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Rail Transit Fare Collection: Policy and Technology Assessment

Govind K. Deshpande
John J. Cucchissi
Ronald C. Heft

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena CA 91109

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16. Abstract

This study was conducted by the Jet Propulsion Laboratory in support of the UMTA Program in Fare Collection Research and Development.

The objective of the study was to evaluate the impact of fare policies and fare structure on the selection of equipment, describe fare collection systems, document hardware and technology related problems, and outline the requirements of a fare collection simulation model. The analyses in the report are based on extensive discussions supplied and documented by transit properties regarding operations and specifications of equipment.

Major findings of the study include: (1) a wide variation in the fare collection systems and equipment, caused primarily by historical precedence; (2) the reliability of AFC equipment used at BART and WMATA discouraged other properties from considering use of similar equipment; (3) existing equipment may not meet the fare collection needs of properties in the near future; (4) the cost of fare collection operation and maintenance is high; and (5) the relatively small market in fare collection equipment discourages new product development by suppliers.

Recommendations for fare collection R&D programs include development of new hardware to meet rail transit needs, study of impacts of alternate fare policies, increased communication among policymakers, and consensus on fare policy issues.

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PREFACE

This study was conducted in support of the Urban Mass Transportation Administration's Subsystem Technology Applications to Rail Systems (STARS) Program.

The work was sponsored by UMTA's Office of Technical Assistance, Office of Systems Engineering of the U.S. Department of Transportation. The Study is an assessment of policy and technology used in the collection of fares at rail transit properties in the United States and Canada. The Study is based primarily on the information supplied by the properties. At each property, extensive discussions were held by the study team regarding the policies, procedures, reliability, and technology related to the fare collection equipment.

We acknowledge the cooperation of the staff of the following properties:

Bay Area Rapid Transit

Mass Transportation Administration, Baltimore

Chicago Transit Authority

Dade County Department of Transportation

Greater Cleveland Regional Transit Authority

Illinois Central Gulf Railroad

Metropolitan Atlanta Rapid Transit Authority

Massachusetts Bay Transportation Authority

Montreal Urban Community Transit Commission

New York City Transit Authority

Port Authority Trans-Hudson Corporation (NY, NJ)

Port Authority Transit Corporation (PA, NJ)

Southeastern Pennsylvania Transportation Authority

Toronto Transit Commission

Washington Metropolitan Area Transit Authority.

Joe Koziol of the Transportation Systems Center, technical monitor of the study, provided valuable guidance throughout the study. The research described in this report was conducted by the Jet Propulsion Laboratory, California Institute of Technology and was sponsored by the Department of Transportation through an agreement with the National Aeronautics and Space Administration (NASA Task RD-152, Amendment 239). Other members of the JPL staff who contributed to the study include Ed Bahm, Louis Rubenstein, Joel Sandberg, Barry Harrow, and Frank Surber.

ORIGINAL PAGE IS
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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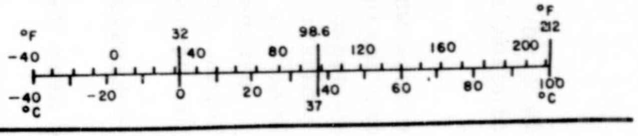
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ACRONYMS USED IN REPORT

AFC	Automatic Fare Collection
APTA	American Public Transit Association
BART	Bay Area Rapid Transit
CBD	Central Business District
CTA	Chicago Transit Authority
DPM	Downtown People Mover
EEPS	Entry/Exit Processing Systems
EFT	Electric Funds Transfer
EPS	Entry Processing Systems
GCRTA	Greater Cleveland Regional Transit Authority
ICGR	Illinois Central Gulf Railroad
LIRR	Long Island Railroad
MARTA	Metropolitan Atlanta Rapid Transit Authority
MBTA	Massachusetts Bay Transportation Authority
MTA	Maryland Transit Authority
MUCTC	Montreal Urban Community Transit Commission
NRI	National Rejector
NYCTA	New York City Transit Authority
PATH	Port Authority Trans-Hudson Corporation (NY, NJ)
PATCO	Port Authority Transit Corporation (PA, NJ)
ROM	Read-Only Memory
SCRTD	Southern California Rapid Transit District
SEPTA	Southeastern Pennsylvania Transportation Authority
TTL	Transistor-Transistor Logic
TTC	Toronto Transit Commission
WMATA	Washington Metropolitan Area Transit Authority

1.0 EXECUTIVE SUMMARY

1.1 Introduction

The transit industry is the focus of attention of everyone concerned: the riders, local governments, and the taxpayers. Interest in rail transit planning has been on the rise among policymakers and planners in several cities such as Los Angeles, Houston, and San Diego. Despite unprecedented increases in the price of gasoline, there have been only modest increases in mass transit ridership. The inability of mass transit operations to pay for themselves through revenues is being increasingly questioned. With the threat of impending withdrawal of federal subsidies and more frequent fare increases expected in the near future, fare policies and fare collection systems are being scrutinized.

There has been a rapid escalation of operating and maintenance costs of U.S. transit systems due largely to the recent high inflation rates. During this time period, despite increased O&M costs, the fares charged to the transit users have not kept pace with inflation. The increased costs are being met by subsidies both from local governments and federal sources. Since 1974 there have been requirements upon transit systems to provide increased mobility to the elderly and handicapped by including a 50% discount during the off-peak hours. Although adding to the fare collection system complexity, these requirements must be met by transit systems to be eligible for operating subsidies from UMTA.

Fare collection equipment in recent years has received more than its share of attention. This is primarily due to well-publicized fare collection equipment reliability problems encountered both at BART and WMATA. These systems possess complex fare structures, requiring sophisticated equipment to implement them. In addition, the emphasis at these systems on passenger convenience and system attractiveness resulted in an array of complex equipment.

In an attempt to resolve the reliability problems, lower the operation and maintenance cost, and simplify fare collection, transit authorities are focusing on the fare collection system. Many of the transit properties have existing fare collection equipment which is inflexible in terms of meeting special fares, such as monthly pass, elderly, and handicapped fares and fares differentiated by time of day. The fare structures of transit systems are constrained to a large extent by fare policies and available fare collection equipment. This study was conducted as a systems analysis of fare collection in support of the UMTA program in Fare Collection Research and Development. Several aspects of the fare collection systems in general were considered. The basic objectives of the study were:

1) to evaluate how fare policies and fare structures affect the selection of fare collection equipment;

2) to provide a description of existing fare collection equipment;

3) to document hardware-related problems at various properties and methods used to collect reliability data;

4) to describe the fare collection systems and specifications being chosen at new properties;

5) to assess existing analytical tools and outline additional requirements for fare collection simulation models for properties evaluating fare collection equipment performance, performing analyses of alternatives, and conducting system specification studies.

1.2 Approach

To develop supporting data for various aspects of the study, interviews were held with the fare collection staff of several of the transit properties. The interviews involved such issues as fare policies, fare structures, equipment and related problems, and current hardware development efforts. Information concerning maintenance and reliability data collection methods was also gathered. Several of the properties provided specification documents concerning the fare collection equipment that had been purchased in recent years. Information concerning the fare collection equipment at new systems was collected primarily by telephone contacts and documents supplied by these properties. The data on policy and technology of fare collection systems described above were analyzed and are described in subsequent chapters. Major findings and recommendations are summarized below.

1.3 Organization of the Report

Chapter 1 discusses the findings and recommendations of the study. Chapter 2 is a discussion of fare collection policies and their evolution. The fare collection systems concepts and equipment technology are discussed in Chapter 3. Fare collection systems implementation process including procurement practices are described in Chapter 4 with special reference to new properties. Chapter 5 outlines the requirements for a fare collection simulation model.

1.4 Findings

1. Rail transit properties use a wide range of fare policies, fare structures, and fare collection equipment. These range in simplicity from flat fares utilizing tokens at NYCTA to distance-related fares differentiated by time of day implemented through the use of magnetically encoded stored value farecards at WMATA. Among the new systems, San Diego light rail system uses the barrier free system, widely used in Europe.

2. Flat fares are used in most large city transit systems such as NYCTA and CTA and distance-based fares are used by systems which operate in more than a single political jurisdiction such as BART and WMATA. Fare policies that determine fare structures and fare collection equipment used by properties vary considerably. This variation occurs primarily because transit properties differ considerably in terms of the size of service area, characteristics of modes, number of political jurisdictions in the service area, and the nature of operating subsidies (local, state, and federal).

The rationale used by a majority of transit systems that use flat fares is that they are simple to understand and are convenient to the users. A big disadvantage of flat fares is that for a given ridership, they result in lower revenues and are perceived to be inequitable. The need to increase the revenues due to possible loss of federal subsidies will induce properties to change the flat fare structures to distance-based fare structures in the near future.

3. The poor reliability of AFC equipment during the early years in operation at BART and WMATA has discouraged some new properties from considering the use of similar equipment. A major cause of AFC reliability problems can be attributed to money handling associated with bill verifiers and coin acceptors which were designed for vending. Farecard jams was a major failure mode. Newer money handling equipment and redesigned transports have improved the level of fare gate reliability at WMATA to an acceptable level.

   The reliability aspect of AFC equipment forced WMATA to conduct a study of alternate fare collection systems. The study concluded that retaining the existing equipment and modifying it to improve the reliability was the best alternative available. The cost of new equipment, revenue considerations, fare equity, and the allocation of local share of subsidies among various political jurisdictions were some of the major factors in the WMATA conclusion.

   A major cause of WMATA AFC related problems can be attributed to fixed price contract during the equipment development phase. However, the installation of equipment prior to adequate testing in transit environment could have reduced some of the problems associated with equipment reliability.

4. Fare collection policies allowing properties to offer a range of services to various market segments resulting in efficient operation have not been implemented in the rail transit environment primarily due to lack of flexibility in fare collection equipment currently available. For example, numerous studies have shown that peak hour price elasticities are lower than off-peak and yet WMATA is the only property utilizing differential fares based on time of day. Lower fares during the off-peak hours result in higher load factors and increased revenues without significantly increasing operating costs. Monthly pass systems and special fares for the elderly and children are difficult to implement with existing fare collection equipment even though they result in lower fare collection costs and/or improved service.

5. The cost of operating and maintaining fare collection systems is generally high. They represent a range from 10% to 30% of the revenues collected. Most of this cost is labor related and consists of station attendants, operation and maintenance personnel, or security guards. Smaller systems like PATCO have been able to utilize TV surveillance and unmanned stations successfully. U.S. rail transit fare collection systems tend to be costly in terms of operations and maintenance compared to self-service (honor based) systems used widely in Europe. Hamburg fare collection system operation and maintenance costs represented only 7% of the revenues in 1978.

The level of fraud in fare collection systems is a major concern among all properties, independent of technology or procedures used. Security measures used to reduce fraud are costly.

6. No major innovations have occurred in the last decade in terms of equipment technology. The use of electronic funds transfer (EFT) technology for monthly pass systems used at MBTA is a significant improvement over the current AFC technology which relies heavily on electro-mechanical equipment. The relatively small market for fare collection equipment may have discouraged the manufacturers from conducting research and developing new equipment.

1.5 Recommendations

An assessment of the policy and technology issues reveals that fare collection will play a major role in the ability of transit systems to provide efficient service in the near future. Changes in fare policies are imminent at most properties to meet the higher revenues required by the expected loss of subsidies. Fare collection systems are expected to undergo a major overhaul to allow the adoption of new fare policies demanded by changes in the fiscal environment. There will be increasing incentive to raise fares, a trend that started in 1980 with fare increases ranging from 25% at NYCTA to 100% at MARTA. Predictions of base fares over a dollar have been made for major systems such as NYCTA and CTA by 1985. Properties will generally address two issues in their future fare collection needs: (1) reduce the cost of collecting fares, and (2) flexibility in fare collection system to meet special fares, increased fare levels, or alternate fare structures. A fare collection research and development program addressing the following issues is recommended.

1. Technology development is needed to design fare collection systems that are reliable, have lower life cycle costs, and are flexible in terms of alternate fare structures.

   Currently available AFC equipment is based on electro-mechanical devices which tend to have lower reliability. The annual cost of fare collection systems based on these devices is also high. Major properties, such as NYCTA, or a new property will find it difficult to implement distance-based fare structure based on current technology. Several advances have occurred in EFT technology and security access systems that are directly applicable to fare collection systems. A major advantage of these systems is high reliability and lower cost. In addition, these technologies can be retrofitted on the bulk of existing equipment such as turnstiles which can stay in place.

   Credit-card-based or microprocessor-chip-on-a-farecard systems allow the flexibility of fare structures and fares based not only on the basis of time, but also in terms of special fares for the elderly or other users. Computer-based systems are affecting all facets of life today. A promise of reduced overall costs with these systems and high reliability will find acceptance in the transit community.

Any technology development activity should be coordinated with the needs of bus fare collection. The functional needs of the fare collection equipment between bus and rail are similar, and the intermodal transfer is an integral part of both bus and rail fare collection systems. Development of this equipment will result in great convenience to transit users and will improve the service provided by transit in general.

2. Transit properties need assistance in determining the impact of alternate fare policies. In order to increase revenues, transit properties have generally resorted to increasing fare levels. Increases in fare levels result in some loss of ridership and, if the levels of fare increases are high, the result is a loss of revenue also. A policy option allowing an alternate fare structure can result in higher revenues, but has other socio-political impacts. The exact nature of these impacts needs to be studied. In addition, the cost of changeover and fare collection during transition is a significant problem. A study which provides guidelines to evaluate the alternative fare structures based on site specific data is highly desirable for properties considering such changes.

3. Increased communication among the policymakers at various properties is needed to help achieve consensus on policy aspects of fare collection. Uniformity of policy issues will result in uniform equipment requirements on the equipment. The operating costs of any fare collection system increase with the number of cash transactions. A policy option which suggests that a fare collection system be designed with less than 5% of riders using cash transactions will open up several alternative fare collection systems that have not been used, but for which technology exists. Another policy goal might be to design the fare collection system which costs, on an annual basis no more than 10% of the revenues collected. Other fares; options that require consensus include the desired level of fare collection equipment reliability, the role of the station attendant, and the use of intermodal transfer and its price.

2.0 FARE COLLECTION POLICIES

2.1 Fare Policy Evolution

In the early stages of transit development during the early 1900's transit companies in the U.S. utilized both flat fares and distance-related fares. The flat fare was justified on smaller lines and required payment on entry to the driver. In the distance-related fare structure, the collection of fares was accomplished by using a conductor onboard. In this time period up to 1940's, the transit companies were regulated to the extent that fares were set to allow for a reasonable return on investment.

These earlier transit systems had a great impact in shaping the structure of cities in terms of land use, especially in the northeastern U.S. However, transit could not expand to meet the needs of suburban residents and the competition of the automobile both because of declining ridership and the dispersed nature of suburban developments. The early sixties saw a major consolidation and public takeover of transit systems throughout the country. The primary reason for this consolidation was the deteriorating financial condition brought about by declining ridership and aging plant and equipment. The public ownership of these agencies changed the situation by massive infusion of local and federal aid into plant and equipment rehabilitation. However, public ownership had its adverse impacts - the level of fares was now politicized.

The philosophy that transit revenues pay for all transit operating costs was a common policy objective for a long time. However, decline in transit ridership was so severe that even grants from local, state, and federal governments were not sufficient to offset the deficits. Labor costs - a large proportion of transit operating costs - kept rising with inflation, and the popular political philosophy of keeping fare levels low has resulted in fare policy that relies more and more on operating subsidies from local, state, and federal sources. APTA data indicate that from 1973 to 1978 transit operating costs increased at an average annual rate of 13.2%, but the fares in the same time period rose at the annual rate of only 3.5% (1). That aspect of fare policy concerning the transit revenues to operating costs ratio will be increasingly debated in years to come. Consideration of the cost-recovery policy is important because of its effect on other fare collection policies. The scope of this study is limited to fare policy issues affecting the functional requirements of the fare collection system.

Fare policy decisions have a major impact on the quality of service provided by the transit system. A fare structure is the interpretation of fare policies into detailed pricing principles, subject to operational and technological constraints. The ultimate purpose of fare structure is to produce from passengers a total revenue which fare policy has determined as an objective (2). The operational constraints dictate not only equipment requirements and the role of the station attendant, but also affect intermodal transfer policies.

In general, fare policies adopted by properties are a reflection of the socio-economical, geographical, and fiscal considerations of their service area. The fare policies change with the changing environment in which transit properties operate. The fare levels, for example, have been increased at most properties during the last year to offset operating cost increases brought about by inflation. In the future, fare level increases or fare structure changes may be necessary to offset the loss of operating subsidies.

2.2 Fare Structures

There are three basic types of fare structures: (1) flat fare, (2) zone fare, and (3) distance-related. The flat fare structure prices all rides a given charge equal to the flat fare. A large majority of transit systems in the U.S. use the flat fare structure because of the simplicity of implementation. No differentiation has to be made among patrons based on the length of the ride. Flat fare requires only entry control; exits are freewheeling.

The zone fare structure implies that the coverage areas are divided into several zones based on geometric patterns of grids, concentric circles, distinctly identifiable land uses or political jurisdiction. The zone fare structure implemented by automatic fare collection equipment requires certain predetermined fares between any two zones be collected from the patrons. Implementation of zone fare structure requires a fare processing mechanism both on entry and exit.

Most distance-related fare structures involve pricing based on two components to which the cost of service can be attributed: (1) the fixed charge, representing the fixed costs per trip, and (2) a charge which is a function of the distance traveled, representing the variable cost of the trip. The distance-related fare structure requires that fares be processed on entry and exit. Fare structures, fare levels, and special fares charged for rail transit systems in the U.S. as of June of 1980 are shown in Table 2-1.

The flat fare structure utilizing coins or tokens is the simplest one to implement, with fare processing equipment needed only at the entry point. The most popular media with automatic fare collection equipment are tokens which are purchased from the station attendant. Some properties utilize coins. The fare media matrix for various properties is shown in Table 2-2.

Flat fares are perceived by many transit riders to be inequitable. Those traveling a short distance feel that they should be charged a lower fare than someone who is going a substantial distance. However, since fare box revenues have not been required to provide for all the operating costs, the flat fare structure has been accepted as a compromise between the complexity of equipment required and the ability to collect higher revenue under a different fare structure. There is reason to believe that within the near future, with an increase in emphasis on obtaining a higher proportion of operating funds from passenger revenues, there will be an incentive to pursue alternate fare structures that are more equitable for transit users. By then, equipment reliability may not be a hindrance to the consideration of alternate fare structures.

Table 2-1 Fare Structures, Fare Levels, and Special Fares at Rail Transit Properties

PROPERTY:	MARTA	MBTA	CTA	GCRTA	NYCTA	PATH	SEPTA	MUCTC	TTC	ICG	PATCO	BART	WMATA
TYPE OF FARE STRUCTURE:	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Flat	Zone	Zone	Distance	Distance/Flat
FULL FARE: (Peak/Off-peak)	50¢	50¢(1)	60¢	50¢	60¢	30¢	65¢	60¢	60¢	$1-2.05	55¢-$1.15	50¢-$1.75	55¢-$1.70/50¢
DISCOUNT FARE (bulk purchase):	No	No	No	No	No	No	No	46-2/3¢	50¢	No	No	No	No
REDUCED FARE													
Senior Citizen:	50¢/25¢	25¢	25¢	25¢/free	30¢	No	30¢/free	25¢	25¢	50% off	Full/27.5¢	90% off	50% off(8)
Handicapped:	50¢/25¢	50¢/25¢	25¢	25¢/free	30¢	No	65¢/30¢	No	No	50% off	Full/27.5¢	75% off	50% off(8)
Student:**	No	25¢	25¢	¢	Yes(4)	No	30¢	25¢	30¢	50% off	No	75% off(7)	10¢(9)
Child:	No	25¢	25¢	25¢/20¢	No	No	No		20¢	50% off	No	75% off	No
DISCOUNT REDUCED FARE (bulk purchase)													
Senior Citizen:	No	No	No	No	No	No	No	20¢	25¢	No	No	No	No
Handicapped:	No	No	No	No	No	No	No	No	No	No	No	No	No
Student:**	No	No	No	No	No	No	No	20¢	25¢	No	No	No	No
Child:	No	No	No	No	No	No	No		16-2/3¢	No	No	No	No
PASS													
Monthly	$20*	$34.20*(2)	$30*	$20*	No	No	$32*	$16*	$26*	$27-$55(5)	No	No	No
Weekly	No	No	No	$4*(3)	No	No	$8.25*	No	No	$8-$17(6)	No	No	No
Two Week	No	No	No	No	No	No	No	No	No	No	No	No	$11-$20(10)

Data as of June 1980.

* Unlimited multimodal
** for students through high school during school hours
(1) additional charges beyond inner zone
(2) five other passes available, but usage restricted to specific MBTA services.
(3) plus 10¢/ride for rapid transit
(4) reduced and free fares available
(5) 60-62 stored ride monthly ticket
(6) 14 stored ride weekly ticket
(7) on field trips
(8) 50% off peak period fare up to a maximum of 50¢ at all times
(9) D.C. school children only, traveling within the District of Columbia
(10) five flash passes available for unlimited bus rides in defined areas. Fixed Metrorail value ($5-$6) is magnetically encoded on flash pass.

Table 2-2 Fare Media Matrix

MEDIA	TOKENS	COINS	TICKETS(3)	PASS (4)	MAG CODED (5)
MARTA	*	*		*(1)	
MBTA	*	*		*(1)	
CTA	*	*		*	
GCRTA		*	*	*	
NYCTA	*				
PATH		*			
SEPTA	*	*		*	
MUCTC		*	*	*	
TTC	*	*	*	*	
ICG					*
PATCO					*
BART					*
WMATA				*(2)	*

(1) Magnetically encoded monthly pass.
(2) Flash pass for unlimited bus rides in a defined area. Fixed Metrorail value is magnetically encoded. Bus rides good until expiration date. Rail portion has no expiration date and a value is deducted per ride.
(3) Single ride paper tickets.
(4) Unlimited multimodal flash pass, except where noted.
(5) Magnetically encoded stored ride or stored value farecards.

A recent study (3) conducted for NYCTA concluded that a flexible fare collection system can be installed and operated with a high probability of ultimate success. However, the major drawback in the implementation of such a system was the cost of physical and structural changes at stations. The study recommended that further analysis was required to estimate the costs of these structural changes, effect on passenger flow rates, security, and impact on revenues and riderships. However, the final decision to change the fare structure, a major policy decision, will have to be made on the basis of political considerations and the cost-effectiveness of the overall system.

In general, flat fare system deters the expansion of existing rail systems because the marginal revenue would not be sufficient to justify the marginal cost; at the same time, flat fare further enhances the notion of inequity. With this in mind, Miami Metro has selected a flat fare system with the flexibility to accommodate a zone fare structure in the event of future expansion.

The zone fare system is generally perceived to be more equitable to users than the flat fare system. In the U.S., zone fare structures have been implemented primarily by systems operating in more than one political jurisdiction. Zone fares have been used by commuter railroads such as the Long Island Railroad (LIRR) for a long time but are collected by utilizing a conductor onboard the train. Illinois Central Gulf Railroad (ICGR) was the first property to utilize the zone fare structure with automatic fare collection (AFC) equipment.

For the sake of uniformity, a transit property may select a fare structure for its new rail system that is extant on its bus system. This is reflected in the choice of a zone fare structure for the Baltimore MTA, and the apparent desire of SCRTD for a zone fare system for the Wilshire starter line.

MBTA uses a variant of a three zone fare structure which requires payment on both entry and exit for travel between zones. Within the central zone, no payment is required on exit. The AFC equipment at ICGR and PATCO requires magnetic encoding and decoding of farecards at both entry and exit to assure that the appropriate fare has been paid. Both PATCO and ICGR utilize unmanned stations with telephone lines to central control in case of a patron problem with the farecard or the equipment. Fare level changes in a zone fare structure with AFC equipment require only software modifications or changes in read-only memories (ROMS). Minor changes in equipment and software could allow the use of differential peak and off-peak fares, but neither PATCO nor ICGR use time-based fare differentiation.

Distance-related fare structures have been widely used with manually implemented fare systems. London Transport has used this fare structure for many years. However, because of the high costs involved in a manual system, this fare structure was not seriously considered in the U.S. until a decade ago with the projected availability of suitable AFC equipment. BART and WMATA, two recently built regional rail systems, are unique in the sense that they provide local service in downtown areas and commuter service for suburbs. The fiscal requirements of several political jurisdictions and the notion of equity have dictated that distance-related fare structures be used at these properties.

In analyzing the history of fare collection system development at both BART and WMATA, it was noted that the decision to utilize AFC equipment to implement a distance-related fare structure was made before the equipment was adequately tested for transit usage. This may have been a major cause of reliability problems encountered at both properties. Though the operation of fare collection equipment at both BART and WMATA now shows improvement over earlier years of operation, the well-publicized reliability problems still deter new properties from considering the distance-related fare structure with current automatic fare collection equipment. As a new property, Miami has explicit goals of implementing a simpler fare collection system.

The AFC equipment utilized to implement a distance-related fare structure has some inherent advantages in allowing time differentiated fares; however, the overall equipment is highly complex. The fare processing requires encoding of the entry station, determination of fare between entry and exit stations, deduction of the trip fare from the farecard value, and, finally, encoding and printing the remaining value on the farecard. The AFC equipment also allows the patron to enter the system with a minimal value on the farecard; the required fare can be paid before exiting by using the addfare machine. This results in great convenience to the patron, but at the cost of maintaining highly complex electromechanical equipment.

2.3 Transfer Policy

In most cities with rail transit, a bus system provides complementary service. The concept of intermodal transfer is to provide fare equality and convenience to the user by permitting him to travel on both modes by paying the full fare only once with perhaps a nominal fare on the linked mode.

There are substantial differences among U.S. properties regarding transfer policy. Table 2-3 shows the kind of transfers allowed and the costs to a patron for the purchase of the intermodal transfer at various properties. The primary transfer policy issue deals with allowing the use of the intermodal transfer. Transit properties such as NYCTA and MBTA, which have extensive rail and bus systems with wide coverage, do not allow transfers for full fare riders. The primary concern at these properties is that allowing transfers would result in misuse of the transfer and loss in revenues since transfers are often free or discounted. The policy of not allowing transfers between modes results in duplicate and competing modes with the net effect of lower load factors and higher operating costs. Eliminating or reducing services are difficult decisions to make because of public opposition.

The rail to bus transfer is generally implemented by utilizing a transfer issuing machine in the paid area of the station, and the transfers are generally free. This technique is used at BART for rides on AC Transit in Oakland. There is extensive misuse of transfers when they are free. Both CTA and MARTA restrict only one transfer per patron by installing the transfer issuing machines in the turnstiles. At CTA, transfers cost a dime but are free at MARTA. At WMATA, the free rail to bus transfer allows a discount on the bus trip. In the early discussions of transfer policy at WMATA, which has a zone fare on its bus system, the economic argument led to the adoption of the discount fare. The governments of the region felt that they could not afford a free bus to rail transfer.

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Table 2-3 Transfer Policy

	RAIL TO BUS	BUS TO RAIL
MARTA	Free	Free(1)
MBTA	No	No
CTA	10¢	10¢
GCRTA	Free	Free
NYCTA	No(2)	No(2)
PATH	No	No
SEPTA	10¢	10¢
MUCTC	Free	Free(3)
TTC	Free	Free
ICG	No	No
PATCO	Yes(4)	No
BART	Free(5)	No
WMATA	Yes(6)	No

(1) Magnetically encoded card.
(2) Free transfers allowed where bus line has replaced former trolley or elevated lines.
(3) Optically encoded on vehicle.
(4) Transport of New Jersey round trip bus tickets issued for payment of one-way bus fare. PATCO validation required.
(5) To Alameda/Contra Costa County buses only.
(6) Free transfer dispensed. It is good for reduced bus fare.

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Few properties allow the bus to rail transfer. The implementation of a bus to rail transfer in many cases requires machine-readable transfer dispensers on buses. The cost of equipping buses with equipment to issue transfers has been a major factor in discouraging wider application of bus to rail transfer. The bus to rail transfer has been implemented only at properties which have flat fares on both the bus and the rail systems, such as at MARTA, MUCTC, TTC, SEPTA, and GCRTA. At Montreal, the bus to rail transfer is an optically coded paper ticket which can be read by turnstiles for validity.

2.4 Special Fares Policy

Special fares, such as those designated for use by senior citizens, the handicapped, and school children, are generally discounted compared to adult full fares. The impetus to utilize special fares comes from the social goal of assisting the mobility of these groups. UMTA requires properties to adopt special fares for these groups to be eligible for transit operating grants. Special fare and transfer implementation at various properties is shown in Table 2-4. Media distribution matrix is shown in Table 2-5.

Fare collection equipment at most properties is automated to the extent that station agent participation is not required to process the fare media. Adoption of special fares requires extensive station agent interface. If station agent interface is to be avoided, as is the policy at BART and WMATA, inducement for fraud results.

The special fare tickets can be purchased for the elderly at BART for a 90% discount at off-station locations. They are of a different color from the regular ticket. The software at BART gates does not discriminate between full fare and special fare patrons. There is nothing in the equipment or fare collection procedures to prevent the misuse of these farecards. Although it is not known how widespread this practice is, it does illustrate the consequences of adopting fare policies beyond equipment capabilities.

Most of the properties utilizing station agents to implement special fares have fewer problems. Properties such as NYCTA and GCRTA issue ID cards to these patrons which allow them to purchase fare media at a discount.

The properties that use station agents to process special fares do so because of the operational nature of their processing equipment. Cleveland and Philadelphia collect most of their fares through an agent-activated turnstile. New York, Boston, and Toronto are token turnstile systems; of these, only Toronto discounts tokens. However, these are full fare tokens discounted for bulk purchase. Chicago has coin-accepting turnstiles. Despite

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Table 2-4 Special Fares and Transfers Implementation

Property	SPECIAL FARES		TRANSFERS	
	Station Agent	Automatic Gates	Station Agent	Automatic Gates
MARTA		*(1)		*(1)
MBTA	*			
CTA	*		*	
GCRTA	*		*	
NYCTA	*		*	
SEPTA	*		*	
MUCTC	*			*(2)
TTC	*		*	
ICG		*(1)		
PATCO		*(1)		
BART		*(1)		
WMATA		*(1)		

(1) Magnetically encoded card
(2) Optically encoded card

Table 2-5 Media Distribution Matrix

PROPERTY	STATION AGENT	VENDING MACHINES	OFF-STATION OUTLETS
MARTA			*
MBTA	*		*
CTA	*		*
GCRTA	*		*
NYCTA	*		
SEPTA	*		*
MUCTC	*		*
TTC	*	*	*
ICG	*(1)	*	
PATCO	*(1)	*	*
BART		*	*
WMATA		*	*

(1) Ticket agents at certain stations

having the capability to accept tokens which could possibly be used for special fare riders, at CTA only one-third of the rail stations are equipped with automatic turnstiles, thus requiring agent processing at the remaining stations. Finally, Montreal has automatic turnstiles that accept magnetically encoded tickets. Like BART and WMATA, the software is limited to acceptance of full fare tickets only.

Whereas, in the past, station agents primarily vended tokens or made change, they are now involved in the surveillance of reduced fare riders. Although many systems may have an alternative to manual processing, agent surveillance is considered a deterrent to fraud. Agent processing allows the use of a diversity of fare media without the need for exotic equipment. Since the agents are necessary to perform other functions, some properties use their presence to the fullest extent.

3.0 FARE COLLECTION SYSTEMS CONCEPTS AND EQUIPMENT TECHNOLOGY

3.1 Introduction

The rail transit fare collection system performs several functions including the collection of fare, entry and exit control at the stations, and accounting of both passengers and revenues. These functions are accomplished by a combination of equipment, personnel, and procedures. The fare collection system complexity increases as the number of functions involved in collecting fares increases. These may include collection of distance-based fares which vary from patron to patron, fares for elderly and handicapped, and issuance of intermodal transfers.

For example, the NYCTA utilizes a flat fare (60¢) structure and has simple token-activated turnstiles at station entrances. The exit turnstiles are free wheeling. The station attendants sell tokens, account for the turnstile actuations, and process the reduced elderly and special fares. The revenues are collected from the transit stations by the crews of revenue trains.

By comparison, the fare collection system at WMATA relies more on equipment. It utilizes the distance-related fare structure. The farecard vendor accepts currency and coins up to $20 and magnetically encodes the farecard. On entry, the farecard is inserted in the entry gate slot. It is read for minimum value and the entry station and time are encoded on the card and returned to the patron. On exit, the card is again inserted for exit processing in the exit turnstile. The fare for the trip is calculated, deducted from the value of the farecard, and the value remaining in the farecard is encoded and printed on the farecard. Thus, the equipment performs both vending and fare extraction functions.

The gate logic stores two fare tables for trips made during peak hours and off-peak hours and charges patrons accordingly. The station attendant serves to help patrons with information at WMATA and with farecard jams. The revenue is collected from the farecard vendors and addfare machines by the revenue train crew. Freestanding machines at WMATA stations dispense transfers which are good for a prescribed discount on the bus trip. The special fares are collected by utilizing color coded farecards which are sold at a discount to eligible patrons. The gate logic does not distinguish among the regular and special farecards; color coding assists the attendants in fare surveillance.

Comparison of these two fare collection systems shows a wide range of equipment complexity, role of station attendant, and procedures. The fare collection systems used at other properties show equipment capabilities and other functions performed that lie between the simpler NYCTA system and the more complex WMATA system.

3.2 Systems Concepts

To develop a better understanding of the fare collection systems concepts and equipment functional requirements, a classification of fare collection systems was made on the basis of how a patron fare is processed. Based on an analysis of fare collection at rail transit systems in the U.S. and Canada, systems can be classified into three basic systems concepts:

1. The Entry Processing System
2. The Entry/Exit Processing System
3. Barrier-Free Processing System

3.2.1 Entry Processing System

The entry processing system (EPS) is the simplest of the fare collection systems concepts and is ideally suited for flat fare systems. The EPS requires no exit processing. A flow diagram of a customer using EPS is shown in Figure 3-1. Tokens and combinations of coins to make up the fare are most widely used on entry into the turnstiles which activate the entry. Tickets are used by GCRTA, MUTUC, and TTC. The GCRTA tickets require a check by the station attendant whereas the MUTUC ticket is magnetically encoded and is inserted in the turnstile for a valid entry.

Coins are used as fare media at most properties which utilize AFC. The coins are a convenient media because there is no need to interface with station attendant for purchase of media. However, systems accepting coins require interface with a station attendant for change at MBTA, GCRTA, MUTUC and TTC. The turnstiles at PATH, MARTA, and CTA are capable of accepting coins. The reliability of token-operated turnstiles is generally higher than the coin operated. Use of coins also slows down the processing rates.

Most EPS systems in the U.S. utilize the station attendant to distribute tokens and tickets. The MARTA fare collection system is designed for unmanned operation. It is interesting to note that change makers are generally not used in conjunction with the coin-operated turnstiles. Token vending machines are available only at TTC where tokens cost only 50¢ each when purchased from a token vending machine compared to 60¢ paid to the station attendant. It is possible to purchase fare media at off station locations at several properties, reducing the station attendant interface.

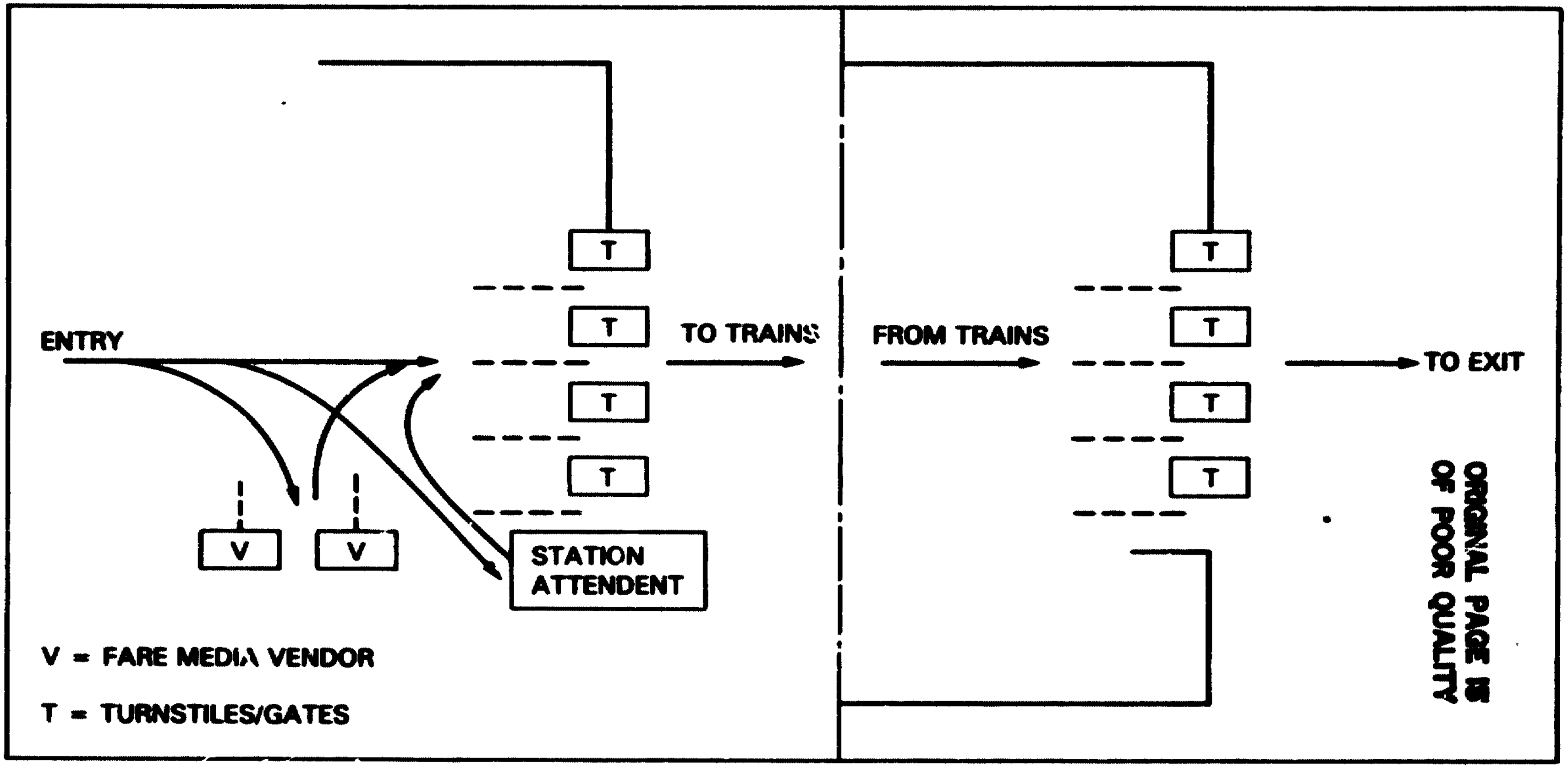

Figure 3-1 Entry Processing System

3.2.2 The Entry/Exit Processing System (EEPS)

The Entry/Exit Processing system is widely used where fares are based on distance such as zone fares or distance-related fares. The need to assure appropriate fare for a given trip has been paid requires that each patron be processed both at entry and exit. The flow diagram of the EEPS is shown in Figure 3-2. Systems using this concept include zone fare structure properties such as ICGR and PATCO, and distance related fare structure properties such as BART and WMATA. These systems require magnetically encoded fare cards.

In this concept, the patron requires no station attendant interface. The fare cards can be purchased from vendors for a single ride, and multiple ride (zone) or stored value (distance-based) either for a single ride or a high value from which multirides can be deducted. At some properties, these fare cards are also sold at off station sites. The station attendant, even if present, handles no cash or farecards. However, he will help in case of providing information or to relieve a fare card jam, or some other fare collection equipment-related problem.

Monthly passes similar to the ones being implemented at MBTA are not used at BART or WMATA. However, higher value farecards can be used at both BART and WMATA to avoid frequent use of the vending machines. PATCO and ICGR vend multiple ride farecards. There is generally no discount in the purchases of higher value farecards or multiple ride farecards. The policy of not discounting seems to have been adopted due to lack of appropriate equipment at the properties and resulting reduced revenues.

Recent experience of properties using EEPS has been mixed. From the patron point of view exit processing has meant a complicated fare collection system. The operation of these systems causes difficulties for the occasional rider or tourist. The reliability of these systems during early years of operation was lower than expected. There has been some improvement in recent years.

3.2.3 Barrier-Free System

The barrier-free system is a fare collection systems concept used widely in Europe. San Diego, implementing it for its Light Rail System, will be the first U.S. property to use this concept. Figure 3-3 shows the flow diagram of this system. This system relies on the patron to purchase ticket and have it validated for a given trip. The proof of purchase of ticket and validation would have date and time stamped on it. The system is simple and there are no hassles of turnstile farecard jams. The system is designed so that only a spot check of passengers is performed by either uniformed or plain clothed inspectors. This concept is expected to cost considerably less than the other fare collection systems concepts.

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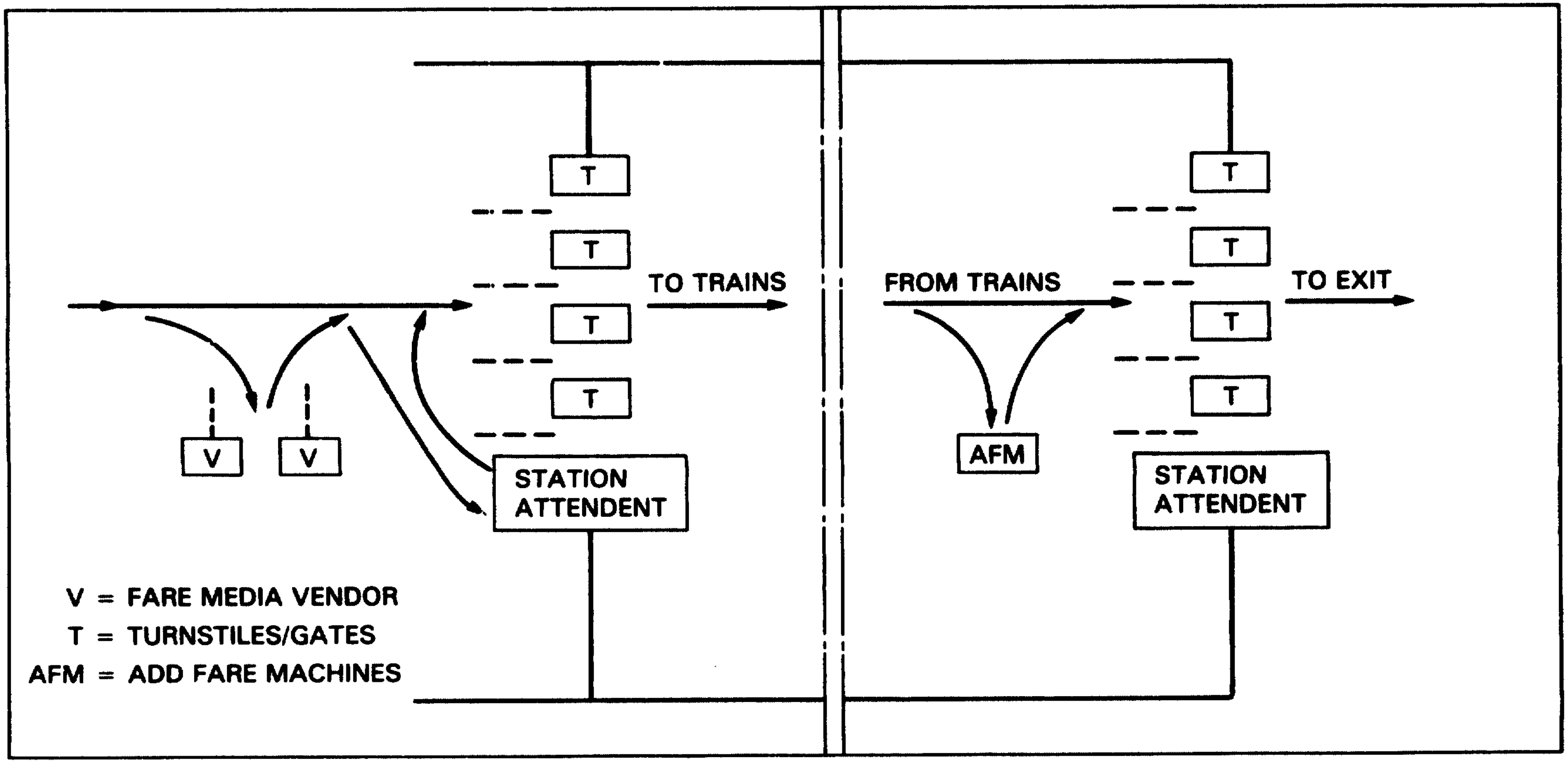

Figure 3-2 Entry/Exit Processing System

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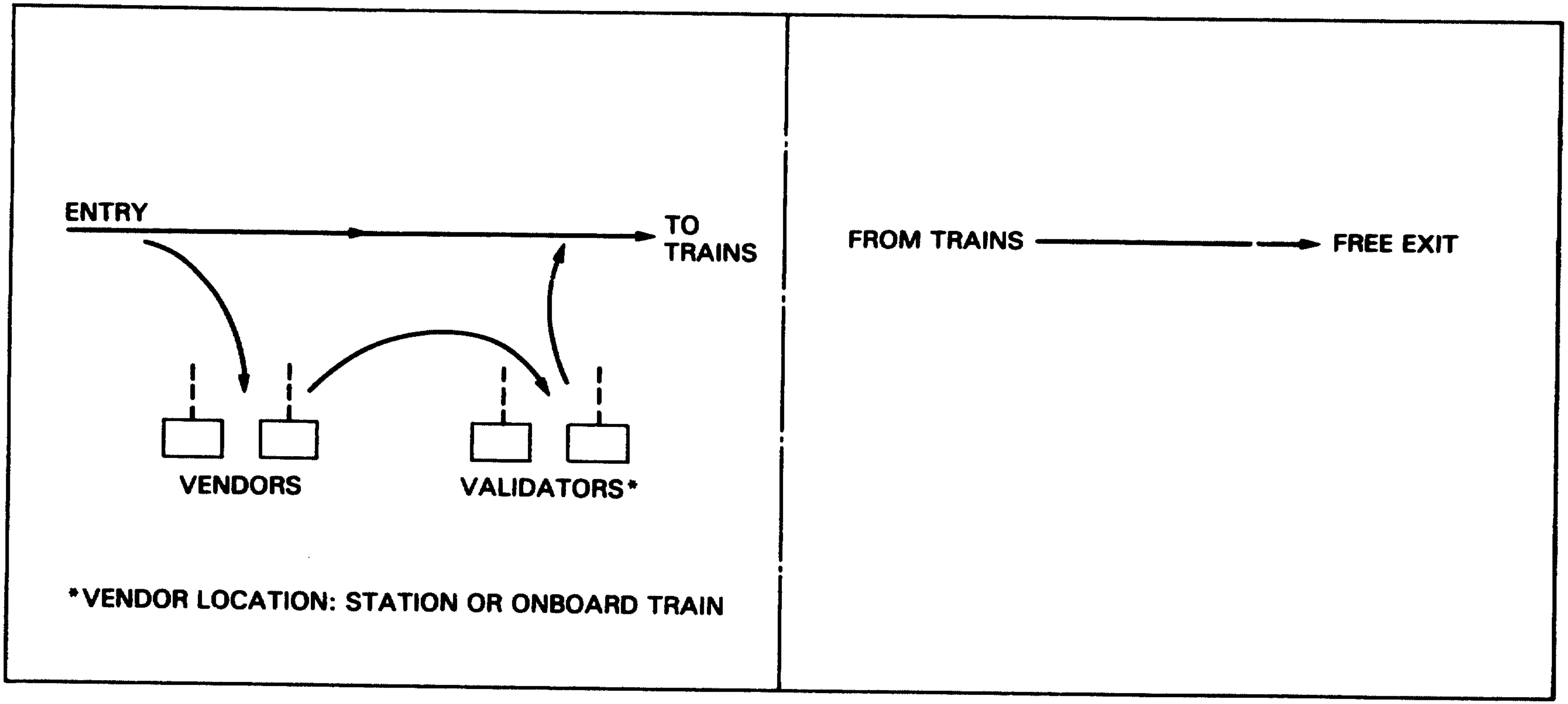

Figure 3-3 Barrier-Free System

The barrier-free concept can be used for any fare structure, flat, zone or distance-related. The vending machine will vend the appropriate ticket for a ride upon the insertion of the fare. The ticket is then validated for station, date and time. Monthly passes for unlimited rides would require no validation. Upon request from an inspector, the passenger has to show he validated the ticket or monthly pass. Barrier-free systems allow the use of multiple ride tickets and monthly passes without imposing complex requirements on equipment. This system is attractive from both the user and transit system management perspective. It is simple, and with a monthly pass the patron can walk straight to the station platform and take the ride and return at the exit without any processing. Fare collection costs can be quite low compared to other concepts.

Based upon European experience, the system can perform quite well; however, its performance in the U.S. is somewhat uncertain. The confrontation of patron without a valid ticket with the ticket inspector is a sensitive issue. Appropriate legislation and imposition of fines that are well publicized could result in low fare evasion rides. The experience from San Diego could help several properties in considering this concept as a viable option.

3.3 Fare Collection Equipment

A wide variety of fare collection equipment is in use in the U.S. and Canada. Fare collection at any property may consist of combinations of turnstiles or fare gates, vendors (token or ticket), change makers, transfer issuing machines, and addfare machines. Other equipment in recent years has included high speed encoders, and data acquisition and recording equipment associated with magnetically or optically encoded fare cards.

Other fare handling equipment not generally found in stations consists of revenue counting machines, safes, and vaults. This chapter discusses the capabilities associated with the fare collection equipment and its performance.

3.3.1 Turnstiles and Fare Gates

Turnstiles act as barriers that control passenger entry and exit. Entry turnstiles allow a passenger to enter the system upon payment of a fare in the form of a token, coin, or machine readable pass, or in response to a station-agent-activated signal. Exit turnstiles are usually used to maintain a one-way passenger flow. Passengers disembarking from a train generate a very high flow rate per unit time on a station's exit control system. The entry flow rates are generally much lower than the exit rates. Turnstiles are usually reversible, but the slam gate which allows only exit is often the faster route.

If a fare is to be collected from passengers upon entry, it is imperative to maintain high flow rates and avoid long queues. Reliability and flow rates of entry gates associated with various types of fare media as reported by properties are shown in Table 3-1. Turnstiles can also be used in conjunction with automatic pass readers or a station-attendant-operated gate to accept transfers and monthly passes. Several turnstiles, such as those used by MARTA and CTA, issue transfers encoded with time, date, and station. Requiring that a passenger pass through the turnstile before a transfer is issued insures against a passenger obtaining more than one transfer.

Some turnstiles have been equipped to accept magnetically encoded transfers or monthly passes (MARTA) or punched hole encoded transfers (Montreal). Depending upon the distributions of types of coin, value of tokens, or security of the money container, turnstiles can store between $500 and $1500 in coin and/or tokens. A station with 9000 boarding passengers per day - a fare of 50¢ - and 5 turnstiles might require that the turnstiles be emptied at least once a day.

3.3.2 Bill Validators

Bill validators used in transit accept or reject $1 and $5 bills and indicate via a signal the acceptance to the control logic of a ticket vendor or bill changer. A major problem with bill validators is their frequent rejection of worn but valid bills, their tendency to jam when rejecting a bill, and their susceptibility to jamming by insertion of small foreign objects. It is difficult to develop reliability statistics on bill validators, since they rarely stand alone, and are usually associated with other subsystems such as a bill stacker or escrow. These three subsystems are rarely used together in the vending industry, but their joint use in the transit industry is common. Since a transit ticket can cost a few dollars, the escrow is utilized to hold the dollars inserted until the transaction is finalized. If cancelled, the same dollars inserted are returned to the patron.

Table 3-1 Reliability and Flow Rates for Gates and Turnstiles

Turnstile Reliability	Reliability Transactions per Failure
NYCTA - Token accepting (PEREY)	40,000
CTA - Coin accepting-transfer issuing (DUNCAN)	2,500
PATH - Coin Accepting (TILTMAN LANGLEY)	11,000

	Flow Rates Persons/Minute
Doors - Free Swinging	40-60
Registering Turnstiles	
Free Admission	40-60
with Ticket Collector (manual)	25-35
Coin Operated	
Single Slot	25-50
Single Slot - one coin	45
two coins	30
Double Slot	15-25
Fare Gates, Magnetically Encoded Farecards	20-30

Data from the WMATA farecard vendor field test program conducted between October 1978 and March 1979 at six selected stations indicate a reliability rate of 427 transactions per bill jam. Only part of these failures can be attributed to the validator. WMATA uses a bill validator manufactured by National Rejector (NRI).

PATH uses the NRI bill validator on 16 bill changers that accept a $1 bill, deduct the fare, return change, and activate the turnstile. No escrow or bill stacker is used. Use of a stacker was attempted but it was considered less troublesome to sort the bills manually in the counting room than to accept the lowered reliability associated with the stacker. Problems were reported with operation of the validator in cold weather. These were solved by enclosing a light bulb to provide heat.

The bill validator failure rates as estimated by PATH staff are:

	Transactions/Failure
Bill Jam	2857
Half Operations (one of two magnetic head readers out of service)	4000
Fail Safe-Shortchange	10,000
Unfounded patron reports of machine failures	10,000
Readjustment Required	10,000

PATCO uses bill changers that have bill stackers. Their reported failure rate is 2000 transactions/failure. Several vending machine operators report a reliability rate of 4000 transactions per failure on their bill changers. It is evident that there is substantial variation in bill validator performance. Engineering modifications to the existing bill validators could lead to significant improvement in performance.

3.3.3 Coin Acceptors

Coin acceptors are an integral part of most ticket vendors and some turnstiles or gates. Their performance in existing fare collection equipment has not been satisfactory and has been a frequent cause of jams. Based on a survey of equipment suppliers, it appears that products with improved performance are expected to be marketed.

The functional requirements of coin acceptors vary with their application. If used in a turnstile, their speed of operation is a critical feature. The acceptance of an occasional slug is not a major problem. The philosophy in the industry is that passengers stealing a ride from a turnstile present a less critical problem than stealing cash from a changemaker or a high value ticket from a vendor.

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Coin acceptors are sometimes sold as part of a larger coin changer unit that includes an escrow function and a change return function. The prices of transit tickets are usually higher than those of items sold from vending machines. Increase in the escrow capacity would be required before some commercial vending equipment could be used in transit.

Earlier models of coin acceptors were very sensitive to dirt picked up from coins and also to bent dimes. Surveys conducted of farecard vendors by WMATA at six stations during November 1978 and March 1979 indicate a reliability rate of 545 vends per coin jam. PATH reports that the vast majority of their turnstile failures are caused by bent dimes in the coin-accepting mechanism. PATH estimates its turnstiles to have a reliability rate of 11,000 transactions per failure.

In the area of new developments, Coinco has developed and is marketing a plastic mechanical acceptor. MARS Money Systems, Folcroft, PA, has had an electronic coin changer that accepts the dollar coin on the market for several years.

WMATA has tested several of the new plastic mechanical coin acceptors and reports significant improvements in performance and reduced adjustment requirements (8). This unit is inexpensive enough so that it could be replaced in field vendors on a periodic basis as a preventive maintenance measure.

3.3.4 Monthly Pass Readers

General Description

Many transit systems have expressed interest in the use of a pass reader. These could be used to process monthly passes for commuters, the elderly, handicapped persons, and students as well as single ride tickets.

A desirable feature of such a system is that the ticket or pass not leave the passenger's hand. Fare collection systems in which the passenger must temporarily surrender his card to a card transport result in frequent farecard jams. They also inhibit the sale of high valued farecards.

The design of the pass and pass reader depends on its use. A monthly pass system would only require a time and location validation check on entry and passback protection. Different codes in the reader could implement a zone system where differently priced tickets would only work at stations in a particular zone. Depending upon the fare structure, the zone could be checked on entry only or both entry and exit.

Use of a monthly pass implies the use of a durable card. As cards are made more durable, they become more expensive. One method to keep the card cost per trip low is to reuse cards after they have expired. This requires a special collection operation since one feature of the pass system is that the passenger never lose possession of the card. Recycling can be accomplished by charging a reasonable deposit for the monthly pass.

MBTA has just completed installation of monthly pass equipment supplied by Electron. Chicago Transit Authority is in the process of developing a system to process monthly passes. The system will be an add-on unit to its existing turnstiles. A comparison of various systems compiled by CTA is shown in Table 3-2.

3.3.5 Ticket Vendors

General Description

Two generic types of ticket vendors have been used in automatic fare collection. Multiprice vendors store blank tickets or paper stock and encode a value onto the ticket as it is sold. Fast vendors store and sell pre-encoded tickets with a fixed value. Experience at WMATA, BART, and PATCO indicates that nearly 50% of passengers will purchase a one or two ride ticket. Use of a fast vendor to accommodate this demand allows the use of less complex, cheaper and more reliable equipment. Failure rates of vendors in transit usage at WMATA and BART are shown in Tables 3-3 and 3-4, respectively (4, 5).

The data in Tables 3-3 and 3-4 indicate a potential increase in reliability due to the use of pre-encoded tickets. Ticket transports represent 45% of vendor farecard jams at WMATA, and 42% of vendor ticket transport failures at BART. The vendors at BART and WMATA are very similar. Only 25% of failures would be related to encoding or printing. The prime benefits of a fast vendor derive from its lower cost, the advantages of using vendors that may have been developed, tested, and proven in other markets and the simplifications derived from selling exact fare tickets without the use of an escrow or coin return function.

Several types of ticket feeding mechanisms are used in fast vendors. The simplest and most reliable method is feeding from a roll or fanfold. This method is widely used in Europe (for the Edmonston size ticket, which is smaller and thicker than the WMATA type ticket). A second method is feeding from a stack of tickets. The bottom ticket can be picked by a mechanical plunger or moved by a drive roller. This procedure is less reliable when the tickets are very thin as at WMATA, BART and PATCO. Feeding from the top of the stack and using compressed air to move the tickets can also be used.

One disadvantage of fast vendors is the increased security required in handling of the pre-encoded tickets. Placing an identifying code number on batches of pre-encoded tickets could offset this.

3.4 Hardware Problems and Maintenance Practices

The transit properties whose fare collection systems include vending equipment experience generic problems with money handling equipment, specifically coin acceptors and bill validators. Many of the units are labor intensive, requiring frequent adjustments to meet specification. Stringent acceptance thresholds and numerous redundancy checks make some units more complex and, often, less reliable.

Table 3-2 Comparison of Monthly Pass Systems

Chicago Transit Authority
General Operations Division
Operations Planning Department
Passenger Controls/Graphics

Preliminary report	OP-y80087
Pass Reader Task Force	Rev. 4-14-80

Potential Suppliers - interviewed

Supplier	type of reader	type of/ cost/size card	estimated cost of system (150 units)	estimated annual cost of cards (number of annual cards)	estimated annual maintenance cost	additional support equipment req'd	pass back
Duncan	insert	plastic 1½¢ to 25¢ credit card	$1,500,000	$470,000 - $900,000 (3,600,000)	$75,000	yes	none
Cubic	slide-thru	plastic 13¢ credit card	$2,250,000	$470,000 (3,600,000)	$112,500	yes	self contained clock, time
Electron	slide-thru	plastic 1½¢ to 20¢ credit card	$1,500,000	$512,000 - $720,000 (3,600,000)	$75,000	yes	station controller, serial #, time
Wiegand*	slide-thru	plastic $4 - $6 credit card	$1,000,000	#$860,000 @ $4 (215,000 1st year) $720,000 (180,000 thereafter)	$50,000	yes	none
CardKey	insert	plastic $1.35 credit card	$1,500,000	#$290,250 (215,000 1st year) $243,000 (180,000 thereafter)	$75,000	yes	central computer serial #, time
Automatec	transport	plastic coating 4¢ ticket stub	$2,000,000	$144,000 (3,600,000) ticket size to small for CTA use	$100,000	yes	station clock at each station

Supplier	advantages	disadvantages	in use elsewhere	recommended for test
Duncan	-adaptability with existing Duncan TC/TR -little packaging required	-does not include pass-back add $500,000 -annual cost at least $550,000 -location of insert type reader	-no, manufacturing now for fare boxes	yes
Cubic	-self contained pass back	-packaging problem -large reader head, location limited -annual cost at least $550,000	yes, airline industry	yes
Electron	-small reader -little packaging req'd	-all equipment at each station req'd to be interconnected -requires high energy tape, limited supply -annual cost at least $690,000	-no, MBTA testing only	yes
Wiegand*	-positive system	-cost of cards requires reusing# also supply questionable -does not include pass-back add $500,000 -annual cost at least $800,000	-yes, not transit	-
CardKey	-computer printout of all info -proven system in banking industry	-Central computer concept impractical -cost of cards requires reusing# -annual cost at least $320,000	-yes, banking industry	-
Automatec	-proven system in transit industry	-transport doesn't fit -size of tickets, too small for CTA application cannot produce credit card size	yes, Mexico, Paris	no

* not thoroughly investigated

\# Number of cards required based on only passengers using entrances with card readers purchasing these special cards. System requires reusing same cards from month to month. May require $1 deposit. Foresee problems with this type approach. Maybe cost/function prohibitive. Policy change required.

General comments

advantages -

1) Allow immediate access for CTA's monthly pass users at about 1/3 of CTA's rail entrances.
2) Could expand system to all rail agent positions and all buses if deemed acceptable.
3) Printing of monthly passes in-house eliminated.
4) Duplication of monthly pass would become more difficult.

disadvantages -

1) Unproven technology, no transit system presently use the type of reader CTA requires.
2) Cost of system
   a) May require part time computer operator, full time personnel to operate encoding machines and two to four additional electricians. Support personnel also required trained in the electronic/computer field could be in lieu of electricians reqired.
   b) Support equipment must be purchased.
   c) Estimated initial cost for 150 readheads for 50 to 66 rail entrances with pass-back feature is two million dollars.
   d) Estimated annual cost for cards/maintenance will be between $550,000 and $800,000. If the card reading system is not instituted the off setting cost to be reflected for adding 20 additional agents would be $255,000 annually. Therefore it is estimated the initial estimated cost of a card reading system would be $300,000 to $550,000 annually.
3) It is estimated this initial direction will help a little over one percent of CTA's riders, about 30,000 monthly pass users. The 30,000 monthly pass users is based on the estimated future purchase of 250,000 monthly passes, monthly. Presently between 70,000 and 80,000 are sold.
4) CTA must move cautiously and observe what direction the RTA is going.
5) It is anticipated revenue may decrease slightly in the coin turnstiles due to increase in passengers using coin turnstile entrances.
6) The Wiegand and CardKey systems are based on selling magnetic card monthly passes to rail turnstile users only. Even with a deposit requirement for these expensive cards, it is not believed these systems can be easily adapted for CTA's application.

Time element

1) Recommend slow and cautious approach.
2) UMTA, Research, Development and Demonstration project. Estimated $250,000.
   a) Initial funding may begin 7-1-80.
   b) estimated six months before CTA has card reader samples, 1-1-81.
   c) six month test period, 7-1-81.
      (Maintenance warns, it may be longer)
   d) require federal funding, prepare recommendation and get concurrences 10-1-81.
   e) purchase/manufacture process 4-1-82.
   f) installation process, about one year 4-1-83.
   g) begin full operation of initial 150 card readers 6-1-83.
3) CTA Research, Development and Demonstration Project.
   May cut time element by six months.
   Funding required for demonstration project unless manufacturers agree to loan equipment.

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Table 3-3 WMATA Farecard Vendor Failure Rates

	Transactions/ Failure	Failures/1000 Transactions
Hard Failure	306	3.26
Soft Failure	126	7.93
Total		11.19
Farecard Jam	287	3.48
Bill Jam	427	2.34
Coin Jam	545	1.83
Money Handling Jam	20,790	.05
		7.7

Table 3-4 BART Farecard Vendor Failure Rates

	Mean Time Between Failures	Hard Failures/ 1000 hours
Bill Validator	1542 hours	.64
Coin Acceptor	2160	.46
Internal Bill Handling	1080	.92
Internal Coin Handling	1390	.72
Ticket Transport	396	2.52
Logic	2880	.35
Power Supply	10,800	.09
Security	3927	.25
Other	696	1.43
		7.38

The primary problem areas in bill validators are the transport mechanism and the magnetic head/bill interface. Transport belts and magnetic read heads frequently wear out, requiring replacement often done as preventive maintenance. Wet and limp bills are often the reason for high rejection rates. WMATA experienced a high rejection of valid bills prior to the modifications which included electrical line noise filters. Often, bill validators are equipped with a bill stacker or escrow, thus making it difficult to isolate problems related to the bill validator alone. Extreme environmental conditions such as heat, cold, and humidity have a significant effect on the electronic equipment. Humidity exacerbates oxidation of integrated circuit pins. Metallic and carbon dust, as well as spilled drinks, often causes short-circuiting of printed circuit boards.

Extensive preventive maintenance programs have been developed at several properties. Besides mitigating patron inconvenience, preventive maintenance decreases the chance of needing major and costly repair work. In addition, properties have expressed a preference for component modularity and accessibility to facilitate repair.

Microprocessor technology, which is in use at a few properties, offers significant improvement over TTL (transistor-transistor logic). However, it is felt that current software design philosophies do not utilize the full capability of the technology. The stress on system security results in frequent use of the "out of service" mode rather than only a partially degraded mode. In some cases, software changes may be of limited value. A recent software modification program at BART demonstrated an increase in system performance and reliability; however, the electromechanical shortcomings of the fare collection equipment made the performance gains only modest and, hence, not cost-effective. In addition, transient voltage spikes have been known to affect the microprocessor and cause erratic processing.

Equipment failure modes are as diverse as the types of equipment used for fare collection. The causes of failure are quite numerous; however, they often fall into two major categories: design-related and environment-related. It is important to note that hardware problems do not necessarily indicate that equipment is flawed. They may point to a more basic concern: the inherent unsuitability of some technologies for fare collection. Despite the viability and performance of certain technologies in controled environment, their application in the transit world needs serious review. Worn and limp bills are rejected by bill validators; wet and abused farecards become jammed in gate transports.

All of the properties studied have maintenance data collection programs. The data collected is generally not analyzed. However, properties indicated that the data is periodically analyzed if persistent hardware problems exist. Since all maintenance data is recorded, reliability and maintenance parameters, such as transactions per failure, mean time between failures, mean time to repair, mean cycles between failures, and equipment availability, can be estimated.

Newer properties such as BART, WMATA, and MARTA have computerized data base management systems for maintenance data. These evolved as a part of management function during the warranty period, usually the first year of operation. Properties have chosen to continue the maintenance reporting function as a routine procedure.

3.5 Fare Collection Costs

Fare collection costs have been analyzed in a recent study (6) by JPL for UMTA. Table 3-5 shows a summary of fare collection equipment costs. The capital costs shown were gathered from several sources including bids by suppliers in recent equipment procurements. These cost figures are approximate and should be used only as a guide to relate equipment cost as it relates to equipment function. The cost of an entry turnstile at NYCTA costs only $2,000, but an entry gate similar to the one at WMATA performing several other functions costs $29,000. Table 3-5 shows that equipment costs go up with the number of functions performed by the equipment. In addition, the cost of securing money in equipment such as vendors and turnstiles increases their total cost by making them tamper proof. The cost of equipment used in fare collection systems which have other applications such as turnstiles and changemakers is generally less because they are manufactured in large quantities.

The equipment costs attributable to the fare collection system include not only the equipment with which a patron interfaces, but equipment such as data acquisition and display systems at stations and ticket encoders. Other equipment such as TV surveillance equipment at unmanned stations and money counting equipment is included in the total fare collection system.

However, in the long run, the costs of operating and maintaining a fare collection system are comparatively higher for most fare collection systems than the capital costs of the equipment. A well-designed fare collection system with flexibility, allowing installation of add-on devices in the area of patron interface, can last for up to 30 years.

A comparison of operating and maintaining various types of fare collection systems is shown in Table 3-6, based on a survey (3) conducted by NYCTA. The WMATA costs are based on maintenance performed by the manufacturer of the equipment under contract during the initial phase of operation of the system in 1978. Exact comparison of the costs shown could be misleading because of the fare collection functions performed by the station attendant and compliance enforcement personnel who perform other functions. Fares have also increased substantially since 1978 at most properties compared to increases in operations and maintenance costs shown.

Analyses of the data show that for systems utilizing station attendants as part of the fare collection process, the costs are high. PATH and PATCO systems based on unmanned stations have relatively lower costs. A large variation in the operating and maintenance costs for various systems indicates that it would be meaningful to analyze such data at all the properties to provide guidelines of the expected operations and maintenance costs with a given fare collection system.

Table 3-5 Estimated Fare Collection Equipment Capital Costs

Equipment	Unit Cost
Mechanical Turnstile	
Token Accepting	$2,000
Coin Accepting - 1 or 2 identical coins with safebox	$3,500
Electrical Turnstile	
Accepts no coins or tokens, unlocked from station attendant booth	$3,200
Coin operated single slot, with safe box, time of day clock, microprocessor	$8,000
Above plus issues paper transfer from fanfold (accordion fold)	$11,000
Above plus reads magnetically encoded cards	$14,000
Similar to above, another manufacturer	$21,000
Ticket transport type for stored value farecard	$27,000
Farecard Vendors	
Prints, encodes, and dispenses magnetic farecard. Accepts bills, coins, returns change	$29,000
Dispenses one value, pre-encoded farecard. Accepts bills, no change	$14,000
Dispenses one value, pre-encoded farecard from fanfold feed. Accepts bills	$2,000
Addfare	
Upgrades value-stored value, magnetically encoded card	$27,000
Data Acquisition and Display System (per station)	$14,000
High Speed Farecard Encoders	$29,000
Bulletproof Agent Booth	$40,000
Changemaker, or Token Vendor	$2,000
Pass Readers - used as addon to gate	$1,500-$5,000
Transfer Dispensers - machine readable punched holes	$3,000

Source: Reference 6

Table 3-6 Estimated Annual Fare Collection Costs

SYSTEM	5.11 STATIONARY STATION PERSONNEL	5.12 MOBILE STATION PERSONNEL	5.21 EQUIPMENT MTCE COST (CENTRAL)	5.22 EQUIPMENT MTCE COST (FIELD)	5.32 & 5.64 COLLECTION COST	5.42 REVENUE COUNTING	5.43 REVENUE ACCOUNTING	5.52 COMPLIANCE ENFORCEMENT	5.61 & 5.62 OTHER	TOTAL COST (ACROSS)	% OF PASSENGER REVENUE	$/COLLECTED PER $/SPENT ON COLLECTION
NYCTA (R.T.)	$80,898,000		$3,346,966		$3,095,345	$2,211,108	$344,949	$ 308,485	$1,677,126	$91,881,975	19.2	$ 5.20
BART	3,933,184	863,434	152,924	660,582	399,601	250,428	95,719	N/A	366,975	6,730,847	30.99	$ 3.23
HAMBURG	315,000	270,000	83,000	27,700	229,000	35,000	195,000	1,010,000	322,000	2,486,700	6.99	$14.31
ICG	573,060		402,720		18,350 (PARTIAL)	86,548	INCLUDED IN 5.42	NOT REPORTED	-	1,080,678	9.18	$10.90
LONDON	* * * * * *	* * * * * *	* * * * * *	* * * * *	* * * * * *	* * * * * *	* * * * * *	* * * * * * *	* * * * * * *	* * * * * *	* * * * * *	* * * * * * * *
MARTA			1,867,000			N/A	N/A	N/A	N/A	1,867,000		
MONTREAL	3,893,173		--		54,587	N/A	N/A	N/A	N/A	3,951,760	12.9	$ 7.70
PARIS	* * * * * *	* * * * * *	* * * * * *	* * * * *	* * * * * *	* * * * * *	* * * * * *	* * * * * * *	* * * * * * *	* * * * * *	* * * * * *	* * * * * * * *
PATCO	0	149,790	160,594		121,647	26,453	12,589	PATCO POLICE 393,128	83,012	947,213	W/O POLICE 7.06 W/POLICE 12.08	$ 8.28
PATH	0	582,800	21,444	158,780	28,500		225,000	NOT REPORTED	49,000	1,065,524	8.73	$11.50
WMATA *	1,735,000	213,101	750,000		391,936	236,461	57,000	19,400	785,000	4,187,898	21.15	$ 4.73

* ESTIMATED F/Y 1978

Source: Reference 3

4.0 FARE COLLECTION SYSTEM IMPLEMENTATION

Fare collection systems have been implemented in recent years at PATCO, BART, WMATA, and MARTA. Several new transit properties are now in the process of implementing fare collection systems. MBTA recently installed a monthly pass system, and several other properties are interested in modifying equipment to improve the fare collection system capabilities. The nature of the fare collection equipment market and the procurement process have had a significant impact on system implementation. This chapter discusses the nature of the fare collection market, procurement practices, and status of fare collection systems at new properties.

4.1 Fare Collection Equipment Market

For many years, the U.S. fare collection industry consisted of manufacturers of turnstiles and fare boxes. The bulk of fare collection equipment in use at transit properties is still the basic coin or token-operated turnstile. Fare collection equipment was only a small portion of the market for this industry which mainly supplied equipment to supermarkets, amusement parks, etc. where any kind of entry control was needed. Only minor changes were required on turnstiles to meet the needs of transit fare collection industry.

Declining transit ridership during the fifties and sixties also contributed to reduced demand for transit fare collection equipment except on buses. The vending industry was well established by the early sixties. The coin acceptors from vending industry were available now for transit, and could be used in conjunction with the turnstile. Transit patrons could deposit coins directly into the entry turnstiles at stations rather than tokens, resulting in added passenger convenience. A major factor in reducing demand for new transit fare collection equipment in this time period was the flexibility of the existing equipment with minor modification to respond to fare level increases. The only changes required were the size of tokens acceptable to the turnstile and, on coin accepting turnstiles, a change in read-only-memory (ROM) to reflect the new value of the fare. Station attendants were still involved in sale of the tokens.

Concepts from the vending industry and computer technology, especially magnetic encoding, eventually led to the development of a new generation of fare collection equipment such as that at BART. The sophistication of the equipment in terms of technology led such major companies as IBM, Control Data, and Litton to enter the field and develop fare collection equipment that met the needs of distance related fare structures. This equipment provided substantial convenience to the patrons; they could now purchase farecards of higher value and use them for several trips. ICGR was the first property to install this new generation of fare collection equipment.

The demand for transit fare collection equipment, however, did not grow as expected by the major companies in the fare collection market. In addition to BART, only a few other properties such as PATCO and WMATA bought this equipment. IBM and several other major computer manufacturers decided to pull out of the fare collection equipment business. However, CUBIC, a much smaller company in electronics, purchased from IBM the rights to the IBM equipment. CUBIC made extensive changes to the IBM equipment; some of these changes resulted in functional improvement of the equipment. The CUBIC vendor has a built-in bill verifier, coin acceptor, an escrow, and can vend a ticket of any value up to $20 and return change. CUBIC also installed microprocessors in gates for logic control compared to the TTL (transistor to transistor logic) in IBM gates. CUBIC has supplied equipment to both Hong Kong Metro and MARTA in recent years.

With the advent of computers and a huge growth in the microprocessor-based industry, it seems that at the present time there are several companies eager to supply fare collection equipment in terms of subsystems such as the monthly pass readers. However, among the domestic manufacturers, CUBIC and DUNCAN are the only two companies which can supply whole fare collection systems. The Buy-American Act requiring 50% domestic product has virtually eliminated any foreign suppliers for U.S. properties. Alta Technology was recently selected by Baltimore MTA to supply its fare collection system. ALTA will manufacture the equipment in the U.S. under licensing agreements from CGA, a French company.

The demand for transit fare collection equipment, which was dormant for many years, may change. The increase in demand will not be from the new transit systems but the existing ones. The federal policy shift toward withdrawal of operating subsidies may induce several of the older properties to change their flat fare structures. Properties will also attempt to improve service by installing equipment on buses for bus fare collection. Increased coordination of the rail and bus modes to reduce operating costs will require the installation of intermodal transfer equipment on buses.

4.2 Procurement and Reliability Assurance

The experience of properties which have procured fare collection systems in recent years has been less than satisfactory in terms of equipment reliability. Properties which have installed equipment requiring prototype development had even more problems. Some of these equipment related problems were uncovered under usage and during early phases of operation of the new systems. To some extent, these problems can be attributed to the nature of the fare collection market, the role of new technology using sophisticated electronics to which the transit industry was exposed for the first time in the late sixties and the requirement to buy equipment from the supplier with the lowest bid. Procurement practices at properties even today require at least two bidders for routine supplies of farecards. At WMATA, this resulted in severe equipment tolerance problems because of differences in overall thickness of farecards from two suppliers.

Historically, reliability in transit equipment in the early years was assured by slow introduction of new technology, with close monitoring of new equipment and industry-wide acceptance only after the performance met the needs. Equipment introduction was a joint effort between the supplier and the transit property with both working together on design, development, and validation of concepts to meet new needs. They shared the resources, talents, risks, and rewards. Incremental deployment was built in, each new subsystem was added after extensive testing, and all needed modifications were made and tested before massive deployment took place.

The fare collection equipment industry had a much broader base. Turnstiles, in particular, were used extensively in supermarkets and amusement parks. Coin operated turnstiles used at most transit properties then were simple and could be operated with mechanical devices.

Transit policies at many properties in the last decade have dictated fare structures other than flat fares to meet the fiscal considerations of several governmental units involved in developing regional rail systems. The need to collect fares on the basis of distance traveled imposed requirements on equipment for which the conventional suppliers of fare collection systems had no expertise. Because of the complex electromechanical equipment required, the logical suppliers were computer manufacturers whose peripheral equipment had characteristics similar to that needed for fare collection equipment. The system requirements also involved coding and decoding to keep track of individual transactions of travel on a farecard. Several suppliers attempted to develop equipment for use at BART, but IBM was the successful bidder.

There were two major differences between computer peripheral equipment and transit fare collection equipment: environment and transactions per unit time. The transit environment was harsh not only in terms of temperature variations, but also in terms of effects induced by high voltage dc used in traction. It has taken several years for properties to modify the equipment and establish maintenance procedures which now allows the operation of fare collection systems at an acceptable level of reliability.

In a study of the overview of rail transit fare collection problems (6), the issue of procurement has been addressed for prototype equipment extensively. The study concluded that lower than expected reliability of the fare collection equipment may have been caused at these properties primarily due to: 1) not adhering to the historical practice of shared development and incremental deployment, and 2) the procurement of systems en masse using fixed price contract. That fixed price contracts are inappropriate for such procurements is indicated by the Federal Procurement Regulations (7) Section 1-3.404-2 in part states that "the firm fixed price contract is suitable for use in procurements when reasonably definite performance specifications are available and whenever fair and reasonable prices can be established at the outset, such as where:

(1) Adequate competition has made initial proposals effective;

(2) Prior purchases of similar supplies or services under competitive conditions or supported by valid cost or pricing data provide reasonable price comparisons;

(3) Cost or pricing information is available permitting the development of realistic estimates of probable costs of performance;

(4) The uncertainties involved in contract performance can be identified and reasonable estimates of their possible impact on costs made, and the contractor is willing to accept a firm fixed price at a level representing assumption of a reasonable portion of the risks involved.

The firm fixed price contract is particularly suitable in the purchase of standard or modified commercial items, or of any other items for which sound prices can be developed."

An analysis of recent fare collection equipment specifications (8,9,10) indicates that reliability of equipment is specified in terms of mean cycles between failures and/or mean time between failures, but consistent definitions of failure are lacking. At WMATA, failures of coin acceptors and bill validators were not considered failures (not manufactured by fare collection equipment supplier) even though they accounted for about 50% of all failures. The specifications generally do not provide for graceful failures. For example, if the transfer issuing machine on the MARTA turnstile fails, the turnstile is inoperative rather than just the issuance of transfer.

Some of the properties require a contractor supplying fare collection equipment to have past experience in supplying such equipment to other transit companies. This procurement policy in the long run results in fewer suppliers since companies with innovative technologies, but no transit experience, have difficulty in competing and entering the market. The recent experience at U.S. transit properties indicates that this policy may be a major contributor to equipment reliability problems because it suppresses competition which is generally the driving force in product innovation and improved quality. This also may account for no innovations in over a decade in fare collection technology.

4.3 Status of New Systems

Several new rail transit systems are currently being implemented in the U.S. They are in various stages of design and construction. Transit systems which have made major decisions relating to fare collection include San Diego, Baltimore, and Miami. Los Angeles has just started the preliminary engineering work for its subway along the Wilshire corridor and is leaning toward a zone fare system. The status of San Diego, Baltimore, and Miami is discussed below.

4.3.1 San Diego

San Diego is developing a light rail system connecting the downtown with the Mexican border. It will be a 16 mile system with 20 stops. Eleven of these stops will be at stations. The prospects of street level stops imposes unique requirements on the fare collection system.

Adequate assurance of fare payment as on buses would require stop times to be excessive and the use of conductors on board would not be cost-effective due to high labor costs.

A zone fare structure has been selected for the six zones comprising the coverage of the light rail system. The choice of a barrier-free fare collection system represents a significant departure from conventional practice. However, the major criteria for the choice stems from the need to reduce labor costs. Other reasons cited by San Diego officials include simplicity and passenger convenience of the barrier-free system.

A major cost of the fare collection system in the long run tends to be labor costs. The station attendant's role was eliminated by a decision to have unmanned stations. The signs and directions which will be bilingual (English and Spanish) will provide all instructions to patrons at stations. San Diego predicted an average fraud rate of 5% which is what was estimated by European systems visited by San Diego officials. All fare collection systems are subject to fraud which takes various forms depending on the fare

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collection system and includes: jumping turnstiles, use of slugs in the turnstiles, and re-encoding the magnetic farecard. San Diego officials concluded that efforts by other properties to reduce fraud have not been cost-effective and they feel that fraud on a barrier-free system will not be excessive and such a system will meet their goal of reducing fare collection operating costs.

To provide some measure of positive control over the fare collection system, the San Diego system will have 17 roving inspectors operating between 6:00 AM and 1:00 AM randomly checking passengers for proof of purchase of a ticket required to be carried by all passengers. A passenger on the San Diego system will carry either a pass, multiride ticket or a single ticket; these tickets must be validated at the entry station, street level stops or inside the vehicle.

The equipment selected is made by Autelca, a Swiss manufacturer. Restrictions of the Buy American Act do not apply because no federal funds were utilized. The procurement process resulted in the development of broad and functional specifications with capability to operate under flat or zone fare structures. The issue of intermodal transfers is currently being addressed. The bus system in San Diego uses flat fare.

The use of barrier-free systems is innovative for a major system in the U.S. The results from San Diego may provide a valuable experience to other properties who are looking at alternate fare collection systems. The confrontation between roving inspectors and ticketless passengers is a complicated issue and peace officer status for the inspectors is being implemented through state legislature.

4.3.2 Baltimore

Baltimore Mass Transit Administration is operated by Maryland State Department of Transportation. The choice of zone fare structure was dictated by the existing bus system which operates on zoned fares. The fare collection system was designed with active participation of the station attendant in the fare collection process. The system was also designed for two zones, with capability of accommodating up to four zones.

Transfers will be allowed from bus to rail and rail to bus at a nominal cost of $0.10. The CBD area is expected to be a single zone. The fare media will consist of coins and weekly and monthly passes. MTA officials expect over 35% of the users to utilize monthly passes. The passes and multiple ride tickets will be magnetically encoded. Based on a competitive procurement process, MTA has chosen Alta Technology to supply the fare collection equipment. The equipment will be supplied by a joint venture of Alta/CGA.

4.3.3 Miami

Miami has chosen the flat fare structure for its heavy rail system. The choice of the fare collection system is reflected in the goals set forth by the management of the Dade County Transportation Administration. The primary goals of the fare collection system were: it should be simple, easy to understand, have low life cycle cost for equipment, and high reliability.

The process used by Miami to arrive at the fare structure and fare collection system was unique. The choice of flat fare structure to be implemented by coins/tokens and monthly passes was recommended by three independent groups: a citizens advisory committee, consultants, and a group comprising experts in fare collection. The details of the preliminary fare collection system selection process are described in a report (11) and are summarized in Table 4-1.

The rail fare collection system is expected to be complementary to the downtown people mover (DPM) and the existing bus system. Specifications are currently being developed for procurement of the fare collection equipment.

4.3.4 Summary

Fare collection systems at new properties are being increasingly chosen to reflect local perceptions of the transit systems. This is evident from the choice of the systems and the reasons behind the selection. There is little consistency in the choice of fare collection systems regarding the role of station attendant and the level of fare box revenues collected. While San Diego and Baltimore have mechanisms built in for equitable fare structure, Miami apparently has chosen flat fares in favor of reduced equipment complexity.

Table 4-1 Summary of Recommended Fare Collection System Features at Miami

STATION EQUIPMENT

- Turnstiles
- Change dispensers
- Transfer Dispensers
- Attendant booth equipment

BUS TO RAIL ACCESS

- Via machine readable transfer
- Via barrier free station entrance

TURNSTILES

- All free-wheeling in exit direction
- All capable of accepting passes and being set to accept reduced fares (except those permanently set to exit only)

FARE MEDIA

- Coins
- Permits for reduced fare
- Passes
- Machine readable transfers

RAIL TO BUS ACCESS

- Via machine dispensed transfer at rail station
- Via barrier free station exit

EMERGENCY EGRESS

- Through crash bar exits
- Through free-wheeling (exit direction) turnstiles
- Through crash-bar equipped handicapped gate

HANDICAPPED ACCESS

- Pays fare, attendant admits through special gate

ATTENDANT BOOTH EQUIPMENT

- Turnstile patron count
- Power on/off control for all equipment
- Intrusion alarms for all cash vaults (except handicapped farebox)
- Status indicators for all equipment

5.0 FARE COLLECTION ANALYSIS TOOLS AND SIMULATION MODEL REQUIREMENTS

5.1 Background

Discrete event simulation models are being increasingly used to analyze the performance of complex systems. Rapid transit systems have used simulation models to perform studies on alternative operational strategies. UMTA (12) has developed a station simulation model to analyze the operation of a rapid transit station. The station simulation model also serves as a station design tool.

Among the operational factors affecting a station in rapid transit systems, the fare collection system is critical. One of the problems faced by several of the operating properties is to reduce the size of queueing at the fare gates. Analytical tools such as queueing models (2) have been used in the past to analyze the performance of the fare collection systems. These models are useful, but fail to give an adequate representation of transient conditions encountered at the stations.

Equipment reliability problems at several properties have led to evaluation of alternative improvements to equipment subsystems or installation of new equipment such as the monthly pass systems. A fare collection simulation model will be a helpful analytical tool to properties which are considering equipment modifications. This chapter reviews existing simulation models and outlines the requirements and development strategy for a fare collection simulation model developed primarily for:

1. Performance and alternatives analyses, and system specification studies, and

2. Determining property specific design requirements.

5.2 Review of Existing Simulation Models

Two transit station simulation models developed by UMTA and Carnegie Mellon (13) were reviewed in evaluation of the simulation models that are currently available. Both models were funded by UMTA as an aid to the design of rapid transit stations and are reviewed briefly in this section. The fare collection aspects in both models are essentially similar. In both, the fare collection process is assumed to work with precision. Reliability of equipment was not considered at all in either model. The review also uncovered the need for additional data on patron behavior at the station.

5.2.1 Carnegie-Mellon Simulation Model

The development of this model was an academic exercise to point out the usefulness of a station simulation model. The model is simple and has utilized existing data on pedestrian flows for escalators, turnstiles, and revolving doors.

The model basically analyzes pedestrian flows through a transfer facility. The elements considered include stairs, escalators, corridors, and turnstiles. An analysis of these elements by the user can help in identifying bottlenecks, adequacy of the station design in terms of physical location, densities of people, and process time.

5.2.2 The UMTA Station Simulation Model

The Urban Mass Transportation Administration has developed a station simulation model called USS-1. An updated version of this model is being developed. USS-1 has been used by the Metropolitan Dade County Transit Administration for station design including the fare collection subsystem.

USS-1, in principle, may be able to handle most of the requirements for simulation of the fare collection subsystem and USS-2 upgrade should be able to handle all of the requirements. However, USS was developed as a design aid for overall station planning, not as a fare collection analysis tool. USS is a large program which requires considerable front-end effort and cost on the part of the user before he can readily utilize it. To use USS for evaluation of fare collection equipment reliability may be possible, although it appears to be very difficult.

Due to the difficulties in using existing models for fare collection simulation, the best approach appears to be the development of a simulation model specifically focused on the fare collection process. Such a model is envisioned to be modest in size and simple for users to operate.

5.3 Specific Requirements for Fare Collection Simulation

The simulator should provide measures of performance for both the fare collection subsystems and its impact on the total passenger processing. Such measures of fare collection system performance include, but are not limited to: total time in system, subsystem downtime, queue lengths, subsystem maintenance statistics, and relationship between device performance and reliability and the measures of performance for subsystems and systems. The model should be capable of simulating the performance of any given fare collection system based on sequence of equipment usage to complete fare processing. The following functions must be ultimately performed by the fare collection simulation model.

1. Provide for a probability assignment of both inbound and outbound passengers to the various fare collection alternatives ("intransit stopover"). For example: an outbound passenger has a given probability of going either to and through the gate or to an addfare device and then to the gate for an automatic fare collection system.

2. Passengers should be able to "loop" in the system. An example of this behavior is a outbound passenger going to an automatic gate, receiving notification of addfare requirements, going to the addfare machine and then returning to the gate.

3. Capability should exist to simulate the "soft failure mode" as a function of device reliability. Failures such as card jams in automatic fare collection devices which are corrected within a minute or two by a station attendant should be incorporable into the model and the transient response of the patrons to such failures should be analyzable.

4. Capability should also exist for simulation of hard failures which require the assignment of maintenance personnel and imply that the device is out of service for a considerable length of time. This capability should be incorporated into the model.

5.4 Development Strategy for Fare Collection Simulation Model

A sequential model development strategy for a fare collection simulation is recommended. Four stages of development are outlined with the last stage being the integration of a detailed fare collection simulation system into a then existing subway station simulator. Each stage of the development increases both the detail at which the fare collection system can be simulated and the depth or variety of systems or configurations which can be simulated. This procedure insures the existence of a usable product at each stage without the early commitment to a major software development process. Technical assistance via simulation can be made available to operating properties in the near term without holding such activities in abeyance until large and complicated station simulation systems are developed.

For each of the stages of the simulation system development, the most appropriate programming language is suggested. Briefly, the considerations behind these suggestions are as follows. Fortran is an efficient and extremely common language with which most, if not all scientific programmers, are well acquainted. However, in queueing and simulation programs the requisite bookkeeping can become extremely cumbersome. GPSS is a common queueing oriented simulation language. For large systems or systems with long simulation running time, GPSS can be extremely expensive. Simscript has the efficiency of Fortran and additionally contains bookkeeping and simulation functions. In general, it is more difficult to program in Simscript than in GPSS and Simscript doesn't have the portability of Fortran. The strongest determinant of the programming language chosen should be the availability of strong, technical support in that language. If such support exists for all three simulation languages, Simscript is probably the best choice since it is appropriate at each stage and no effort will be lost in translating to a new language.

5.4.1 First Stage Model

The first stage in the development of a fare collection simulation model will be the integration of a simple "closed form" queueing model for patrons at fare collection devices with a probabilistic steady state device reliability model. The fare collection system configuration would be modeled as a sequence of queueing systems either multiple queue, multiple servers, or if appropriate, single queue multiple servers.

The effects of the fare collection system reliability would be modeled parametrically from an exogenous determination of the proportion of time each device type is available per service. The probability for a given number of devices being available for service would be computed. The queueing model would then be used to assess the service characteristics of the station for each combination of devices available for service. The overall performance characteristics of a given choice of number and type of devices with given reliabilities would then be assessed by considering the probabilistic weighted average of the service characteristic. The data required for this stage of the simulation modeling would be the percent of time that a given device is available for service, and the average service time for each device, and the average peak and off-peak arrival rates at the fare collection system.

At this stage of the development of a fare collection simulation model, the use of closed form queueing equations encourages an assumption of either uniform or poisson distributed arrival times. The uniform arrival would be appropriate for the peak periods, whereas poisson distributed arrival times would be more appropriate for off-peak times. The distribution of service times for each device can be assumed to be uniform.

For a small, simple model of this type the inefficiencies of GPSS would not be a major concern. Furthermore, the bookkeeping requirements and requisite queueing and simulation functions are not so major as to preclude the use of Fortran. The input, output, and model flow diagrams are shown in Table 5-1.

5.4.2 Second Stage Model

The second stage of development would be an expansion from the simple closed form queueing model to a queueing based discrete event simulation. If the first stage of development can be characterized as parametric steady state, this stage of development can be characterized as semi-transient in that while the number of devices in service at any given time would be endogenous within this model, the transient behavior of patrons when a device fails would not be explicitly modeled. Multiple paths within the fare collection system would be allowed at this level of development, thereby more correctly modeling the behavior of patrons within real systems. For example, a patron can upon entering the system proceed directly to a gate or proceed to a card vendor and then to a gate. The spatial configuration of fare collection devices within the station need be modeled only implicitly as they effect patron's choice of devices.

The reliability of the fare collection system would be modeled at the device level. A device could drop out of service according to the distribution of the time between failures and be returned to service as function of the distribution of time to repair. At this second stage of development of a simulation model, assumptions on patron behavior are requisite. These include the probability of choosing specific paths within the fare collection system such as the choice between card vendors and gates and assumptions on which of multiple similar devices would be chosen as in the choice of the gate with the shortest queue.

The data requirements to simulate at this level of detail are more stringent. These requirements include arrival counts to determine the distribution of arrival times at various times of day, the distribution of service times for each device type, the number of people choosing various paths within the fare collection system, and the distribution of the time between failures and the time to repair for each device type. Because this data differs significantly between various operating properties, it may be advantageous at this stage to focus on only a few operating properties which appear to be experiencing the greatest fare collection system problems or have the most development need.

Table 5-1 First Stage Model

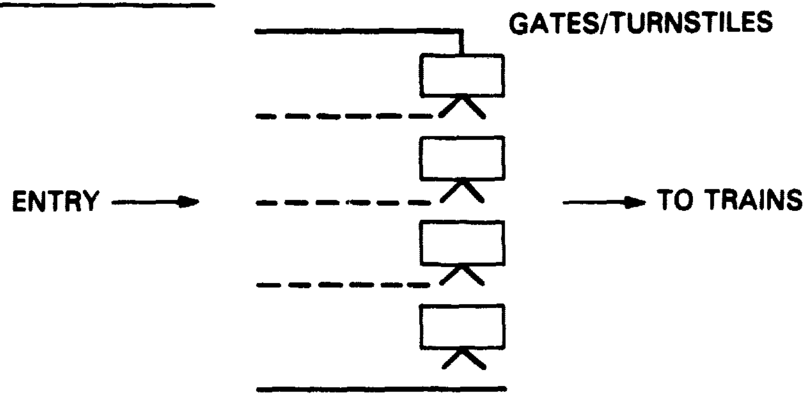
INPUT

1. FARE COLLECTION EQUIPMENT DESCRIPTION: NUMBER OF GATES (TURNSTILES)
2. STOCHASTIC COMPONENTS: ARRIVAL DISTRIBUTIONS (ENTRY & EXIT)
   EQUIPMENT SERVICE TIME DISTRIBUTION
3. PATRON BEHAVIOR: GO STRAIGHT TO GATES
4. EQUIPMENT RELIABILITY: PARAMETRIC

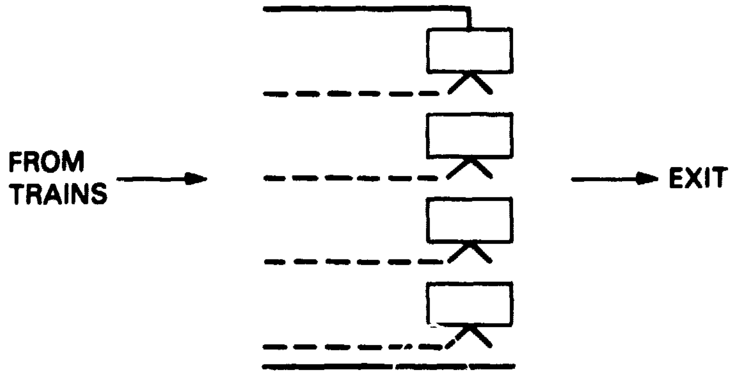
OUTPUT

1. DESIRED QUEUING STATISTICS

ENTRY MODEL TRAFFIC FLOW



EXIT MODEL TRAFFIC FLOW



At this stage of development, it would be appropriate to statistically fit the observed arrival times and service times to specific distributions rather than assuming a uniform or poisson distribution. At this stage of development, GPSS would be the easiest language in which to code, Fortran the most cumbersome, and Simscript somewhat more difficult than GPSS, but significantly more efficient. The input, output, and model flow diagrams are shown in Table 5-2.

5.4.3 Third Stage Model

The third stage in the development of fare collection systems simulation would be as in the second stage model, a queueing based discrete event simulator with additional network attributes of the fare collection subsystem fully explicated and the transient behavior of patrons at a device which failed fully modeled. The fare collection system configuration would be generalized to include the spatial attributes of the devices (physical separation between them and the areas allowed for queues to form). Rather than uni-directional patron flow, "looping" of patrons would be allowed. For example, the following situation would be possible to model at this stage: a patron exiting at a gate can discover the fare card does not contain sufficient funds, necessitating a return to an addfare or card vendor machine, adding the appropriate fare and then returning to the gate.

The reliability of the fare collection system would be modeled at the device subsystem level. An example of this would be the separate modeling of the stochastic reliability of the validation, transport, and escrow functions of a card vendor. Further assumptions on patron behavior become necessary at this stage of simulation. These include reneging of patrons at long queues to short queues and the transient behavior of patrons who discover a device has failed and move to a new device. The data requirements are increased by the need for information on the reliability of the subsystems within each device in the fare collection system and on the behavior of patrons described above. At this stage of development, it may be justified to abandon an analytic formulation for arrival time and service time distributions and to base the simulation on the empirical data specific to stations of individual operating properties. For a simulation model of this detail and size, Simscript appears to be the most attractive programming language. The input, output, and model flow diagrams are shown in Table 5-3.

5.4.4 Fourth Stage Model

The final stage in modeling the fare collection system would be the integration of the fare collection system configurations and device reliability portions of the model with a then existent subway station simulation model such as USS-2. Presumably, patron behavior would have been determined for such a model and arrival and service time distributions would be endogenously computed. The language chosen for a subway station simulation model should be considered for compatibility during the development of the third or perhaps even second stage of this activity.

Table 5-2 Second Stage Model

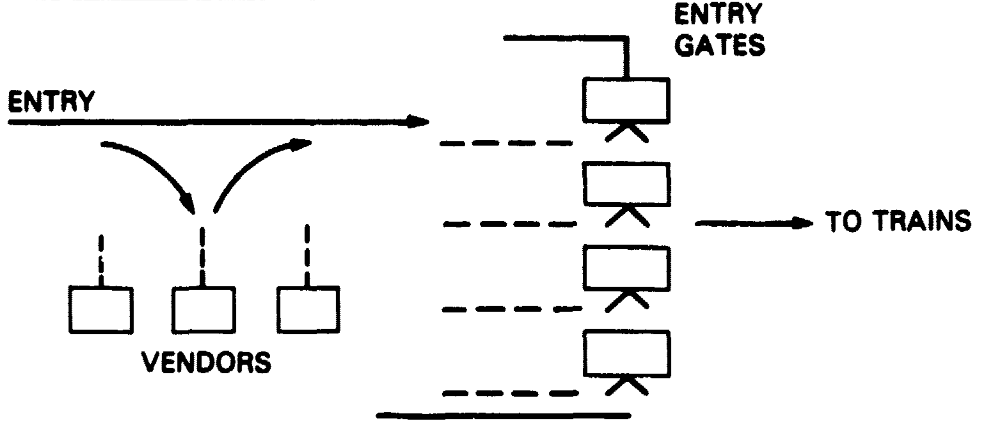
INPUT

1. FARE COLLECTION EQUIPMENT DESCRIPTION: NUMBER OF GATES, VENDORS
2. STOCHASTIC COMPONENTS: ARRIVAL DISTRIBUTIONS (ENTRY/EXIT), EQUIPMENT SERVICE TIME DISTRIBUTION, PATRON, EQUIPMENT USAGE DISTRIBUTION
3. PATRON BEHAVIOR: QUEUE ORDERING ON EQUIPMENT BREAKDOWN
4. RELIABILITY: MTBF, MCBF FOR GATES AND VENDORS

OUTPUT

1. QUEUING STATISTICS
2. EQUIPMENT AVAILABILITY

ENTRY MODEL TRAFFIC FLOW



EXIT MODEL TRAFFIC FLOW

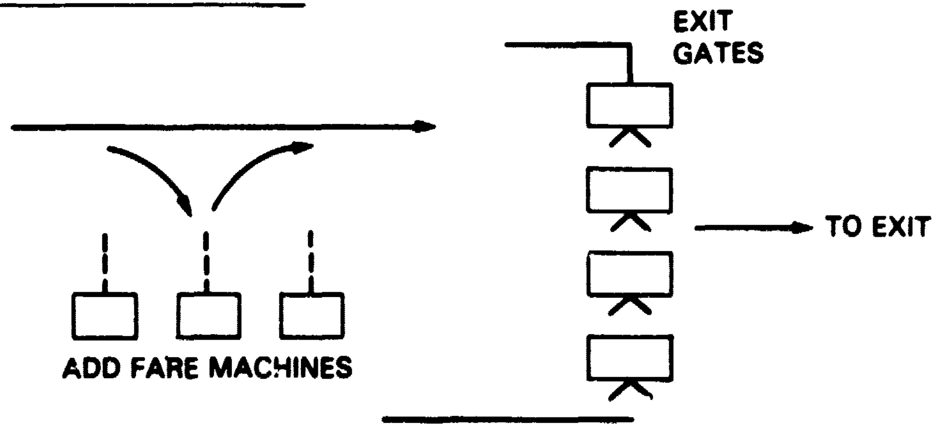


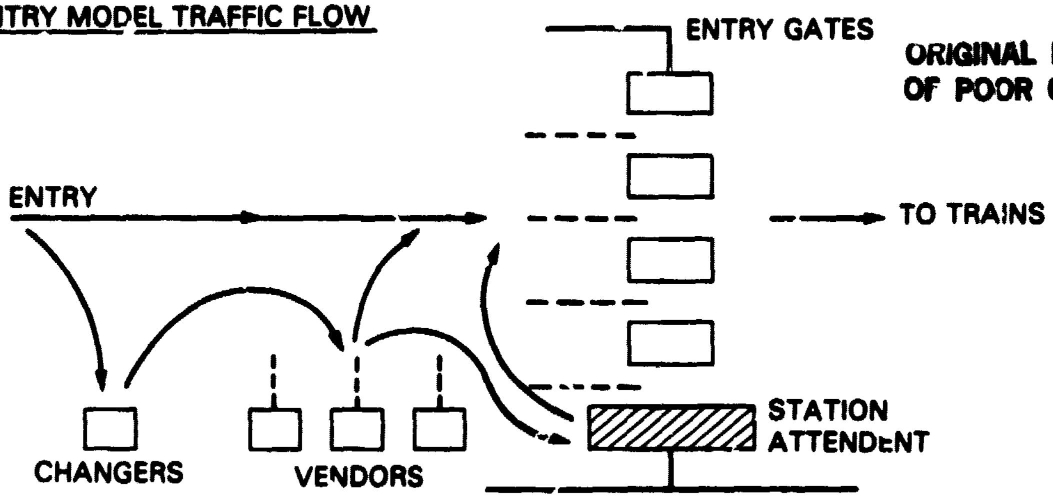
Table 5-3 Third Stage Model

INPUT

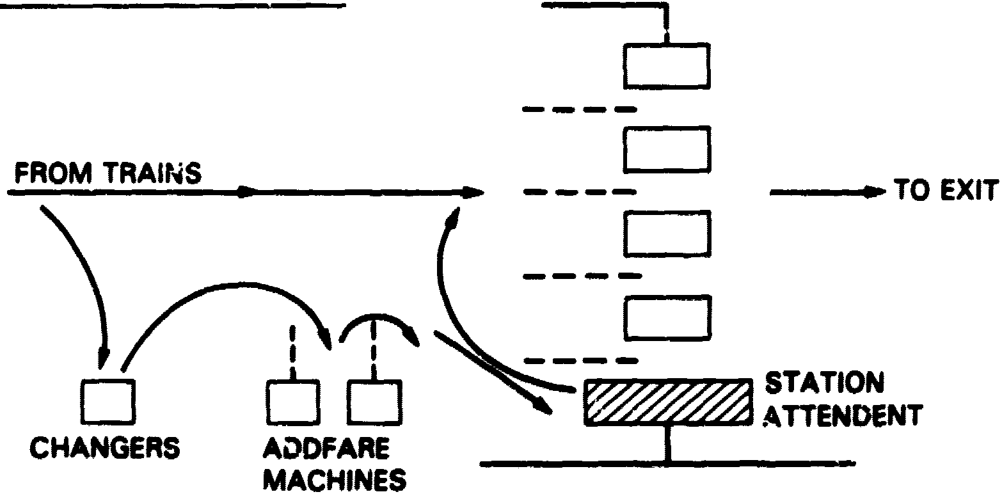
1. EQUIPMENT DESCRIPTION: NUMBER OF GATES, VENDORS AND CHANGERS
2. STOCHASTIC COMPONENTS: ARRIVAL DISTRIBUTIONS (ENTRY/EXIT), EQUIPMENT SERVICE TIME DISTRIBUTION, PATRON EQUIPMENT USAGE DISTRIBUTION, EQUIPMENT REPAIR TIME DISTRIBUTION
3. PATRON BEHAVIOR: QUEUE ORDERING, STATION ATTENDENT SERVICE
4. EQUIPMENT RELIABILITY: MTBF, MCBF, MTTR FOR ALL EQUIPMENT BY SUBSYSTEM

OUTPUT:

1. QUEUING STATISTICS
2. EQUIPMENT AVAILABILITY
3. SUBSYSTEM PERFORMANCE EVALUATION



ENTRY MODEL TRAFFIC FLOW



EXIT MODEL TRAFFIC FLOW

5.5 Model Data Base, Cost, and Schedule

Simulating the performance of a variety of fare collection equipment at a given station requires that appropriate parameters related to each piece of equipment be used as inputs to the model. Simulation data base for fare collection requires an extensive data base on two entities in the process: (1) equipment performance and (2) patron behavior.

The data on equipment performance consists of equipment processing rates, failure rates, and repair times experienced in terms of statistical distributions. For example, the processing rate for coin-operated turnstiles can be expressed in terms of service times which are normally distributed with certain mean and standard deviation which is empirically derived from actual observations of equipment performance. Similarly, the data from equipment failure reports and maintenance records from properties can be used to derive the distributions for failure rates and repair times.

The patron behavior data used as input to the simulation model relates to the arrival distributions of patrons at various pieces of fare collection equipment. For example, only 25% of patrons may go to the vending machines to buy farecards at WMATA compared to 40% going to the station attendant to purchase tokens at NYCTA before going to the gates and turnstiles for fare processing respectively. The assumption of uniform arrival rates at exit gates when trains disembark passengers at the station requires validation based on actual observations for use as input to the simulation model.

In terms of developing a data base, the first step should be to accumulate information from existing literature on equipment performance and reliability. A major source of data on equipment reliability is the maintenance data base on fare collection equipment existing at most rail transit properties.

The second step in the development of a simulation data base should be to collect patron behavior information. Extensive data needs to be collected on patron behavior at existing stations. The arrival rates at stations from buses, peak hour arrivals, and train disembarkments need to be established. The patterns of farecard purchases and their values also provide useful information for simulations of alternate vending equipment and their impact.

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APPENDIX A
MAGNETIC ENCODING TECHNOLOGY

A.1 Conventional Magnetic Tape Medium

Most digital (magnetic) recording tape currently made utilizes gamma ferric oxide magnetic material in the form of small needle-shaped particles. During the manufacture of the tape medium, the oxide particles are uniformly dispersed in a resinous lacquer containing solvents, wetting agents, and flow agents. A film base, usually a polyester material, is then coated with this lacquer. While the lacquer coating is still wet, the film is passed through a magnetic field resulting in the alignment of the oxide particles with their long axis parallel and oriented along the length of the tape. This orientation is then fixed by evaporating the solvents on the tape in a drying oven.

The oxide particles are, hereafter, magnetized such that they behave like small bar magnets. Data is recorded by creating zones on the tape having north poles facing alternately right and left as the tape passes the recording (i.e., write) head. The change between right and left magnetization (flux reversal) at the zone boundaries can subsequently be detected by a read head. The recorded pattern shown in Figure 7-1 is known as two-frequency coherent phase F/2F encoding. It is a sub-class of codes known as Manchester codes. Equally spaced flux reversals labeled C represent a clock. If a flux reversal appears between two consecutive C's, a binary 1 is being represented. If no flux reversal appears between consecutive C's, a binary 0 is being represented.

The foregoing recording method is known as longitudinal encoding. Information is erased by removing flux reversals. This can be done by applying a high-frequency alternating magnetic field or a direct field via the write head. Once a tape has been erased, new data can be recorded. The property of recording, erasing, and rerecording is associated with the term "soft encoding." The relative ease of encoding and erasing makes magnetic tape an attractive data storage medium. However, this same versatility causes the tape to be vulnerable to duplication and alteration.

A.2 Watermark Magnetic Tape Medium

Watermark Magnetics is functionally analogous to the paper watermark. A paper watermark is a permanent, unalterable and recognizable pattern created in the paper material by structuring its constituents (pulp) and fixing that structure at the time of manufacture. Data subsequently written or printed on the paper is thus secured. If the embedded pattern does not appear, recorded data is suspect and screened for rejection. A paper watermark should be detectable in the presence of recorded data. Furthermore, it should not interfere with the readability of the data.

ORIGINAL PAGE IS
OF POOR QUALITY

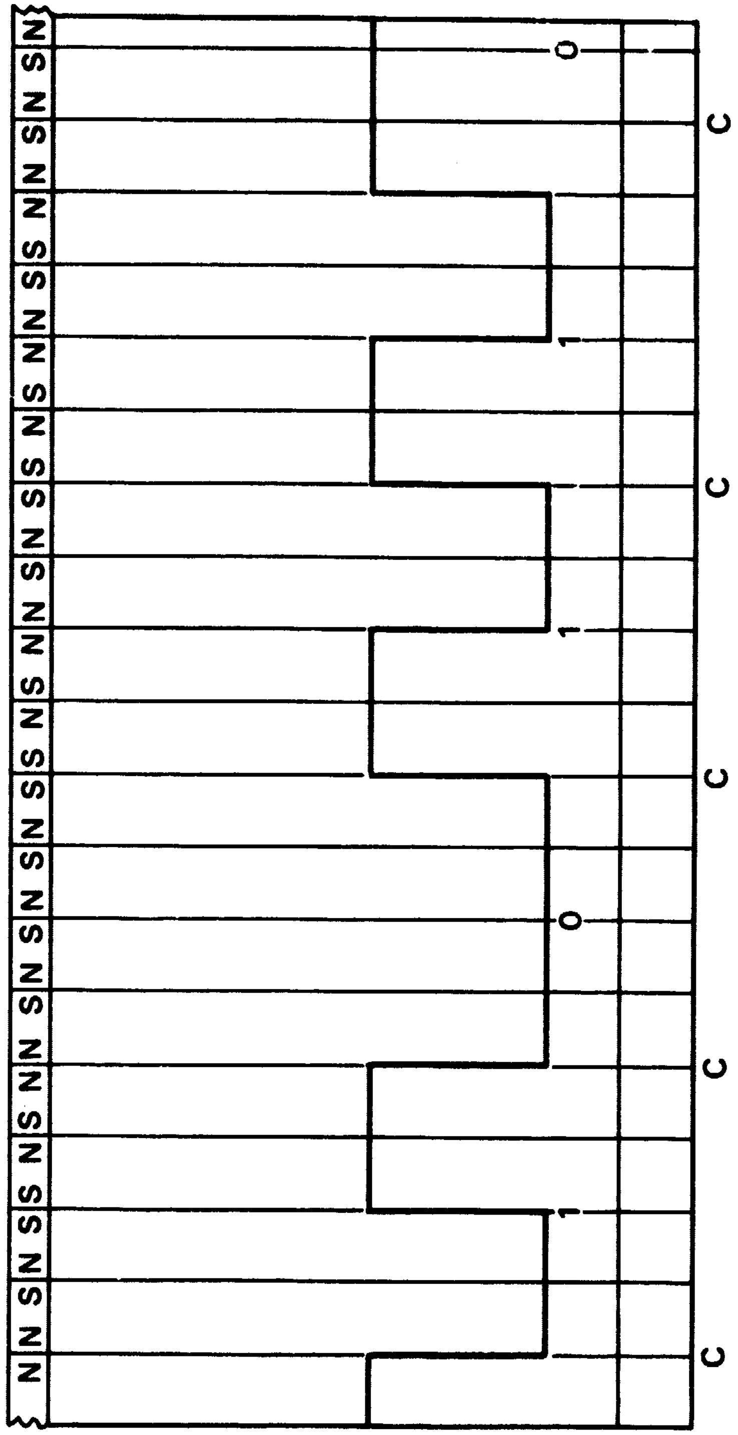

Figure A-1 Two-Frequency Coherent Phase (F/2F) Encoding

The Watermark Magnetics concept developed by EMIDATA/MALCO in Garrison, Maryland (a subsidiary of EMI of England), is a magnetic equivalent of the paper watermark. Its creation also takes place at the time of manufacture. The paper watermark and accompanying recorded data is read by a human. Whereas, the magnetic watermark and magnetically recorded data is "read" electronically.

The concept of Watermark Magnetics is introduced into the structure of the magnetic medium by the following selective orientation of the oxide particles. Two alignments are chosen, one at 45 degrees clockwise (minus) and the other at 45 degrees counterclockwise (plus) to the conventional longitudinal axis. All particles of one angular orientation are grouped in zones which extend diagonally across the tape; adjacent zones have orientations which are alternately plus 45 degrees and minus 45 degrees. The zone boundaries, where orientations change through 90 degrees, correspond to flux reversals in conventional recording and can be detected by a special read head set at 45 degrees to the length of the tape. The zones can be defined such that zone boundaries represent either a binary 1 or a binary 0, in accordance with the F/2F encoding. Any specific numerical code can be assigned to the Watermark. The boundaries of the zones can always be detected provided the oxide particles have been magnetized. In the event that all remnant magnetism has been removed (e.g., by an alternating field erasure), the particles must first be magnetized by a direct magnetic field; this field can be supplied by a permanent magnet or a direct field write head. And, thus, the Watermark code can always be retrieved even if the tape is deliberately subjected to an erasing field.

Watermark encoding is classified as "hard encoding." EMIDATA/MALCO claims a proprietary method of encoding the Watermark which cannot be altered or permanently erased.

The two encodings, conventional and Watermark, can exist on one piece of Watermark Magnetics material. A conventional read head, which senses changes in magnetic flux only in the longitudinal direction, is indifferent to whether this flux is carried by particles at either of the complimentary 45 degrees angles. Thus, the Watermark does not interfere with conventional coding.

A.3 Application of Watermark Magnetics to Securing a Magstripe

Should a watermark be copied by skimming techniques onto a magstripe made from a piece of conventional tape material, it would be in soft encoded form. By subjecting the copy to a direct erasing field, the counterfeit Watermark will be erased and, unlike the genuine Watermark, it will no longer be readable.

Given a plastic card with a magstripe made of Watermark Magnetic material and assuming the magstripe bears a genuine Watermark, it remains to provide protection against the alteration of the data conventionally encoded. This can be done by encrypting the data relative to the Watermark. That is, data to be encoded conventionally undergoes a one-to-one transformation before it is encoded. The Watermark necessarily participates in that transformation. For example, the Watermark could serve as a key for an encipherer, where the encryption algorithm is known only to the transit property and the supplier. Periodic changes of the algorithm would be required to prevent an accumulation of sufficient blocks of clear and encrypted pairs of data to determine the algorithm.

Consider a multitrip ticket for a mass transit system in the form of a plastic card bearing a magstripe made of Watermark Magnetic material. When dispensed data such as value and time expiration would be encoded conventionally on the magstripe in encrypted form. When used, electronics incorporated into an entry or exit turnstile would decrypt the data (relative to the Watermark), validate, erase, and re-encode in encrypted form such data as the remaining value.

APPENDIX B
REPORT OF NEW TECHNOLOGY

The work performed under this contract has examined the impact that local policy decisions on fares and fare structures have on the selection and application of fare collection equipment. In addition, this report describes various fare collection systems and documents hardware and technology related problems. The report is based primarily on the information supplied by U.S. transit properties. The results provide a better understanding of the fare collection systems concepts and equipment functional requirements by classifying the fare collection systems on the basis of how a patron fare is processed, i.e., entry processing, entry/exit processing and barrier free processing. Since this was primarily a study of existing technology and methods, no new technology was developed. The findings and recommendations of this study are expected to assist the properties in making more informed decisions in regard to the selection of fare collection equipment that best suits their needs, minimizes their costs, and maximizes their revenues.

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