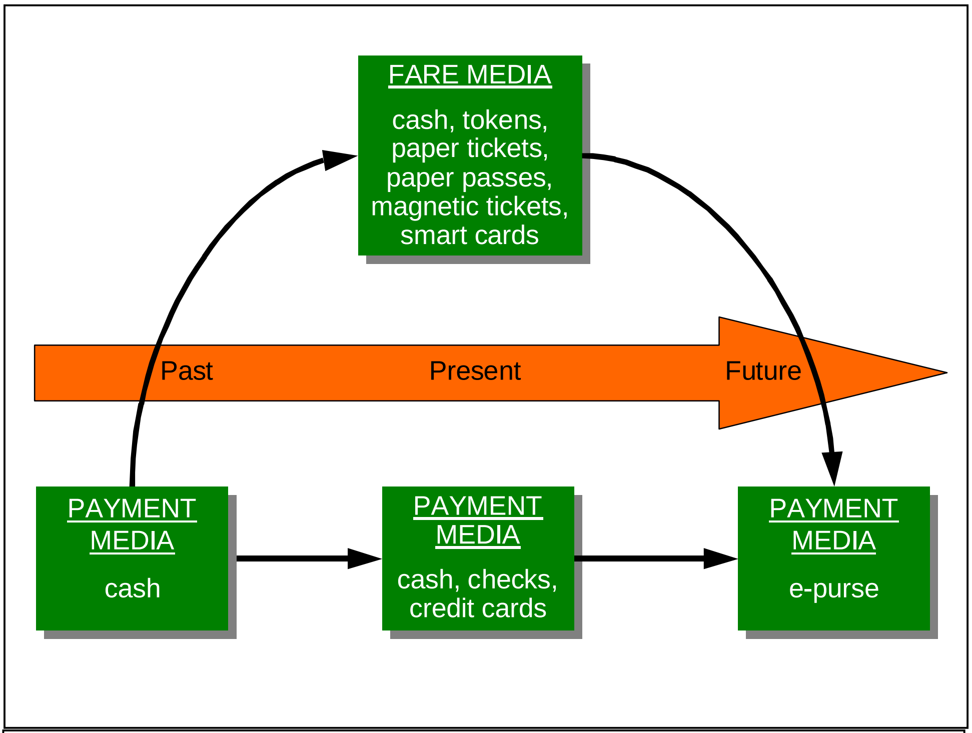

Figure 2-21. Evolution of transit payment and fare media.

Fare media validation and collection facilities and equipment occupy dedicated space situated close to an entrance of either a transit station or transit vehicle. Fare media validation and collection equipment may include faregates, turnstiles, fareboxes, fare media readers, ticket validators, and other equipment (APTA 1993, Fleishman 1996).

Communication and data collection facilities and equipment may include different types of wire lines (twisted-pair, coaxial, fiber-optic, etc.), modems (modulators/demodulators), codecs (coders/decoders), amplifiers, station and garage controllers, premises to house this equipment, and other equipment.

Finally, back office facilities and equipment include money room and central computer facilities, secure vaults, sorting, counting, and packaging equipment, host computer(s), data storage equipment, uninterrupted power supply units, and other equipment.

Figure 2-22 depicts major components of a TFC system and broad categories of TFC equipment.

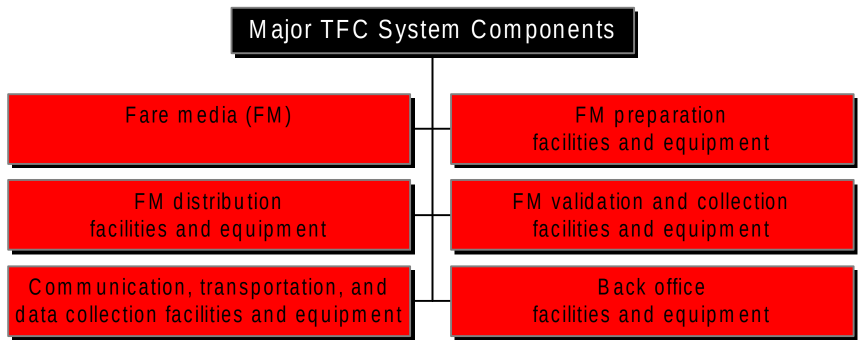

Figure 2-22. Major TFC system components.

CHAPTER 3: RESEARCH METHODOLOGY

In this chapter of the dissertation report, the author addresses primarily the first objective of this research, which is the formulation of a conceptual evaluation framework and a plan to assess alternative TFC technologies in transit.

A conceptual evaluation framework is formulated in Section 3.1. It starts with a discussion of broad issues associated with TFC operations on transit from the transit agency perspective as well as transit customer standpoint. Then, more specific objectives for the selection of an optimal TFC technology are defined and the primary objective (as deemed appropriate for the purposes of this research) is selected for the development of a plan to evaluate performance of alternative TFC technologies. Finally, TFC system alternatives with respect to transit mode, payment and fare media, and level of TFC automation are identified and listed.

To address the second objective of this research and to facilitate the analysis of TFC operating expenses on heavy rail and bus systems, a research methodology is developed in Section 3.2. It outlines the general theory regarding the performance of a transit TFC system and presents a set of hypotheses that are utilized and tested in the following chapter.

Finally, Section 3.3 presents a plan to evaluate alternative TFC systems. First, the author identifies and selects several performance measures to be used to compare TFC system alternatives. Following that, there is a discussion and selection of analytical methods and techniques to examine performance of alternative TFC systems. In conclusion, the author outlines data requirements, identifies available data sources, and selects a primary data source to conduct the selected analyses.

Figure 3-1 depicts the relationship between Chapters 3 and 4 and the objectives of this research. It also illustrates the research approach followed in this dissertation. The evaluation framework formulated in Section 3.1 provides a foundation for an evaluation plan described in Section 3.3, which, in turn, serves as a basis for data analysis performed in Chapter 4.

3.1 FORMULATION OF EVALUATION FRAMEWORK

This section begins with an overview of broad issues associated with TFC operations on transit as perceived by both transit operators and users. It is followed by a discussion of more specific objectives that transit agencies commonly pursue when selecting a new TFC system. The section concludes with a presentation of TFC system options available to transit operators in the U.S.

3.1.1 Issues Associated with Fare Collection

Issues associated with fare collection on transit can be generally viewed from either a transit operator's or transit customer's perspective. In addition, these issues may be influenced by site-specific factors.

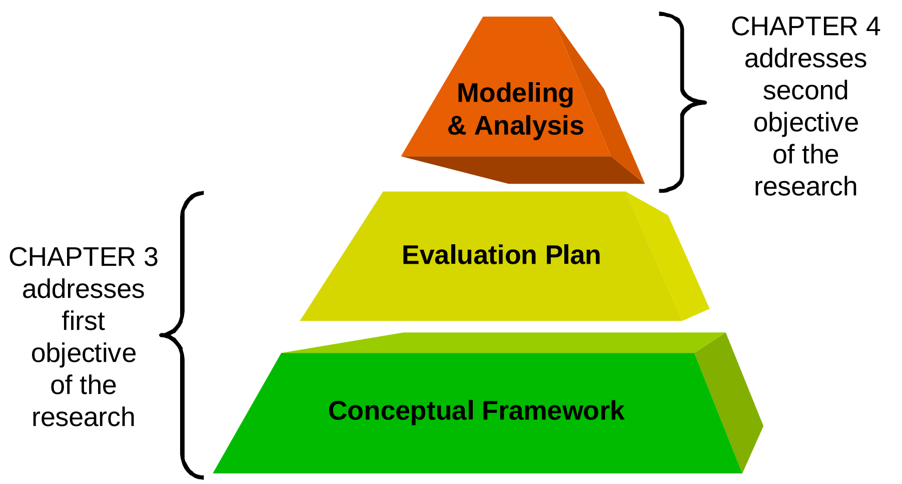

Figure 3-1. Content of Chapters 3 and 4.

From a transit operator's standpoint, the major issues associated with fare collection are generally related to the provision of an efficient, effective, and reliable service. These issues can be further grouped into two broad categories—financial and management-related issues.

Financial issues associated with fare collection center on the need to increase revenues, that a transit operator collects through fare payment, and reduce costs of fare collection. By increasing revenues and reducing operating costs, a transit agency can improve the efficiency and effectiveness of its operations.

Management-related issues associated with fare collection involve a variety of transit operator's needs and concerns focusing primarily on improvements in transit operations. These issues include the need to handle the increased complexity of fare structure, improve data collection for policy and operations planning, improve modal and regional transit service integration, and improve reliability and throughput of a fare collection system.

From a transit customer perspective, the issues associated with fare collection (payment) on transit involve the need to increase convenience of the fare medium, increase fare payment options, reduce the complexity of fare payment, and maximize social equity of using transit services.

Finally, the site-specific issues associated with fare collection on transit may include the need to improve the image of transit as an alternative to the automobile, the need to promote the use of transit by elderly and disabled people, or the need to achieve a certain recovery ratio requirement.

3.1.2 Objectives for TFC Technology Selection

Although there are many business needs and challenges associated with revenue collection in transit, transit operators typically pursue two main goals when considering a new TFC system. These goals are to improve financial situation in a transit agency and to enhance customer satisfaction of using transit services. These two goals encompass a number of other, lower-level objectives (see Figure 3-2).

By implementing a new TFC system, transit operators are looking primarily for the inherent financial opportunities associated with this implementation. More specifically, transit operators seek to:

a) Reduce revenue collection costs. The costs of revenue collection vary significantly for transit applications. It is estimated that revenue collection costs can be as high as 20 percent of revenues collected, whereas the industry-wide average is around 5 percent (Fleishman et. al., 1998).

b) Reduce revenue loss. Transit agencies report that a substantial part of their revenues are lost due to fare evasion, revenue theft, and fraud. Although it is believed that these kinds of revenue loss do not exceed five percent of revenues collected, their reduction can improve the overall financial picture of a transit agency.

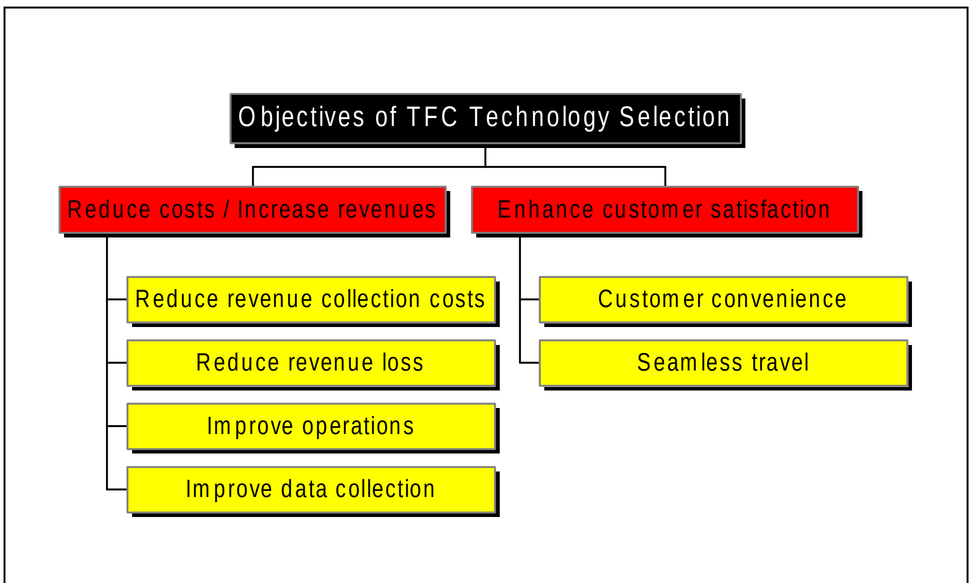

Figure 3-2. Objectives of TFC technology selection.

c) Improve operations. Traditional revenue collection activities on transit often result in a noticeable slowdown of the general service. By implementing a more efficient TFC system, major improvements in transit operations can be achieved which, in turn, should result in a greater cost-efficiency of the service.

d) Improve data collection. Since transportation agencies extensively collect data on its services for planning and reporting purposes, any improvement in a data collection process can be translated into cost savings.

The second main goal of implementing a new TFC system is to enhance customer satisfaction with using transit services. This goal encompasses improvements in customer convenience associated with the fare payment process and customer benefits from integration of various transit and non-transit applications with a single payment medium.

a) Customer convenience. The use of electronic fare media such as a contactless smart card can radically change the way a traveler pays for transit services. The ease in handling an electronic payment medium and the payment options that become available to the user should increase the attractiveness of the transit services and expand their market.

b) Seamless travel. The customer satisfaction involved with using transit services can be greatly improved by introducing a single payment instrument for different transit and non-transit applications.

As selected for the purposes of this research, the single objective considered in the evaluation of alternative TFC technologies is a minimization of TFC operating costs as viewed from a transit operator's perspective. This objective is followed in the development of the research methodology and evaluation plan in Sections 3.2 and 3.3 and in the data analysis in Chapter 4.

3.1.3 Alternative TFC Systems

The last major part of the proposed evaluation framework is a formulation of TFC system options and alternatives available to transit agencies in the U.S.

One of the challenges associated with categorization of alternative TFC systems is that there are several major independent factors affecting the composition, functions, and performance of a TFC system. To a large extent, the type of payment media, fare media, and TFC equipment define the overall layout and functions of a TFC system. For further information regarding the functions, advantages and limitations associated with a particular type of payment media, fare media, or TFC equipment, the reader can refer to Section 2.3 of the Literature Review that provides an extensive review of these factors.

In addition to the three independent factors mentioned above, the mode of transit and organization of a transit service plays a significant role in the final composition of a TFC system. Figure 3-3 illustrates the four major determinants of a TFC system that are discussed further in the following paragraphs.

The first major determinant of a TFC system is the type of payment media a transit agency accepts to pay for its services. As described in Section 2.3.1, there are three categories of payment media that transit agencies in the U.S. accept: cash, negotiable instruments (checks), and financial institution magnetic cards (credit cards).

The second major factor affecting the composition and functions of a TFC system is the fare media utilized by a transit agency. The most common fare media alternatives available to transit operators in the U.S. include cash (as fare media), tokens, paper tickets, flash passes, magnetic tickets and passes, and smart cards (see Section 2.3.2).

The type of TFC equipment employed on a transit system is another key parameter of a TFC system. The spectrum of TFC equipment can be categorized by the level of automation associated with various fare media preparation, distribution, validation, collection, and processing equipment. For example, TFC equipment (including facilities) for manual and automated distribution of fare media would be ticket sales booths with cash registers and ticket vending machines correspondingly. Mechanical versus electronic fareboxes or turnstiles is another example of categorizing TFC equipment by the level of automation.

Finally, the fourth key determinant of a TFC system composition and functions is the transit system mode. Typically, the way the fare is paid, validated, and collected on a bus

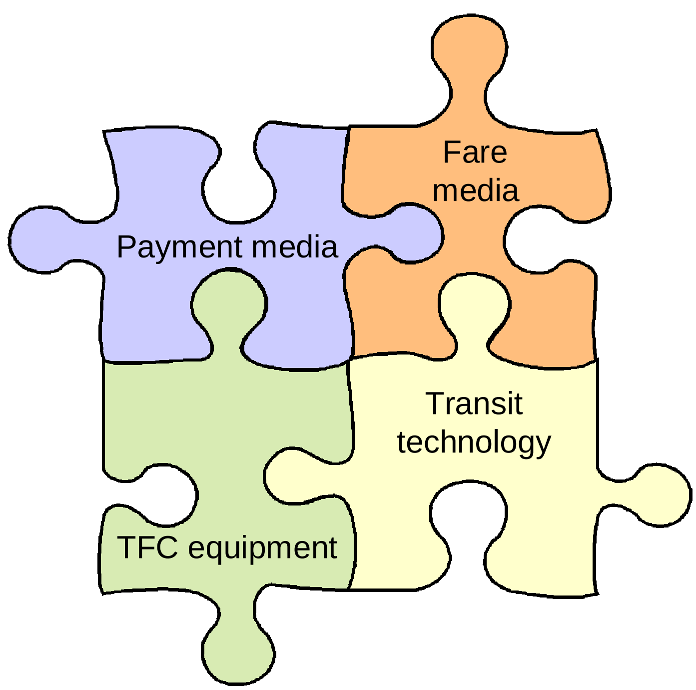

Figure 3-3. TFC system determinants.

system is different from the way it is handled and processed on a heavy rail, light rail, or commuter rail system. Usually, bus transit systems require riders to pay fares upon boarding the vehicle; rapid rail systems require riders to pay fares upon entering or exiting a station, and; light rail and commuter rail systems require riders to purchase fare media at fare media distribution locations and have a proof of payment prior to boarding the vehicle. The mode of transit is also likely to affect the number of fare media distribution, validation, and collection points that might be associated with the number of vehicles for a bus service and the number of stations for a heavy rail service.

In conclusion, figure 3-4 summarizes TFC system options available to transit operators in the U.S. to address their fare collection needs.

3.2 Research Methodology

As stated in the beginning of this dissertation report, the second objective of this research is to analyze the operating expenses of alternative TFC technologies on heavy rail and bus transit with the aid of the developed evaluation framework and plan. This section presents the research methodology utilized for this analysis. Section 3.2.1 outlines the general theory regarding the performance of a transit TFC system and Section 3.2.2 presents a set of hypotheses that are utilized and tested in the following chapter.

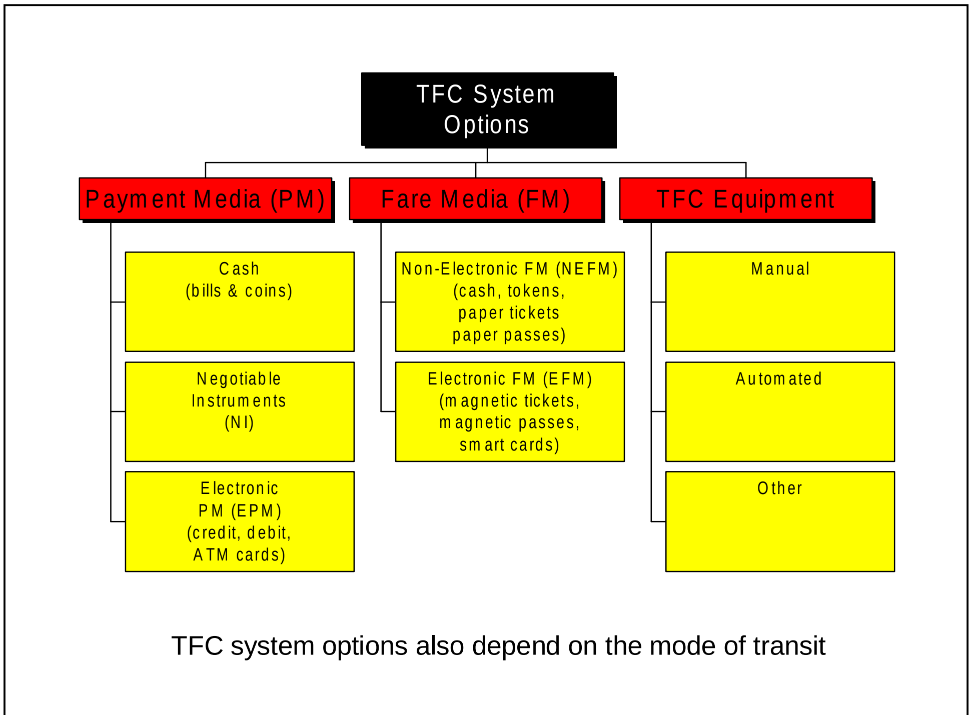

Figure 3-4. TFC system options.

3.2.1 General Theory

The conceptual evaluation framework developed in the previous section shows that an assessment of a TFC system performance will be influenced by a set of broad issues related to fare collection operations on a transit system and will specifically depend on the objective(s) pursued by installation of a new TFC system. Depending on the extent of modernization, a new TFC system may affect and change many aspects of the existing TFC system operations. A new TFC system will have distinct technical, economic, organizational, user acceptance, and other characteristics. Consequently, the performance of a new TFC system can be evaluated in different terms depending on the purposes of the evaluation (see figure 3-5). Since the focus of this study is an analysis of operating costs associated with different TFC systems, it is the economic characteristics of a TFC system performance that are under investigation in this research. It should be noted, however, that the economic characteristics of a TFC system performance involve a set of distinctive variables that are likely to be investigated separately. These economic variables may include revenue impacts, capital costs, operating costs, and other. Once again, the research methodology presented in this report focuses on the analysis of operating costs associated with TFC systems on heavy rail and bus services in the U.S.

One of the common definitions of the word “theory” is “a formulation of apparent relationships of certain observed phenomena which has been verified to some degree” (Merriam-Webster, Inc., 1980). Therefore, it is important to begin the discussion of the

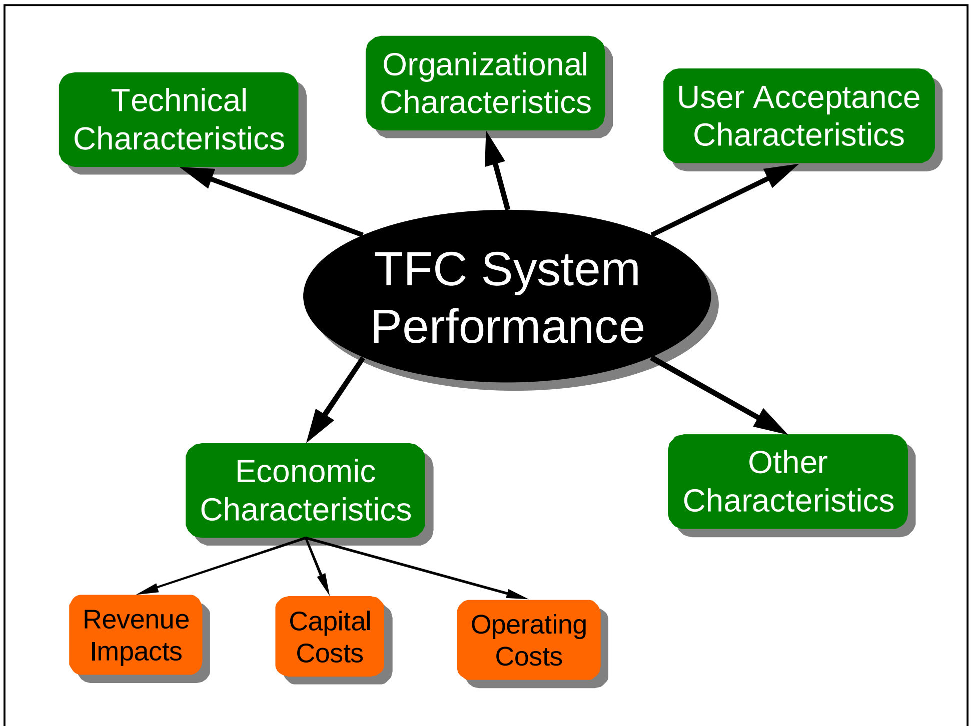

Figure 3-5. Characteristics of TFC system performance.

research methodology by introducing the theory underlying this research.

A general theory investigated in this research is that the operating costs (OC) to collect fares on public transit are related to transit system demand, TFC and transit system technologies, labor rules, and fare policy.

$$TFC\ OC = f(x_i) \qquad [3.1]$$

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC technology;

x_4 = fare policy;

x_5 = labor rules.

To get a better picture of the relationships among the factors affecting TFC operating costs on transit, it is useful to consider a cause-and-effect aspect of these relationships. Figure 3-6 presents a diagram showing how different factors affect TFC operating costs.

As discussed in Section 2.2.4.2 of the Literature Review (discussion of transit operating costs) and as evident from the NTD data, transit TFC operating costs are composed primarily of Labor (501), Fringe Benefit (502), and Materials and Supplies (504) expenses. These three groups of expenses represent, on average, more than 98 percent of TFC operating costs. Moreover, the Labor and Fringe Benefits object classes are the biggest contributors to the total TFC operating costs. For most transit agencies, these two object classes make up some 90-95 percent of the total TFC operating costs.

In figure 3-6, the Labor and Fringe Benefits object classes are combined and shown as “Labor Costs”. Apparently, the magnitude of these costs depends on two key factors: the amount of labor consumed and the rate at which this labor is priced. In figure 3-6, these two factors are shown as “Amount of Labor” and “Labor Rules”. The amount of labor can be assessed and counted in terms of full-time and part-time employees engaged in TFC activities or in terms of TFC employee work hours (EWH) spent. Similarly, the labor rules can be assessed in terms of average wage rates and fringe benefit payments for a transit agency’s TFC employees.

Since wage rates and fringe benefit payments depend on a variety of socio-economic factors that are not directly related to either TFC operations or the objectives of this research, the “mechanics” of the “Labor Rules” variable will not be investigated further and this variable will be considered as a basic independent variable.

The amount of labor spent on TFC activities, however, depends on other factors central to both TFC operations and this research. Generally, the amount of labor spent on TFC

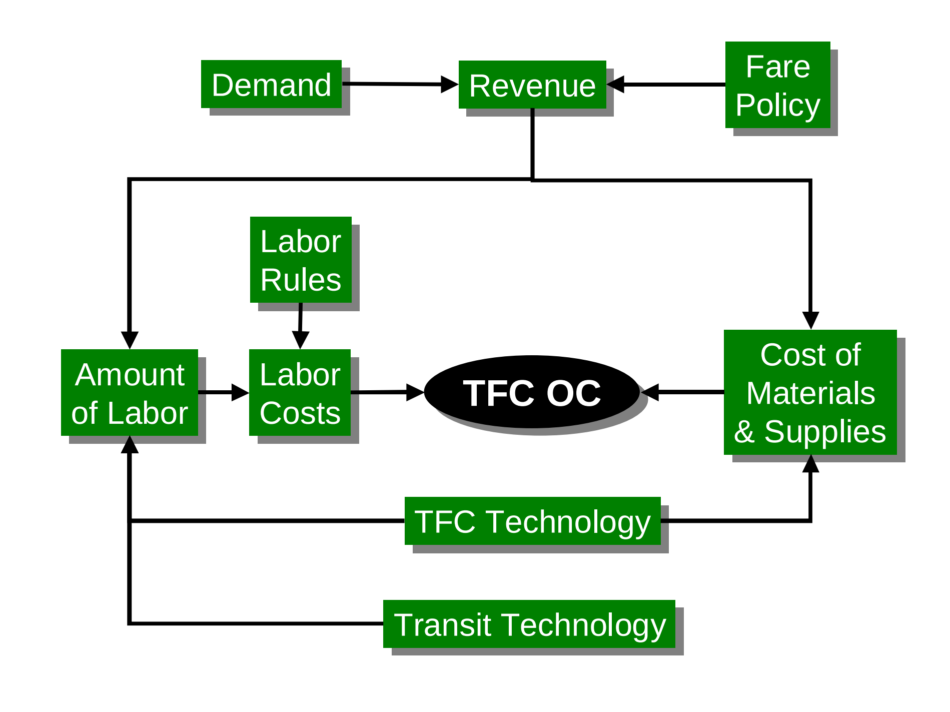

Figure 3-6. Factors affecting TFC operating costs.

activities depends on the amount of revenues collected and the rate at which these revenues are processed.

The amount of revenues collected is, typically, assessed in terms of passenger fare revenues (PFR) and depends on two major factors: transit demand and transit agency's fare policy. Although there is a myriad of factors that influence transit demand and a transit agency's fare policy, for the purposes of this research, both of these variables will be considered as basic independent variables. Transit demand is usually measured in unlinked passenger trips (UPT), whereas fare policy can be represented in terms of the average fare charged on a transit system.

The second major factor that influences the amount of labor spent on TFC activities is the rate at which these activities are conducted or a level of productivity associated with these activities. Perhaps the most important factors that affect the level of productivity associated with TFC activities are the transit technology (mode) and TFC technology.

The transit technology is a significant factor affecting productivity of TFC employees since the greater part of TFC activities takes place on transit vehicles, stations, and other facilities that differ considerably from one mode of transit to another. Physical, operational, and other characteristics of transit vehicles and stations (stops) specify, to a large degree, the way certain TFC activities are conducted as well as the extent of this activities.

Another major factor affecting productivity of TFC employees is the TFC technology used. Even for a person unfamiliar with all aspects of ticketing and fare collection, it is reasonable to suggest that operation of a TFC system utilizing the contactless smart card technology (see. Section 2.3.2.6 for a discussion of smart card fare media) is likely to be less labor intensive than operation of a TFC system that relies on bills and coins as fare media.

Finally, the costs of materials and supplies for TFC operations will also be influenced by some of the factors that influence the amount of labor spent on TFC activities. Wear and tear of TFC equipment as well as the amount of fare media issued and sold is directly related to the amount of revenues collected and processed. The costs of materials and supplies are also dependent on the type of TFC technology employed.

3.2.2 Hypotheses

As opposed to a theory, which serves as a broad formulation of a certain phenomenon and does not require immediate verification, a hypothesis is a more specific and testable statement of a problem. Although the word "hypothesis" has many meanings and definitions, in this research a definition provided by the Academic Press Dictionary of Science and Technology is adopted. It states that a hypothesis is "a proposition that is based on certain assumptions and that can be evaluated scientifically" (Academic Press, 1992). By a scientific evaluation of a hypothesis, the author assumes a statistical procedure commonly referred to as hypothesis testing.

As formulated in the previous section, the general theory investigated in this research is that the operating costs to collect fares on public transit are related to transit system demand, TFC and transit system technology, labor rules, and fare policy. From this theory, a set of testable hypotheses can be developed to help verify the validity of the theory.

A general form of a hypothesis to be tested in this research is the following:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 \quad \textbf{[3.2]}$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC technology;

x_4 = fare policy;

x_5 = labor rules.

The null hypothesis to be tested, in this case, is H_0: $b_i = 0$, for i = 1, 2, …, k. Then the alternative hypothesis, i.e. the hypothesis that supports our theory, would be formulated as follows: H_A: $b_i \neq 0$. The test statistic, in this case, is:

$$t = \frac{\hat{\beta}_i - \beta_i}{s_{\hat{\beta}_i}}$$

which is Student t distribution with n – k – 1 degrees of freedom.

Since one of the objectives of this research is the analysis of TFC operating costs on transit in the U.S. with the aid of the developed evaluation framework and plan, the focus of this analysis is the impact of TFC technology on TFC operating costs. However, other factors influencing TFC operating costs should also be identified and analyzed in order to separate the effect of those factors from the effect of TFC technology on TFC operating costs. In the following sections, several hypotheses relating TFC operating costs to various factors are formulated. Also, an approach to how to exclude the effect of some factors (which are not of the main concern of this research or could not be easily assessed) from the analysis of TFC operating costs is presented.

3.2.2.1 Effect of Labor Rules and Fare Policies

As discussed in Section 3.2.1 and depicted in figure 3-6, there are several variables that affect TFC operating costs but whose composition and behavior are not in the focus of and beyond the scope of this dissertation. Particularly, the author believes that labor rules and fare policies are often determined and driven by factors (such as political, social, organizational) that are substantially different from the factors investigated in this research (i.e. technological and economic factors). Consequently, in this section the author suggests an approach to how to exclude the impact of these factors from the analysis.

In Section 3.2.1 it is stated that transit TFC operating costs are composed primarily of Labor Costs and costs of Materials and Supplies whereas the magnitude of Labor Costs depends on two key factors: the amount of labor consumed and the rate at which this labor is priced, marked as “Amount of Labor” and “Labor Rules” in figure 3-6. It is also stated that the Amount of Labor is often assessed in terms of TFC employee work hours spent while the Labor Rules can be described in terms of average wage rates of TFC employees. In addition, it is mentioned that for most transit agencies, TFC labor costs make up to 90-95 percent of the total TFC operating costs.

Taking the above premises into account, it can be suggested that for each transit agency, TFC operating costs should be highly correlated to the Amount of Labor spent on TFC activities. The Labor Rules expressed as an average wage rate for a transit agency’s TFC employees and measured in dollars per hour serve as a constant multiplier that transforms the Amount of Labor into Labor Costs. Furthermore, since Labor Costs account for 90-95 percent of total TFC operating costs, this variable can be used as a proxy for TFC operating costs. Table 3-1 shows that the coefficient of correlation between TFC operating costs and TFC employee work hours is about 0.996 suggesting a very strong positive relationship between these two variables.

Since TFC operating costs and the Amount of Labor measured in TFC employee work hours are so highly correlated, a general form of the hypothesis expressed in Equation 3-2 can be transformed into the following form:

$$\boldsymbol{y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4} \qquad \textbf{[3.3]}$$

where,

y_1 = amount of labor associated with TFC activities;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC technology;

x_4 = fare policy.

The null hypothesis to be tested in this case is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$. The test statistic is:

$$t = \frac{\hat{\beta}_i - \beta_i}{s_{\hat{\beta}_i}}$$

which is Student t distribution with n – k – 1 degrees of freedom.

The transformation described above is graphically depicted in figure 3-7.

An approach described above can also be used to exclude the effect of the differences in fare policies among transit agencies on both the TFC operating costs and the Amount of Labor associated with TFC activities.

Table 3-1. Correlation between TFC operating costs and TFC employee work hours.

Selected bus and heavy rail transit agencies (1993 FY and 1998 FY)

TFC OC		*TFC EWH*	
Mean	$10,763,787	Mean	381,643
Median	$1,171,464	Median	30,577
Minimum	$30,640	Minimum	2,004
Maximum	$211,013,900	Maximum	7,415,896
Count	100	Count	100

Correlation	*TFC OC*	*TFC EWH*
TFC OC	1	
TFC EWH	0.996	1

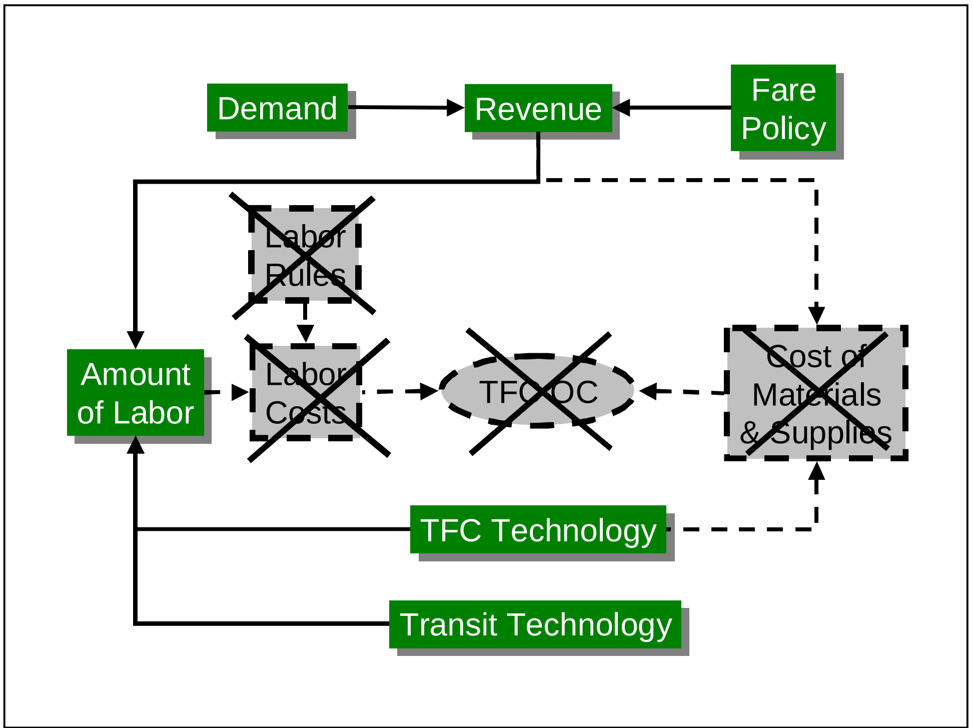

Figure 3-7. Factors affecting labor intensiveness of TFC operations.

As stated in Section 3.2.1, the amount of revenues collected depends primarily on two major factors: transit demand and transit agency's fare policy. Transit demand is usually measured in unlinked passenger trips, whereas fare policy can be described in terms of the average fare charged on a transit system.

Similar to the scenario with the TFC operating cost and amount of labor discussed above, it can be suggested that for each transit agency the revenues collected should be highly correlated to the transit demand. The transit agency's fare policy, expressed as an average fare charged on the transit system, serves as a constant multiplier that transforms the transit demand into the amount of revenues collected. Table 3-2 shows that the coefficient of correlation between passenger fare revenues and transit demand expressed in UPT is about 0.98 suggesting a very strong positive relationship between these two variables.

Since the amount of revenues collected and transit demand measured in UPT are so highly correlated, a general form of the hypothesis expressed in Equation 3-3 can be further transformed into the following form:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 \quad [3.4]$$

Table 3-2. Correlation between transit demand and passenger fare revenues.

Selected bus and heavy rail transit agencies (1993 FY and 1998 FY)

RFR		*UPT*	
Mean	$111,294,088	Mean	126,960,711
Median	$17,865,435	Median	42,362,868
Minimum	$1,480,616	Minimum	4,255,417
Maximum	$1,549,626,440	Maximum	1,579,782,509
Count	100	Count	100

Correlation	*PFR*	*UPT*
PFR	1	
UPT	0.989	1

where,

y_1 = amount of labor associated with TFC activities;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC technology.

The null hypothesis to be tested in this case is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$. The test statistic, in this case, is:

$$t = \frac{\hat{\beta}_i - \beta_i}{s_{\hat{\beta}_i}}$$

which is Student t distribution with n – k – 1 degrees of freedom.

The transformation described above is graphically depicted in figure 3-8.

From the above discussion, the following conclusion can be made. The amount of labor associated with TFC activities is highly correlated to and can serve as a proxy to TFC operating costs. This variable is likely to depend on transit demand (ridership), TFC technology used, and transit technology (mode) (see figure 3-9). The above proposition is divided into three individual hypotheses formulated in the following sections.

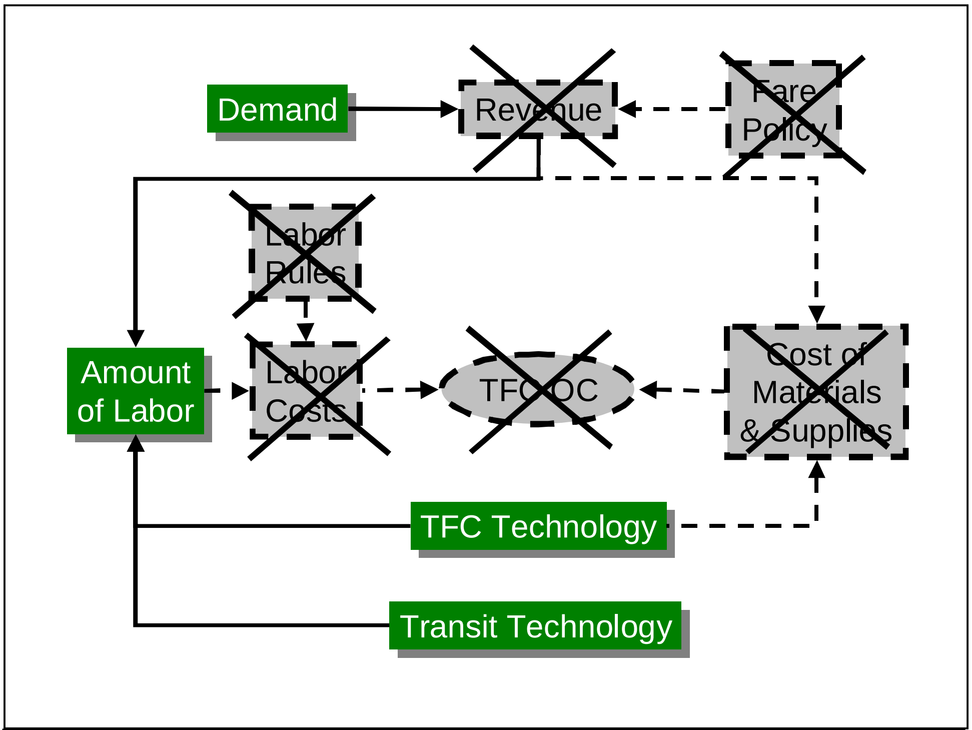

Figure 3-8. Factors affecting labor intensiveness of TFC operations (simplified 1).

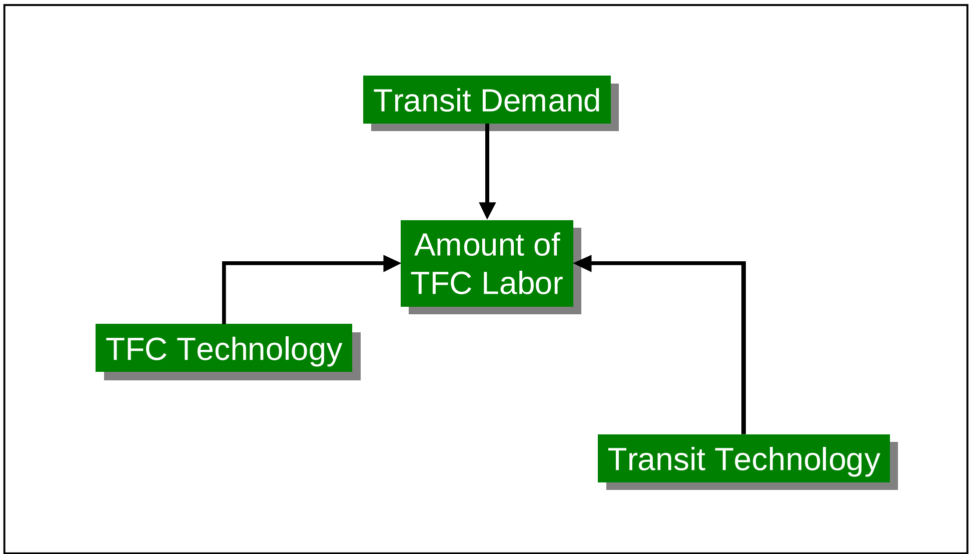

Figure 3-9. Factors affecting labor intensiveness of TFC operations (simplified 2).

3.2.2.2 Hypothesis 1: TFC Operating Costs are a Function of Transit Demand

The first hypothesis to be investigated in this dissertation is that TFC operating costs are a function of transit demand.

$$y_1 = b_0 + b_1 x_1 \quad [3.5]$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership).

The null hypothesis to be tested is H_0: $b_1 = 0$, and the alternative hypothesis is H_A: $b_1 \neq 0$.

It is logical to expect that one of the most important factors (if not the most important factor) affecting the costs of fare collection on transit would be the number of transit riders who pay fares.

3.2.2.3 Hypothesis 2: TFC Operating Costs are a Function of Transit Demand and Transit Technology (Mode)

Another hypothesis to be tested in this dissertation is that in addition to transit demand, the transit technology (mode) is also a factor that affects TFC operating costs.

$$y_1 = b_0 + b_1 x_1 + b_2 x_2 \quad [3.6]$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode).

The null hypothesis to be tested in this case is H_0: $b_i = 0$, for i = 1, 2 and the alternative hypothesis is H_A: $b_i \neq 0$.

3.2.2.4 Hypothesis 3: TFC Operating Costs are a Function of Transit Demand, Transit Technology (Mode), and TFC Technology

The formulation of hypotheses relating TFC operating costs to transit demand and transit technology (mode) was relatively simple and straightforward since there is a well-defined and commonly accepted measure for transit demand and a well-defined and commonly accepted classification of transit technology (mode). It is more difficult, however, to formulate a hypothesis relating TFC operating costs to the TFC technology since there is no common classification of TFC technologies available to researchers at this time.

To overcome this problem, the author suggested a TFC technology classification scheme, which is presented in Section 2.3 of Literature Review and Section 3.1.3 of this chapter. However, another challenge, associated with a formulation of the given hypothesis, is how to examine the effect of individual technologies comprising a TFC system on TFC operating costs.

As suggested in Section 3.1.3, there are four major determinants of a TFC system: payment media, fare media, TFC equipment, and transit technology. Beside the transit technology, which specifies a single transit mode environment for a given TFC system, each of the other three determinants may contribute more than one TFC technology to the composition of a TFC system. For example, a particular heavy rail TFC system, may accept cash, checks, and credit cards as valid payment media; feature coins, tokens, and magnetic-stripe cards as valid fare media, and; provide different kinds of fare media distribution, validation, and collection equipment.

One way to deal with this challenge would be to try to formulate a hypothesis relating TFC operating costs to a set of individual TFC technologies comprising a TFC system, each represented as a separate variable in the equation. For example, a hypothesis relating TFC operating costs to individual TFC technologies can be stated in the following form:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \ldots + b_ix_i \qquad \textbf{[3.7]}$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = checks are accepted as payment media (yes/no);

x_4 = tokens are used as fare media (yes/no);

x_i = ticket vending machines are used to sell tickets (yes/no).

The null hypothesis to be tested in this case is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$.

Unfortunately, the problem with such a formulation of a hypothesis is the difficulty to isolate and trace the effect of each individual TFC technology on TFC operating costs. Although it could be possible to observe some expected correlation between TFC operating costs and individual TFC technologies, it is likely to be very difficult, if not impossible, to find enough statistical evidence to reject the null hypothesis and support the alternative hypothesis for each individual variable.

Another way to formulate a hypothesis relating TFC OC to TFC technology is to map all existing sets of TFC technologies and investigate how a particular combination of TFC technologies affects TFC operating costs. This hypothesis could be described in the following way:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + \ldots + b_ix_i \qquad \textbf{[3.8]}$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC technology set 1 (yes/no);

x_4 = TFC technology set 2 (yes/no);

x_i = TFC technology set i (yes/no);

The null hypothesis to be tested in this case is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$.

However, this approach might also not be suitable since it may require a very large sample size (due to the need to have at least several independent observations for each unique set of TFC technologies) and a clear rationale explaining why one set of TFC technologies has a different effect on TFC operating costs than another.

To overcome the shortcomings and limitations of the two approaches discussed above, the author proposes the concept of a TFC System Technology Index that assigns a numeric value to any transit TFC system based on the qualities of TFC technologies that comprise the TFC system.

Since different TFC systems can be generally described in terms of payment media, fare media, and TFC equipment, these groups of TFC technologies can serve as scales for mapping a certain quality of an individual TFC technology. For example, a particular payment medium can be assigned a certain score based on the cost associated with processing a payment transaction made by this medium. If a cash payment transaction is given a score of 1.0, then a similar payment transaction made by check may have a score of 0.7 and a transaction made by credit card may have a score of 0.3. In a similar fashion, numeric scores can be assigned to different types of fare media and TFC equipment depending on the level of automation, reliability, or some other quality associated with these TFC technologies (see figure 3-10).

The relative impacts of individual TFC technologies on TFC system performance within their groups can be approximated based on the extent of the actual utilization of these technologies on a given TFC system. Thus, if a transit system accepts cash, checks, and credit cards for a purchase of its fare media, and if it is known that 60 percent of all fare media purchases are made with cash, 10 percent with checks, and 30 percent with credit cards, then these percentage values can be used to approximate the relative impact coefficient (weight) of each technology on a certain aspect of TFC system performance.

As mentioned before, it may be difficult to examine the overall impact of an individual TFC technology on TFC operating costs or another aspect of TFC system performance. However, it should be less difficult to trace the effect of a group of similar TFC technologies such as payment media, fare media, and TFC equipment and then draw conclusions about the effect of individual TFC technologies.

The impact of a group of similar TFC technologies on TFC operating costs can be assessed as a sum of products of scores and weights associated with individual TFC technologies within their group. This notion can be expressed mathematically in the

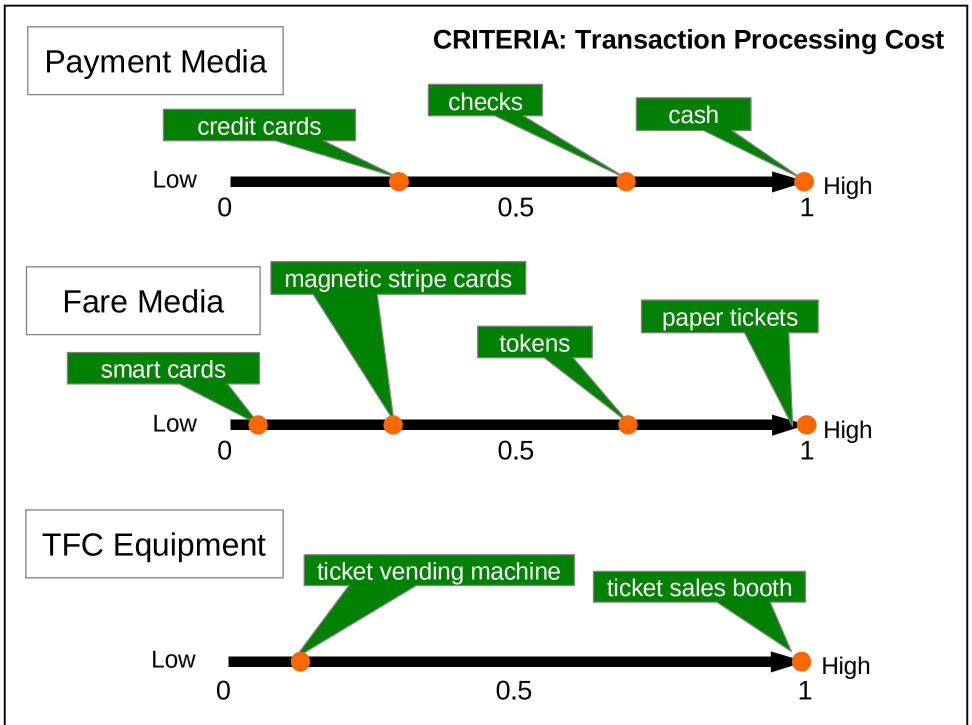

Figure 3-10. Example of rating certain TFC technology performance characteristics.

following form:

$$\boldsymbol{TFC\ TG = w_1 * t_1 + w_2 * t_2 + \ldots + w_i * t_i} \quad \textbf{[3.10]}$$

where,

TFC TG = TFC technology group (i.e. payment media, fare media, or TFC equipment) score;

t_1, t_2, …,t_i = individual technology scores;

w_1, w_2, …,w_i = relative impact coefficients (weights) of individual TFC technologies within their group.

Then, the hypothesis relating TFC operating costs to TFC technologies can be expressed in the following form:

$$\boldsymbol{y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5} \quad \textbf{[3.11]}$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = payment media TFC technology group score;

x_4 = fare media TFC technology group score;

x_5 = TFC equipment TFC technology group score.

The null hypothesis to be tested is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$.

Furthermore, TFC technology group scores associated with their TFC system can be added together to represent a TFC System Technology Index (TFCSTI). Each TFC technology group can be assigned a weight to gauge the relative impact of this TFC technology group on TFC operating costs or another aspect of TFC system performance. For instance, if the total effect of TFC system technologies on TFC operating costs constitutes 100 percent, then the effect of the payment media, fare media, and TFC equipment TFC technology groups may be 30, 50, and 20 percent correspondingly. The relative impact coefficients (weights) associated with TFC technology groups may depend on various factors such as the size and complexity of the TFC system and can be assessed empirically.

Ultimately, each TFC system can be given a certain score depending on the ratings of its component technologies and mapped on a TFCSTI scale. The TFC System Technology Index may compare TFC systems in terms of their level of automation, reliability, security, convenience, etc., and can be expressed mathematically in the following form:

$$TFCSTI = w_1 * PM + w_2 * FM + w_3 * EQ \quad [3.12]$$

where,

TFCSTI = TFC System Technology Index;

PM = payment media TFC technology group score;

FM = fare media TFC technology group score;

EQ = TFC equipment TFC technology group score;

w_1, w_2, w_3 = coefficients (weights) reflecting the relative impact of fare media, payment media, and TFC equipment on a certain aspect of a TFC system performance.

Then, the hypothesis relating TFC operating costs to the TFC System Technology Index can be presented in the following form:

$$y_1 = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 \quad [3.13]$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC System Technology Index.

The null hypothesis to be tested is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$.

This section concludes the discussion of methodology used in this dissertation research. However, some specific techniques developed to test the hypotheses formulated above are described and discussed in Section 4.3 Data Analysis.

3.3 DEVELOPMENT OF EVALUATION PLAN

This section presents a plan to evaluate alternative TFC systems. First, the performance measures to be used to compare TFC system alternatives are identified and selected.

Following that is a discussion and selection of analytical methods and techniques to examine performance of alternative TFC systems. In conclusion, the author outlines data requirements, identifies available data sources, and selects a primary data source to conduct the selected analyses.

3.3.1 TFC system performance measures

As formulated during the development of the evaluation framework, the single objective in the evaluation of alternative TFC technologies, for the purposes of this research, is assumed to be minimization of TFC operating costs as viewed from a transit operator's standpoint (see section 3.1.2). Furthermore, as stated in the previous section, the general theory investigated in this research is that TFC operating costs are related to transit system demand, TFC and transit system technologies, labor rules, and fare policy (see equations 3-1 and 3-2). It is also stressed that while it is important to identify all factors affecting TFC operating costs, the focus of this research is the effect of TFC technologies on TFC operating costs.

In the following sections, an attempt is made to develop several TFC system performance measures to facilitate the evaluation of TFC technologies with respect to TFC operating costs.

3.3.1.1 Cost Effectiveness of TFC System

One of the most common economic measures used to compare alternative systems, projects, and investments is cost effectiveness. Cost effectiveness is a measure that describes how different system inputs (expressed in monetary terms) affect the consumption of a particular service. In transit environment, cost effectiveness and cost efficiency are among the most important transit system performance measures.

In order to develop a measure of TFC system cost effectiveness, TFC system inputs and outputs should be identified and expressed in terms of costs and consumption.

As pointed out during the discussion of the research methodology in Section 3.2, TFC system inputs include primarily labor, materials, and supplies necessary for TFC system operations. These inputs can be accounted in both monetary and non-monetary terms. Referred to as Labor (501), Fringe Benefit (502), and Materials and Supplies (504) expenses in the Uniform System of Accounts, these inputs represent, more than 98 percent of all TFC system inputs expressed in monetary terms (i.e. TFC operating costs).

Since the main purpose of ticketing and fare collection is to facilitate payment for consuming transit services, the transit service consumption and the TFC system service consumption can be expressed in similar terms, most conveniently, in terms of ridership. Some difference between transit service consumption and TFC system service consumption may come from the fact that certain categories of transit riders (e.g. young children) may be considered as consumers of transit services but may not be subject to fare payment and, thus, not be accounted in TFC system service consumption.

Thus, TFC system service consumption can be assessed in terms of transit demand and measured in unlinked passenger trips. It can also be assessed in terms of amount of passenger fare revenues collected and measured in dollars of PFR.

Consequently, the measure of TFC system cost effectiveness can be formulated as either TFC operating costs per unlinked passenger trip (TFCOC/UPT) or TFC operating costs per unit of passenger fare revenues (TFCOC/PFR). The TFCOC/UPT reflects the average cost of processing a fare payment transaction whereas the TFCOC/PFR shows the average cost of processing a unit of passenger fare revenues.

3.3.1.2 Labor Intensiveness of TFC Operations

Another way to compare alternative TFC systems is to evaluate labor intensiveness associated with TFC operations. As opposed to cost effectiveness, labor intensiveness assesses the amount of labor required to satisfy the demand for a particular service.

Although both cost effectiveness and labor intensiveness relate service inputs to service consumption, there are some differences between these two measures. First, labor intensiveness excludes service inputs other than labor from the analysis. Second, this measure ignores the differences in the cost of labor associated with such factors as location of the employer, level of education required from employees, and other.

The amount of labor associated with TFC system operations can be measured in TFC employee work hours. TFC system service consumption can be measured in the same terms for both cost effectiveness and labor intensiveness, i.e. in unlinked passenger trips and passenger fare revenues.

The measure of TFC system labor intensiveness can be formulated as either the amount of TFC employee work hours per unlinked passenger trip (EWH/UPT) or the amount of TFC employee work hours per unit of passenger fare revenues (EWH/PFR). The EWH/UPT reflects the productivity of processing a fare payment transaction whereas the EWH/PFR shows the productivity of processing a unit of passenger fare revenues.

With respect to evaluating TFC system alternatives, labor intensiveness has some advantages and disadvantages as compared to cost effectiveness. The measure of labor intensiveness allows the researcher to exclude the effect of differences in wage rates and fringe benefits from the analysis of TFC system performance. However, the exclusion of wage rate information and the costs of materials and supplies associated with different TFC systems from the analysis may distort the evaluation results since these factors may be correlated to some degree with the type of TFC technology and other variables.

Finally, figure 3-11 lists the TFC system performance measures suitable for the analysis conducted in this dissertation and depicts the relationship among these measures.

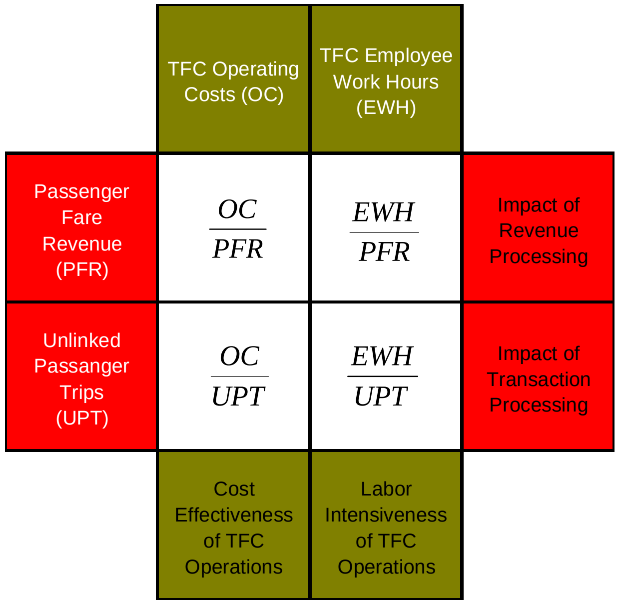

Figure 3-11. TFC system performance measures.

3.3.2 Analytical methods/techniques

To investigate the hypotheses that TFC operating costs are related to transit system demand, transit system technology (mode), and TFC system technology, two types of statistical analyses will be performed. It is proposed that a preliminary analysis of data should be conducted to check the validity and reasonableness of data in the sample and to assess if there is some relationship between variables. Following that, simple and multiple regression analyses will be conducted to enable testing of hypotheses formulated for this research.

3.3.2.1 Preliminary Data Analysis

Before analyzing and interpreting particular data, it is first necessary to check the validity and reasonableness of these data. It is also desirable to obtain a general idea about how the data is distributed and to compute a few objectively determined values regarding the data set that can be easily interpreted and manipulated.

Consequently, the first step in the preliminary data analysis will be computation of common measures of data central location and relative standing. The measure of central location computed will be the median value of the data set and will help to answer the question where the approximate center of the data set is. The measures of relative standing will include the minimum, maximum, first quartile, third quartile, and interquarter range of the data set and will help to answer the question whether the observations are close to one another or widely dispersed.

The next task in the preliminary data analysis will be to assess if there is some relationship between data sets representing different variables. To do this, correlation analyses will be performed and scatter diagrams will be constructed.

Since the coefficient of determination (R-squared) used in the regression analysis is the coefficient of correlation squared, the correlation analysis should give a general outlook of whether the regression analysis will yield meaningful results. As for scatter diagrams, they should help in determining whether some relationship between the two variables exists, whether the relationship is positive or negative, and whether the relationship appears to be linear or non-linear. Scatter diagrams should also help to identify outliers and influential observations in the data sets, and may provide further clues regarding whether these observations should be included into the data set.

3.3.2.2 Regression analysis

Following the preliminary data analyses, regression analyses will be employed to examine the validity of the relationships among variables described in the hypotheses formulated in Section 3.2.2. Unlike the correlation analysis, which only helps to determine whether a relationship between two variables exists and how strong the relationship is, the regression analysis facilitates the development of a mathematical model that accurately describes the nature of the relationship between the dependent variable and independent variables. It also helps in assessing and testing how well the model fits the actual data.

Although the relationship between the dependent variable and independent variables may be described in different ways (i.e. linear, polynomial, first-order, second-order, logarithmic, etc.), in this research only first-order linear models will be considered.

$$y = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_i x_i$$

where,

y = dependent variable;

x_i = independent variables;

b_i = coefficients of the linear model.

Therefore, to define the relationship between the dependent variable and independent variables, the value of coefficients b_i of the linear model needs to be determined.

Once the coefficients of the linear model are determined, the overall utility of the model will be assessed based on the results of t-tests for each of the coefficients and the value of the coefficient of determination (R-squared). While the t-test of the linear model coefficients addresses the question of whether there is enough evidence to infer that a linear relationship exists, the coefficient of determination helps to measure the strength of that linear relationship. Unlike the value of the t-test, the coefficient of determination does not have a critical cut-off value. The higher the value of the coefficient of determination, the better the model fits the data. Generally, as the model is improved, the value of the coefficient of determination increases.

3.3.3 Data Requirements

Once the performance measures and analytical methods for the evaluation plan and data analysis are selected, the requirements of the data and data collection can be stipulated. The main questions regarding data requirements that need to be addressed include the quality of the data to be used in the analysis, type of data, and sample size requirements.

3.3.3.1 Quality of Data

Since the validity of the results of a statistical analysis depends on the reliability and accuracy of the data used, the data quality is a key issue that should be clarified before data acquisition. Two types of error may occur when a sample of observations is drawn from a population: sampling error and nonsampling error.

Sampling error is caused by the difference between the sample and population and exists only because of the observations that happened to be selected for the sample. This type of error is expected to occur when the conclusion regarding the population is drawn from the analysis of a sample taken from the population. The sampling error can be reduced by increasing the sample size. On the other hand, nonsampling error does not diminish with a larger sample size and is due to mistakes made in the selection of the sample and data acquisition.

Nonsampling errors include errors in data acquisition, nonresponse bias, and selection bias. Errors in data acquisition may be caused by incorrect measurements, mistakes made during data recording, and mistakes due to misinterpretation of terms. Nonresponse bias is introduced when observations are not recorded for some members of the sample. Finally, the selection bias is introduced when the designed sampling plan precludes some members of the target population from being selected into the sample.

3.3.3.2 Types of Data

The analytical methods selected during the previous step of the evaluation plan development set certain requirements regarding the type of data analyzed. Being the primary analytical method to test the formulated hypotheses, the regression analysis permits the use of both quantitative and qualitative data.

The values of the TFC expense, amount of TFC labor, and transit demand variables are examples of the quantitative data that will be used in regression analyses. These values are real numbers and arithmetic calculations and manipulations can be performed with these values.

The other type of data that will be used in the analyses is qualitative (categorical) data. For this type of data, the values are arbitrarily assigned to different categories. For example, the mode of transit service represents categorical data. In order to be used in regression analyses, the values of qualitative data will be transformed to satisfy the requirements of indicator (dummy) variables. These variables will assume either "0" or "1" values where "1" represents the existence of a certain condition and "0" indicates the absence of the same condition.

Furthermore, the data used for the analyses specified above can also be categorized as cross-sectional data and time-series data. Cross-sectional data refers to the observations that are measured at the same time. Data reported by various transit agencies to the National Transit Database for a particular year is an example of cross-sectional data that will be employed in this research. On the other hand, time-series data relates to the observations about a certain subject that are recorded at successive points in time. The data submitted by a certain transit agency to the National Transit Database over several years represent time-series data that will be used in this research.

Regarding the sample size, the procedure that takes into account the desired confidence level and the bound of error of estimation will be followed to the extent possible. According to this procedure, the sample size needed to estimate a certain parameter of the variable is directly related to the standard deviation of the sample and desired confidence level and inversely related to the bound of the error of estimation and can be computed using the following formula:

$$n = \left(\frac{z_{a/2} * \sigma}{B} \right)^2,$$

where

$z_{a/2}$ = desired confidence level;

σ = standard deviation of the sample;

B = bound of the error of estimation.

However, the author realizes that the final selection of the data set for the analyses will depend heavily on the availability of the data, data quality, and other conditions.

3.3.4 Data Sources

As discussed in Section 2.2.1 of the Literature Review, the major sources of transit cost information available to researchers and planners include transit properties' budgets, NTD and APTA peer property data, and peer property cost models. It is also acknowledged that while transit properties' budget may provide a fine level of detail of cost and operational data, the data-reporting format and terminology may differ significantly from one transit agency to another. Peer property cost models, on the other hand, provide, in general, little detail and usually incorporate assumptions applicable to a particular transit agency only. On this basis, the author concludes that the primary source of data for this research will be acquired from the annual National Transit Database and APTA Transit Fare Summary reports.

Although NTD and APTA reports will serve as primary sources of information for this research, the composition of the final database employed for testing the hypotheses formulated above will be complemented by the results of a questionnaire designed to validate the accuracy of data found in NTD and APTA reports and sent out to selected transit agencies. The design of this questionnaire as well as well as the replies received from the transit properties are discussed in the following chapter.

CHAPTER 4: DATA ANALYSIS

This chapter addresses the second objective of the research and presents an analysis of TFC operating costs on heavy rail and bus transit systems in the U.S. This analysis builds upon the research methodology and evaluation plan presented in Chapter 3 of this dissertation report and focuses on testing the hypotheses formulated in Section 3-2.

The chapter begins with a discussion of decision factors for a preliminary selection of transit systems to include in the analysis. The factors such as data availability, transit system size, and mode of transit are considered in Section 4.1.

Following that, there is a description of NTD and APTA databases, their structure, terminology, and organization. An approach toward the final selection of transit agencies and decision variables, the composition of the final database, and data validation and verification approaches are described in Section 4.2.

Finally, Section 4.3 presents the testing of the hypotheses formulated in the previous chapter. For each hypothesis, a preliminary analysis of data and regression analysis are conducted. Preliminary analyses may include examination of descriptive statistics and scatter diagrams whereas regression analyses cover discussion of t-statistic and coefficient of determination.

4.1 PRELIMINARY SELECTION OF TRANSIT SYSTEMS FOR ANALYSIS

According to the American Public Transportation Association (APTA, 1999), in 1999 some 587 transit systems representing 15 transit modes in the U.S. reported their operational and financial data to the National Transit Database. As described in Section 2.2.1.2 of the Literature Review, NTD is the largest and most comprehensive source of transit information in the U.S. It is produced by the FTA and designed to provide transit financial and operating data for public transit operators, Federal, state, and local governments, and the public.

Although it was the author’s intention to include in the analysis presented in this research as many transit systems as possible, several factors affected the scope of the analysis and warranted a preliminary selection of transit systems for the analysis.

As stated in the general theory underlying this research (see Section 3.2.1), TFC operating costs on public transit are related to transit system demand, TFC and transit system technologies, labor rules, and fare policy. Furthermore, the hypotheses investigated in this research shift the focus of the research on the effect on transit demand, transit technology (mode), and TFC technologies only. As a result, the transit systems considered for the analysis needed to have: (a) information on their TFC systems and TFC system operating budgets reported, (b) represent a transit mode whose effect on TFC operating costs would be significantly different from those of other modes, and (c) have the level of demand for their services comparable to that of other transit systems selected for the analysis. In summary, the four factors that the author used for a preliminary selection of transit systems for the analysis were: 1) transit mode, 2) certain level of transit demand, 3) availability of information on a transit agency's TFC system operating budget (as reported to NTD by some agencies on an optional basis), and 4) availability of information describing a transit agency's TFC system (as reported to APTA and published in annual Transit Fare Summaries).

The transit mode was the first factor that the author used for selecting transit systems for the analysis. The reason for excluding the systems representing some transit modes from the analysis is that the fare collection practices on these modes are either relatively similar to those of other modes or are not clearly defined as a separate function of transit operations. Also, the transit modes that are represented by only few systems in the U.S. were excluded from the analysis. The following 6 modes were excluded from the analysis primarily because there are only few systems representing these modes in the U.S.: automated guideway, cable car, ferry boat, inclined plane, monorail, and aerial tramway. Vanpool, jitney, and publico modes were excluded from the analysis primarily because fare collection activities on these modes are not clearly defined or set aside as a separate function of transit operations. Demand response and trolleybus systems were excluded from the analysis primarily because fare collection activities on these systems tend to be similar to those on motorbus systems although somewhat different. The remaining four modes—motorbus, heavy rail, light rail, and commuter rail—have unique to these modes approaches toward fare collection (i.e. pay-on-entry for motorbus; barrier for heavy rail; proof-of-payment for light rail; and conductor assisted, pay-on-train for commuter rail) and were selected for the analysis.

The second factor that the author used for selecting transit systems for the analysis was the level of transit demand. Particularly, small transit systems that operate less than 10 vehicles or have demand of less than 1,000,000 unlinked passenger trips per year were excluded from the analysis. This was done because of the concern that these systems might perform fare collection activities in a fashion very different from that of bigger systems of a given mode. For example, many fare collection activities that are typically performed by designated TFC stuff on medium and large motorbus systems, on small transit systems might be performed by vehicle operators and might be accounted under different categories of expense. This limitation applied primarily to motorbus systems since no heavy rail systems and very few light rail and commuter rail systems have annual demand of less than 1,000,000 unlinked passenger trips.

Finally, the last two factors that the author considered during the preliminary selection of transit systems for the analysis were the availability of information on a transit agency's TFC system operating budget (which is reported to NTD on a voluntary basis) and availability of information describing a transit agency's TFC system. As it turned out, only 3 commuter rail, 5 light rail, 9 heavy rail, and about 50 motorbus systems with an annual demand of 1,000,000 UPT reported their annual TFC operating costs or TFC employee work hours for a period from 1993 to 1998. Because of the limited number of commuter rail and light rail systems reporting their TFC operating statistics, the author decided to exclude these two modes from the analysis and examine the formulated hypotheses with the data on heavy rail and motorbus systems only. However, the author believes that limiting the scope of the analysis to motorbus and heavy rail modes only should not affect the significance of the results since these two modes generated about 90 percent of transit UPT in the U.S. during the last decade (see figure 4-1).

4.2 ASSEMBLING AND VERIFYING DATA

As specified in the development of the evaluation plan (see Section 3.3.4), the primary sources of data to investigate the hypotheses relating TFC operating costs to transit demand, transit technology (mode), and TFC technology include annual National Transit Database reports and APTA Transit Fare Summaries. In the following sections, a general description of the structure and content of these data sources as well as a description of the data extracted from these sources for the purposes of this research are presented.

4.2.1 National Transit Database

One way to describe the structure and content of the National Transit Database is to associate the data it consists of with basic categories that characterize a transit agency. The NTD data can be grouped into four major categories: resources, inputs, organization, and outputs (FTA, 1997).

In this categorization scheme, resources represent fares, other earnings, and subsidies that are expended to purchase inputs consisting of labor, fuel, materials, and capital equipment. Transit organization’s managerial processes denoted as “organization” category link the inputs and outputs. Management makes decisions how to utilize different resources to accomplish the objectives of the transit organization and produce certain outputs. These decisions may relate to investment and purchasing strategies, technology selection, adding or eliminating service, or contracting for service. Finally,

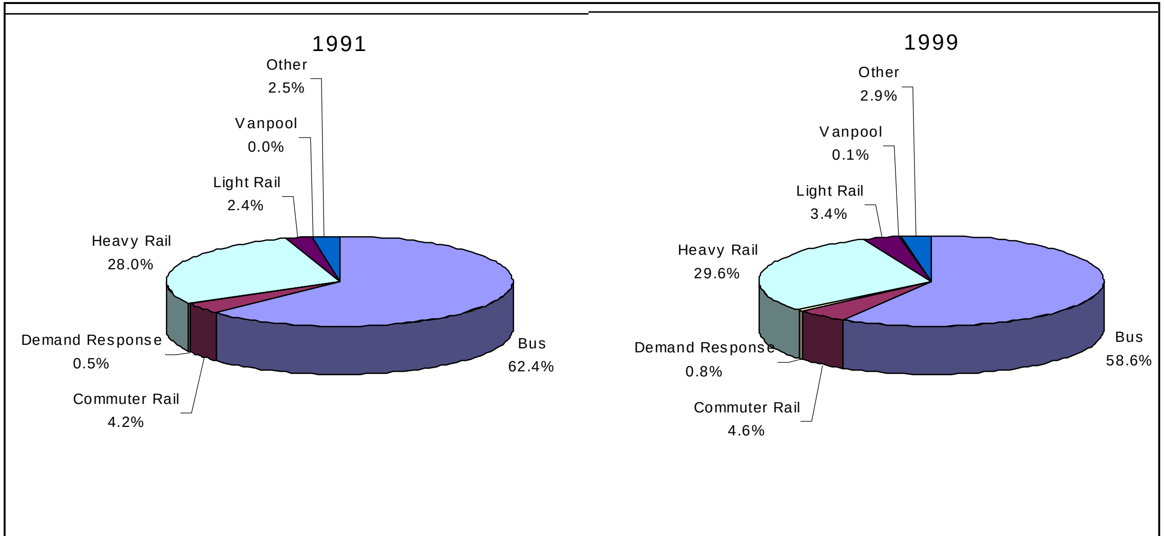

Figure 4-1. Breakdown of transit ridership in the U.S. by mode (APTA, 2001).

transit outputs involve the service delivered to the public and can be measured in terms of service supplied and service consumed (FTA, 1997).

According to this categorization scheme, NTD data items can be grouped in the following manner:

a) Resources: fares, charters, advertising, concessions, subsidies (for capital or operating expenses);

b) Inputs: labor year equivalents, salaries and wages, energy units consumed, energy costs, depreciation, balance sheet, fleet inventories, infrastructure;

c) Organization: contracting, service by time-of-day, labor functional structure, operators' time, fringe benefits, pensions;

d) Outputs: vehicle and vehicle revenue miles and hours, capacity miles, unlinked passenger trips, passenger miles, accidents, road calls, scheduled versus actual revenues miles (FTA, 1997).

The actual NTD reports consist of a series of forms that provide a summary of the reporting transit system's characteristics for a particular fiscal year. These forms include financial and non-financial operating statistics for all services that the reporting transit system provides. The forms are grouped into the following six categories:

a) The Basic Information Forms (000's) detail a basic transit agency profile;

b) The Capital Funding Form (103) specifies the origin, amount, and uses of a transit agency's capital funding;

c) The Operating Funding Form (203) presents information on the origin and amount of operating funding and passenger fare revenues earned during the reporting year;

d) The Operating Expenses Forms (300's) detail operating expenses by function;

e) The Non-Financial Operating Data Forms (400's) report various operating data such as service levels, maintenance, safety and security, vehicle inventories, and employee work hours; and

f) The Federal Funding Allocation Statistics Form (901) (FTA, 1999).

A detailed description of all NTD reporting forms as well as data items consisted in these forms goes far beyond the scope of this section. Therefore, only the variables and data items pertaining to the analysis conducted in this research are discussed below.

4.2.1.1 NTD Reporting Terminology

A good understanding of NTD terms is critical to the proper analysis of NTD data and interpretation of its results. In this section of the dissertation report, several NTD terms and parameters relating to the matter of this research are defined and explained. These terms include: public transportation, transit technology (mode), transit ID, type of transit service, unlinked passenger trips, passenger fare revenues, TFC operating costs, and TFC employee work hours.

Public transportation (also synonymous with the terms mass transportation and transit) is transportation by bus, rail, or other conveyance, either publicly or privately owned, that provides regular and continuing general or special service to the public (FTA, 1999).

Transit mode describes a type of transit technology and can be grouped into two broad categories—rail and non-rail. Rail modes include automated guideway, cable car, commuter rail, heavy rail, inclined plane, light rail, and monorail. Non-rail modes include motorbus, demand response, ferryboat, jitney, bus, publico, trolleybus, aerial tramway, vanpool, and other (FTA, 1999). In this research, only heavy rail and motorbus modes are investigated.

Transit ID is a unique NTD identification number assigned to all participating transit agencies. A transit agency operating different modes of transit would have a single transit ID but would report operating and financial statistics separately for each mode.

Type of service relates to the way in which public transportation is provided. A transit agency provides a directly operated service if it uses its own employees to operate the transit vehicles and deliver the transit service. A transit agency provides a purchased transportation service if it contracts with a public or private provider to operate the transit vehicles and deliver the transit service (FTA, 1999). In this research, only directly operated transit services are investigated.

Unlinked passenger trips are a measure of the amount of transit service consumed by passengers counted as the number of passengers who board public transportation vehicles. A new unlinked passenger trip is counted each time a passenger boards the vehicle even though the passenger may be on the same journey from origin to destination (FTA, 1999).

Passenger fare revenue is a measure of the revenue earned from carrying passengers in regularly scheduled and demand response services. It includes the base fare, zone premiums, express service premiums, transfers, and discounts applicable to the passenger's ride. Types of passenger fares include full adult fares, senior citizen fares, student fares, park and ride, and special ride fares (FTA, 1999).

Ticketing and fare collection operating costs are the expenses associated with the activities relating to fare collection and counting including supervision and clerical support. Ticketing and fare collection includes printing, distributing, selling and controlling of fare media; pulling and transporting vaults to counting facilities; counting and auditing of fare collection; and, providing security for the fare collection process (FTA, 1999).

Ticketing and fare collection employee work hours are the labor hours of transit agency's TFC employees, both full-time and part-time, permanent and temporary. TFC EWH do not include fringe benefit hours such as sick leave, holidays, or vacations (FTA, 1999).

4.2.1.2 Variables Selected for the Analysis

As discussed in Section 3.2 and Section 3.3, the data required to test hypotheses 1, 2, and 3 as well as the data needed for computation of TFC system performance measures include the following: annual TFC operating costs, annual TFC labor, annual transit demand, annual revenues, type of transit technology (mode), and type of TFC system technology. Except for the type of TFC technology data, the data items required for the analyses performed in this dissertation can be found in the National Transit Database electronic files available to the public in ASCII (American Standard Code for Information Interchange) format. These files contain the original data from all NTD reporting forms submitted by participating transit agencies and can be obtained from:

The National Transit Database Program, DTS-49
U.S. DOT
The Volpe National Transportation Systems Center
Kendall Square
Cambridge, MA 02142

The data used by the author in this research was extracted from the original NTD ASCII files for six years from 1993 through 1998. The data items extracted included the following: transit ID, transit mode, type of transit service, transit agency name, fiscal year, passenger fare revenues, TFC operating costs (expenses), TFC employee work hours, and unlinked passenger trips. The location of these data within the National Transit Database is discussed in the following paragraphs while definitions of these terms are given in Section 4.2.1.1.

Transit ID, transit mode, and type of transit service are the key identifiers of the data entries in the National Transit Database. These identifiers are attached to all data entries reported on different NTD forms and help to track an agency's statistics throughout different subsets of the database. In case a reported statistic applies to all types of transit agency's services and modes, only the agency's transit ID is used to identify the data.

Transit agency name and the fiscal year of the report can be found on the NTD's Transit Agency Identification Form (001). As mentioned above, NTD data are grouped by a reporting form (each form representing a separate database containing certain data on all reporting transit agencies) and all reporting forms are batched for a particular reporting year. Thus, the first database in the batch (Form 001) provides basic organizational and transit service information about transit agencies (FTA, 1999). Since each agency reporting to NTD has its unique transit ID, a transit agency statistics can be easily traced throughout the remaining forms without a direct reference to the transit agency name.

Similarly, the fiscal year of a particular statistic reported can be easily traced throughout the remaining forms because it is closely associated with the report preparation date shown in all NTD forms.

Passenger fare revenues are reported on the Operating Funding Form (203). The purpose of this form is to identify the origin and amount of operating funds that transit agencies receive from different sources and apply to pay for operating expenses. Reporting passenger fare information by mode and type of service on this form is optional (FTA, 1999); consequently, the agencies operating several modes while reporting a single agency-wide passenger fare revenue statistic were either excluded from the analysis or further queried for disaggregate data.

TFC operating costs (expenses) are reported on the Operating Expenses Form (301). This form details operating expenses for each object class by function and allocates direct and joint expenses to modes by type of service (see Section 2.2.4 of Literature Review for discussion of expense functions and object classes). Reporting Ticketing and Fare Collection (151) expenses is optional (FTA, 1999); consequently, only the agencies reporting this statistic were selected for the analysis.

TFC employee work hours are reported on the Transit Agency Employee Form (404). This form details the number of employees and hours worked by labor classification for employees of the transit agency. The agencies are required to report the totals for operating and capital labor only. Categorization of the number of employees and hours worked by expense functions is optional (FTA, 1999); consequently, only the agencies reporting TFC employee work hours were selected for the analysis.

Unlinked passenger trips are reported on the Transit Agency Service Form (406). This form reports transit service characteristics such as the number of vehicles in maximum service, times of service, service supplied and consumed, and days operated. This form is required for all transit agencies and the data is separated by type of transit service and mode (FTA, 1999).

4.2.2 APTA Transit Fare Summaries

The American Public Transportation Association (APTA) is an international organization that has been representing the transit industry for over 100 years. APTA provides a wide range of services to its members as well as other transit industry organizations, government, and the public. One of APTA's primary duties is collection and dissemination of statistical information about different aspects of transit operations. APTA's Transit Fare Summaries published annually is the most comprehensive source of information about ticketing and fare collection practices on transit in the U.S. and Canada. In the following paragraphs, the structure of Transit Fare Summaries and the data from these reports used for the analysis conducted in this research are described.

4.2.2.1 Structure and Composition of APTA Transit Fare Summaries

Transit Fare Summaries consist of a number of information tables describing different aspects of ticketing and fare collection on transit in North America. The Transit Fare Summaries published in 1991, 1993, 1995, 1997, and 1998 present nearly 150 statistics relating to transit fares and fare collection organized in about 20 sections. The Transit Fare Summaries published in 1992, 1994, 1996, and 1998 are shortened reports covering about half of the statistics presented in odd-year reports. Although the presentation of information in Transit Fare Summaries has somewhat changed over the past decade, the content of the Summaries has not changed significantly.

Since the emphasis in the Transit Fare Summaries is on the fare structure, fare categories, and fare options, the content of the Summaries is organized around the types of fare structure and fare options available on different transit systems. Another way to summarize the content of the Transit Fare Summaries is to group the material into the following categories: fare structures, fare media, fare media distribution methods, payment media, fare collection equipment, and fare collection policies.

As stated earlier (see Section 3.3), the information required for the analysis conducted in this research includes the description of TFC technologies employed on different transit systems. Therefore, the Transit Fare Summaries were used as a primary source of data on payment media, fare media, fare media distribution methods, and fare collection equipment. The following section describes selected variables that were extracted from the Transit Fare Summaries for the purposes of this research.

4.2.2.2 Variables Selected for the Analysis

Four categories of data extracted from the Transit Fare Summaries for the purposes of this research describe payment media, fare media, fare media distribution methods, and fare collection equipment on different transit systems in the U.S. These data is collected and published biannually and can be found in 1991, 1993, 1995, 1997, and 1999 Transit Fare Summary reports that were available to the author at the time the research was conducted. Since the NTD data obtained by the author for the purposes of this research was from 1993 to 1998 years only (see Section 4.2.1.2), the Transit Fare Summary data used for this research was for 1993, 1995, 1997, and 1999. An assumption was made that changes in transit TFC systems from 1998 and 1999 were relatively small; thus, 1999 Transit Fare Summary data can be used to describe TFC systems in 1998. Ultimately, the author planned to use merged data from the National Transit Database and APTA's Transit Fare Summaries for 1993, 1995, 1997, and 1998 for the analysis conducted in this research.

The first category of data extracted from the Transit Fare Summaries was that relating to payment media. These data can be found in the section of the Transit Fare Summaries titled "Non-cash Fare Payment Methods". The variables extracted from the Summaries under this category are indicator variables that can assume either of only two values—"yes" (1) or "no" (0). These variables describe the following non-cash payment media accepted: (a) personal checks, (b) organizational checks, (c) credit cards, (d) ATM cards, (e) money orders, (f) federal benefit check, and (g) other.

The second category of data extracted from the Transit Fare Summaries was that relating to fare media. These data can be found in the section of the Transit Fare Summaries titled "Fare Media Available". The variables extracted from the Summaries under this category are indicator variables that can assume either of only two values—"yes" (1) or "no" (0). Also, the method of selling a particular fare medium was recorded as sold by either a machine or person. These variables describe the following fare media available: (a) tokens, (b) single-ride tickets, (c) multi-ride tear-off tickets, (d) punch cards, (e) non-magnetic passes, (f) magnetic stored-value cards, (g) magnetic stored-time passes, (h) computerized stored-value cards (smart cards), and (i) other.

The third category of data extracted from the Transit Fare Summaries was that relating to the venues of distributing transit fare media. These data can be found in the section of the Transit Fare Summaries titled "Where Fare Media May Be Obtained". The variables extracted from the Summaries under this category are indicator variables that can assume either of only two values—"yes" (1) or "no" (0). These variables describe the following venues of distributing transit fare media: (a) by mail, (b) at transit headquarters or transit divisions, (c) at information centers, (d) at parking or other outdoor sites, (e) at transportation terminals, (f) at government offices, (g) at commercial or service outlets, (h) non-government employment sites, and (i) on vehicles.

The fourth category of data extracted from the Transit Fare Summaries was that relating to the fare collection equipment used on transit systems. These data can be found in the section of the Transit Fare Summaries titled "Equipment Used". The variables extracted from the Summaries under this category are indicator variables that can assume either of only two values—"yes" (1) or "no" (0). These variables describe major types of TFC equipment used on transit systems and include the following: (a) mechanical fareboxes, (b) electronic fareboxes, (c) mechanical turnstiles, (d) electronic turnstiles, (e) transfer issuers, (f) change making machines, (g) cash-only vending machines, (h) credit card vending machines, (i) fare validation machines, (j) magnetic card coders, (k) magnetic card non-swipe readers, (l) magnetic card swipe readers, and (m) other fare-related equipment.

Since many variables mentioned above tend to be self-explanatory, APTA's definitions of these variables are omitted here. However, the reader can refer to Transit Fare Summaries for concise definitions of these variables provided by APTA.

4.2.3 Composition of Final Database

As discussed in Section 4.1, the preliminary selection of transit systems for the analysis presented in this research limited the number of transit modes analyzed to motorbus and heavy rail only. In addition, it was mentioned that transit systems with the annual level of demand of less than 1,000,000 UPT would also be excluded from the analysis and that the composition of the final sample of transit systems would be a subject to data availability.

Sections 4.2.1 and Section 4.2.2 provided an overview of NTD and APTA databases and description of selected variables in these databases that were of interest for this research. As noted in Section 4.2.1, the National Transit Database has two reporting levels: basic and optional. The basic level applies to all transit operators and specifies the minimum data that must be reported by all grant applicants and beneficiaries of Section 9 funds. The basic level structure is further expanded into detail for optional reporting.

Several financial and operating statistics that are of interest for this research (specifically TFC operating costs TFC employee work hours) are optional to report. Therefore, the availability of these data was another factor that affected the composition of the final database as described below.

4.2.3.1 Selection of Transit Agencies

As described in Section 4.1, the major factors that the author used for a preliminary selection of transit systems for the analysis were: 1) transit mode, 2) certain level of transit demand, 3) availability of information on a transit agency's TFC system operating budget, and 4) availability of information describing a transit agency's TFC system.

Furthermore, the author decided that only heavy rail and motorbus transit systems that operate more than 10 vehicles and have demand of more than 1,000,000 unlinked passenger trips per year would be included into the analysis. As it turned out to be, only 9 heavy rail and about 50 motorbus systems with the annual demand of 1,000,000 UPT reported their annual TFC operating costs or TFC employee work hours for a period from 1993 to 1998 and, thus, were pre-selected for the analysis.

However, to make the final selection of transit systems for the analysis the author applied another two filtering criteria to the data set.

The first filtering criterion was that a transit system's annual TFC operating costs should be greater than $40,000 and annual TFC employee work hours should be greater than 2,000 hours. Satisfaction of this criterion suggests that the transit agency's annual TFC operations involve at least the equivalent of one full-time employee. Table 4-1 presents a list of 9 heavy rail and 39 motorbus systems that passed this additional criterion.

The second filtering criterion was that a transit system should consistently report TFC operating costs and TFC employee work hours for 1993, 1995, 1997, and 1998 fiscal years in order to be selected for the analysis. As it turned out, less than a half of preliminary selected heavy rail and motorbus systems reported these two statistics for all four years specified.

Consequently, the author decided to prepare and send out a questionnaire to all transit systems listed in table 4-1 in order to verify the existing data extracted from NTD and APTA's Transit Fare Summaries and to complete the missing data. The author also decided to include into the questionnaire a request for some additional information relating to transit TFC systems. The design of the validation questionnaire and description of the resulting final database are presented in the following two sections.

4.2.3.2 Design of Validation Questionnaire

As mentioned above, the primary purpose of the validation questionnaire was to complete the missing TFC operating cost and TFC employee work hour data since these data were not consistently reported by the selected transit agencies for 1993, 1995, 1997, and 1998 fiscal years. Once the need for the missing data became apparent, and it was concluded that a telephone survey might not yield reliable results, the author decided to prepare a validation questionnaire that would ask each transit agency for: (a) reporting of missing data, (b) verification of all the data extracted from the National Transit Database and APTA Transit Fare Summaries and intended for the analysis in this research, and (c) provision of additional information relating to transit TFC systems.

For each transit agency, the questionnaire was designed as a set of tables filled with data extracted from the NTD and APTA reports where empty cells corresponded to missing data. Transit agencies were asked to verify the existing data and fill in the missing data for 1993, 1995, 1997, and 1998 fiscal years. The variables included into the questionnaire tables are the same as those described in Section 4.2.1.2 and Section 4.2.2.2. These variables are also summarized in table 4-2.

Another set of data tables was designed with the intent to seek additional information relating to transit TFC systems in a format facilitating the testing of hypotheses developed in Section 3.2.2.4. In this part of the questionnaire, the transit agencies were

Table 4-1. Transit systems selected for the mail survey.

Heavy Rail Systems		Motorbus Systems	
NTD ID		NTD ID	
2008	MTA New York City Transit	3019	Southeastern Pennsylvania Transportation Authority
2075	Port Authority Transit Corporation	3022	Port Authority of Allegheny County
2098	Port Authority of New York and New Jersey	3030	Washington Metropolitan Area Transit Authority
3019	Southeastern Pennsylvania Transportation Authority	3034	Mass Transit Administration of Maryland
3030	Washington Metropolitan Area Transit Authority	4004	Metropolitan Transit Authority
3034	Mass Transit Administration of Maryland	4022	Metropolitan Atlanta Rapid Transit Authority
4022	Metropolitan Atlanta Rapid Transit Authority	4034	Miami-Dade Transit Agency
4034	Miami-Dade Transit Agency	5008	Milwaukee County Transit System
9003	San Francisco Bay Area Rapid Transit District	5017	Miami Valley Regional Transit Authority
		5027	Metro Transit
Motorbus Systems		5033	Grand Rapids Area Transit Authority
NTD ID		5060	Champaign-Urbana Mass Transit District
0001	King County Department of Transportation	6008	Metropolitan Transit Authority of Harris County
0002	Spokane Transit Authority	6011	VIA Metropolitan Transit
0008	Tri-County Metropolitan Transportation District of Oregon	6019	City of Albuquerque Transit Department
0024	Clark County Public Transportation Benefit Area Authority	7005	Kansas City Area Transportation Authority
1001	Rhode Island Public Transit Authority	7006	Bi-State Development Agency
1048	Connecticut Transit	8001	Utah Transit Authority
1055	Connecticut Transit	8006	Regional Transportation District
2004	Niagara Frontier Transportation Authority	9009	San Mateo County Transit District
2008	MTA New York City Transit	9014	Alameda-Contra Costa Transit District
2018	CNY Centro	9015	San Francisco Municipal Railway
2113	Regional Transit Service	9019	Sacramento Regional Transit District
3005	Tidewater Transportation District Commission	9033	City of Tucson Mass Transit System
3006	Greater Richmond Transit Company	9154	Los Angeles County Metropolitan Transportation Authority
3018	Red Rose Transit Authority		

Table 4-2. NTD and APTA Fare Symmary variables included into the questionnaire.

NTD statistic	Where fare media may be obtained
Passenger Fare Revenues Earned	By mail
Ticketing and Fare Collection (151) Total Modal Expense	Transit headquarters division
Ticketing and Fare Collection (151) Employee Work Hours	Infocenter
Unlinked Passenger Trips	Parking outdoor facility
Payment option	Transportation terminal
Personal check	Government toffice
Organizatonal check	Retail outlet
Credit card	Employment sites
ATM card	On vehicle
Money order	**TFC equipment used**
Federal payment	Mechanical fareboxes
Other payment	Electronic fareboxes
Fare media	Mechanical turnstiles
Tokens	Electronic turnstiles
Punch cards	Transfer issuers
Tearoff tickets	Fare validators
Non-magnetic passes	Change making machines
Non-magnetic single-ride tickets	Ticket vending machines (accepts cash only)
Magnetic stored-value cards	Ticket vending machines (accepts credit/debit cards)
Magnetic stored-time cards	Magnetic card coders
Computerised (smart) cards	Magnetic card readers
	Other equipment

asked to estimate the utilization level of certain payment media, fare media, and TFC equipment expressed as percent of the total for each category in 1993 and 1998 fiscal years (see table 4-3). Also, the transit agencies were asked to estimate the number of fare media distribution locations (i.e. sales offices, transportation terminals, parking outdoor facilities, etc.) and fare media collection locations (i.e. rail stations, bus garages, etc.) in 1993 and 1998 fiscal years.

4.2.3.3 Description of the Final Database

In mid January 2001, the transit operators listed in table 4-1 were contacted via telephone with the intent of introducing the forthcoming questionnaire and verifying the proper addressee for this questionnaire. In most cases, the questionnaires were addressed to either the same persons who report transit agencies' statistics to the National Transit Database or to their assistants. The verification questionnaires described in the previous section were mailed out to 42 transit agencies in the U.S., operating 9 heavy rail and 39 motorbus systems, on January 25, 2001. A month and a half later, the non-respondents were telephoned again and reminded regarding the questionnaire. By the end of April 2001, some 25 responses (6 heavy rail and 19 motorbus systems) were received and integrated into the final database for the analysis. Although several agencies did not provide all of the data requested, the author included these agencies into the final database and substituted the missing data with the values estimated based on other information available. Only four responses from bus operators were not included into the analysis based on the insufficient data provided. In addition, the 3 non-responding heavy

Table 4-3. Additional variables included into the questionnaire.

Payment option	25%	50%	75%	100%	Other
Cash					
1993					
1998					
Checks, vouchers, etc.					
1993					
1998					
Credit/Debit/ATM cards					
1993					
1998					
Fare media	25%	50%	75%	100%	Other
Non-electronic (tokens, paper tickets and passes)					
1993					
1998					
Electronic (magnetic stripe and smart cards)					
1993					
1998					
TFC equipment	25%	50%	75%	100%	Other
Percentage of fare media sold by machines					
1993					
1998					
	1993	1998			
Number of fare media DISTRIBUTION locations					
Number of fare media COLLECTION locations					

rail operators were still included in the analysis since the data on these systems reported to NTD were relatively complete. The final database prepared for the analysis is presented in table 4-4 (numbers in bold denote estimated values).

4.3 DATA ANALYSIS

This section presents the testing of the hypotheses formulated in the previous chapter. For each hypothesis, a preliminary analysis of data and regression analysis are conducted. The preliminary analysis may include examination of descriptive statistics and scatter diagrams, while the regression analysis covers discussion of t-statistic and coefficient of determination.

4.3.1 Testing Hypothesis 1: TFC Operating Costs are a Function of Transit Demand

The first hypothesis investigated in this dissertation research is that TFC operating costs are a function of transit demand. It is logical to expect that one of the most important (if not the most important) factors affecting fare collection costs on transit would be the number of transit riders who pay fares.

Table 4-4. Final database used for the analyses.

NTD ID	Year	NTD statistics		PM utilization (percent of the total fare revenue)			# of PM options in addition to cash	FM utilization (percent of the total fare revenue)			# of FM options in addition to cash	Percent of FM sold by machine	# of FM collection locations
		UPT	TFC OC	Cash	Checks	Credit Cards		Cash	Non-Electronic	Electronic			
Heavy rail systsms													
2008	93	1,178,121,493	$ 188,495,819	100	0	0	0	0	100	0	1	0	469
2008	98	1,535,830,314	$ 202,687,176	90	0	10	1	0	25	75	2	0	468
2075	93	11,232,302	$ 1,262,707	**90**	**10**	0	1	0	0	100	1	**95**	**13**
2075	98	10,751,747	$ 1,332,125	**90**	**10**	0	1	0	0	100	1	**95**	**13**
2098	93	61,814,595	$ 1,700,000	98	0	2	1	70	0	30	1	87	13
2098	98	69,974,295	$ 2,945,000	94	0	6	1	58	0	42	1	67	13
3019	93	94,332,492	$ 17,904,981	75	5	20	2	24	42	34	2	10	260
3019	98	81,219,794	$ 20,003,679	75	5	20	2	19	42	39	2	11	260
3030	93	191,428,020	$ 3,802,612	**65**	**15**	**20**	2	0	0	100	1	**90**	**70**
3030	98	213,044,900	$ 3,895,772	**65**	**15**	**20**	2	0	0	100	1	**90**	**75**
3034	93	11,114,213	**$ 2,682,195**	**95**	0	**5**	1	0	50	50	2	50	17
3034	98	12,833,591	**$ 2,827,025**	95	0	5	1	0	50	50	2	50	17
4022	93	65,005,000	$ 1,621,079	**90**	**10**	0	1	**33**	**34**	**33**	2	**90**	**33**
4022	98	77,802,000	$ 1,300,810	**65**	**15**	**20**	2	**33**	**34**	**33**	2	**90**	**36**
4034	93	14,817,894	$ 1,162,967	90	10	0	1	**33**	**67**	0	1	10	**21**
4034	98	13,482,522	$ 727,636	80	15	5	2	**33**	**67**	0	1	10	**21**
9003	93	78,301,800	$ 4,060,262	100	0	0	0	0	0	100	1	**60**	34
9003	98	80,256,779	$ 5,405,513	65	0	35	1	0	0	100	1	60	39
Motorbus systems													
0002	93	7,510,779	$ 80,896	90	10	0	1	50	5	45	2	0	1
0002	98	7,944,416	$ 99,006	88	10	2	2	47	5	48	2	0	1
0008	93	52,421,883	$ 985,374	60	40	0	1	0	100	0	1	25	30
0008	98	67,072,805	$ 959,260	40	60	0	1	0	100	0	1	25	30
0024	93	4,255,417	$ 338,701	**100**	**0**	0	0	0	100	0	1	0	1
0024	98	7,208,587	**$ 710,175**	**100**	**0**	0	0	0	100	0	1	0	1
1048	93	18,479,404	$ 220,931	75	25	0	1	0	62	38	2	0	**1**
1048	98	16,816,826	$ 287,469	75	20	5	2	0	57	43	2	0	**1**
1055	93	11,623,692	$ 153,049	75	25	0	1	0	62	38	2	0	**1**
1055	98	10,518,633	$ 157,169	75	20	5	2	0	57	43	2	0	**1**
2004	93	23,101,063	$ 681,872	95	3	2	2	50	50	0	1	0	3
2004	98	19,765,737	$ 660,003	92	5	3	2	50	50	0	1	0	3
2008	93	620,555,564	$ 12,599,176	100	0	0	0	0	100	0	1	0	19
2008	98	689,246,563	$ 18,758,754	90	5	5	2	0	25	75	2	0	19
3006	93	18,724,993	$ 193,950	75	25	0	1	50	50	0	1	0	1
3006	98	15,624,112	$ 211,863	75	25	0	1	20	75	5	2	0	1
3019	93	166,639,551	$ 5,305,814	75	5	20	2	24	42	34	2	10	**10**
3019	98	134,213,028	$ 6,365,042	75	5	20	2	19	42	39	2	11	**10**
3034	93	84,836,122	**$ 1,250,000**	**95**	**0**	**5**	1	**50**	**50**	0	1	0	**5**
3034	98	79,944,812	**$ 1,251,275**	95	0	5	1	**50**	**50**	0	1	30	**5**
4034	93	63,806,513	$ 2,510,317	90	10	0	1	0	100	0	1	10	**4**
4034	98	62,269,585	$ 2,553,270	85	14	1	2	0	90	10	2	10	**4**
6008	93	83,419,977	$ 825,139	50	50	0	1	0	25	75	2	0	5
6008	98	94,373,280	$ 1,029,632	55	40	5	2	0	25	75	2	0	6
6011	93	43,666,032	$ 264,872	85	15	0	1	85	15	0	1	0	1
6011	98	41,059,704	$ 453,357	65	35	0	1	75	25	0	1	0	1
6019	93	6,419,422	**$ 66,110**	100	0	0	0	**50**	**50**	0	1	0	1
6019	98	6,630,080	$ 71,830	100	0	0	0	**50**	**50**	0	1	0	1
9033	93	18,180,511	**$ 82,000**	50	50	0	1	50	50	0	1	0	3
9033	98	15,739,805	**$ 40,360**	50	50	0	1	50	25	25	2	0	4

$$y_1 = b_0 + b_1 x_1$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership).

The null hypothesis tested is H_0: $b_1 = 0$, and the alternative hypothesis is H_A: $b_1 \neq 0$.

To test this hypothesis, the TFC operating cost and transit demand annual data from the National Transit Database were used. A sample of 15 bus and 9 heavy rail systems was used for the analysis. Annual data for the fiscal years 1993 and 1998 yielded 48 observations for each variable.

4.3.1.1 Preliminary Analysis

The preliminary analysis of the sample data shows that TFC operating costs range from about $40,000 to more than $202,000,000 with the median value of about $1,000,000. The first quartile of the sample is about $213,000; the third quartile of the sample is about $3,291,000; and the interquarter range of the sample is about 3,000,000. NYCTA heavy rail TFC operating costs ranging from $188M to $202M for two fiscal years are clear outliers in this sample.

The ridership of the transit systems included into the sample ranges from about 4.3 million UPT to more than 1,535 million UPT with the median value of about 42.4 million UPT. The first quartile of the sample is about 11.7 million UPT; the third quartile of the sample is about 82.9 million UPT; and the interquarter range of the sample is about 71.2 million. NYCTA heavy rail annual ridership ranging from 1,178 million UPT to 1,535 million UPT for two financial years and NYCTA bus annual ridership ranging from 621 million UPT to 689 million UPT for two financial years are clear outliers in this sample.

The correlation analysis of the sample TFC OC and UPT data yields a relatively high coefficient of correlation of 0.92. However, the scatter diagram of the data shows that NYCTA heavy rail and bus systems are clear outliers and may excessively influence the outcome of the analysis (see figure 4-2).

Figure 4-3 shows the correlation between TFC OC and UPT when NYCTA heavy rail and bus systems are excluded from the analysis. The coefficient of correlation for this sample of 44 observations drops to 0.47.

Although SEPTA heavy rail system annual TFC operating costs of about $20 million, WMATA heavy rail system annual ridership of about 200 million UPT, and SEPTA bus system annual ridership of about 150 million UPT are also appear to be significantly different from the rest of the sample, the author believes that they should remain in the sample.

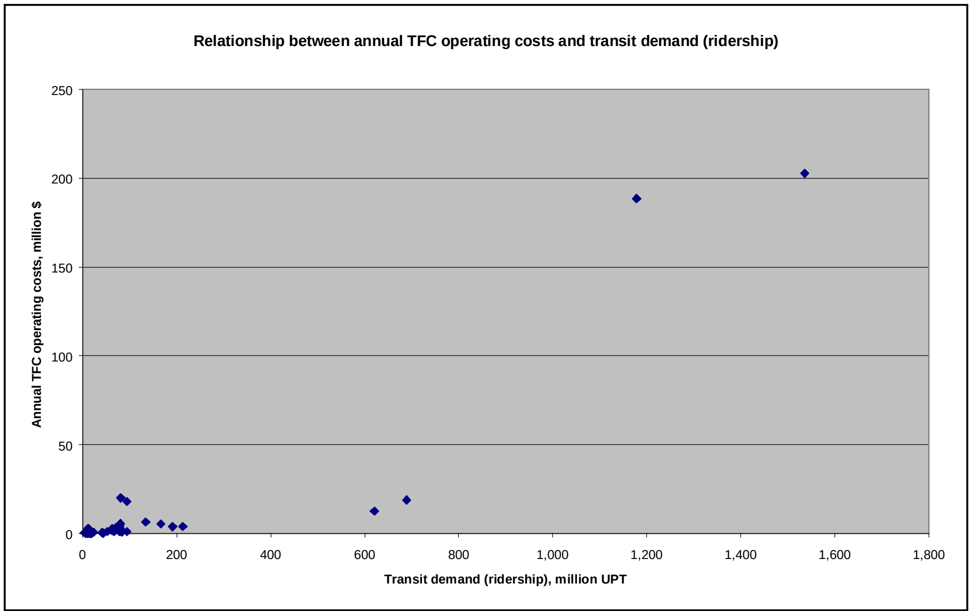

Figure 4-2. Relationship between annual TFC operating costs and transit demand (ridership) for selected transit systems.

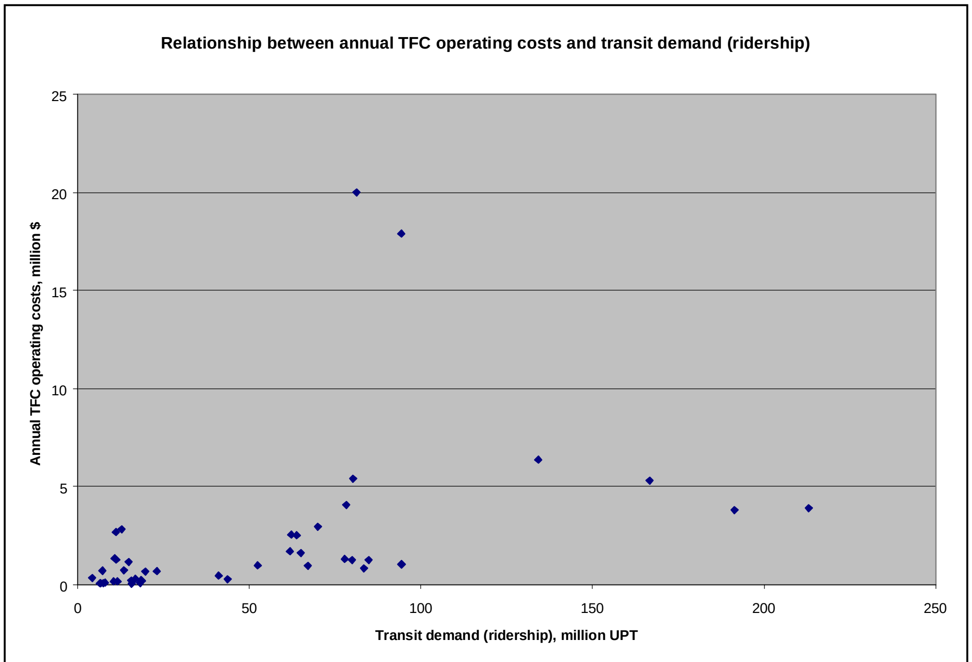

Figure 4-3. Relationship between TFC operating costs and ridership for selected transit systems without NYCTA.

4.3.1.2 Regression analysis

The next step in the examination of the hypothesis is to conduct a regression analysis and perform a hypothesis testing of the t-statistic, where:

$$t = \frac{\hat{\beta}_i - \beta_i}{s_{\hat{\beta}_i}}$$

which is Student t distribution with n – k – 1 degrees of freedom.

The results of the simple regression analysis are presented in table 4-5.

The t-test of the slope yields the value of 3.044 and indicates that the coefficient associated with the independent variable is significantly different from zero. The t-test suggests that the null hypothesis should be rejected at the significance level of more than 99.6 percent, and supports the alternative hypothesis, which states that TFC operating costs are associated with transit demand.

On the other hand, the coefficient of determination (R-square) obtained from the above regression analysis suggests that only a small portion of the variation in the dependent variable (TFC operating costs) can be explained with the variation in the independent variable (transit demand). This fact further supports the notion that other factors, such as the type of transit and TFC technologies, may influence TFC operating costs.

Table 4-5. Testing hypothesis 1: results of regression analysis.

Y =503,403 + 0.034*X
where
Y = TFC Operating Costs, $
X = Demand, UPT

Regression Statistics	
Multiple R	0.43
R Square	0.18
Adjusted R Square	0.17
Standard Error	3,677,882
Observations	44

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	503,403	796,240	0.682	0.498
Demand, UPT	0.034	0.011	3.044	0.004

4.3.2 Testing Hypothesis 2: TFC Operating Costs are a Function of Transit Demand and Transit Technology (Mode)

Another hypothesis tested in this dissertation research is that in addition to transit demand, the transit technology (mode) is also a factor that affects TFC operating costs.

$$y_1 = b_0 + b_1x_1 + b_2x_2$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode).

The null hypothesis tested in this case is H_0: $b_i = 0$, for i = 1, 2 and the alternative hypothesis is H_A: $b_i \neq 0$.

To test this hypothesis, the TFC operating cost, transit demand, and transit technology (mode) annual data from the National Transit Database were used. A sample of 14 bus and 8 heavy rail systems was used for the analysis. Annual data for the financial years 1993 and 1998 yielded 44 observations for each variable.

4.3.2.1 Preliminary Analysis

The description of TFC operating cost and transit demand data used to test this hypothesis is similar to that described in Section 4.3.1.1, therefore, the reader can refer to that section for details. The transit technology variable is presented as an indicator (dummy) variable with the “0” value denoting a motorbus technology and “1” value denoting a heavy rail system.

4.3.2.2 Regression analysis

The results of the multiple regression analysis are presented in table 4-6. The t-test of the coefficient for the transit demand variable yields the value of 2.505 and indicates that the coefficient associated with this independent variable is significantly different from zero. The t-test suggests that the null hypothesis should be rejected at the significance level of more than 98.4 percent. The t-test of the coefficient for the transit technology (mode) variable yields the value of 2.551 and indicates that the coefficient associated with this independent variable is also significantly different from zero. The t-test of this coefficient suggests that the null hypothesis should be rejected at the significance level of more than 98.5 percent. Consequently, the alternative hypothesis stating that TFC operating costs are associated with transit demand and transit technology (mode) should be accepted.

Table 4-6. Testing hypothesis 2: results of regression analysis.

Y = -144,152 + 0.027*X1 + 2,853,173*X2
where
Y = TFC operating costs
X1 = Demand, UPT
X2 = Transit technology (mode)

Regression Statistics	
Multiple R	0.541
R Square	0.293
Adjusted R Square	0.258
Standard Error	3,458,158
Observations	44

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-144,152	795,714	-0.181	0.857
Demand	0.027	0.011	2.505	0.016
Mode	2,853,173	1,118,527	2.551	0.015

The coefficient of determination (R-square) obtained from the above regression analysis shows some improvement in the explanatory power of the independent variables (0.29 vs. 0.18), further suggesting that both transit demand and transit technology influence TFC operating costs.

The coefficient associated with the transit demand variable suggests that TFC operating costs increase by 2.7 cents for each additional unlinked passenger trip. The coefficient associated with the transit technology (mode) variable suggests that, on average, TFC operating costs tend to be greater by $2,853,173 for heavy rail systems than for bus systems assuming that the demand variable is held constant. It also should be mentioned that these results are valid for the given sample of transit systems only and that the coefficients associated with the variables simply reflect the best fit of the given model for the data at hand.

4.3.3 Testing Hypothesis 3: TFC Operating Costs are a Function of Transit Demand, Transit Technology (Mode), and TFC Technology

As formulated in Section 3.2.2.4, the hypothesis relating TFC operating costs to transit demand, transit technology (mode), and TFC technology can be expressed in the following form:

$$y_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3$$

where,

y_1 = TFC operating costs;

x_1 = transit demand (ridership);

x_2 = transit technology (mode);

x_3 = TFC System Technology Index.

The null hypothesis tested is H_0: $b_i = 0$, for i = 1, 2, …, k and the alternative hypothesis is H_A: $b_i \neq 0$.

As described in Section 3.2.2.4, the TFC System Technology Index is a weighted sum of ratings associated with TFC technology groups comprising a certain TFC system and can be computed in the following way:

$$\boldsymbol{TFCSTI = w_1 * PM + w_2 * FM + w_3 * EQ}$$

where,

TFCSTI = TFC System Technology Index;

PM = payment media TFC technology group score;

FM = fare media TFC technology group score;

EQ = TFC equipment TFC technology group score;

w_1, w_2, w_3 = coefficients (weights) reflecting the relative impact of fare media, payment media, and TFC equipment on a certain aspect of a TFC system performance.

Furthermore, a TFC technology group score represents the impact of a group of similar TFC technologies on a particular aspect of TFC system performance (in this case TFC operating costs). A TFC technology group score is computed as a sum of products of scores and weights associated with individual TFC technologies within their group.

$$\boldsymbol{TFC\ TG = w_1 * t_1 + w_2 * t_2 + \ldots + w_i * t_i}$$

where,

TFC TG = TFC technology group (i.e. payment media, fare media, or TFC equipment) score;

t_1, t_2, …,t_i = individual technology scores;

w_1, w_2, …,w_i = relative impact coefficients (weights) of individual TFC technologies within their group.

In order to test the hypothesis presented above, the following set of computational steps is performed and described below:

1. A measure of cost effectiveness of TFC operations expressed as TFC operating costs per unlinked passenger trip (TFCOC/UPT) is calculated for each transit system and the data set is differentiated by transit mode to separate the effect of transit demand and transit technology from the effect of individual TFC technologies on TFC operating costs.

2. A series of simple linear regression analyses testing the impact of individual TFC technologies on cost effectiveness of TFC operations are run to make a preliminary assessment of impacts of individual TFC technologies on TFC operating costs.

3. Based on the regression coefficients computed in Step 2, scores are assigned to individual TFC technologies within their TFC technology groups.

4. TFC technology group scores are computed for all transit systems in the data set.

5. A series of multiple regression analyses testing the impact of TFC TG scores on cost effectiveness of TFC operations are run for each transit mode separately to validate that scores assigned in Step 3 are reasonable.

6. Based on the regression coefficients computed in Step 5, weights reflecting the relative impact of fare media, payment media, and TFC equipment on cost effectiveness of TFC operations are assigned to TFC technology groups.

7. TFC System Technology Index (TFCSTI) ratings are computed for all transit systems in the data set.

8. The hypothesis relating TFC operating costs to transit demand, transit technology (mode), and TFC System Technology Index (TFCSTI) is tested.

To test this hypothesis, the following data were used:

a) National Transit Database data:

    i. TFC operating cost;

    ii. transit demand;

    iii. transit technology (mode);

b) APTA Transit Fare Summary data:

    i. number of different payment media accepted by a transit agency;

ii. number of different fare media accepted by a transit agency;

c) Transit system questionnaire conducted by the author:

i. usage of cash, check, and credit card payment media (in percent);

ii. usage of cash, non-electronic, and electronic fare media (in percent);

iii. percent of fare media sold by machines;

iv. number of fare media collection locations.

A sample of 14 bus and 8 heavy rail systems was used for the analysis. Annual data for the financial years 1993 and 1998 yielded 44 observations for each variable.

4.3.3.1 Preliminary Analysis

The description of TFC operating cost and transit demand data used to test this hypothesis is similar to that described in Section 4.3.1.1; the reader can refer to that section for details. The transit technology (mode) variable is similar to that presented in Section 4.3.3.1 and expressed as an indicator (dummy) variable with the "0" value denoting a motorbus technology and "1" value denoting a heavy rail system.

Table 4-7 presents several measures of data central location and relative standing for the variables describing TFC technologies utilized on the transit systems included into the analysis.

4.3.3.2 Regression analyses

Step 1: A measure of cost effectiveness of TFC operations expressed as TFC operating costs per unlinked passenger trip (TFCOC/UPT) is calculated for each transit system and the data set is differentiated by transit mode to separate the effect of transit demand and

Table 4-7. Testing hypothesis 3: results of the preliminary analysis.

	Payment Media (% used)			PM factor	Fare Media (% used)			FM factor	% of FM sold by machine	# of FM collection locations
	cash	checks	credit cards		cash	non-electronic	electronic			
Minimum	40	0	0	0	0	0	0	1	0	1
Maximum	100	60	35	2	85	100	100	2	95	260
Median	82.5	10	0.5	1	19.5	50	33	1	10	5
Average	79.9	14.8	5.3	1.2	24.4	43.1	32.5	1.4	24.7	24.3
1st Quartile	72.5	0	0	1	0	22.5	0	1	0	1
3rd Quartile	94.25	21.25	5	2	50	58.25	45.75	2	50	21

transit technology from the effect of individual TFC technologies on TFC operating costs. The results of these data manipulations are presented in table 4-8.

Step 2: A series of simple linear regression analyses testing the impact of individual TFC technologies on cost effectiveness of TFC operations are run to make a preliminary assessment of impacts of individual TFC technologies on TFC operating costs. The results of these regression analyses are shown in table 4-9.

As the reader may observe, based on the regression analyses performed, there is no sufficient evidence that the "Percent of FM purchased with CREDIT CARDS", "Number of PM OPTIONS available", and "Percent of fares validated with ELECTRONIC FM"

Table 4-8. TFC cost effectiveness of selected transit systems.

NTD ID and fiscal year	Cost effectiveness of TFC operations (TFCOC/UPT)	NTD ID and fiscal year	Cost effectiveness of TFC operations (TFCOC/UPT)
Heavy rail systems		Motorbus systems	
3019-98	$ 0.25	0024-98	$ 0.10
3034-93	$ 0.24	0024-93	$ 0.08
3034-98	$ 0.22	3019-98	$ 0.05
3019-93	$ 0.19	4034-98	$ 0.04
2075-98	$ 0.12	4034-93	$ 0.04
2075-93	$ 0.11	2004-98	$ 0.03
4034-93	$ 0.08	3019-93	$ 0.03
9003-98	$ 0.07	2004-93	$ 0.03
4034-98	$ 0.05	0008-93	$ 0.02
9003-93	$ 0.05	1048-98	$ 0.02
2098-98	$ 0.04	3034-98	$ 0.02
2098-93	$ 0.03	1055-98	$ 0.01
4022-93	$ 0.02	3034-93	$ 0.01
3030-93	$ 0.02	0008-98	$ 0.01
3030-98	$ 0.02	3006-98	$ 0.01
4022-98	$ 0.02	1055-93	$ 0.01
		0002-98	$ 0.01
		1048-93	$ 0.01
		6011-98	$ 0.01
		6008-98	$ 0.01
		6019-98	$ 0.01
		0002-93	$ 0.01
		3006-93	$ 0.01
		6019-93	$ 0.01
		6008-93	$ 0.01
		6011-93	$ 0.01
		9033-93	$ 0.00
		9033-98	$ 0.00
Median	$ 0.06	Median	$ 0.01
Average	$ 0.10	Average	$ 0.02

Table 4-9. Impact of individual TFC technologies on cost effectiveness of TFC operations: regression results.

Independent variables	Indep. variable coefficient		t-statistic		p-value		R-squared	
	HR	MB	HR	MB	HR	MB	HR	MB
Percent of FM purchased with CHECKS	-0.0056	-0.0006	-1.75	-2.74	0.10	0.01	0.18	0.22
Percent of FM purchased with CREDIT CARDS	-0.0001	0.0007	-0.03	0.86	0.98	0.40	0.00	0.03
Number of PM OPTIONS available	0.0025	-0.0061	0.07	-0.96	0.95	0.35	0.00	0.03
Percent of fares validated with NON-ELECTRONIC FM	0.0014	0.0004	1.84	3.49	0.09	0.00	0.20	0.32
Percent of fares validated with ELECTRONIC FM	-0.0002	-0.0002	-0.40	-1.19	0.70	0.25	0.01	0.05
Number of FM OPTIONS avaliable	0.0970	-0.0082	2.67	-0.98	0.02	0.34	0.34	0.04
Percent of FM sold by machine	-0.0013	0.0001	-2.23	0.19	0.04	0.85	0.26	0.00
Number of FM collection locations	0.0005	-0.0001	1.95	-0.20	0.07	0.84	0.21	0.00

variables significantly influence TFC operating costs on either heavy rail or motorbus systems. Also, based on the regression analysis performed, there is no sufficient evidence that the "Number of FM OPTIONS available", "Percent of FM sold by machine", and "Number of FM collection locations" variables significantly influence TFC operating costs on motorbus systems. As a result, these variables are excluded from the further steps of computing TFC System Technology Index.

<u>Step 3</u>: Based on the regression coefficients computed in Step 2, scores are assigned to individual TFC technologies within their TFC technology groups.

A TFC technology group score represent the impact of a group of similar TFC technologies on a particular aspect of TFC system performance (in this case TFC operating costs). A TFC technology group score is computed as a sum of products of scores and weights associated with individual TFC technologies within their group.

$$TFC\ TG = w_1 * t_1 + w_2 * t_2 + \ldots + w_i * t_i$$

where,

TFC TG = TFC technology group (i.e. payment media, fare media, or TFC equipment) score;

t_1, t_2, …,t_i = individual technology scores;

w_1, w_2, …,w_i = relative impact coefficients (weights) of individual TFC technologies within their group.

Table 4-10 summarizes the variables representing specific TFC technologies utilized to compute TFC TG scores as well as the scores assigned to individual TFC technologies. The scores are assigned based on the regression coefficients obtained in Step 2. The variables that do not pass a 90 percent significance level (p-value of 0.1 and less) are assigned scores of zero.

Table 4-10. Scores assigned to the variables representing selected TFC technologies.

Indipendent variables	Score	
	Heavy Rail	Motorbus
PAYMENT MEDIA TFC Technology Group (PM TFC TG)		
Percent of FM purchased with CHECKS	-56	-6
Percent of FM purchased with CREDIT CARDS	0	0
Number of PM OPTIONS available	0	0
FARE MEDIA TFC Technology Group (FM TFC TG)		
Percent of fares validated with NON-ELECTRONIC FM	14	4
Percent of fares validated with ELECTRONIC FM	0	0
Number of FM OPTIONS avaliable	97	0
TFC EQUIPMENT TFC Technology Group (EQ TFC TG)		
Percent of FM sold by machine	-13	0
Number of FM collection locations	5	0

Consequently, the formulas employed to compute TFC TG scores for heavy rail and motorbus systems are as follows:

for heavy rail:

*PM TFC TG = (Percent of FC purchased with CHECKS) * (- 56)*

*FM TFC TG = (Percent of fares validated with NON-ELECTRONIC FM) * (14) + (Number of FM OPTIONS available) * (97)*

*EQ TFC TG = (Percent of FM sold by machine) * (-13) + (Number of FM collection locations) * (5)*

for motorbus:

*PM TFC TG = (Percent of FC purchased with CHECKS) * (- 6)*

*FM TFC TG = (Percent of fares validated with NON-ELECTRONIC FM) * (4)*

In summary, ,the scores are assigned to individual TFC technologies within their TFC technology groups based on the regression coefficients obtained in Step 2. Thus, if the use of a certain TFC technology tends to decrease TFC operating cost (all other factors remain the same), this technology would be given a "negative" score (e.g. "*Percent of FC purchased with CHECKS*" is given a "- 56" score). Likewise, if the use of a certain TFC technology tends to increase TFC operating cost (all other factors remaining the same), this technology would be given a "positive" score (e.g. *"Percent of fares validated with NON-ELECTRONIC FM"* is given a "14" score*)*. Finally, if there is not enough statistical evidence that the use of a certain TFC technology has an effect on TFC operating cost (all other factors remain the same), this technology would be excluded from the process of calculating a technology group score.

<u>Step 4</u>: TFC Technology Group (TFC TG) scores are computed for all transit systems in the data set. Table 4-11 presents TFC TG scores for all transit systems included into the analysis.

<u>Step 5</u>: Multiple regression analyses, testing the impact of TFC TG scores on cost effectiveness of TFC operations, are run for each transit mode separately to validate that weights assigned in Step 3 are reasonable. The results of these regression analyses are shown in table 4-12 and table 4-13.

Table 4-11. TFC Technology Group scores associated with selected transit systems.

NTD ID and fiscal year	TFC Technology Group Scores			Transit system ID and fiscal year	TFC Technology Group Scores		
	PM	FM	EQ		PM	FM	EQ
Heavy rail systems				Motorbus systems			
2075-93	-560	97	-1,170	1048-93	-150	248	0
2075-98	-560	97	-1,170	1048-98	-120	228	0
2098-93	0	97	-1,066	1055-93	-150	248	0
2098-98	0	97	-806	1055-98	-120	228	0
3019-93	-280	782	1,170	2004-93	-18	200	0
3019-98	-280	782	1,157	2004-98	-30	200	0
3030-93	-840	97	-820	3006-93	-150	200	0
3030-98	-840	97	-795	3006-98	-150	300	0
3034-93	0	894	-565	3019-93	-30	168	0
3034-98	0	894	-565	3019-98	-30	168	0
4022-93	-560	670	-1,005	3034-93	0	200	0
4022-98	-840	670	-990	3034-98	0	200	0
4034-93	-560	1,035	-25	4034-93	-60	400	0
4034-98	-840	1,035	-25	4034-98	-84	360	0
9003-93	0	97	-610	6008-93	-300	100	0
9003-98	0	97	-585	6008-98	-240	100	0
Motorbus systems				6011-93	-90	60	0
0002-93	-60	20	0	6011-98	-210	100	0
0002-98	-60	20	0	6019-93	0	200	0
0008-93	-240	400	0	6019-98	0	200	0
0008-98	-360	400	0	9033-93	-300	200	0
0024-93	0	400	0	9033-98	-300	100	0
0024-98	0	400	0				

Table 4-12. Impact of TFC Technology Group scores on cost effectiveness of TFC operations: regression results (heavy rail systems).

Heavy Rail

Regression Statistics	
Multiple R	0.72
R Square	0.52
Adjusted R Square	0.41
Standard Error	0.06
Observations	16

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.12	0.04	3.10	0.01
PM TFC TG Score	0.0000995	0.0000483	2.06	0.06
FM TFC TG Score	0.0000703	0.0000512	1.37	0.19
EQ TFC TG Score	0.0000376	0.0000280	1.35	0.20

Table 4-13. Impact of TFC Technology Group scores on cost effectiveness of TFC operations: regression results (motorbus systems).

Motorbus

Regression Statistics	
Multiple R	0.72
R Square	0.53
Adjusted R Square	0.49
Standard Error	0.02
Observations	28

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.01	0.007265	1.45	0.16
PM TFC TG Score	0.000091	0.000028	3.30	0.00
FM TFC TG Score	0.000105	0.000026	3.99	0.00

As the reader may observe, based on the results of the regression analyses performed there is some statistical evidence that the TFC technology group scores computed are closely associated with TFC operating cost for both heavy rail and motorbus systems.

<u>Step 6</u>: Based on the regression coefficients computed in Step 5, weights reflecting the relative impact of fare media, payment media, and TFC equipment on cost effectiveness of TFC operations are assigned to TFC technology groups.

Table 4-14 summarizes the relative impact coefficients (weights) assigned to TFC TG variables. The procedure of assigning weights to TFC TG variables is similar to the procedure employed to assign scores to individual TFC technologies described in Step 3. Consequently, the formulas employed to compute TFC Systems Technology Index for heavy rail and motorbus systems are as follows:

for heavy rail:

*TFCSTI = 0.995 * PM TFC TG + 0.703 * FM TFC TG + 0.376 * EQ TFC TG*

for motorbus:

*TFCSTI = 0.910 * PM TFC TG + 1.050 * FM TFC TG*

<u>Step 7</u>: TFC System Technology Index (TFCSTI) ratings are computed for all transit systems in the data set. Table 4-15 presents TFCSTI ratings for all transit systems included into the analysis.

To normalize the raw TFCTSI score, the following procedure was used: a) the lowest negative score number was identified; b) an absolute value of the lowest negative score was added to all values in the sample so that the lowest value in the sample equals zero; c) all values in the sample were divided by the highest value in the sample so that the highest value in the sample equals 1; d) all values in the sample were subtracted from 1 since the low values in the raw TFCSTI score are associated with "higher" technology systems and it might be desired (for presentation or other purposes) to associate high values in the normalized TFCSTI score with "higher" technology systems. The resulting

Table 4-14. Relative impact coefficients (weights) assigned to TFC TG variables.

Variables	Relative impact coefficients (weights)	
	Heavy Rail	Motorbus
PM TFC TG score	0.995	0.910
FM TFC TG score	0.703	1.050
EQ TFC TG score	0.376	0.000

Table 4-15. TFC System Technology Index scores associated with selected transit systems.

NTD ID and fiscal year	TFC System Technology Index (TFCSTI)	Normalized TFCSTI	NTD ID and fiscal year	TFC System Technology Index (TFCSTI)	Normalized TFCSTI
Heavy rail systems			Motorbus systems		
3019-93	711.07	0.0%	0024-98	420.00	16.3%
3019-98	706.18	0.3%	0024-93	420.00	16.3%
3034-93	416.04	16.5%	4034-93	365.40	19.3%
3034-98	416.04	16.5%	4034-98	301.56	22.9%
4034-93	161.01	30.8%	3034-98	210.00	28.0%
4034-98	-117.60	46.4%	3034-93	210.00	28.0%
9003-98	-151.77	48.3%	6019-98	210.00	28.0%
9003-93	-161.17	48.8%	6019-93	210.00	28.0%
2098-98	-234.87	52.9%	0008-93	201.60	28.5%
2098-93	-332.63	58.4%	2004-93	193.62	29.0%
4022-93	-464.07	65.8%	2004-98	182.70	29.6%
4022-98	-737.03	81.0%	3006-98	178.50	29.8%
2075-98	-928.93	91.8%	3019-98	149.10	31.4%
2075-93	-928.93	91.8%	3019-93	149.10	31.4%
3030-98	-1,066.53	99.5%	1048-98	130.20	32.5%
3030-93	-1,075.93	100.0%	1055-98	130.20	32.5%
			1055-93	123.90	32.9%
			1048-93	123.90	32.9%
			0008-98	92.40	34.6%
			3006-93	73.50	35.7%
			6011-93	-18.90	40.8%
			0002-98	-33.60	41.7%
			0002-83	-33.60	41.7%
			9033-93	-63.00	43.3%
			6011-98	-86.10	44.6%
			6008-98	-113.40	46.1%
			6008-93	-168.00	49.2%
			9033-98	-168.00	49.2%

normalized TFCSTI score ranks transit TFC systems from low technology (0.0-0.2 low score) to high technology (0.8-1.0 high score)

Step 8: The hypothesis relating TFC operating costs to transit demand, transit technology (mode), and TFC System Technology Index (TFCSTI) is tested.

The results of the regression analysis shown in table 4-16 indicate that all coefficients associated with the independent variables are significant at greater than 99.9 percent significance level. The coefficient of determination for this set of independent and dependent variables is also relatively high (R-square = 0.67). The use of a normalized TFCSTI score in the regression analysis yields results identical to those when a raw TFCSTI score is used.

Table 4-16. Testing hypothesis 3: results of regression analysis.

Y = -1,579,899 + 0.041*X1 + 4,909,749*X2 + 6,790*X3
where
Y = TFC operating costs
X1 = Demand, UPT
X2 = Transit technology (mode)
X3 = TFCSTI

Regression Statistics	
Multiple R	0.82
R Square	0.67
Adjusted R Square	0.65
Standard Error	2,383,262
Observations	44

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-1,579,899	587,557	-2.69	0.01
Demand	0.041	0.008	5.38	0.00
Mode	4,909,749	827,963	5.93	0.00
TFCSTI	6,790	998	6.81	0.00

Furthermore, stepwise regression analysis yields results identical (in terms of R-squared and t-values) to those of the regression analysis where all three variables are "forced" into the equation. The variable "Mode" enters the regression first followed by " TFCSTI" and "Demand".

4.3.3.3 TFCSTI computation example

The following is an example of computing a TFCSTI score for the SEPTA heavy rail system in 1993.

Step 1. A measure of cost effectiveness of TFC operations expressed as TFC operating costs per unlinked passenger trip (TFCOC/UPT) is calculated.

TFCOC/UPT = $17,904,981 / 94,332,492 = $0.19

Step 2. A series of simple linear regression analyses testing the impact of individual TFC technologies on cost effectiveness of TFC operations are run to make a preliminary assessment of impacts of individual TFC technologies on TFC operating costs (see table 4-9).

Step 3. Based on the regression coefficients computed in Step 2, scores are assigned to individual TFC technologies within their TFC technology groups.

PM TFC TG = (Percent of FC purchased with CHECKS) * (- 56)

FM TFC TG = (Percent of fares validated with NON-ELECTRONIC FM) * (14) + (Number of FM OPTIONS available) * (97)

EQ TFC TG = (Percent of FM sold by machine) * (-13) + (Number of FM collection locations) * (5)

Step 4. TFC technology group scores are computed.

PM TFC TG = (5) * (- 56) = -280

FM TFC TG = (42) * (14) + (2) * (97) = 782

EQ TFC TG = (10) * (-13) + (260) * (5) = 1170

Step 5. A series of multiple regression analyses testing the impact of TFC TG scores on cost effectiveness of TFC operations are run for each transit mode separately to validate that scores assigned in Step 3 are reasonable (see table 4-12).

Step 6. Based on the regression coefficients computed in Step 5, weights reflecting the relative impact of fare media, payment media, and TFC equipment on cost effectiveness of TFC operations are assigned to TFC technology groups.

TFCSTI = 0.995 * PM TFC TG + 0.703 * FM TFC TG + 0.376 * EQ TFC TG

Step 7. TFC System Technology Index (TFCSTI) score is computed.

TFCSTI = 0.995 * (-280) + 0.703 * (782) + 0.376 * (1170) = 711.07

Step 8. The hypothesis relating TFC operating costs to transit demand, transit technology (mode), and TFC System Technology Index (TFCSTI) is tested (see table 4-15).

CHAPTER 5: FINDINGS AND RESULTS

Over the course of this research, a number of expected and unexpected findings and observations were made. Some of these findings and observations stem from the results of regression analyses performed in this research while others are obtained from simple mathematical manipulation and visual examination of the data sample. The findings of this research are listed in Section 5.1 and other results are presented in Section 5.2.

5.1 FINDINGS

The findings made during this research include the following:

1. The cost effectiveness of TFC operations differs significantly between heavy rail and motorbus systems. The median value of TFCOC/UPT is about $0.061 for a sample of heavy rail systems and is about $0.014 for a sample of motorbus systems (see table 4-8). The cost effectiveness of TFC operations on most heavy rail systems in the sample falls between $0.02 per UPT and $0.12 per UPT. SEPTA and Maryland MTA heavy rail systems exhibit the cost effectiveness of TFC operations between $0.19 per UPT and $0.25 per UPT (see table 4-8). The cost effectiveness of TFC operations on most motorbus systems in the sample falls between $0.01 per UPT and $0.02 per UPT. Clark County Transportation Benefit Area Authority, SEPTA, Maryland MTA, and Niagara Frontier Transportation Authority motorbus systems exhibit the cost effectiveness of TFC operations between $0.03 per UPT and $0.10 per UPT (see table 4-8).

2. All heavy rail and motorbus systems in the sample accept cash for fare purchases. Between 40 and 100 percent of fare purchases on heavy rail and motorbus systems in the U.S. are made with cash, with the average value being 83 percent for heavy rail systems and 78 percent for motorbus systems (see table 5-1). About 60 percent of the heavy rail systems and 80 percent of motorbus systems in the sample accept checks for fare purchases. However, the average percent of fare purchases made with checks is only 7 and 19 for heavy rail and motorbus systems correspondingly (see table 5-1). About 70 percent of the heavy rail systems and 40 percent of motorbus systems in the sample accept credit cards for fare purchases. However, the average percent of fare purchases made with credit cards is 10 and 3 for heavy rail and motorbus systems correspondingly (see table 5-1). About 50 percent of the heavy rail systems and 60 percent of motorbus systems in the sample accept cash as fare media. The average percent of fares paid and validated with cash is 19 and 28 for heavy rail and motorbus systems correspondingly (see table 5-1). About 50 percent of the heavy rail systems and all motorbus systems in the sample accept some kind of non-electronic fare media. The average percent of fares validated with non-electronic fare media is 24 and 54 for heavy rail and motorbus systems correspondingly (see table 5-1). About 90 percent of the heavy rail systems and 50 percent of motorbus systems in the sample accept some kind of electronic fare media. The average percent of fares validated with electronic fare media is 57 and 18 for heavy rail and

Table 5-1. Selected TFC system statistics.

NTD ID	Year	PM utilization (percent of the total fare revenue) Cash	PM Checks	PM Credit Cards	FM utilization (percent of the total fare revenue) Cash	FM Non-Electronic	FM Electronic	Percent of FM sold by machine
Heavy rail systsms								
2075	93	**90**	**10**	0	0	0	100	**95**
2075	98	**90**	**10**	0	0	0	100	**95**
2098	93	98	0	2	70	0	30	87
2098	98	94	0	6	58	0	42	67
3019	93	75	5	20	24	42	34	10
3019	98	75	5	20	19	42	39	11
3030	93	**65**	**15**	**20**	0	0	100	**90**
3030	98	**65**	**15**	**20**	0	0	100	**90**
3034	93	**95**	0	**5**	0	50	50	50
3034	98	95	0	5	0	50	50	50
4022	93	**90**	**10**	0	**33**	**34**	**33**	**90**
4022	98	**65**	**15**	**20**	**33**	**34**	**33**	**90**
4034	93	90	10	0	**33**	**67**	0	10
4034	98	80	15	5	**33**	**67**	0	10
9003	93	100	0	0	0	0	100	**60**
9003	98	65	0	35	0	0	100	60
Minimum		65	0	0	0	0	0	10
Maximum		100	15	35	70	67	100	95
Median		90	8	5	10	17	46	64
Average		83	7	10	19	24	57	60

Numbers in bold are estimates

NTD ID	Year	PM utilization (percent of the total fare revenue) Cash	PM Checks	PM Credit Cards	FM utilization (percent of the total fare revenue) Cash	FM Non-Electronic	FM Electronic	Percent of FM sold by machine
Motorbus systems								
0002	93	90	10	0	50	5	45	0
0002	98	88	10	2	47	5	48	0
0008	93	60	40	0	0	100	0	25
0008	98	40	60	0	0	100	0	25
0024	93	**100**	**0**	0	0	100	0	0
0024	98	**100**	**0**	0	0	100	0	0
1048	93	75	25	0	0	62	38	0
1048	98	75	20	5	0	57	43	0
1055	93	75	25	0	0	62	38	0
1055	98	75	20	5	0	57	43	0
2004	93	95	3	2	50	50	0	0
2004	98	92	5	3	50	50	0	0
3006	93	75	25	0	50	50	0	0
3006	98	75	25	0	20	75	5	0
3019	93	75	5	20	24	42	34	10
3019	98	75	5	20	19	42	39	11
3034	93	**95**	**0**	**5**	**50**	**50**	0	0
3034	98	95	0	5	**50**	**50**	0	30
4034	93	90	10	0	0	100	0	10
4034	98	85	14	1	0	90	10	10
6008	93	50	50	0	0	25	75	0
6008	98	55	40	5	0	25	75	0
6011	93	85	15	0	85	15	0	0
6011	98	65	35	0	75	25	0	0
6019	93	100	0	0	**50**	**50**	0	0
6019	98	100	0	0	**50**	**50**	0	0
9033	93	50	50	0	50	50	0	0
9033	98	50	50	0	50	25	25	0
Minimum		40	0	0	0	5	0	0
Maximum		100	60	20	85	100	75	30
Median		75	15	0	22	50	0	0
Average		78	19	3	28	54	19	4

Numbers in bold are estimates

motorbus systems correspondingly (see table 5-1). All heavy rail systems and about 25 percent of motorbus systems in the sample employ ticket vending machines or some other kind of automated fare media distribution equipment. The average percent of fare media sold by machine is 60 and 4 for heavy rail and motorbus systems correspondingly (see table 5-1).

3. Based on the data analysis conducted in this research, it can be suggested that TFC operating costs are related to: (a) transit demand (see table 4-5); (b) transit demand and transit technology (mode) (see table 4-6); (c) transit demand, transit technology (mode), and TFC System Technology Index that takes into account the impact of different payment and fare media and the extent of TFC system automation (see table 4-16).

4. Based on the data analysis conducted in this research, it can be suggested that controlling for transit demand, TFC operating costs on heavy rail systems: (a) decrease as the percent of fare media purchased with checks increases; (b) increase as the use of non-electronic fare media increases; (c) increase as the number of fare media used on a transit system increases; (d) decrease as the percent of fare media sold by machines increases; and (e) increase as the number of payment and fare media collection and counting locations increases (see table 4-9). Likewise, it can be suggested that controlling for transit demand, TFC operating costs on motorbus systems: (a) decrease as the percent of fare media purchased with checks increases; and (b) increase as the use of non-electronic fare media increases (see table 4-9).

5.2 OTHER RESULTS

In addition to the findings obtained from regression analyses and other statistical processing of the data, other results of this research included the following:

1. To exclude the effect of labor rules and fare policy from the analysis of the effect of TFC technologies on TFC operating cost, the author suggested using variables representing TFC labor and transit ridership as proxies to TFC operating cost and transit revenues correspondingly.

2. Based on the literature review conducted, the author suggested that the following TFC system performance measures can be used to assess the impact of TFC system technologies on TFC operating costs: (1) measures of TFC system cost effectiveness: (a) TFC operating costs per dollar of revenue collected (TFCOC/PFR) and (b) TFC operating costs per unlinked passenger trip (TFCOC/UPT); and (2) measures of TFC operations labor intensiveness: (a) TFC employee work hours per dollar of revenue collected (TFC EWH/PFR) and (b) TFC employee work hours per unlinked passenger trip (TFC EWH/UPT) (see figure 3-11).

3. To take into account impacts of different TFC system technologies on TFC operating costs, the author suggested using the following TFC System Technology Index (TFCSTI):

$$\boldsymbol{TFCSTI = W_{PM} * \Sigma\, w_{PMi} * t_{PMi} + W_{FM} * \Sigma\, w_{FMi} * t_{FMi} + W_{EQ} * \Sigma\, w_{EQi} * t_{EQi}}$$

where,

t_{PMi}, t_{FMi}, and t_{EQi} – individual payment media, fare media, and TFC equipment technology scores;

w_{PMi}, w_{FMi}, and w_{EQi} – relative impact coefficients (weights) of individual TFC technologies within their groups;

W_{PM}, W_{FM}, W_{EQ} – coefficients (weights) reflecting the relative impact of fare media, payment media, and TFC equipment on a certain aspect of a TFC system performance.

Figures 5-1 through 5-4 illustrate relationships between TFC system performance measures and TFCSTI. It can be observed that all four relationships are similar and that TFC operating costs are highly correlated with TFC employee work hours whereas transit demand is highly correlated with the amount of revenues collected.

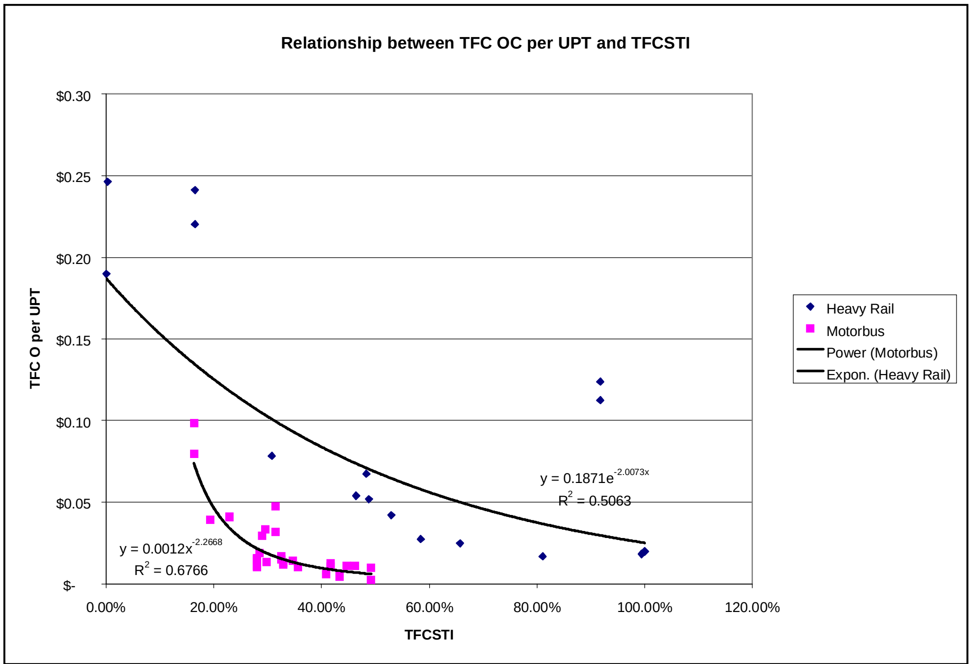

Figure 5-1. Relationship between TFCOC/UPT and TFC System Technology Index.

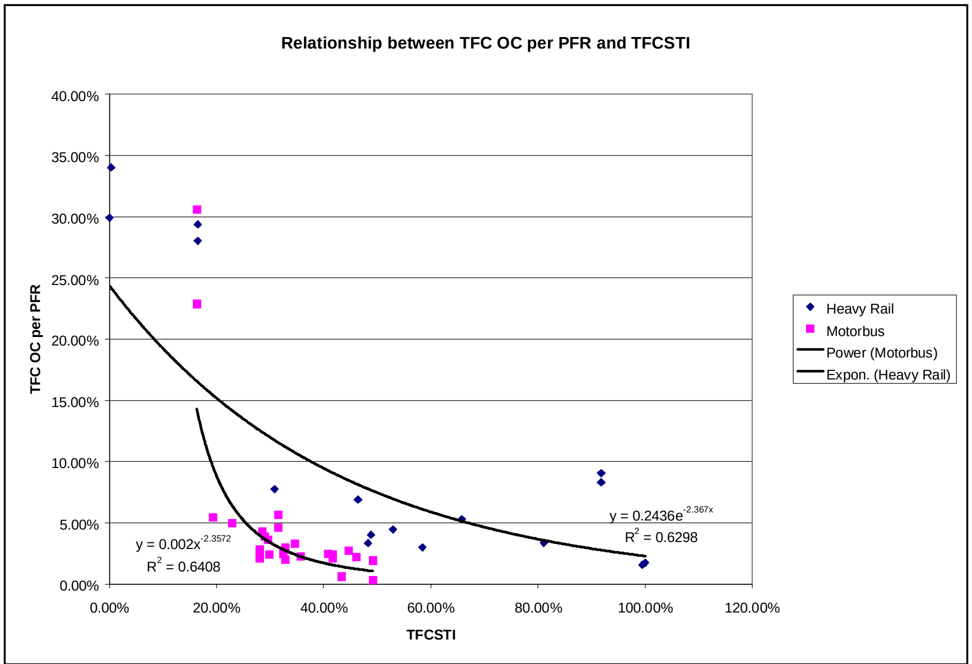

Figure 5-2. Relationship between TFCOC/PFR and TFC System Technology Index.

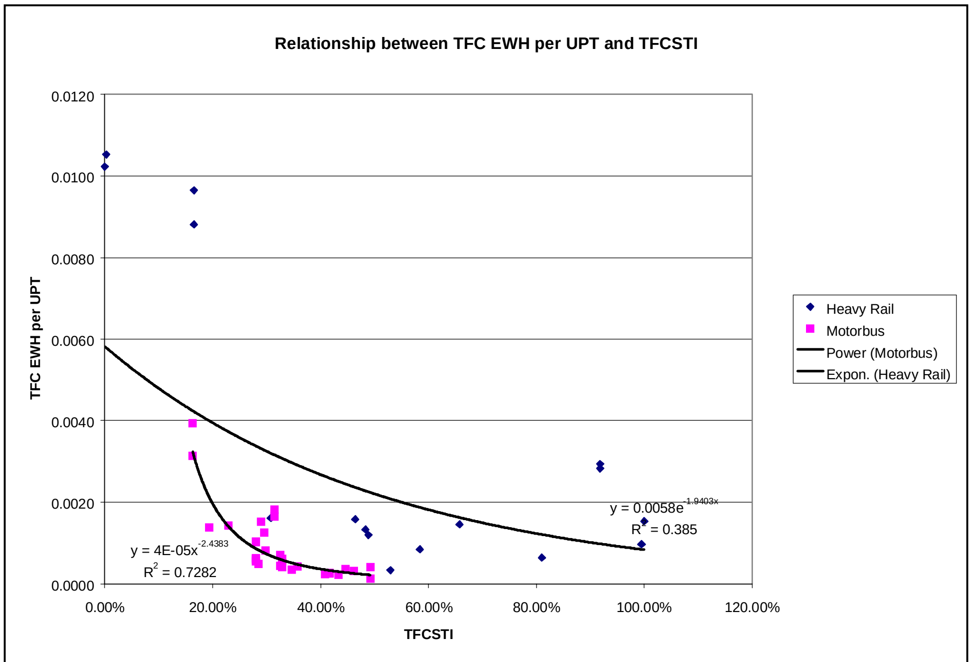

Figure 5-3. Relationship between TFCEWH/UPT and TFC System Technology Index.

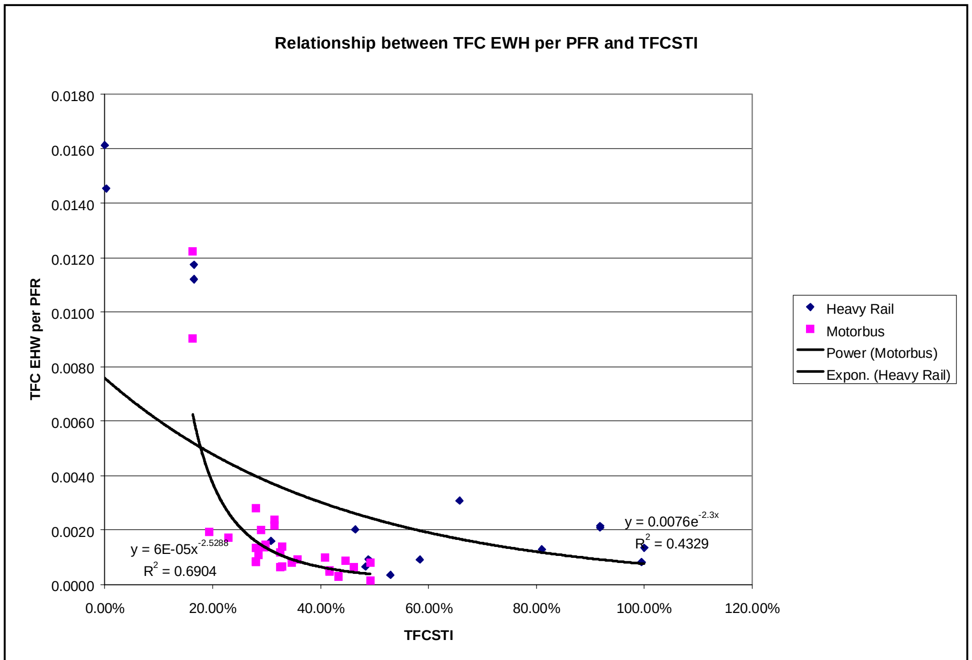

Figure 5-4. Relationship between TFCEWH/PFR and TFC System Technology Index.

CHAPTER 6: SUMMARY AND CONCLUSIONS

This chapter of the dissertation provides a summary of the work conducted, discusses the limitations of the research, states major conclusions, and outlines recommendations for further research.

6.1 SUMMARY

In this research, an effort has been made: (1) to develop a conceptual evaluation framework and evaluation plan to examine TFC operating costs on heavy rail and motorbus systems in the U.S. and (2) to analyze the impact of TFC system technologies on TFC operating costs with the aid of the evaluation framework and plan developed.

The following list presents a summary of the major tasks that were undertaken to address the above objectives:

1. A literature review was conducted to assess the present state of knowledge in the area of TFC system evaluation, the economics of public transit operations, and fare collection practices and technologies.

2. Building upon the research conducted by Collura (1992), Casey and Collura (1994), Fleishman et al. (1996), Collura and Plotnikov (2000), and Collura and Plotnikov (2001), a conceptual evaluation framework and evaluation plan were developed to examine the impact of TFC technologies on TFC operating costs. The author proposed that the evaluation framework and plan include the following major components: (1) discussion of issues associated with TFC operations on transit as perceived by transit operators and transit customers; (2) a statement of objectives for a selection of TFC system technologies; (3) description of TFC system alternatives available; (4) selection of TFC system performance measures; (5) selection of analytical methods and techniques to assess alternative TFC system technologies; and (6) determination of data requirements and selection of data sources to analyze alternative TFC system technologies.

3. Based on the literature review conducted, a research methodology was developed. The key elements of this methodology include the following:

    a. General theory relating TFC operating costs to transit demand, transit technology (mode), TFC technology, labor rules, and fare policy.

    b. Hypothesis relating TFC operating costs to transit demand, transit technology (mode), and TFC technology.

    c. Proposition that the major TFC system determinants are: (1) payment media accepted on the system; (2) fare media used on the system; (3) type of TFC equipment installed on the system; and (4) transit technology (mode). Also, it was suggested that payment media and fare media be considered and assessed separately as independent variables affecting TFC operating costs.

d. Proposition that TFC labor and transit ridership can serve as proxies for TFC operating cost and transit revenues correspondingly.

e. Proposition that the following TFC system performance measures can be used to assess the impact of TFC system technologies on TFC operating costs: (1) measures of TFC system cost effectiveness: (a) TFC operating costs per dollar of revenue collected (TFCOC/PFR) and (b) TFC operating costs per unlinked passenger trip (TFCOC/UPT); and (2) measures of TFC operations labor intensiveness: (a) TFC employee work hours per dollar of revenue collected (TFCEWH/PFR) and (b) TFC employee work hours per unlinked passenger trip (TFCEWH/UPT).

f. Proposition that the TFC System Technology Index (TFCSTI) should be developed and used to take into account impacts of different TFC system technologies on TFC operating costs.

4. The National Transit Database reports and APTA's Transit Fare Summaries were identified as the most suitable and readily accessible sources of information on fare collection practices in the U.S. These two sources were used to build a data set for this research. In addition, a verification questionnaire was developed and administered to ensure the reliability of the data.

5. Regression analyses and hypotheses testing examining TFC operating costs on heavy rail and motorbus systems in the U.S. were conducted with the aid of the evaluation framework, evaluation plan, and research methodology developed. The results obtained provided further evidence to support the general theory and hypotheses formulated in this research.

6.2 RESEARCH LIMITATIONS

As stated at the beginning of this report, the objectives of this research were twofold: (1) to formulate a conceptual evaluation framework and an evaluation plan to assess the operating costs of existing TFC systems in transit and (2) to analyze the operating expenses associated with existing TFC systems on heavy rail and motorbus transit in the U.S. with the aid of the evaluation framework and plan. Although both of the objectives were successfully accomplished, several reservations should be made with respect to the interpretation and utilization of this research results.

First, the conceptual evaluation framework and evaluation plan developed in this research are intended to be used for assessment of peer group TFC systems rather than evaluation of TFC system operational tests or assessment of alternative TFC technologies for a particular transit operator. The most likely use of the evaluation framework and plan developed would be for a broad industry-wide evaluation of alternative TFC technologies.

Second, the results of the data analysis examining the impact of TFC technologies on TFC operating costs are influenced, to a certain degree, by the way that the independent variable (TFC technology or TFC System Technology Index) is defined and formulated. For example, during the data analysis it was found that the effect of the electronic fare media (as opposed to cash or non-electronic fare media) utilization on TFC operating costs is insignificant. However, if more disaggregate data showing the utilization of specific fare media (i.e. smart cards, magnetic stripe tickets, tokens, paper tickets, flash passes, etc.) were available the results might be more revealing. Furthermore, the weighting scheme employed in calculating TFC System Technology Index needs to be further investigated and developed.

Third, the number of transit systems analyzed in this research was limited to 22 (8 heavy rail and 14 motorbus). Only two years of data—1993 and 1998—were available. Expanding the data sample would provide a better insight into the relationship between TFC technologies and TFC operating costs and would definitely improve the reliability of the results. Furthermore, some of the data used for the analysis in this research was estimated and might differ from the actual numbers. Although the author has attempted to use a sound rationale for making estimates, there is still some uncertainty regarding the accuracy of these estimates.

Finally, the data used for the analysis pertain primarily to large and medium transit systems. A better mix of small, medium, and large systems would be desirable and might affect the results.

6.3 CONCLUSIONS

In conclusion, this research has resulted in a number of significant contributions that are likely to be found useful to both researchers and practitioners.

First, this research provides a good review of the current state of knowledge in the areas of transit evaluation, economics of public transit operations, and fare collection practices and technologies. It assists in determining aspects and scope related to the assessment of TFC operating costs and presents a conceptual evaluation framework and an evaluation plan facilitating further work in the area of the TFC system evaluation.

Next, this research presents a systematic approach to define and describe alternative TFC systems and suggests that the major TFC system determinants are payment media, fare media, TFC equipment, and transit technology (mode).

Another key result of this research is the development of measures of effectiveness to evaluate alternative TFC systems. These measures assess cost-effectiveness and labor-intensiveness of TFC operations and include TFCOC/UPT, TFCOC/PFR, TFCEWH/UPT, and TFCEWH/PFR.

Perhaps, the most significant contribution that resulted from this research is the development of the TFC System Technology Index. Inherent in this index is recognition of the fact that TFC systems may consist of different sets of TFC technologies, both traditional and innovative. As a result, the assessment of TFC systems becomes the assessment of their component technologies.

Finally, this research presents statistical results that support the hypothesis that TFC operating costs are related to transit demand, transit technology (mode) and TFC technologies. These results further suggest that: (1) TFC operating costs per unlinked passenger trip on heavy rail systems are higher than on motorbus systems; and (2) controlling for transit mode, TFC operating costs per unlinked passenger trip tend to increase as the use of non-electronic fare media increases.

6.4 RECOMMENDATIONS FOR FURTHER RESEARCH

The findings and results obtained during the course of this research generated a number of unanswered questions, which if addressed in future research would likely further expand the pool of knowledge relating to the evaluation of TFC systems and contribute to the state-of-the-practice in this area. The following steps are recommended to address these questions:

1. Examine the impact of TFC technologies on labor-effectiveness.

2. Increase the number of transit systems investigated.

3. Increase the number of independent variables constituting the TFC System Technology Index.

4. Increase the number of modes investigated including light rail and commuter rail.

5. Investigate alternative schemes for calculating scores associated with individual TFC technologies and weights associated with TFC Technology Groups in the TFC System Technology Index.

6. Conduct time-series analyses over the period of 10-15 years for systems such as New York City Transit where a transition from one set of TFC technologies to another has taken place.

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EDUCATION

- **Virginia Tech, Falls Church, VA** — **Jan. 1999 - Present**
  Registered student in the Northern Virginia MBA Program.

- **Virginia Tech, Falls Church, VA** — **2001**
  Ph.D. degree in Civil Engineering. Concentration in Transportation Economics and Planning.

- **University of Massachusetts-Amherst, Amherst, MA** — **1997**
  M.S. degree in Civil Engineering. Concentration in Transportation Engineering and Planning.

- **Moscow Institute of Transportation Engineering, Moscow** — **1992**
  M.S. degree in Mechanical Engineering. Concentration in Manufacturing and Repair of Transportation Equipment.

EXPERIENCE

- **Virginia Tech, Falls Church, VA** — **Jan. 1998 - Present**
  Research Associate

  Current research relates to electronic payment systems and economics of transit.

- **E-Squared Engineering, Ashburn, VA** — **Summer 2000**
  Senior Specialist

- **University of Massachusetts, Amherst, MA** — **1996 - 1997**
  Research Assistant

- **Bureau of Planning, Design, and Manufacturing of Locomotives, Moscow** — **1989 - 1992**
  Research Associate

PROFESSIONAL / INTERESTS

- Areas of professional interest include electronic payment systems, transportation economics and planning, and application of technology and innovations in transportation.
- Member of the Intelligent Transportation Society of America (ITSA).
- Recipient of the ITS America 2001 Student Essay Competition Award.
- Co-author of the Electronic Payment Systems (EPS) Primer, a guideline document on EPS in transportation published by ITS America.
- Served as a committee member of the ITS Virginia Bulletin.

Held the offices of Vice-President and President for UMass Amherst Student Chapter of the Institute of Transportation Engineers.