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# OVERVIEW OF RAIL TRANSIT FARE COLLECTION

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California Institute of Technology
Pasadena, California
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16. Abstract

A study was conducted on the performance of rail transit fare collection equipment. The results can be used to evaluate new and improved fare collection systems.

Options in fare collection were illustrated by examining four transit systems. Reliability data, in terms of transactions per failure, were gathered for elements of these systems. Detailed investigations and subsystems failure analyses were conducted for two graduated, distance-related fare systems. Several models were developed for evaluating the impact of equipment reliability on operating costs and passenger delays. These utilized the binomial probability distribution to calculate the incidence of simultaneous machine failures as a parameter in multi-server queueing and delay frequency models.

Significant findings were that the reliability of distance-related fare collection equipment could be improved by: (1) using procurement methods appropriate for development contracts, (2) reducing desirable but non-essential functional requirements in specifications, (3) providing more precise description of field operating environments, and (4) use of reliability criteria that distinguish between component replacement and the clearing of temporary blockages. It was also found that fare collection operating and maintenance costs account for 7-31% of revenues collected. One transit system, with less than one component malfunction per 5000 passenger/equipment interactions operates with unattended stations. The development of improved paper currency validators was one of the higher priority R&D needs.

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Fare Collection, Rail Transit, Automated Fare Collection, Reliability, Maintenance, Procurement, Passenger Flows, Passenger Delays, Stations, Research and Development Needs

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This is one of a series of reports from a study titled, Study of Research and Development Planning for the Rail and Construction Technology Program of UMTA. Other study reports develop a general method for identifying and prioritizing rail transit research and development projects, and provide an overview of escalator applications in rail transit.

# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |

### AREA

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $in^2$ | 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)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
|  | short tons (2000 lb) | 0.9 | tonnes | t |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| 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)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

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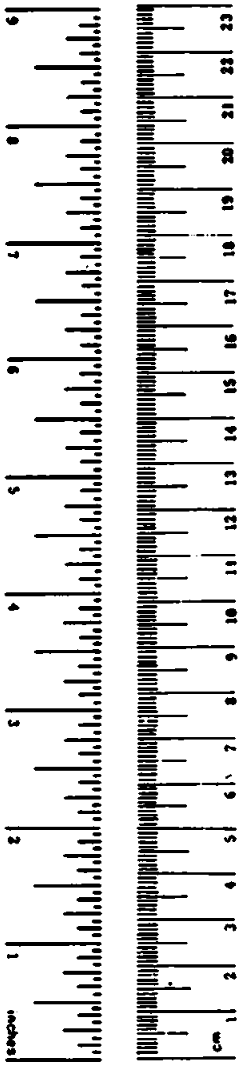
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

### LENGTH

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| 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

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| $cm^2$ | 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)

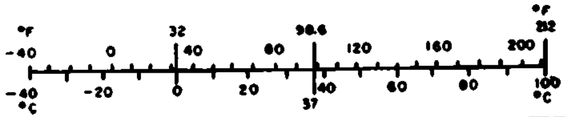
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons |  |

### VOLUME

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| 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)

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1. INTRODUCTION

As support to the Department of Transportation and the UMTA Subsystem Technology Application to Rail Systems Program (STARS), JPL conducted an analysis of rail transit fare collection systems. There were several reasons for this analysis. First, new rail systems in planning and construction stages require improved data to help select the fare collection system for their needs. Fare collection needs vary between systems due to regional objectives as well as variations in operational, political, geographical and socio-economic factors. Second, some existing rail transit systems are considering fare collection modifications and are, likewise, in need of data. Third, while the equipment cost for any fare collection system is small compared to the total system cost, the impact on operations, public acceptance and net operating revenue can be dramatic. Examples where this impact has been less than satisfactory exist at two U.S. systems, Bay Area Rapid Transit District (BART) and the Washington Metropolitan Area Transit Authority (WMATA) which chose automatic fare collection (AFC) equipment.

The emphasis of this report is on AFC equipment for two reasons. First, AFC equipment employs the most advanced technology in modern fare collection equipment and is a logical starting point for considering technological advancements. Secondly, the level of service experienced with two AFC systems (at BART, Bay Area Rapid Transit District and WMATA, Washington Metropolitan Area Transit Authority) is far below that expected from the planners of those systems. This has led to both systems receiving considerable scrutiny, leading to the availability of good data on system performance. In addition, both BART and WMATA are now developing systems improvement programs. It is hoped that this report will be helpful to the staffs at BART and WMATA in the decisions which they are now making. Much of the BART and WMATA data presented in this report indicates important trends. Of special importance are the relative performance levels at BART which now has several years of operational and maintenance experience and the relatively new system at WMATA with its expected difficulties during the initial years of operation.

The remainder of this report is presented in the following sequence. Chapter 2 is a summary of the findings of the analysis, including options which could lead to an improved generation of equipment and specific research and development actions which should be initiated.

Chapter 3 presents an overview of several current fare collection approaches used in the U.S. In this section, it is shown that important non-technical planning decisions dictate the type of fare collection system which can be used.

Chapter 4 reviews operating characteristics and experience with modern AFC equipment and undertakes some failure analysis. It is shown that high failure rates can be traceable to a few electro-mechanical components. It is also shown that there are some systematic failures which if isolated and corrected could lead to some improvement without wholesale equipment replacement.

Chapter 5 addresses the areas of reliability, operability, and maintainability, including a guideline for procuring improved fare collection equipment.

Chapter 6 presents a system evaluation model which could be useful for system planners and analysts in determining practical reliability goals for fare collection equipment.

Chapter 7 develops a method for comparing alternative improvement strategies and applies it to an automatic, stored-value, baseline fare collection system.

Chapter 8 describes long-term fare collection development needs for the entire rail rapid transit industry.

# 2. SUMMARY OF FINDINGS AND RECOMMENDATIONS

This report describes various fare collection systems ranging from the simple to the complex. The performances of automatic fare collection (AFC) systems are emphasized including methods for procuring, maintaining, evaluating, and improving them. Also, longer term fare collection development needs for the industry are discussed.

Several of the more significant findings and recommendations developed in the course of the project are listed separately to highlight their importance.

## 2.1 System Characterization

In the U.S. in 1977, there were over 1.3 billion rapid rail passenger trips at an average price of less than 50¢ to the passenger. The average trip was slightly more than seven miles. Each of those trips involved a relatively small revenue transaction which was repeated twice a day, five days a week for the typical rail transit rider. Collecting all fares, accounting for each trip and dispersing the revenues for operation, and maintaining each element in the system; equipment, traffic management, accounting, facilities, etc., is an enormous task. This and more is the task placed on the fare collection system.

Two types of fare structures have emerged in the U.S. They are the predetermined (flat) and the variable (related to distance traveled, or other simple variables). The fare collection system characteristics are made more complex by the added functions and services which they perform. These services and other functions result in variations in types of equipment and in some cases in equipment complexity.

Additional functions which the fare collection system performs are: (1) Entrance and exit control at stations (2) Services to the revenue accounting function (i.e., money handling after collection of the fare), (3) Acquisition of passenger/trip statistics and (4) Implementation of marketing and public service functions such as reduced fares to the elderly and school children and weekend and off-peak specials.

Thus, fare collection system is really a misnomer. In fact, if the task were simply to collect and store a fare from each passenger, the equipment would be relatively simple, reliable and inexpensive even for zone or variable fares. To be complete, the fare collection system includes the system of people, equipment, materials and procedures to acquire passenger revenues and process the resulting revenue through the transit authority. In this report, the concern is more with that portion of the system at the stations, and its interaction with passengers.

During analysis, a review was made of the characteristics of several specific fare collection systems chosen to represent the variety of systems in use. A summary of their characteristics is presented here.

The New York City Transit Authority (NYCTA) fare collection equipment performs only flat fare collection. Within the fare collection system, the passenger service of "change making" is provided by personnel. The majority of the entrance gates are mechanical turnstiles activated by deposit of a single token. This approach results in minimum equipment requirements with attendant low equipment cost and the highest level of reliability. The operating cost of the system excluding station personnel is only about 2% of revenue collected. But the use of station personnel, for change making and revenue collection plus the ancillary benefit of deterring vandalism and crime adds 17% to the cost. The total operating cost is 19% of revenues collected.

When any system chooses to provide other than a flat fare, single token approach, the equipment complexity quickly compounds. At Port Authority Transit Corporation (Philadelphia area), a zone fare structure is used through the aid of a reusable, magnetically encoded, multiple-ride thin plastic ticket. Equipment complexity is avoided by having separate, commercially rented changemaking machines with some tickets being sold at retail outlets. Even the new MARTA System (Atlanta area) has a simpler approach as enabling legislation specified a flat fare. However, the MARTA equipment does accept three types of fares: exact change, magnetically encoded monthly pass, and magnetically encoded single ride bus transfer. The gate equipment is configured to accept these three. The flat fare avoids any processing at exit. Thus, only the entrance gate is required to transact with the passenger. At entrance, passengers can also receive a bus transfer by button request. As can be seen, the intermodal requirement and the monthly pass provisions add to the equipment functions and services provided. They can also be expected to add to equipment cost and will most certainly require more frequent service than simple, token-operated, mechanical turnstiles.

The most complex systems examined are at WMATA and BART. These systems provide for variable fares (distance and time-of-day related) through use of a thin, paper farecard which magnetically records and prints the currency value on the card. A variable fare structure dictates that the passenger carry to his exit point information for determining the condition of his entrance by the exit gate.

The WMATA system is somewhat more complicated by the data acquisition and display function and the full set of change-making services which the equipment provides. Essentially, while in the WMATA system, passengers use a different currency, the farecard. The only requirement to enter the system is that the passenger possess a card with 5¢ or more value. Farecard vendors provide complete currency exchange services in increments of 5¢ and the ability to change farecard values through the addfare machine prior to exit. Although the system represents the ultimate in fare flexibility, all of these services result in a relatively complex design for the existing equipment and in a burdensome maintenance load and a strong requirement for passenger assistance.

## 2.2 Findings

(1) The reliability of elements in commonly used fare collection systems varies from 40,000 transactions/failure for a flat fare turnstile to several hundred transactions/failure for a stored value, farecard vendor. Empirical evidence at one system indicates that for an automatic fare collection system, unattended stations can be successfully operated when the overall system reliability results in 5000 passenger transactions between machine failures. Depending on the system design, the processing of each passenger may lead to several machine interfaces or transactions.

(2) Operating costs of fare collection range between 7% and 31% of revenue dollars collected or 1.4 to 14.7 cents per passenger trip, depending on the functions provided by the fare collection system, station volumes, equipment reliability, and the functions of station attendants. Annual U.S. rail transit revenues are over $700 million with current costs of fare collection amounting to 7-31% of revenue. There is, therefore, a large cost reduction potential from improvements in fare collection.

(3) Three generations of automatic, stored value fare collection systems are in use in the U.S., two at BART and the third and latest at WMATA. Initial performance data indicates that the reliability of each successive generation has decreased.

(4) Failures associated with automatic fare collection are primarily related to the mechanical functions of the equipment and not their electronic functions. Problems occur with the movement of farecards, through a series of transport rollers; of worn dollar bills through a bill escrow; of coins through acceptance mechanisms; and with frequent adjustments for magnetic head readers. Problems associated with functions such as calculation of the fare, processing the magnetic card, or totaling money received are much less frequent.

(5) Fare collection machines operate in a difficult environment and failures can be caused by passenger misuse and maintenance errors, not only by equipment design.

(6) Reliability of automatic fare collection equipment can most likely be increased thru selected technology development and prototype testing. Purchase of large numbers of never-before-built complex machines on a fixed price, low bid contract has led to dissatisfactory results.

(7) Reliability and maintainability of equipment is dependent upon both strict enforcement of a reliability program in the equipment development phase, and on use of a maintenance data base and preventive maintenance program performed by staff with the proper manuals and training for existing equipment.

(8) The impact of equipment reliability on maintenance costs, required station manning levels, and passenger delays can be estimated by a model, based on the binomial probability distribution, which considers the incidence of simultaneous failure of two or more units of the same type of fare collection equipment at the same station entrance. The model can be used to relate the portion of passengers delayed for various reliability performance levels and fare collection alternatives. By use of a multi-server queing model, waiting times for different numbers of machines in operation can be developed and used to estimate the magnitude of the delays in addition to their frequency.

(9) Transit is a relatively small industry (compared to vending, banking, computers) and often uses specialized equipment. The diversity of complex specialized equipment in a small market drives up the cost and increases the difficulty of providing proper aftermarket support. Standardization of Automatic Fare Collection equipment could reduce these problems.

Development programs in the following areas would be useful.

(1) Money handling equipment - An organized testing program of coin acceptors, bill verifiers, escrows, and stackers should be conducted in a controlled laboratory setting. If commercially available equipment cannot be found, then engineering designs and modifications must precede any such testing program.

(2) Further analyis of AFC equipment - There is at this time only limited operational data on equipment at BART and WMATA. In that data, however, are some systematic behaviors not explainable through the data available. For example, gate failure frequency varies dramatically among stations. This could be a function of the type of patron, the magnitude and rate of use of the equipment, the level of aggregation of the data, quality control for the model of the equipment, operations and maintenance practice variations among stations or the station's protection from the weather. These relationships must be understood in order to guide the development of improved equipment.

A controlled field testing and analysis program involving operators, manufacturers, and independent analysts could determine the precise cause of failures and map solutions.

(3) Developing a fare collection system architecture - An architecture of fare collection elements must be developed. This would be basically a design guide which would specify functions of each module in the architecture, best methods of locating, installing and operating each module, how each module is related to other system elements and how modules are configured to meet system wide objectives and needs. Levels of reliability would be established as well as other standards of performance. Functional requirements would be balanced against achievable levels of performance and cost. Availability of such a guide would provide a reference for operators and suppliers as well as a basis for dialogue throughout the transit industry. Model specifications for flat, zone, stored ride, and stored value system elements would be developed.

(4) Change in Procurement Practices - The degree of knowledge of user needs and equipment maturity does not yield to fixed price, one-step procurements for system wide purchases of entire transit fare collection systems. Attempts at specification of system reliability, maintainability and availability levels and associated test and validation programs have been less than satisfactory. Until the technology matures, near term buys should be by three-step procurement. The first step should be a design effort with maximum effort and dollar

incentive to the contractor on reliability, maintainability and availability. More than one contractor would participate to assure the availability of the best equipment design. Preference should be given to a contractor who could also produce the production quantity order. The second step would be a prototype stage, again with emphasis on performance and incentive. At the end of the second step, the transit property would have a set of drawings and specifications which it could use for a first buy on a fixed price incentive basis. The third step is the first-buy, end evaluation. The first buy would be a limited production run needed to support the first phase of system deployment. During initial operation, a rigorous data acquisition and test program would be undertaken by an independent, third party to assure that performance is as expected. In this manner, reasonable levels of risk can be assumed in a cooperative environment between equipment suppliers, consultants, contractors and the owner where the maximum level of information is exchanged.

A similar procurement procedure was originally planned for WMATA. However, the procedure was not carried to its completion. Many of the AFC procurement problems at WMATA and BART were similar. Documentation of the recent AFC procurement experience and the lessons that could be learned would be useful. As part of its program to review procurement methods as called for in the Surface Transportation Act of 1978, UMTA's Office of Safety and Product Qualifications is conducting a study which investigates the development of several products, one of which is AFC.

(5) Development of analysis tools - A model should be developed which will allow the designer to assess the impact of equipment performance on station layout and throughput as well as life cycle cost. The initial models developed in this report require lengthy calculations to evaluate different alternatives and conditions, do not consider the import of uneven machine loadings, or the impact of service rate on unit transactions per failure rate, and are steady state rather than dynamic simulation models. The most important advantage of a more complete model is that the designer would be able to assess the impact on station performance and design, of convenience serving and non-fare collection functions which are now provided, and be able to determine whether or not they are warranted.

(6) Alternate technological approaches - Other approaches to the magnetically encoded farecard (optical, punched hole, and electrically-conductive encoded cards) should be examined. These may offer the potential of performing the same functions in a less complex and more reliable manner.

# 3. DESCRIPTIONS OF TYPICAL SYSTEMS

## 3.1 Fare Collection Market

Nearly $3 billion in passenger fares are collected annually in the U.S. (Table 3-1). The largest segment is in bus transit. However, since the bus driver is available to supervise the operation of the fare box, most functions can be completed with a minimum of complexity. Commuter rail collects nearly $400 million annually in passenger revenue. These lines are often vestiges of larger railroad services and they continue several traditions and characteristics which have led to limited deployment of fare collection technology, despite potential for its successful application. Their passenger trip lengths are usually long, and the fares are graduated, i.e., distance related.

High passenger volumes in limited space and time have neccessitated the use of passenger fare processing machinery in urban rail transit. This has been aided by stations often being underground or elevated where access can be easily controlled. Analysis of the cost of maintaining fare collection equipment indicates that the cost of fare collection ranges between 7% and 31% of revenues collected. This implies a considerable potential for large dollar savings from improved technologies.

Table 3-1. U.S. Transit - Fare Collection Market (Reference 1)

| | Linked Passenger Trips (millions) | Revenues (millions) | Average Length Linked Passenger Trip |
|---|---|---|---|
| Heavy Rail | 1335 | $ 653 | 7.3 miles |
| Commuter Rail | 265 | 347 | 20.7 |
| Light Rail | 79 | 25 | 4.9 |
| Trolley Coach | 51 | 15 | 3.7 |
| Motor Bus | 4246 | 1584 | 4.7 |
| Urban Ferry | 55 | 31 | 5.4 |
| | 6043 | $2658 | 5.9 |

There are several industries much larger than the transit industry in dollar volume that can offer insight and assistance in fare collection. These include the vending machine and the computer support equipment industries. Much of the more advanced fare collection equipment employs vending machine elements, upgraded or arranged in new combinations. Many of the card handling problems in fare collection were first tackled in the design of computer support equipment. Although these industries can offer insight, application of their technology to transit must be done with extreme caution. The service rates, environmental conditions, and criticality of need are often much higher or more severe in a transit situation.

## 3.2 System Elements

An urban transit fare collection system contains two essential elements: a method of collecting the revenue from the passenger and a method of controlling access to the station or train. There are other elements, but some form of these two will be found in any system examined.

At a more detailed level additional elements can be identified. These include:

(1) Form of payment
(2) Fare structure
(3) Ticket type
(4) Ticket vending
(5) Change making
(6) Entry/Exit gates
(7) Money processing
(8) Compliance enforcement
(9) Equipment maintenance
(10) Station attendant
(11) Passenger assistance
(12) Management information

Table 3-2: Structural Characteristics of Rail Transit Systems Affecting Fare Collection Method (References 2, 3, 4)

| City or Operator | Route Miles | Stations | Daily Passenger (1000's) | Miles/ Station | Funding | Distance Related Fare | Daily Passenger /Station |
|---|---|---|---|---|---|---|---|
| Chicago Transit Authority | 89 | 142 | 500 | .63 | - | - | 3,500 |
| Greater Cleveland, RTA | 19 | 18 | 42 | 1.06 | - | - | 2,300 |
| Mass.Bay Transp. Authority | 23 | 41 | 90 | .6 | Y | - | 2,200 |
| New York City TA | 230 | 458 | 3320 | .5 | - | - | 7,200 |
| PATH (NY/NJ) | 14 | 13 | 143 | 1.08 | T | - | 11,000 |
| PATCO (Philadelphia/NJ) | 15 | 13 | 39 | 1.15 | - | D | 3,000 |
| SEPTA (Philadelphia) | 29 | 55 | 280 | .53 | T | - | 5,100 |
| BART (San Francisco) | 71 | 34 | 143 | 2.09 | Y | D | 4,200 |
| WMATA (Washington) | | | | | | | |
| Present | - | 33 | 280 | - | Y | D | 8,500 |
| Planned | 101 | 86 | - | 1.17 | Y | D | - |
| MARTA (Atlanta) | 13.5 | 14 | | .96 | - | - | |
| MTA (Baltimore) | 9 | 8 | 83 (est) | 1.13 | | | 10,400 |
| Miami | 21 | 20 | 150 (est) | 1.05 | | | 7,500 |
| Toronto | 32 | 57 | 714 | .58 | | - | 12,600 |
| Montreal | 21 | 35 | 455 | .60 | | - | 12,300 |
| Mexico City | 25 | 48 | 1800 | .52 | | | 37,500 |

Funding - Y - Subsidy provided by several local governments in different parts of the service area.

T - Operated by regional bridge authority.

Many of the definitions of system elements will be obvious from the discussions of Section 3.3. However, there are so many variations to fare structure that it is worthwhile to more precisely define this element. This is done in the following table, which is adapted from a recently completed survey of fare collection equipment. (Reference 5)

Table 3-3: Fare Structures in Order of Increasing Complexity

---

I. Predetermined fare (least complex)
  - Fixed Fare - Single Rate
    - No extra charge for transfers
    - Same rate for all passengers on all routes between any two points
  - Flat Fare - Multi-rate
    - One basic rate
    - May or may not charge for transfers
    - Reduced rate for certain passenger categories
    - Reduced rate for off-peak hours, Sundays, and holidays

II. Variable Fare (computed)
  - Variable Zone Fares
    - Fare rates in increments according to number of zones traversed by passenger
    - Can provide fare classes as a function of day and passenger category
  - Variable Distance Fares (most complex)
    - Fare determined for each journey by distance traveled
    - Reduced-fare classes can be provided by passenger category and time period

---

The term Automatic Fare Collection (AFC) relates to the extent of manual effort required to interface with passengers and operate a system that implements a particular fare structure. Common usage usually associates AFC with a variable fare structure, although it could also apply to a fixed fare system, depending on the specific equipment used. Variable distance fares are also sometimes referred to as graduated fares.

For many of these elements, there may be as many as 10 different methods of performing a function. The number of potential combinations to form different fare collection systems is enormous. A good understanding of the interaction of these elements can be readily obtained by examining several different in-use systems.

## 3.3 System Flow Charts

Four systems that illustrate a variety of fare collection techniques were selected and are indicated in Figures 3-1 to 3-4. These charts describe several of the essential differences between the systems; they are not a complete description. The systems will be examined in order of ascending complexity.

### 3.3.1 New York City Transit Authority (NYCTA)

The form of payment for the NYCTA is cash, paid to the station agent in exchange for a token. The token is placed in a turnstile to gain entry. The fare structure is flat, that is, it is the same between any two stations of the system. This can lead to great inequities in charges per mile for different passengers. Table 3-2 indicates that most urban transit systems, with short distances between stations (less than 1.1 miles), operating within one political subdivision have historically selected a flat fare structure, in spite of this inequity.

The tokens are manufactured especially for the NYCTA, who send inspectors into the contractor's plant to prevent unauthorized production. The token is used thousands of times in its life, and its cost per use is negligible.

As the flow chart (Figure 3-1) indicates, 50% of the passengers will already have a token and proceed directly to the gates. Approximately one-third of the passengers will purchase from one to several tokens from the station agent, who performs the ticket vending and change making functions. Over 8% of weekly riders will request a return coupon valid for a free ride by senior citizens or the handicapped at anytime, and all other persons only on weekends. (The weekend discounted fare program was recently discontinued).

The prime entry/exit gate is a mechanical turnstile which accepts the token. The turnstile turns are recorded on a meter enclosed in a sealed, welded steel box. The station agent collects tokens from the turnstile several times a day which he sells to the public. The agent is financially responsible for any failure of the token sales and cash collected to balance against turnstile registrations. The revenue section collects funds from the station agent. As the agent counts tokens, he visually inspects for counterfeits (slugs). If a pattern is noted at a particular location, a magnet to attract slugs containing iron would be placed in the turnstile and the Transit Police might place the location under surveillance.

Over 15% of the passengers enter without using a token. These include the return portion of senior citizens and weekend half fare trips plus students with passes, purchased through their schools. These passengers would enter through a slam gate, supervised by the agent. In some locations, the gates are equipped with a remote control lock operated by the agent.

The equipment is reliable (in the area of 40,000 transactions per failure) and rarely needs maintenance. The station attendant, in addition to providing information, gives an added sense of security to passengers by his presence. The system has limited use of closed circuit television (CCTV) for fare compliance or station security.

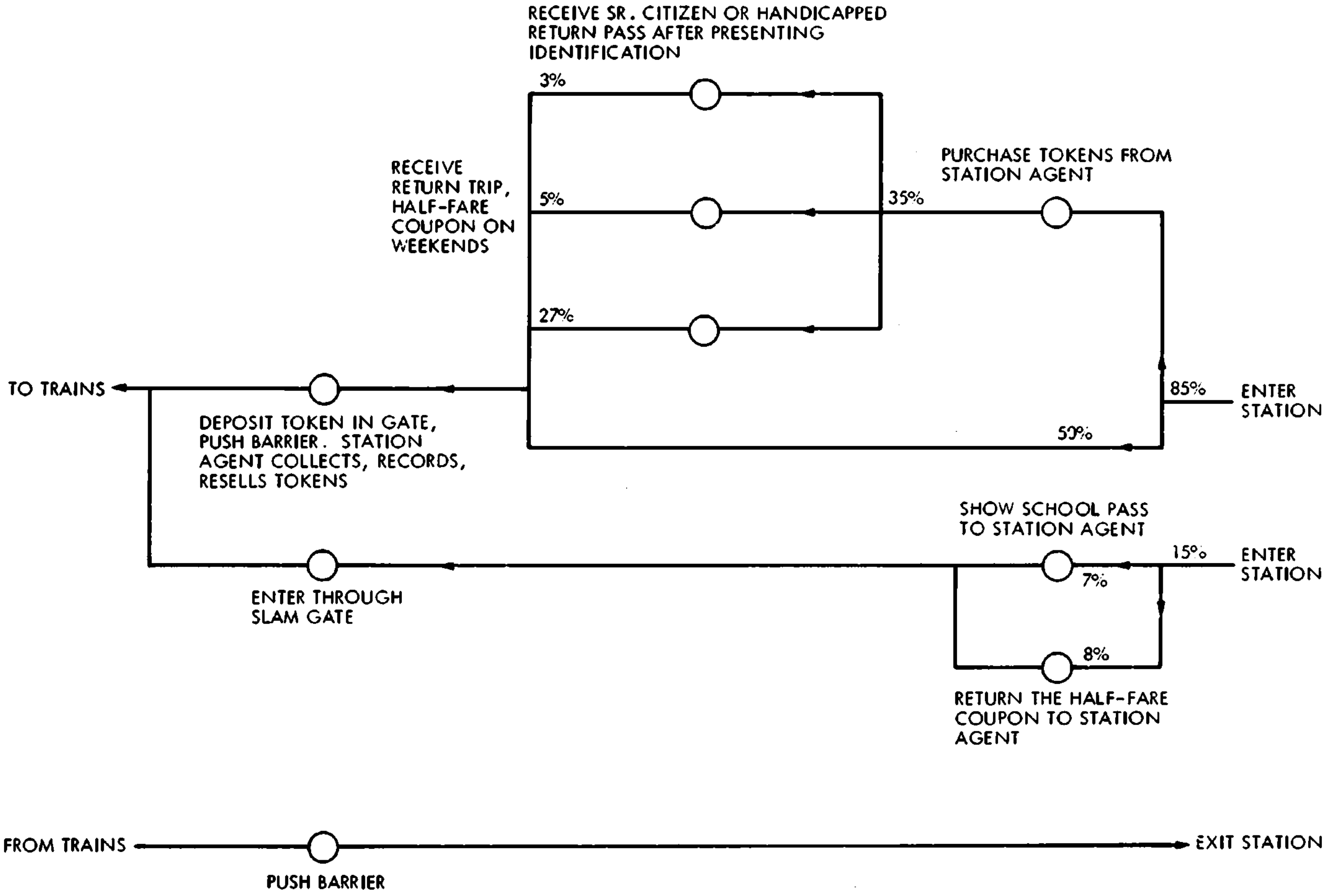


Figure 3-1: NYCTA Flow Chart, Manned Flat Fare

### 3.3.2 Metropolitan Atlanta Regional Transit Authority (MARTA)

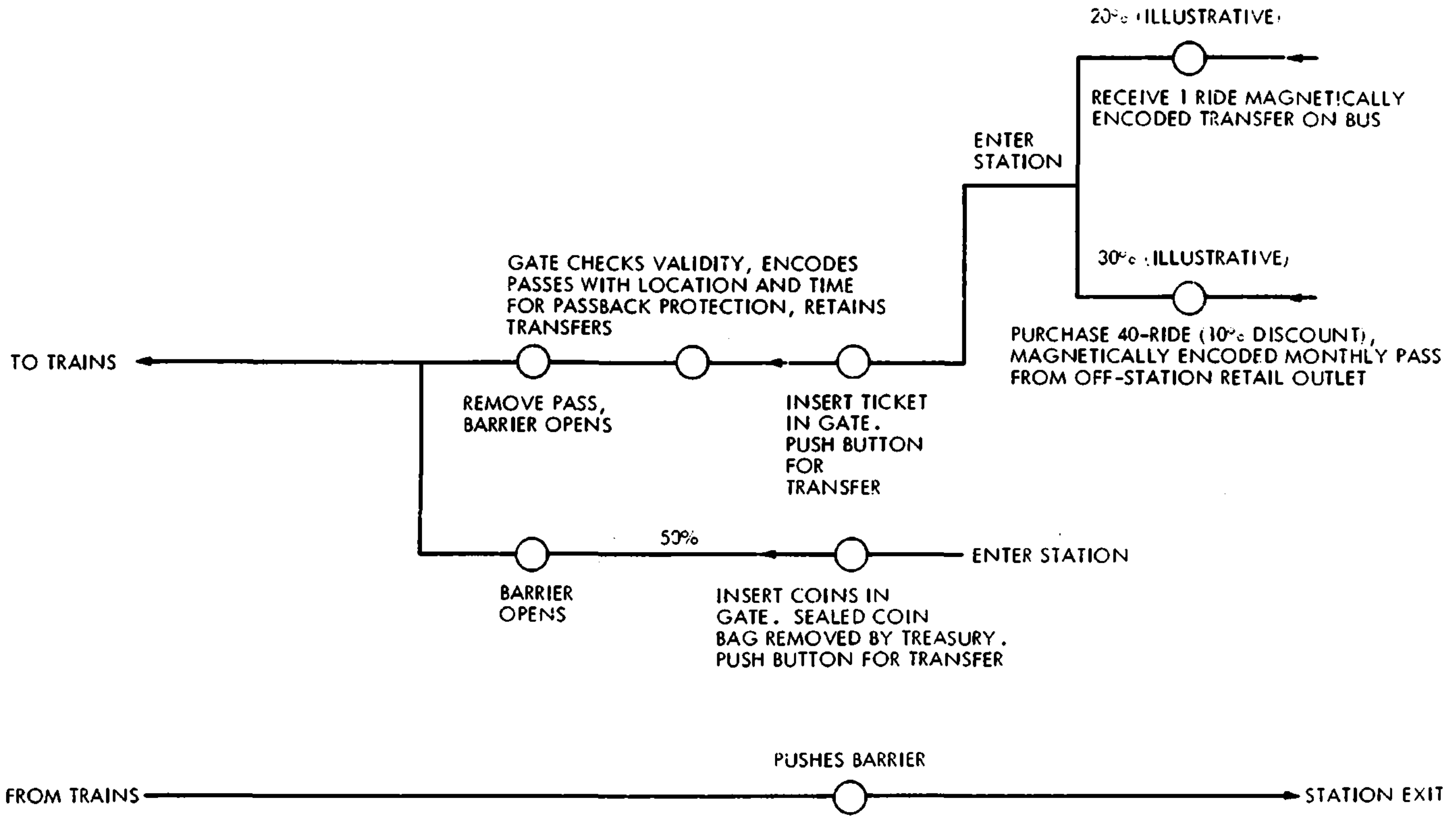
MARTA is the newest transit system in the U.S., having opened July 1979. Figure 3-2 shows its flow. The authorizing referendum for the system required a flat 25¢ fare. It was designed with the intent of being simple and reliable and permitting unmanned stations. Entry can be gained by depositing the exact fare in the gates, a magnetically-encoded 40 ride monthly pass or a magnetically-encoded single ride bus transfer. No printing is done over the ticket and the pass can be reused.

The monthly pass can be purchased at any of 24 different off station retail outlets. These drugstores, hospitals, and newsstands have agreed to sell the passes without taking a commission. A four ride discount is an incentive for passengers to purchase the pass. Connecting buses will issue passes which can be used in the connecting station gates. Hard data is not available because of the newness of the system. However, 20% is a reasonable figure for the proportion of transfers from a feeder bus system, and due to the higher cost of a MARTA monthly pass over 10-ride tickets at other systems, MARTA's pass user percentage is assumed to be 30%. Fifty percent of all patrons are expected to use the exact fare turnstiles.

No vending, change making machines or station agents will be in the stations. This is part of the plan to keep expensive or unreliable system elements out of the stations. Passenger assistance and compliance enforcement are provided by telephones, closed circuit TV and police patrols.

A train to bus transfer is issued to passengers when entering the gate if a request button is pushed. The transfer subsystem prints the transfer from a roll of papers. This type of printing and paper movement is simpler and less subject to jams than moving individual farecards or transfers via rollers.

The gate checks the validity of passes inserted and encodes passes with location and time. This prevents a patron from passing the ticket back over the barrier for use by another person. The gate captures magnetically encoded one ride transfers which can later be reencoded and reissued.



NOTE: DUE TO LACK OF OPERATING DATA, ILLUSTRATIVE VALUES SELECTED. SPECIAL GATE TO ACCEPT HANDICAPPED PASS NOT SHOWN

Figure 3-2: MARTA Flow Chart, Automated Flat Fare

Coins are collected in the turnstiles. At periodic intervals, they are removed in sealed containers by Treasury Department staff. They are brought to a vault room in the station and once a day, a truck picks up accumulated receipts. The money is counted in a central money room.

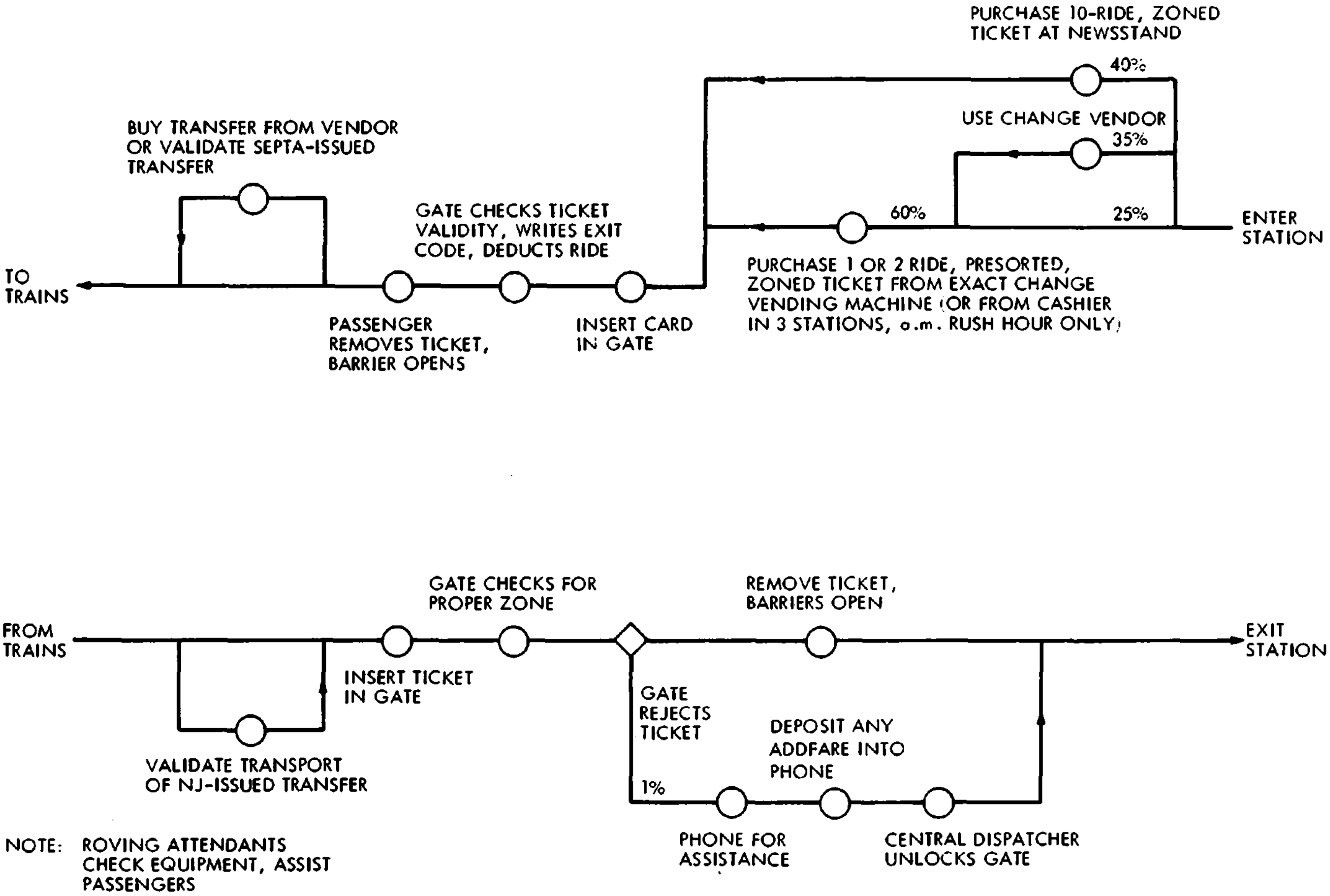
Upon exit the passenger passes through a one-way barrier. Equipment maintenance will be by MARTA staff who will be trained by the manufacturer, Cubic. The equipment is relatively simple and high reliability is expected. The following is a list of several of the reliability requirements in the procurement specification.

| | | | |
|---|---|---|---|
| (1) | Entry Gate (includes all elements, coins, pass, transfers, etc.) | Mean Cycles Between Failure | 34,000 |
| | | Mean Time Between Failure | 489 hours |
| (2) | Exit Gate | Mean Cycles Between Failure | 1,000,000 |
| | | Mean Time Between Failure | 12,000 hours |
| (3) | Handicapped Gate | Mean Cycles Between Failure | 23,000 |
| | | Mean Time Between Failure | 4,700 hours |
| (4) | High Speed Ticket Encoder | Mean Cycles Between Failure | 400,000 |
| | | Mean Time Between Failure | 5,000 hours |

Passenger assistance and compliance enforcement are provided by telephones, closed circuit television, and police patrols.

### 3.3.3 Port Authority Transit Corporation (PATCO)

The PATCO System (Lindenwold Line - Figure 3-3) uses a zone fare structure. The system length is 14 route miles, broken into five zones. Fares range between 55¢ and $1.15 or an average increment of 12¢ per zone.



NOTE: ROVING ATTENDANTS CHECK EQUIPMENT, ASSIST PASSENGERS

Figure 3-3. Patco Flow Chart, Stored Ride, Zone Fare

A thin (.0011") magnetically encoded, stored ride plastic ticket is used. Each costs 12¢ new, but is reused hundreds of times. The cost of reencoding and reissuing a used ticket is 1¢. Printing over the plastic is not done.

Forty percent of riders purchase their tickets in the form of 10-ride tickets from newstands. Newstands in the PATCO stations are required to sell tickets and are allowed 30 days to pay for them. This cash float is a strong incentive which encourages their cooperation. Single ride and two ride tickets are sold in cigarette-type vending machines, stored in separate stacks according to the particular zone-to-zone combination. Usually tickets for different zone combinations are sold at each station.

Thirty-five percent of passengers use a separate changemaker before using the vending machines. These are rented from and maintained by the manufacturer.

The entry gate has a card transport which moves the ticket through the machine. Upon insertion, the ticket is checked for proper entry zone, and a code, indicating that the next transaction must be an exit transaction, is written. One ride is also deducted.

At the exit station, the gate checks the ticket for the proper zone. A ticket with remaining rides will be returned to the passenger, otherwise it will be kept. Used tickets are collected, sorted, reencoded, and resold.

Money processing is greatly simplified due to the bulk sales to newspaper stands. Revenue department staff collects funds from the vendors and changemakers and restocks them. Both magazine-loaded and hopper-loaded changemaker return feeds have been tried. The former is usually more reliable in the laboratory, but requires considerable labor in loading the magazines. PATH reports that hopper-loading is usually more reliable in practice since heavily loaded magazines are often damaged in transit between the money room and the station and are, thereafter, prone to jam.

Compliance is aided by closed circuit televison (CCTV) and police patrols. Equipment maintenance and jam rates are low enough to allow unattended stations. Before each rush hour roving supervisors will check out each machine to ensure that it is working properly. The busier stations will have a supervisor assigned throughout the rush hour.

At other times, a patron may use the phone for assistance. If his ticket is not valid at that station, the additional fare is deposited directly into the phone and a gate is unlocked by the TV monitor observer.

### 3.3.4 Washington Metropolitan Area Transit Authority (WMATA)

The last and the most complex of the four illustrative fare collection systems is WMATA (Figure 3-4). It is a recent version of the earlier BART system. Similar to BART, it serves several separate political entities, and it will be a combination commuter railroad and urban transit system. These conditions encouraged the adoption of a distance-related fare structure which facilitates accounting of subsidies from the separate, supporting local governments.

It is also a stored-value instead of a stored-ride system; a marketing incentive. It has been stated that if a commuter has a valid prepaid fare card in his pocket, he is more likely to use the subway for occasional short noncommuting trips than if he had to pay a separate entry fee.

The fare structure is very precise and charges 40¢ for entry which allows three free miles of travel except for midday when a flat fare is charged. A fee proportional (7-8¢/mile) to the average of the airline and route distance is charged for additional travel on each trip. The charge is rounded off to the nearest 5¢. The system also accomodates special discount fare programs e.g., students, elderly, handicapped, and midday discounts.

A magnetically encoded, thin paper farecard is used to gain entry. The cost of each card is about 1¢. The remaining value of the card can be printed onto the card, over its protective coating. The card is usually used less than ten times before it begins to wear. The coding system is not particularly complex and it is possible that a limited number of persons have broken the code and regularly upgrade low-value farecards to unauthorized higher-value ones. Also, vendors can erroneously issue over-valued cards. Unlike the detection of a counterfeit coin or token, it is very difficult to detect any pattern of fare evasion since there is no physical evidence. One special survey detection method is to have the exit gate collect all cards and reissue new ones. The collected cards would be examined for fraudulent ones.

Fraud in fare collection can be due to either passengers or staff. All systems experience some fraud; however, published data is not readily available. A key principle of fraud control is that its cost should be less than the amount of money saved. European experience for self-cancelling, surface transport fare collection systems indicates that most systems lose between 0.5% and 5% of revenue due to fraud. (Reference 6) Estimates for the discrepancy between the value extracted from AFC tickets and the value of tickets sold at vendors are about the same as the proportion of passengers who evade payment at flat fare turnstiles.

Farecards are sold by a versatile vending machine which accepts $1 and $5 bills, change, or low valued farecards and issues a new farecard with any value between 40¢ and $20.00. It also returns change.

The form of payment is cash, which has led to unexpected problems. Dollar bills which cost about 1¢ to produce are designed to be kept in circulation for 9 months. Its been estimated that they are presently not withdrawn until 18 months. Coins can usually last 17 years. Vending machine manufacturers state that even new coins may not be within their official specification. The lowered physical quality of money leads to increased jams in vending and addfare machines. A common problem is bent dimes that have been used by passengers as emergency screwdrivers and tend to jam.

Thirty-three percent of persons entering a station will use the farecard vendor (Figure 3-4) and 67% will proceed directly to the gates. The September 1978 WMATA survey indicates that approximately one-third of farecard vendor users are trading in lower-value cards for upgraded cards.

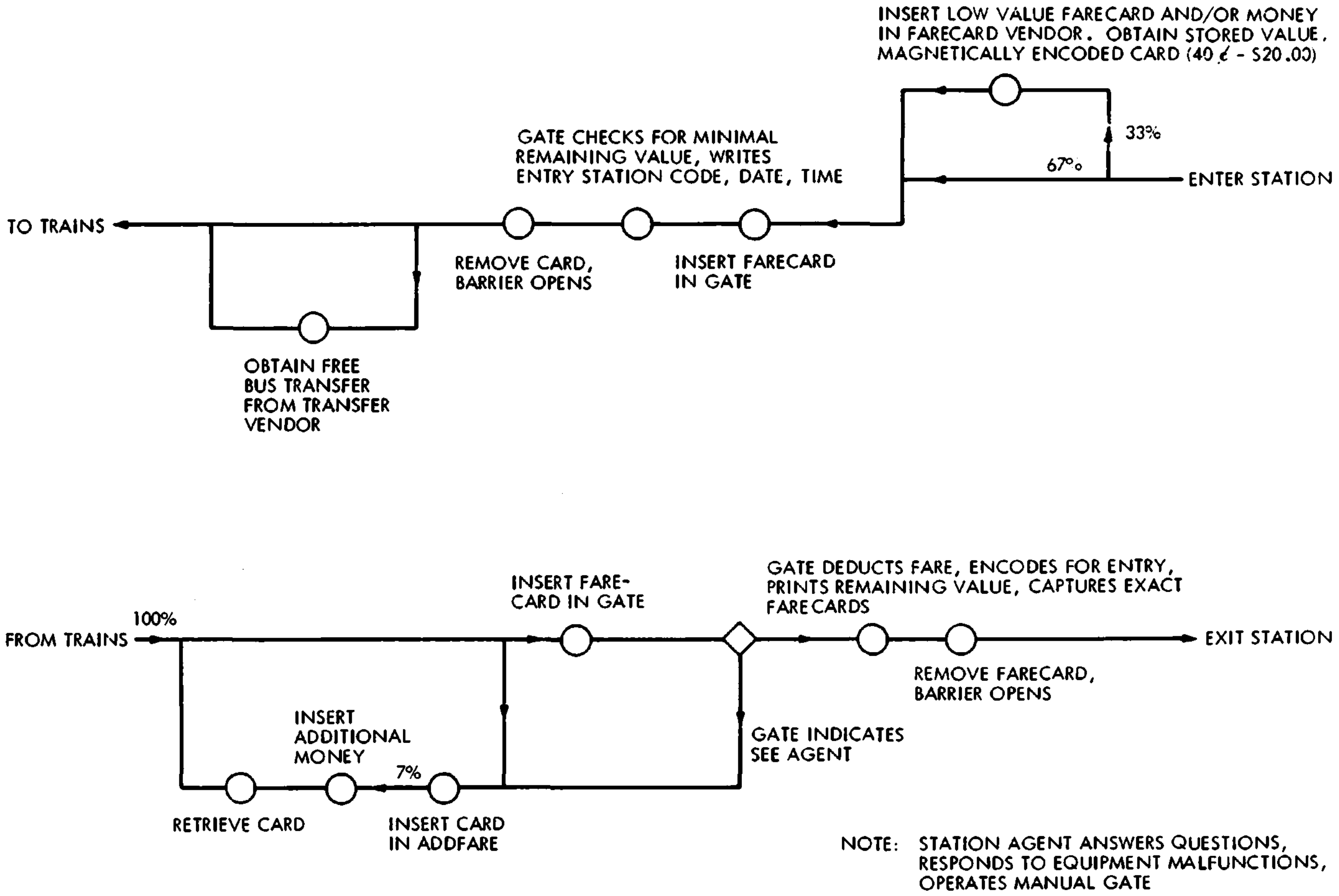


Figure 3-4: WMATA Flow Chart, Stored Value, Distance Related Fare

Upon entering the station, the farecard is inserted in the gate, checked for minimal remaining value and an entry and location code is magnetically written on the ticket. The card moves through the gate via the transport to the exit slot where it is removed by the passenger.

When in the paid area, a passenger may obtain a free rail-to-bus transfer, from a separate transfer dispenser. A need for a machine-issued and readable bus-to-rail transfer has been expressed.

In exiting a station, the farecard is inserted in the exit gate where the travel distance is calculated, and the proper fee deducted from the stored value. The remaining value is printed on the card. If the value is not sufficient, the card is rejected and a message to "see agent" displayed. The patron then goes to the agent who forwards him to the addfare machine, a simplified vendor, which upgrades the ticket upon insertion of the proper fee. The upgraded farecard can then be used in the exit gate where it is collected as the patron exits. At least two addfare machines are at each station, in the event that one is out of service.

Money is collected from the vault chambers in the farecard vendors and addfare machines by Revenue Service and Collection Department staff. The station attendant doesn't have access to the vaults, or perform any functions involving the handling of money. This increases his own security. Compliance is enforced by closed circuit television, the station agent, and the police.

The required equipment maintenance of this system has been much greater than desired. Clearance of jams and calling for maintenance repair are so frequent that the concept of unmanned or reduced level station manning is practically eliminated. Rapid response to maintenance calls by a large, widely-distributed maintenance staff can lead to high equipment availability, in spite of frequent malfunctions, but at great expense. It is not clear whether the station agent would be required even if the equipment functioned very well. He also performs the functions of increasing the passengers' sense of security and answering questions from Washington's many visitors. The present WMATA policy is to require a full-time station attendant at every mezzanine. Passenger assistance is provided by the station attendent.

WMATA has an improved Data Acquisition and Display System (DADS) compared to the BART system. Its most significant new feature is the monitoring of equipment performance. These systems also provide a sealed written record of each machine's transactions and receipts, and a time-varying code which is used by the entry and exit gates to reduce fare evasion.

Cumulative statistics of fares paid, passenger flows, vending machine sales, and vending machine receipts can be centrally polled at each mezzanine kiosk.

## 3.4 System Element Reliability

The reliability of the overall system is determined by its individual components. Table 3-4 illustrates the mean number of transactions per maintenance action, based on reported failures, for several types of fare collection equipment. It indicates vast differences in reliability and shows a trend toward decreasing reliability with increasing complexity. It can be used as a guide in estimating achievable levels of improvement for present automatic fare collection equipment.

Several choices are available in selecting a reliability definition that relates equipment performance to activity. Performance can be described in terms of the capability to complete all functions, complete the more critical functions, be repairable by fingertip maintenance (level 1), or be repairable by maintenance which requires replacement or adjustment of components (level 2). Various definitions are used according to the particular need. Examples of failure classifications that illustrate these definitions include: rejection of slightly worn dollar bills by a bill verifier, nonreturn of a valid farecard with remaining value, quick clearing of jams by station attendants, and parts replacement by maintenance technicians.

Table 3-4. Typical Reliability, Fare Collection Equipment

| | Mean Transactions per Maintenance Action |
|---|---|
| **NYCTA** | |
| Flat fare token accepting turnstile gate | 40,000 |
| **CTA** | |
| Flat fare coin accepting - transfer issuing - turnstile gate | |
| Type 1 | 800 |
| Type 2 | 2,500 |
| **PATH** | |
| Flat fare coin accepting turnstile gate | 11,000 |
| Flat fare pass card reader - conductive ink - turnstile gate | 50,000 + |
| **PATCO** | |
| Entry-exit gate - magnetic card stored ride - zone fare | 6,000 |
| Ticket vendor - sorted tickets | 900 |
| Changemaker | 2,000+ |
| **BART** | |
| Entry-exit gate - magnetic card reading - graduated fare computes & prints remaining value | |
| Type 3 | 4,200 |
| Type 4 | 1,200 |
| Farecard vendors | |
| Type 3 | 1,100 |
| Type 4 | 400 |
| Addfare | |
| Type 3 | 1,100 |
| **WMATA** (Rush Hour Data Only) | |
| Gate - Magnetic card reading - graduated fare | |
| Entry gate | 2,000 |
| Exit gate - computes & prints | 500 |
| Farecard vendors | 100 |
| Addfare | 75 |
| **European Surface Transport** | |
| Cancelling machines | 20,000 |
| Ticket issuing machines | 5,000 - 10,000 |
| **Morgantown Personal Rapid Transit** | |
| Gate - reads magnetic encoded passes - accepts coins for flat fare - passenger indicates destination. | |
| Hard | 38,000 |
| Soft | 15,000 |
| **Montreal Urban Community Transit Commission** | |
| Transfer dispensers - machine readable Punched hole | 22,000 |
| Gate - flat fare - reads magnetic encoded ticket, paper punched transfer | 27,000 |
| **Electronic Coin Acceptors** - Non Transit | 50,000 |

Note: Maintenance actions include repair orders completed by maintenance staff, jams cleared by station attendants, or repairs completed by patrolling maintenance staff. Usually, the ratio of jams to hard failure varies between 3/1 and 5/1. Types in the table refer to different manufacturers of similar equipment.

The mean number of transactions per maintenance action was selected as a definition which best corresponds to the ability of a fare collecting system to process large numbers of passengers with minimal expense and delay. It is also broad enough to apply to the various practices in use at different properties.

The data was collected from different transit systems and, in some cases, excellent records were available. In other cases, estimates (e.g., that one third of the machines are serviced each day by roving teams of maintenance personnel in addition to the logged calls) were the best information available. It should be noted that these are average rates, and in any population there will be better and worse machines.

The definition of failure also varies according to the system. In NYCTA the station attendant performs no repair functions, and any jam will result in a maintenance report. In BART the station attendant will apply fingertip maintenance to clear farecard and money jams. These failures will never be reported, whereas a hard failure requiring a maintenance technician will be reported.

The NYCTA turnstile is simple, inexpensive, and extremely reliable (40,000 transactions/failure). The acceptance mechanism tests the size of the token only. It was estimated that 90% of the failures are actually jams caused by insertion of foreign objects into the token slot. Records indicate that the jam rate will rise by 25% in the year following a fare increase. There is a 100% correlation between the turnstile registrations and turns.

The CTA turnstile accepts coins and issues transfers. Some passengers will overpay for convenience and the money received will not correspond to the barrier turns. Coins are collected in the Type 2 machine in a sealed steel cylinder which is removed from the machine by the Revenue Department. The reported failure rate for those machines appears unusually poor considering their lack of complexity. This data deserves closer investigation.

Post Authority Trans Hudson (PATH) uses turnstiles similar to CTA, except there are no transfers. Their rate is 11,000 transactions per failure. Most of these are attributed to jams from bent dimes. PATH has wired an independent changemaker to several of their machines that accepts dollar bills, returns change after subtracting the fare and releases the barrier lock.

A key observation is that PATH is capable of operating a system with no station attendants using equipment with an overall rate of 11,000 transactions/failure. If this information were to be used as an empirical guide for reliability objectives for stored value systems, it should be multiplied by some factor to take into account the number of machine interfaces a rider might have in sequence.

A more general formulation of this observation is to note that the PATH system operates with a failure rate of 1 per 11,000 passengers for turnstiles plus 1 per 2000 passengers for the changemaker. Assuming that 25% of passengers use the changemaker, the combined system failure rate is $1/11,000 + .25\ (1/2000) = 2.2\text{x}10^{-4}$ failures per passenger. In other words 0.022% of all passengers would encounter a machine failure, or 4540 ($1/22\text{x}10^{-4}$) passengers processed between failures.

"Observations made on other transit systems have indicated that any passenger confusion arising from the man/machine interface, which affects as many as 0.5% of the patrons, could easily be cause for general dissatisfaction." (Reference 7). This would imply that even if a machine were to self clear jams without the aid of a station attendant, at least 99.5% of passengers should be processed by the equipment without resorting to manual assistance.

A year-long demonstration was recently completed of 9 ALMEX multiride ticket cancellers. This device is similar in appearance to a miniature time clock. The passenger inserts his multiride ticket into a slot, one ride is deducted by an internal paper cutter, and the passenger withdraws his ticket.

The canceller makes contact with several electrically conductive stripes on the back of the ticket which form a binary on-off code. The present canceller can be set to recognize seven different codes, any three at one time. A new model is under development that will recognize 62 codes. PATH had placed the cancellers on small stands in front of and wired to the turnstiles. The gate can handle passengers paying with cash or with tickets.

The mean number of transactions per maintenance action was over 50,000, which was superior to any of the other equipment examined. Two passengers out of a thousand (0.2%) reported that they inserted their 10 ride ticket into the machine backwards, and that the ticket was destroyed, but the machine did not jam. Their crumpled ticket was exchanged for a new one by PATH.

The canceller system operated successfully, as it has in many European systems. However, the system was removed after the one year test due to the cost of distributing tickets (commissions to retailers) and the lack of an urgent need for the added passenger convenience.

It is feasible to develop a canceller that punches a hole in the ticket corresponding to the zone of entry. Then on exit, another canceller could recognize the hole and cut an amount off the ticket in proportion to trip length. The canceller could, therefore, be used to readily implement a zoned fare or even a stored value system.

PATCO employs a zone fare system with magnetically encoded plastic cards that are inserted into a card transport in the gate. No printing is done on the card, and few jams are caused by card wear. The mean rate of 6000 transactions per failure is twice that of BART or WMATA. The ticket vendor employs presorted stacks of different type tickets. The rate of 900 transactions/failure is not as high as would have initially been expected for such a simple machine. This is primarily a result of air pressure causing thin farecards to stick together.

Changemakers standing as separate units maintained and owned by the manufacturers and rented to PATCO are used. Their reported failure rate of 2,000 transactions per failure appears to be better than when equipment with the same functions are incorporated as part of a larger more complex machine. Most of the reported failures are associated with the bill validator. Although not considered a failure, active use of a changemaker will require frequent restocking by an attendant. Commercial changemakers can carry on between 200-1000 transactions before restocking is required. Transit agencies can place the changemakers in accessible, but inconvenient locations, thereby discouraging their use.

PATCO is also able to operate stations with no stationary attendants, although they have roving troubleshooters (average passenger volumes per station are about 27% of the volume of PATH).

The performance of BART and WMATA equipment is listed for ease of comparison, and discussed at greater length in Section 4. Although a recent survey found that the ratio of soft to hard failures was more than 3 to 1, the ratio derived for WMATA was applied to BART for comparison purposes.

The information concerning European surface transit was developed in a survey conducted by the International Union of Public Transport, and reported in 1973. The figure excludes servicing resulting from false alarms and vandalism. The specific models of equipment that these figures represent is not clear from the report. Equipment developed since 1973 or used in a station environment rather than on a bus or at a stop might perform better than indicated. The ticket issuing machines described accept coins only. This data does indicate that it is feasible to implement simple ticket-issuing machines in a transit environment with reasonably good reliability.

Since September 1979, the Morgantown Personal Rapid Transit System (PRT) at the University of West Virginia has been using a pass system developed by Duncan Industries. Their fare gates accept a 25¢ flat fare or a plastic card with an encoded magnetic stripe. The gates also provide a means for the patron to indicate his desired destination. This information is used for real time scheduling.

The patron inserts his pass into a slot and withdraws it. The card never leaves his possession. Clocking pulses in the card permit it to be read even when inserted and withdrawn at varying speeds. No passback protection is provided other than closed circuit television observation.

The system processes approximately 20,000 passengers per day, 95% of whom use passes. Approximately one gate out of 29 would be out of service every other day due to a hard failure. The malfunction usually occurred in the destination selection or coin mechanism. These preliminary results would indicate a failure rate of over 38,000 transactions per hard failure. However, a more extended testing period is reqired to determine a failure rate that accounts for machine wear out and cold weather effects.

Gate jams occur approximately once or twice per day. These are usually due to a passenger mistakenly inserting coins into the pass reader slot instead of the coin slot. This corresponds to a failure rate of 15,000 transactions per jam. This might be reduced by improved graphics on the gate.

The Montreal Urban Community Transit Commission (MUCTC) utilizes 2000 bus transfer machines, costing about $3000 (Canadian). They were manufactured by CGA, a French concern. The machines print the direction of travel, and print and punch the time (at 30 minute intervals set by the driver) and a two-letter random code using the letters A through I. The code is set at the start of each day. The vending is done from a roll of ticket stock.

MUCTC reports that there are about eight failures per day which can be repaired by two men working full time. Since there are about 1,224,300 transfer transactions per week, this implies an average of 21,863 transactions per failure.

A turnstile is used in conjunction with the transfers. A valid transfer (good for about 90 minutes from the punched time) is inserted into the turnstile which reads the holes (hour, two-letter code) by means of a light sensor and admits the passenger. Invalid transfers (expired time or invalid code) are rejected.

These turnstiles also accept and validate tickets with magnetic stripes, using a frequency of 333 Hz and a harmonic number 2 or 4. Most of the failures are associated with ticket jams, transport strap wear and magnetic head wear. The straps have to be replaced and the heads can be cleared or replaced, whereas the agent can fix ticket jams. Failures in the optical sensing transfer validator are rare, and are usually due to driver error in setting the code, date or hour.

These turnstiles cost about $17,000 (Canadian) and are manufactured by Automatec. MUCTC reports about 45 failures per week in their 497 machines, or about 27,207 transactions per failure. The total mean time to repair (including travel time) is one hour.

Coin acceptors are an integral part of most ticket vendors and some turnstiles. Their performance in existing fare collection equipment has not been satisfactory, and has been a frequent cause of jams. Fortunately, it appears that equipment suppliers, on their own initiative, are developing new products with vastly improved performance.

The functional requirements of coin acceptors vary with their application. If used in a turnstile, their speed of operation is a critical feature. The accepting 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.

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.

In response to issue of the $1 coin, several equipment manufacturers are developing equipment to accommodate it. The Coin Acceptor Company, St. Louis, MO, 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. Both National Rejector, Inc., Hot Springs, AK, and Coin Acceptor are developing electronic coin validators which they expect to soon have on the market.

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

Variety Vendors, Detroit, MI, has had 250 units of the MARS electronic coin changer in service for three years. The cost of a unit that accepts four different prices, in quantities of 50 units, is $334, whereas a single price unit costs $250. The unit contains validator, escrow, coin addition, and coin return functions. The vending operator reports a reliability rate of 50,000 vends per failure on the coin validator function, no problems with the addition function, and 15,000-20,000 vends per failure for the coin return function.

The changer processes bent dimes and even paper clips without jamming. The only preventive maintenance performed is cleaning once a month with warm water and soap. These units were operated at a rate of 1000 vends per week.

The MARS electronic coin changer presently on the market has a maximum escrow capacity of $3.15 in increments of 5¢. A development contract or a large quantity order would be required to induce the manufacturer to produce a special transit unit with a larger capacity escrow. In succeeding years, MARS expects to market separate coin validators.

The transit industry may have available in the near future highly reliable coin validating equipment, at competitive prices, for use in ticket vendors and turnstiles.

## 3.5 Fare Collection Capital and Operating Costs

Both the capital and operating costs of fare collection systems vary tremendously. Depending on its complexity and function, a gate can cost between $2000 and $30,000. Even in the structural design of the stations, additional costs are incurred, especially at mezzanines providing space for fare collection equipment.

Approximate capital costs of typical fare collection equipment are presented in Table 3-5. This data was derived from price quotations in response to different bids, with different design criteria and can only be used as rough comparisons. The cost to equip a station with stored value fare collection equipment (e.g., 10 gates, 6 farecard vendors, 3 addfares, and 1 data acquisition and display system) would be $510,000. The cost to equip a station with a token-accepting flat fare system (e.g., 1 bullet proof attendant booth, 6 turnstiles) would be $52,000.

The operating costs of several fare collecting systems are shown in Table 3-6, derived from a survey conducted in 1977. Since that time, the WMATA ridership and receipts have more than doubled. The 21% of passenger revenue indicated as the cost of fare collection may have changed. WMATA's fare collection problems have increased, and it is more likely that the 21% is now closer to BART's 31%, rather than NYCTA's 19%. A more up-to-date survey of this information should be conducted.

The fare collection costs shown do not include any component for the annualized portion of their capital costs. They could have also been expressed as a percent of transit system total operating cost. However, it could be difficult to properly distribute costs between fare collection, station operations, and other transit system expenses. Revenue collected is a measure that is closely associated with fare collection, and is one for which precise records are usually available.

The largest cost component of several systems are expenses for station personnel, which range from 88% of fare collection costs for NYCTA, to 70% for BART, to 16% for PATCO. Maintenance costs also vary between 12% for BART and WMATA, 4% for NYCTA and 17% for PATCO. Revenue collection, counting and accounting varies between 18% for WMATA, 12% for BART, 6% for NYCTA and 5% for PATCO.

Table 3-5. Estimated Fare Collection Equipment Capital Costs

| Gates | 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 fare card 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 add on to gate | $1,500-$5,000 |
| Transfer Dispensers - machine readable punched holes | $3,000 |

Table 3-6. Estimated Annual Fare Collection Operating Cost FY78 (Reference 8)

| Fare Collection Costs (millions) | NYCTA | BART | Hamburg | PATCO | PATH | WMATA |
|---|---|---|---|---|---|---|
| Stationary Station Personnel | 80.8 | 3.8 | .3 | 0 | 0 | 1.6 |
| Mobile Station Personnel | " | .9 | .3 | .15 | .60 | .2 |
| Equipment Maintenance - | | | | | | |
| Field | 3.5 | .6 | .03 | .16 | .16 | .8 |
| Central | - | .2 | .08 | - | .02 | - |
| Collection | 3.1 | .4 | .3 | .12 | .03 | .4 |
| Revenue Counting | 2.2 | .3 | .04 | .03 | - | .3 |
| Revenue Accounting | .3 | .1 | .2 | .01 | .22 | .06 |
| Compliance Enforcement | .3 | - | 1.0 | .40<br>(police) | - | .02 |
| Other | 1.7 | .4 | .3 | .08 | .05 | .80 |
| Total | 91.9 | 6.7 | 2.6 | .95 | 1.1 | 4.2 |
| % of Passenger Revenue | 19 | 31 | 7 | 7<br>w/o police<br>12%<br>w/police | 8.7 | 21 |
| cents/ride | 8.5 | 19.4 | 1.4 | 8.6 | 2.7 | 8.6 |

These results are rather surprising. They indicate that the inability of BART or WMATA to achieve high reliability levels on their fare collection systems have led to very large expenses for station personnel and maintenance. At NYCTA, on the other hand, the station agent also counts and stacks money, eliminating the need for extra expense. If one purpose of automated fare collection is to reduce cost, it is not being met at BART and WMATA.

The cost of the farecard, ticket, or token is one component of operating cost that could affect the type of fare collection system selected. This is especially important as transit agencies begin to implement monthly pass programs which utilize more durable and expensive farecards. For several types of farecard mediums, Table 3-7 lists the cost per unit card, estimated number of trips taken per card, and the ticket cost per trip.

Table 3-7. Ticket Costs per Trip

| Tickets | Cost/ Unit (¢) | Trips/ Unit | Cost/ Trip (¢) |
|---|---|---|---|
| Token | 50 | thousands | .01 |
| Magnetic Stored Value Paper Fare card | 1-2 | 5 | .4 |
| Magnetic Encoded Stored Ride Plastic Fare card | 20 | 100's | .02 |
| Magnetic Encoded Flat Fare Plastic Pass | 50-100 | | |
| Semester Pass | | 100 | .50 |
| Monthly Pass | | 20 | 2.5 |
| Conductive Ink Multiride Ticket | 2 | 8 | .2 |

The pass card referenced in Table 3-7 is used in the Morgantown PRT and is issued for a semester, about 5 months. It is a high quality, plastic coated card with the student's picture. It is used for other purposes in the university in addition to fare collection. Duncan charged the transit operator $1 per card. This results in a card cost of 0.5 cents per trip over a semester. Use of this card for a monthly pass system would cost 2.5 cents per trip, which is quite high and probably uneconomical.

PATCO uses similar cards that are plastic coated and contain encoded magnetic stripes. They cost 12 cents per card several years ago and might be expected to cost 20 cents per card now with the increased cost of petroleum-derived products. The PATCO card does not contain the patron's picture, and does not need to be as stiff as the Morgantown card. As noted earlier, the cost of collecting and reencoding the tickets is about 1¢ per ticket.

Using the examples above as guidelines, an estimated cost of a monthly passenger-held pass card without an identifying picture might be 40 cents. This leads to a cost of one cent per ride for the card, which is in the same range as the present cost per ride for the paper tickets used at BART and WMATA.

These costs could be lowered if the expired cards were to be collected, reencoded, and reissued. At PATCO, the gates automatically collect cards with no remaining value. A special collection system would be required to complement a passenger-held monthly system.

Although not otherwise described in this report, mention should be made of the honor system used in Hamburg and many other European systems. Passes are sold through banks, vending machines, and retail outlets. There is no entry or exit control, but inspectors ride the trains and check for valid passes. The operating cost of this system is 7% of revenue collected, or 1.4¢ per ride.

The honor or self-cancelling systems, in spite of successful application in several European cities, probably has useful but more limited applications in the U.S. Although this is changing, American city demographics are different from those in Europe where the wealthier persons tend to live in cities. There are some signs that this may be changing. The level of criminal activity is often less too. In many European cities the police are not even armed. UMTA is investigating the feasibility of a self-cancelling fare collection system for bus transit in the U.S. If it proves successful, potential for very large fare collection cost reductions when applied to rail transit.

Major reasons for using automated fare collection and distance-related fares are to achieve increased revenues by charging more for the longer trips and to fulfill political constraints instituted by separate, supporting local governments. It may be that these functions outweigh the added costs of an automated, stored-value fare collection system. In any event, it is reasonable to ask whether the reliability of these systems can be improved enough to significantly lower the operating costs, or whether a simpler fare collection system might fulfill the same goals in a less costly manner.

## 3.6 Effect of Fare Collection Systems on Revenues

Estimating the impact of a fare collection system on revenues is a multifaceted problem, some aspects of which are outlined in Section 7.1. An order of magnitude estimate for the revenue difference between a flat fare and distance related fare structure can be developed by use of the trip length distributions shown in Table 3-8, which is based on a sample survey of 71,000 persons conducted by the U.S. Bureau of the Census.

The mean trip length for journey to work subway trips taken in the U.S. is indicated as 10.1 miles. This corresponds with Table 3-1 which indicates that the mean length for all subway trips is 7.3 miles, since about one quarter of total riders will be shorter distance, non-peak hour, non-journey to work riders.

Suppose a transit system had the characteristics shown in Table 3-8 and charged a distance-related fare of (C) cents/per mile. The mean revenue per passenger would be 10.1 (C) cents. If this system switched to a flat fare structure, with the same charge for an average trip, then each passenger would be charged a flat fare of 10.1 (C) cents. Passengers who had been traveling distances greater than the mean will now be paying less and there will be a reduction in system revenues. The revenue reduction for the given system is (.26 (2C) + .187 (9C) + .042 (14C) ); 2.78C. Therefore, the percentage reduction in revenue collected from work trips greater than the mean is 2.78/(10.1 + 2.78) = 21.6%.

Table 3-8

Trip Length Distribution from Journey to Work in the U.S., 1975, (Reference 9)

| Means of transportation to work | Total[1] (thousands) | Percentage distribution by distance to work (miles) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Less than 1 mile | 1 to 2 miles | 3 to 4 miles | 5 to 9 miles | 10 to 14 miles | 15 to 24 miles | 25 miles or more | Mean |
| All workers[1]....... | 70,816 | 12.3 | 16.0 | 17.2 | 21.6 | 13.5 | 12.3 | 7.1 | 8.5 |
| Autombile or truck....... | 61,657 | 8.1 | 16.3 | 17.9 | 22.9 | 14.1 | 13.1 | 7.6 | 9.0 |
| Drive alone........... | 47,188 | 8.7 | 16.9 | 18.8 | 23.5 | 13.8 | 12.1 | 6.0 | 8.3 |
| Carpool............... | 14,470 | 6.0 | 14.4 | 15.0 | 20.7 | 15.0 | 16.0 | 12.8 | 11.4 |
| Public transportation.... | 4,587 | 2.8 | 14.3 | 21.3 | 24.1 | 16.9 | 13.5 | 7.0 | 9.1 |
| Bus or streetcar....... | 2,958 | 3.1 | 18.0 | 26.1 | 25.7 | 15.2 | 8.7 | 3.3 | 7.1 |
| Subway or elevated..... | 1,124 | 1.3 | 5.6 | 15.8 | 28.2 | 26.0 | 18.7 | 4.2 | 10.1 |
| Railroad.............. | 387 | - | 2.1 | 0.8 | 3.9 | 8.3 | 39.8 | 45.7 | 24.3 |
| Taxicab............... | 118 | 18.6 | 45.8 | 22.0 | 11.0 | 3.4 | - | - | 2.4 |
| Bicycle................. | 432 | 41.4 | 43.1 | 10.0 | 4.2 | 1.6 | - | - | 1.4 |
| Motorcycle.............. | 285 | 11.2 | 19.3 | 17.2 | 19.3 | 15.8 | 12.6 | 4.6 | 7.5 |
| Walk only............... | 3,645 | 91.4 | 8.3 | 0.2 | 0.1 | - | - | - | 0.1 |
| Other means............. | 210 | 27.1 | 31.4 | 8.1 | 19.0 | 10.0 | 3.8 | - | 3.9 |

[1] Excludes workers with no fixed place of work and workers who worked at home.

(For the United States: 1975. Workers 14 years old and over.

These lost revenues could be made up from increased revenues from passengers who had been traveling less than the mean distance. However, the fare structure change would probably decrease short trip demand more than it would increase long trip demand, and a percentage revenue reduction in the neighborhood of 5% might be expected. In practice, it may be politically impossible to correspondingly raise the short distance fares and the actual revenue loss would be over 20%.

This illustrative example was calculated on national transportation statistics. The method could be applied to particular systems, if the trip distribution were known. It should be noted that trip distributions can vary. The proportion of longer trips could increase with the extent of the system, age of the system, and size of the metropolitan area, and would decrease with the more widespread use of monthly passes, midday discounts and other techniques for promoting short distance trips.

## 3.7 Processing Rates

The efficient movement of high volumes of passengers requires fare collection equipment with high processing rates. Often the limitation in the service rate is due to the ability of the patron to understand the system or walk at appropriate pace. Table 3-9 summarizes processing rates observed at several types of gates.

Table 3-9. Gate Processing Rates

| Gates | Persons/Minute |
|---|---|
| Doors - Free Swinging (Reference 10) | 40-60 |
| Registering Turnstiles | |
| Free Admission (Reference 10) | 40-60 |
| with Ticket Collector (Reference 10) | 25-35 |
| Coin Operated | |
| Single Slot (Reference 10) | 25-50 |
| Single Slot-one coin (Reference 11) | 45 |
| two coin (Reference 11) | 30 |
| Double Slot (Reference 10) | 15-25 |
| (Reference 11) | 15 |
| Fare Gate with Ticket Transport | 20-30 |

# 4. SYSTEM PERFORMANCE OF AUTOMATIC FARE COLLECTION AT BART AND WMATA

## 4.1 Introduction

The next two sections develop quantitative descriptions of the performance of the stored-value automatic fare collection systems at BART and WMATA. It is necessary to more precisely define the present condition before improvements can be effectively sought. By noting the best performance consistently achieved by specific equipment designs at BART and WMATA, a realizable minimal performance objective for the generic class of stored-value systems is established.

An extensive amount of performance data was collected on both systems. The analyses performed were quite useful. Performance may be viewed in at least two ways. One way is to look at statistics such as mean time between failures (MTBF) and mean time to repair (MTTR), and the other way is to look at the statistic known as transactions per failure.

The first method, which deals with time intervals rather than level of use factors, is primarily used where an item is susceptible to failure based on its length of time in continuous operation. For example, a light bulb which is left on continuously has an average time before it fails, and some probability distribution around that average which describes the probability of its failure after a given amount of time.

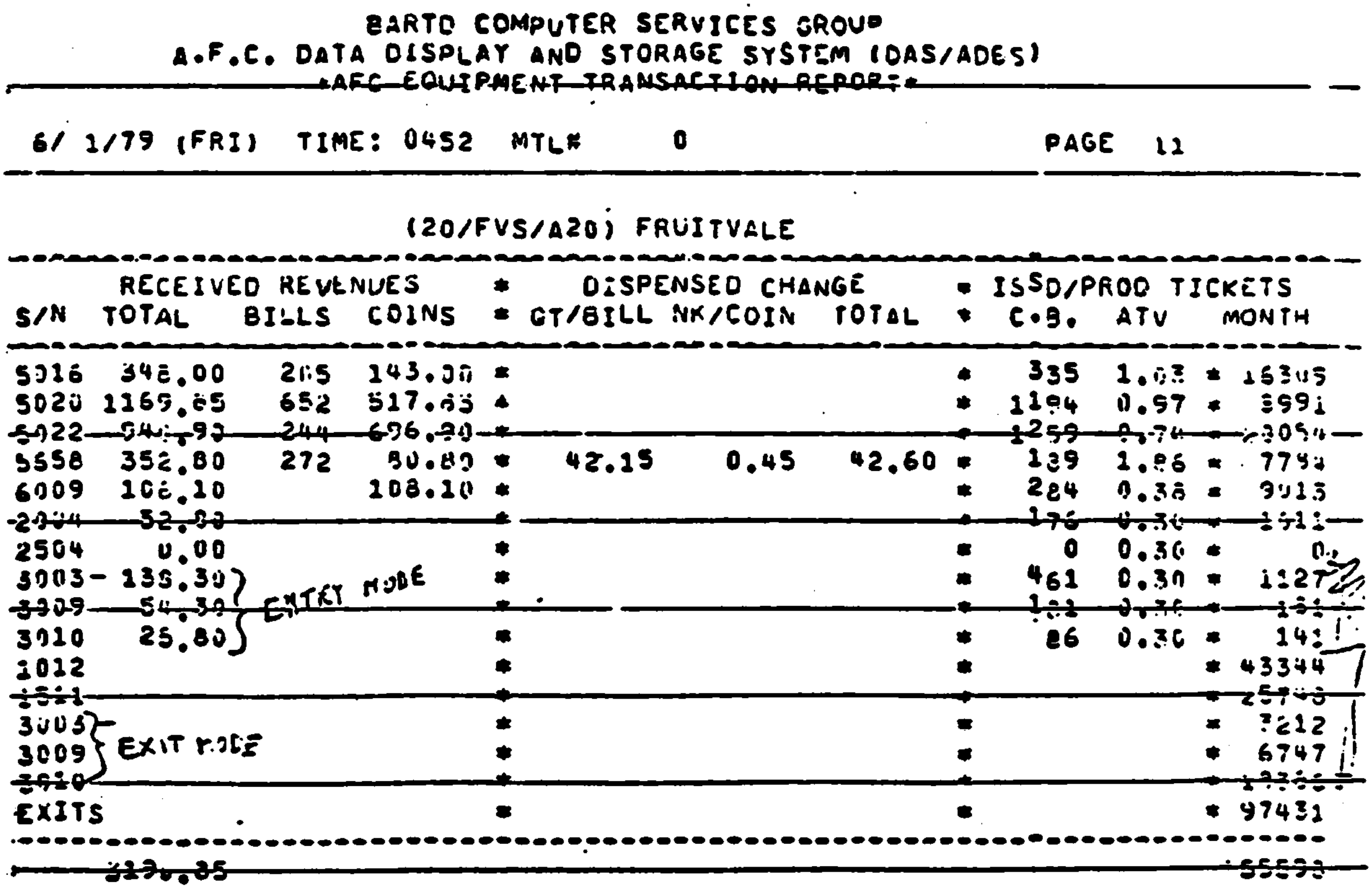
The second method more often applies to the situation where the light bulb is switched on and off with varying frequency, each time leaving the effects of added wear and tear. When all of the bulbs are similarly treated, the statistic which may be analyzed is the cycle life, or number of times the bulb can be switched before failing. AFC equipment has components which fail under both these situations. The electronic components are often best described by mean time between failures, whereas the mechanical components are best described by mean transactions between failures.

The second method is used in this section in viewing the data supplied by BART and WMATA. We have also used the first method to view rush-hour data with a goal of assessing system availability. Both methods are useful, and data can be transformed, by use of transaction rates, from one format to the other. Although the data were not necessarily rigorously validated and there may be some errors present, the overall conclusions are not likely to be affected significantly.

## 4.2 BART Data Base

Two sets of data were provided by BART. The first was the Automatic Fare Collection Equipment Transaction Report of May, 1979. This data displays the number of transactions which occurred in each machine. Information is displayed by station in Table 4-1.

Table 4-1. BART Transaction Report - May, 1979



```
                          BARTD COMPUTER SERVICES GROUP
              A.F.C. DATA DISPLAY AND STORAGE SYSTEM (DAS/ADES)
                     *AFC EQUIPMENT TRANSACTION REPORT*

 6/ 1/79 (FRI)  TIME: 0452  MTL#     0                          PAGE  11

                        (20/FVS/A20) FRUITVALE

     RECEIVED REVENUES      *    DISPENSED CHANGE         * ISSD/PROD TICKETS
S/N  TOTAL   BILLS  COINS   * GT/BILL NK/COIN   TOTAL    *  C.B.  ATV    MONTH

5016  348.00   205  143.00  *                             *   335  1.03 *  16305
5020 1169.65   652  517.65  *                             *  1194  0.97 *   3991
~~5022  940.93   244  696.90  *                             *  1259  0.74 *   3054~~
5558  352.80   272   80.80  *   42.15     0.45   42.60   *   139  1.86 *   7794
6009  108.10        108.10  *                             *   284  0.38 *   9013
~~2004   52.80                *                             *   176  0.30 *   1711~~
2504    0.00                *                             *     0  0.30 *      0
3003- 135.30)               *                             *   461  0.30 *   1127
~~3009   54.30                *                             *   121  0.30 *    131~~
3010   25.80                *                             *    86  0.30 *    141
1012                        *                             *              *  43344
~~1011                        *                             *              *  25743~~
3005                        *                             *              *   7212
3009                        *                             *              *   6747
~~3010                        *                             *              *  13366~~
EXITS                       *                             *              *  97431
------------------------------------------------------------------------------
~~      3190.85                                                               55593~~
```

ENTRY MODE

EXIT MODE

The first column represents the machine's serial number. Serial numbers are grouped to indicate the machine type in Table 4-2.

Table 4-2 Machine Serial Number Designations at BART

| Machine Type | Serial Numbers |
|---|---|
| IBM Exist Gates | 1000-1067, 1500-1566 |
| Cubic Exit Gates | 1600-1612, 1700-1712 |
| IBM Entry Gates | 2000-2068, 2500-2566 |
| Cubic Entry Gates | 2600-2612, 2700-2712 |
| IBM Reversible Gates | 3000-3028 |
| Cubic Reversible Gates | 3600-3618 |
| IBM Ticket Vendors | 5000-5122 |
| Cubic Ticket Vendors | 5600-5660 |
| IBM Addfare Machines | 6000-6058 |
| Cubic Addfare Machines | 6600-6650 |

The data base is incomplete since not all of the existing machines are interfaced with the data collection system. The percentage of machines which are interfaced is shown in Table 4-3. This poses a problem of validity of the data analysis where the sample size for a machine type is small.

Another problem with the data base is that the entry gate information (serial number series 2000 and 3000) represents only the number of entry transactions involving gate ticket purchases. In other words, tickets were obtainable at the gate in addition to the ticket vendor. Only those transactions involving a purchase of this type were recorded. IBM entry gates have the capability of accepting an entry fee and issuing an encoded ticket while Cubic gates do not.

Therefore, in order to analyze transaction information with respect to entries, it was assumed that the number of entries at a station during the 3-month study period was equal to the number of exits at that station during the same period.

Furthermore, a simplifying assumption was made that the distribution of these entries over the entry gates at each station was in proportion to the tickets sold at each gate.

IBM Money Changers (which have serial numbers in the 4000's) are not being analyzed for the purposes of this report, since transaction data was not available and they represent an early design (more advanced bill verifiers have since been incorporated into money changers).

Table 4-3 Percentages of Machines for Which Data Was Available

| Machine | Percent Interfaced |
|---|---|
| IBM Ticket Vendors | 83 |
| Cubic Ticket Vendors | 42 |
| IBM Addfare Machine | 61 |
| Cubic Addfare Machines | 4 |
| IBM Entry Gates | 100 |
| Cubic Entry Gates | 0 |
| IBM Exit Gates | 100 |
| Cubic Exit Gates | 100 |

The second data set which was provided by BART was a listing of "hard" failures for each machine in each station during the first quarter of 1979 (Figure 4-1). A "hard" failure is one which required a maintenance man to repair and could not be repaired by the station attendant. A farecard jam is an example of a "soft" failure which could usually be cleared by the station attendant. Whenever a maintenance technician completes his repair, he completes a report indicating the trouble reported, trouble found, and repair made. These are entered into BART's computerized data base by machine number and date. No records are kept for soft failures.

Hard failure data was available in almost all cases. Where an interfaced machine did not appear on the failure report, it was assumed that no failures had occurred in that machine's operation for the first quarter of 1979. One explanation is that these machines received such little usage that they did not have an opportunity to fail. Another explanation is that they did not fail in spite of a large number of transactions. BART staff acknowledge that there is a wide variation in machine usage, and thought the former reason to be likely.

```
A20 1012 ####
    1511 #######
    2004 ######
    2504 ########
    3003 ########
    3009 ####
    3010 ###########
    3610 #
    4008 ####################
    4405 ############
    4408 #
    4708 ###########
    5008 #
    5016 ###################
    5020 ###########################
    5022 #######################
    5653 #
    5658 #######################
    6009 #######
    6647 ###########
```

Figure 4-1. Failures per Machine (First Quarter, 1979) Fruitvale Station

Note: Each tic mark equals one failure for each machine

For each machine which had both transaction data and failure data, the number of transactions per failure was obtained by dividing an adjusted number of transactions (based on May 1979 data and described below) by the number of failures in the first quarter of 1979. Some representative numbers are shown in Table 4-4.

The data involving transactions per failure arises from the use of the May 1979 transaction data. These numbers were tripled to represent a three-month period to be consistent with the failure data. Transactions for the month of May 1979, however, were found to be approximately 10% greater

Table 4-4: Transactions per Failure for Machines at BART

| Machine Type | Transactions per Failure<br>Mean | High | Low |
|---|---|---|---|
| IBM Ticket Vendors | 5495 | 28937 | 482 |
| Cubic Ticket Vendors | 1855 | 23096 | 20 |
| IBM Addfare Machines | 4583 | 12713 | 308 |
| IBM Entry Gates | 17286 | 122946 | 4 |
| IBM Exit Gates | 24563 | 162308 | 1611 |
| Cubic Exit Gates | 5248 | 32677 | 700 |

than the established normal monthly figures and were suitably adjusted. This was due to the gas shortage that occurred during that time period. (The use of the 10% figure implies a uniform, system-wide increase in ridership). Also, during approximately 80% of the first quarter of 1979, a fire in the transbay tunnel created a significant drop in ridership, especially in the San Francisco downtown section. This closing resulted in a 60% reduction in normal ridership at the four major downtown San Francisco stations and a 15% reduction per station for the remainder of the system. One station, at which a bus shuttle terminated, went up in patronage.

These changes above introduce some measure of error. However, they are necessary to construct any histogram data. Furthermore, this data may be useful as a tool to suggest other similar analyses to be conducted in the future.

Comparison through the use of histograms may help indicate the reliability of different types of machinery. A negative exponential curve may be indicative of a uniformly constructed set of machinery with strict quality control. In comparison, a more constant level histogram may be caused by maintenance problems or machinery inconsistencies.

## 4.3 WMATA Data Base

Monthly survey reports of hard and soft failures were provided by WMATA for six sample stations from their system. Data was collected during two days each month (Tuesday and Wednesday midmonth). It was confined to the rush hours of 7 to 9 a.m. and 4 to 6:30 p.m.

This sample may have led to biased data except for the fact that an underlying assumption is that the occurrence or non-occurrence of failures is almost completely time-independent. In other words, the more important cause behind failures is the number of transactions accomplished by the machine rather than the number of hours in service. Mechanical adjustments tend to change with mechanical activity and temperature rather than the mere passage of time, although there are temperature-caused changes throughout the year. To support this, it was noted at BART that a large drop in ridership (during the period when a tunnel was not used as a result of a fire) accompanied a similar drop in the failures observed throughout the affected stations.

Data was submitted covering 6 months in most cases (Table 4-5). Transaction per failure ratios were calculated based on 6-month totals for addfare machines, entry and exit gates, and farecard vendors (Tables 4-6 through 4-8). Weighted averages based on the level of use at each station were also calculated. The cause for the variation which exists within this data is not apparent at this time.

Equipment availability was measured by summing the out-of-service times for each machine, subtracting the sum from the total survey time and dividing the difference by the total survey time. The average time to clear all failures does not include failures that could not be cleared during the survey.

## 4.4 Comparison of BART/WMATA Data

The different performance experience for AFC at BART and WMATA has been described, and should be interpreted cautiously. The WMATA data is only for the machines at selected active stations and was collected during rush hours. The BART data was for the whole system for a 3-month period.

Table 4-5. A Sample of WMATA Data at One Station

| FARECARD VENDOR | ROSSLYN | | | | | |
|---|---|---|---|---|---|---|
| | OCT 78 | NOV 78 | DEC 78 | JAN 79 | FEB 79 | MAR 79 |
| 1. NUMBER OF MACHINES | 10 | 10 (9) | 10 | 10 | 10 (9) | 10 |
| 2. EQUIPMENT AVAILABILITY (%) | 82.0 | 82.7 | 73.8 | 87.9 | 71.2 | 96.5 |
| 3. NUMBER OF TRANSACTIONS | 6,033 | 6,908 | 6,598 | 5,994 | 6,715 | 6,598 |
| 4. NUMBER OF TRANSACTIONS PER MACHINE | 603 | 768 | 660 | 599 | 746 | 660 |
| 5. TOTAL NUMBER OF FAILURES | 56 | 67 | 119 | 74 | 69 | 61 |
| 6. TOTAL NUMBER OF JAMS | 43 | 49 | 87 | 54 | 50 | 43 |
| 7. TOTAL NUMBER OF FARECARD JAMS | 25 | 28 | 65 | 18 | 13 | 21 |
| 8. TOTAL NUMBER OF BILL JAMS | 4 | 9 | 12 | 20 | 32 | 18 |
| 9. TOTAL NUMBER OF COIN JAMS | 9 | 11 | 10 | 16 | 5 | 4 |
| 10. TOTAL NUMBER OF MONEY HANDLING JAMS | 5 | 1 | 0 | 0 | 0 | 0 |
| 11. AVERAGE TIME TO CLEAR ALL FAILURES (MINUTES) | 8.5 | 6.2 | 11.9 | 6.0 | 7.8 | 3.2 |
| 12. TRANSACTIONS PER FAILURE | 108 | 103 | 55 | 81 | 97 | 108 |

## Table 4-6. Addfare Machine Reliability at WMATA
(October 1978 - March 1979)

| | Station | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rosslyn | Silver Spring | Brookland* | Dupont Circle* | Farragut West (18th Street) | Farragut West (17th Street) | Overall Average |
| Transactions per failure | 85 | 72 | 50 | 95 | 84 | 63 | 75 |
| Transactions per hard failure | 210 | 180 | 239 | 638 | 460 | 167 | 229 |
| Transactions per soft failure | 143 | 121 | 63 | 111 | 102 | 101 | 111 |
| Transactions per farecard jam | 447 | 369 | 154 | 134 | 306 | 283 | 282 |
| Transactions per bill jam | 357 | 539 | 431 | 2553 | 262 | 283 | 403 |
| Transactions per coin jam | 510 | 269 | 144 | 851 | 368 | 354 | 334 |

*Data is from November 1978 to March 1979

## Table 4-7. Entry/Exit Gate Reliability at WMATA
## (October 1978 - March 1979)

| | Station | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rosslyn | Silver Spring | Brookland* | Dupont Circle* | Farragut West (18th Street) | Farragut West (17th Street) | Overall Averages |
| Transactions per failure (entry/exit) | 690 | 468 | 436 | 705 | 532 | 447 | 538 |
| Transactions per farecard jam (entry) | 2209 | 3242 | 1701 | 6276 | 1252 | 1090 | 2057 |
| Transactions per farecard jam (exit) | 830 | 353 | 500 | 622 | 454 | 427 | 505 |
| Transactions per all other failures (entry/exit) | 1633 | 1810 | 946 | 1829 | 2340 | 1181 | 1602 |

*Data is from November 1978 to March 1979

## Table 4-8. Farecard Vendor Reliability at WMATA
(October 1978 - March 1979)

| | Station | | | | | | |
|---|---|---|---|---|---|---|---|
| | Rosslyn | Silver Spring | Brookland* | Dupont Circle* | Farragut West (18th Street) | Farragut West (17th Street) | Overall Averages |
| Transactions per failure | 87 | 88 | 92 | 130 | 92 | 78 | 89 |
| Transactions per hard failure | 324 | 231 | 301 | 414 | 396 | 276 | 306 |
| Transactions per soft failure | 119 | 142 | 132 | 189 | 120 | 108 | 126 |
| Transactions per farecard jam | 229 | 350 | 804 | 339 | 232 | 337 | 287 |
| Transactions per bill jam | 409 | 916 | 643 | 1397 | 339 | 234 | 427 |
| Transactions per coin jam | 706 | 322 | 210 | 621 | 429 | 1531 | 545 |
| Transactions per money handling jam | 6474 | ** | ** | ** | ** | 737 | 20,790 |

*Data is from November 1978 to March 1979

**No reported failures

Normalizing failure rates by transactions should account for this difference. However, if data becomes available, the failure rate for all Cubic machines at WMATA over a 3 month period should be computed and compared with Table 4-8.

There are minor differences in the functions performed by the equipment which explains some of the differences in the data. For example, IBM vendors are simplified by accepting exact change only, and not having a bill stacker. IBM gates are complex since they will accept a cash entry fare and vend a single ride minimum value ticket. Their entry gate is therefore as complex as the exit gate.

## 4.5 Failure Analysis

In studying equipment breakdowns and jams, it is important to ascertain why the existing equipment performs in such a manner. It is necessary that several equipment performance measures be established.

Failures of AFC equipment are caused by a variety of factors. Some of the failures are time dependent, others are based on frequency or rate of equipment usage, and some are based on other factors such as temperature and humidity. Reliability of continuously operating equipment is generally expressed in terms of mean time between failures (MTBF). Another measure of AFC performance is availability (the ratio of the time that the equipment is available for use during the operating period to the total operating period). Using MTBF for fare collection equipment could be quite misleading due to its non-uniform utilization over time. Due to higher availability during off-peak hours offsetting poor equipment performance during the peak hours when its reliability affects patrons most, this also could be misleading.

The individual machine availability depends on the equipment reliability (transactions/failure), passenger arrival rates, and the time required for a station attendent or maintenance technician to arrive at the scene and execute the repair. The transactions/failure may also be a variable that depends on the service rate. There is a contention that when the AFC is used at very high service rates, the solenoids heat up and the equipment does not perform as well. Reference to reliability criteria indicates that even for one type of a component in fare collection equipment, nonmilitary specification quality relays, a cycling rate below 1000 cycles per hour will not cause a decrease in the individual part transactions/failure. (Reference 12) However, a temperature rise of 25°C (40°F) from 77°F to 117°F will cause a 20% increase in the component failure rate. Depending on the number of components and their integration into the overall unit, the system failure rate could be much higher. Conclusive data on this issue was not available for this report, and the models used assume a constant failure rate per rush hour transaction.

Availability also reflects the level of maintenance. Thus, if a machine is quickly placed back in service, its availability is enhanced. Quick repair is most important during the peak hours but relatively unimportant during off-peak hours if there is duplicate equipment at the station.

Another measure of performance is transactions per failure. The failure of AFC equipment to a large degree is affected by usage. However, MTBF, and transactions per failure data for peak hour should give similar results if it is assumed that peak hour transactions per unit time are uniform. The measures of reliability, MTBF and mean transactions per failure are each used in this report.

### 4.5.1 Types of Failures

Failures of AFC equipment are of two types. These are hard and soft failures. A hard failure requires a maintenance action by a maintenance mechanic while a soft failure such as a card jam can generally be fixed by the station attendant or is intermittent and requires no action. However, experience has shown that repeated jams of any equipment requires a maintenance action which is usually requested by the station attendant and results in a hard failure. An analysis of both types of failures is of concern to properties since even a soft failure results in equipment being taken out of service temporarily. However, the mean time to repair on soft failures is generally less than five minutes.

Failure data was collected during a WMATA survey during 9 peak hours at 6 stations over a six-month time period, from October 1978 to March 1979. The data consists of failures, classified by whether they were hard failures or soft. The soft failures were further categorized depending on the type of jam; farecard jam, coin acceptance jam, bill verification jam, or an internal money handling jam.

Similar data from BART consists of hard failures for which maintenance was performed for each type of equipment for the first three months of 1979. The results of failure analysis for each type of equipment are discussed in the following section.

### 4.5.2 Equipment Reliability

In general, AFC equipment fails from three causes. These are hardware failures, patron-induced failures, and maintenance errors.

Basically, hardware reliability can be improved by system design, use of reliable and improved components, and improved maintenance procedures.

Patron-induced failures are unavoidable in this type of equipment. However, their frequency can be reduced by system design and patron education. Many of the equipment failures of this type, such as a farecard vendor rejecting a bill, go unreported. The patron just tries another machine, assuming the equipment not to be functioning properly. Folded farecards, worn bills and bent coins are major causes of patron-induced failure. A plastic card could be a potential solution to reduce the farecard jams. Patrons can be urged to take care of farecards, and avoid worn bills and bent coins which could cause a reduction of failures of this type.

The maintenance personnel are, at times, not able to identify the defective component, and this could result in repeated failure reports for the same problem. At times, the maintenance personnel could install a defective unit. Each unit should be checked for operation prior to installation. In general, the maintenance-related failures can be reduced through maintenance training programs and fault-detection devices.

### 4.5.3 Farecard Vendors

Figure 4-2 shows the fault tree analysis prepared for BART equipment for the month of May 1979. The chart and the others in this section were developed from BART data, in which 1762 failure reports for May 1979 were categorized according to the corrective action taken by the maintenance technician. For approximately 10% of the failures, a defect could not be found and no repair was made.

BART has two equipment manufacturers. Availability of the equipment was not computed because information on mean time to repair was not available.

The mean time between failures is a statistic derived from counting the number of failures from a group of similar machines over a period of time. Some machines will fail sooner than others. In order to predict the probability that a given machine will complete a mission of a given duration, the failure probability distribution must be known. A distribution that has been found to describe many types of equipment failure, and which will be used here, is the exponential distribution. A similar calculation procedure and prediction method applies to mean time to repair.

Table 4-9. Reliability of Machines at BART

| | IBM | Cubic |
|---|---|---|
| No. of Machines | 127 | 60 |
| Total Monthly Failures | 380 | 322 |
| MTBF (hours) | 560 | 134 |
| Reliability | 0.958 | 0.836 |

The reliability (R) described in Table 4-9 is the probability that the equipment will work without a failure for at least 24 hours and assumes an exponential distribution of failures. Thus, if $\theta$ is the MTBF expressed in hours, then:

$$\text{Reliability} = \exp(-t/\theta),\ t = 24 \text{ hrs}$$

Comparison of BART data shows that considerable difference exists between Cubic and IBM farecard vendors. Disregarding the coin acceptor and bill validator, the MTBF for each of the remaining farecard subsystems for IBM equipment is several times higher than that of Cubic equipment. System reliability based on the data is 0.958 for IBM farecard vendor and 0.836 for the Cubic vendor. It should be noted that IBM vendors require exact fare and do not contain a bill stacker.

As indicated in Figure 4-2, the failure of any one subsystem results in a failure of the farecard vendor. The overall reliability of the vendor is the product of the subsystem reliabilities.

The data in Figure 4-2 can also be used to estimate the improved performance of the overall system from an improved subsystem. For example, if the reciprocals of the mean times between failures for each subsystem are added, the result is the failures per hour for the overall system. The data in Figure 4-2 indicates that the Cubic ticket transport accounts for (134/396) or 34% of overall system failures.

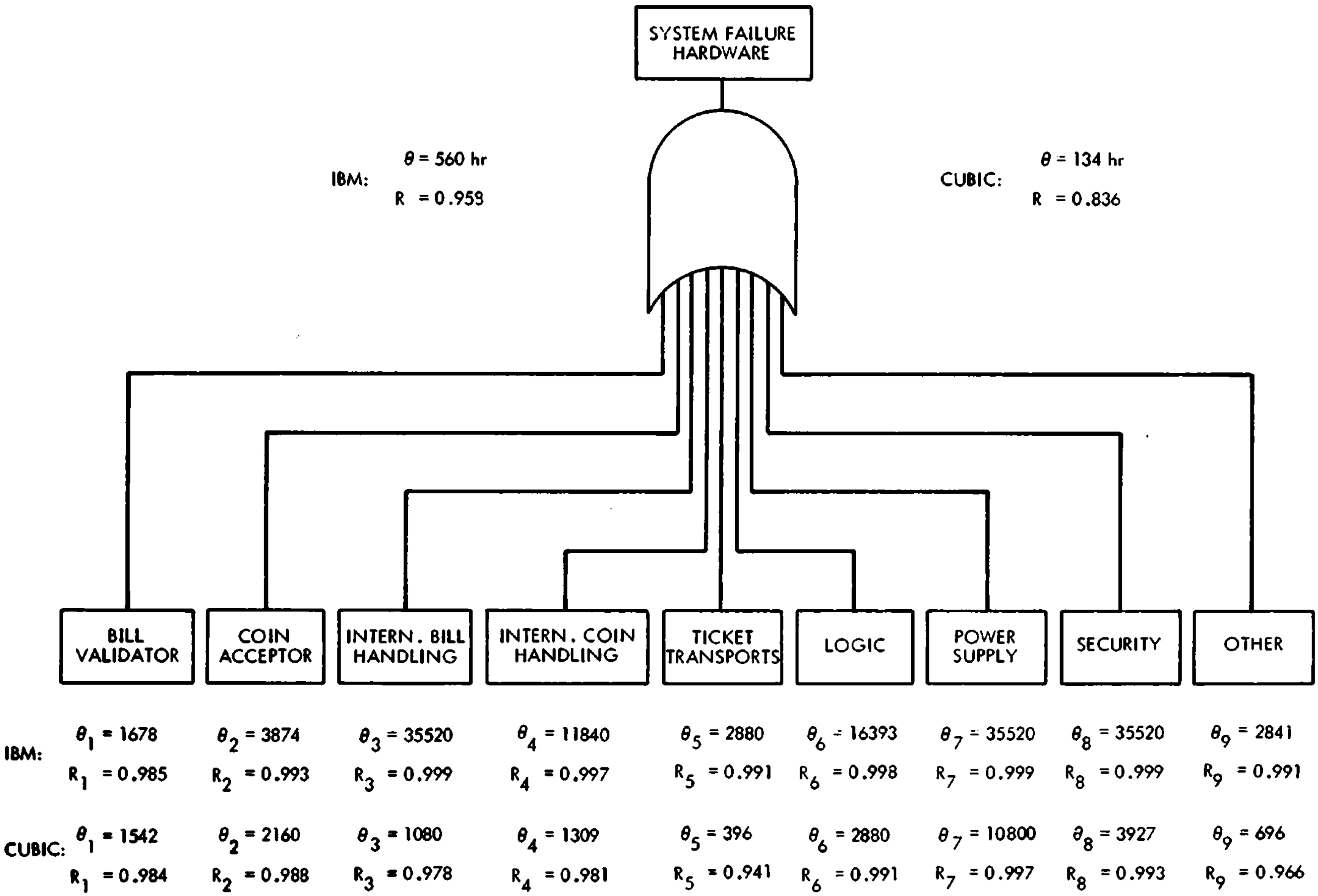


Figure 4-2. Fault Tree Analysis for Fare Card Vendor, BART (May 1979)

Coin acceptors, bill validators and ticket transports are the major causes of failures for both IBM and Cubic equipment.

The use of commercially-available coin acceptors and bill validators to perform major functions results in poor performance. These coin acceptors and bill validators are designed for light use such as in vending equipment and change machines. A coin acceptor that functions well in the vending industry will usually be used more actively in transit and fail in less time. However, there are many instances of vending machines performing satisfactorily in company cafeterias with transaction rates equivalent to transit stations. Manufacturers and canteen service organizations offer four explanations for the difference in performance. First, employees in a factory usually have at least a minimal facility at operating machinery and can become familiar with the equipment, even if they cannot read. Second, transit riders are more likely to be less equipment oriented, or in an unfamiliar location. Third, the cost of vended items usually requires one or two coins. If the first one jams, the patron operated clearance mechanism can usually clear out both coins. The cost of a transit ticket often requires depositing many coins. If one of the first jams, there may be too many backed-up coins to permit the clearance mechanism to work. Fourth, when a coin acceptor or bill validator is integrated into a complex farecard vendor, its interface requirements may conflict with those of another subassembly. There is less likelihood of this happening in a less complex vending machine. In addition, vending machines are usually in a controlled environment while transit equipment can be situated on unheated mezzanines exposed to cold winds and direct sunlight. Vending machines have been around a long time and service organizations have learned how to most effectively maintain them for the needs of that industry.

Fare collection equipment represents less than one percent of the market for makers of coin acceptors. There has been no incentive for them to develop a coin acceptor to meet the special needs of AFC equipment. A need has long existed for such high reliability AFC equipment. Before special developments are undertaken, the capabilities of existing vending equipment must be carefully reviewed.

In response to the introduction of the $1 coin, several vending manufacturers have developed electronic coin acceptors units with reported failure rates of 1 per 50,000 transactions. If these devices were to be modified and used in newer versions of fare collection equipment, improved performance would be expected.

There are two problems with the bill validation and storage function employed in AFC equipment. First, the quality of bills in circulation varies from good to bad, and this causes the farecard vendor to reject large numbers of bills. The patron is then faced with the problem of trying the bill in several different machines. Since he has a valid bill, he assumes the fare card machine is probably not working. Even after the bill is accepted as valid, it travels all the way to a lock box, and the poor quality of the bill can cause a hinderance in the movement of the bill resulting in a jam and the machine going out of service.

When a bill validator rejects a valid worn bill, its probability of jamming is increased significantly. Improper rejections can be reduced by design of validator circuits that are less sensitive to speed variations of the drive motors.

The equipment is designed to stack the bills. The function of stacking the bills is to make it easier for revenue collection by avoiding the time-consuming process of folding and stacking by hand. This results in increased complexity of the machine which does not in any way help the patron. A failure in money handling after selling a farecard can also put the machine out of service. It has proven difficult to develop a system with a combined bill stacker and escrow.

Secondly, some bill validators use up to five different checks for the validity of bills. A rejection on any one of the checks results in the machine deciding the bill is invalid. This number of checks on bills results in a high rejection rate of good bills, a frustrating situation for a patron.

To our knowledge, there have been no instances of counterfeit bills in the AFC equipment either at BART or WMATA. A reduction in the number of bill checks in validators considerably simplifies equipment complexity. The number of checks used should take into consideration the almost negligible incidence of counterfeiting of $1 and $5 bills.

Bill validators have a characteristic found throughout this equipment. Most electronics problems, such as reading magnetic codes on cards, magnetic ink in money, or manipulating large volumes of data have been successfully solved. What has not been successfully solved are the mechanical problems of moving large volumes of objects such as worn farecards or dollar bills. These problems are closely related in that meeting the mechanical design requirements imposed by the electronics systems may be a more difficult task than revising the electronics design to be more tolerant of the less precise mechanical systems.

Analysis of WMATA AFC survey data for the farecard vendors is shown in Table 4-10. The data shows failures per transaction for various types of failures. Soft failures account for more than 2/3 of the total failures. However, the major impact on availability is due to hard failures, which have a MTBF of 5.1 hours during peak hours.

The mean time to repair (MTTR) on soft jams is about 2 minutes and has thus resulted in higher availability due to soft jams of 0.9844. Fare card jams are the most frequent, resulting in a MTBF of 4.8 hours during the rush hour and a failure per 287 transactions on the average. This table was calculated by summing the total failures during the (six month; 2 days per month, 2 rush hours per day) service period, and dividing by service time to obtain mean time between failures.

Based on the failure analysis of the farecard vendor, it is clear that the reliability of the machine can be substantially improved by developing and installing improved coin acceptors, bill validators and ticket transports.

The availability of the system can be increased by reducing the number of transactions at the farecard vendor. By encouraging the use of higher value farecards, the total number of transactions and failures could be reduced.

Corrective actions for other subsystems such as logic and power supply consist of identifying components failing frequently and installing components having lower failure rates.

Table 4-10. WMATA Survey - Farecard Vendor Failures

| Type of Failure | Failures | MTBF* (hr) | Transactions per Failure | Average* MTTR (hr) | Availability |
|---|---|---|---|---|---|
| All | 1396 | 1.489 | 89.4 | 0.1229 | 0.9238 |
| Hard | 408 | 5.095 | 305.7 | 0.3394 | 0.9375 |
| Soft jams | 988 | 2.104 | 126.3 | 0.0333 | 0.9844 |
| FC Jams | 434 | 4.79 | 287.4 | 0.0333 | 0.9931 |
| Bill Jams | 292 | 7.119 | 427.2 | 0.0333 | 0.9953 |
| Coin Jams | 229 | 9.07 | 544.7 | 0.0333 | 0.9963 |
| Money Handling Jams | 33 | 26.18 | 3779.9 | 0.0333 | 0.9987 |

No. of machines = 40
Total number of transactions = 124,738
*Rush hour hours

### 4.6.3 Gates

Figure 4-3 shows the fault tree analysis for all types of gates (entry, exit and reversible) at BART. Of the five subsystems identified as the subsystems with most failures, the ticket transport is the most frequently failing subsystem with a MTBF of 1522 hours for the IBM gates and 528 hours for the Cubic gates. Other systems that fail frequently include logic failures. A closer examination of the software is needed to reduce logic-type failures.

IBM gates show high MTBF for all the subsystems of the gates compared to Cubic. The reliability for the IBM gate was .976 with an MTBF of 1005 hours and the Cubic gate had a reliability of .924 with an MTBF of 306 hours.

Analysis of gate data from the WMATA survey is shown in Table 4-11. The availability of the entry gates averaged 0.9821 as compared to 0.9477 for the exit gate. The MTBF for a hard failure was 12.71 rush-hour hours for the entry gate compard to 6.04 rush-hour hours for the exit gate.

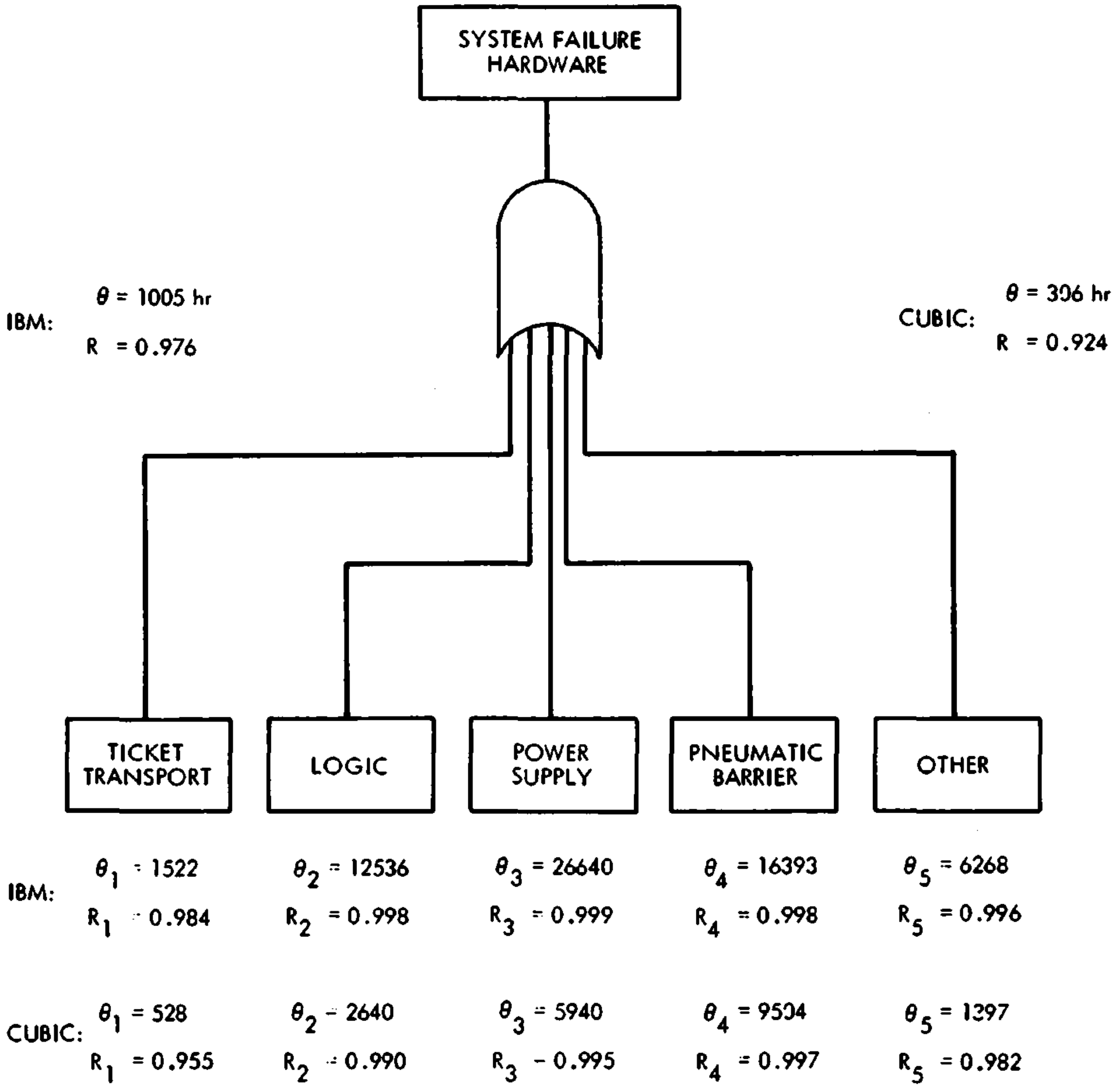


Figure 4-3. Fault Tree Analysis for Gates, BART (May 1979)

Table 4-11. WMATA Survey - Entry/Exit Gate Failures

ENTRY MODE

| Type of Failure | Failures | MTBF* hrs | Transactions per Failure | Average MTTR* hrs | Availability |
|---|---|---|---|---|---|
| ALL | 316 | 5.753 | 1125.9 | .1230 | 0.9791 |
| HARD | 134 | 12.713 | 2488.0 | .2321 | 0.9821 |
| FC JAMS) | 173 | 10.509 | 2056.6 | .0328 | 0.9969 |

EXIT MODE

| Type of Failure | Failures | MTBF hrs | Transactions per Failure | Average MTTR hrs | Availability |
|---|---|---|---|---|---|
| ALL | 1006 | 1.807 | 353.6 | .0998 | 0.9477 |
| HARD | 301 | 6.04 | 1181.7 | .2473 | 0.9607 |
| FC-JAMS | 705 | 2.579 | 504.5 | .0368 | 0.9859 |

*Rush hour hours
Total no. of gates: 35
Total no. of transactions: 711,484
Total entry transactions: 355,788
Total exit transactions: 355,696

The soft jam failure data shows that they occurred at the rate of 2056 transactions per failure for the entry gate and 504 transactions per failure for the exit gate. These would indicate problems with the additional functions performed at exit gates, such as computation and printing.

A basic problem with the AFC equipment is the ticket transport mechanism which results in the most failures for gates, farecard vendors and addfare machines. Several retrofits including the so-called super transport have been tried at WMATA. BART is considering a program for major modification of its Cubic transport mechanism in the near future.

The transport mechanism is the most complex electro-mechanical device in the overall AFC system. The performance of the ticket transport especially in the gates is affected by the quality of the farecard and the intensity of equipment usage. There is a great deal of wear in such components as rubber rollers, which move the cards, and there is a need to frequently adjust the gap between the magnetic heads and the card travel path, on the Cubic equipment.

Changing the quality of farecards may offer some improvement potential but in the long run major modifications to the ticket transport or a system design which requires no ticket transport may be the only way to increase reliability of the AFC equipment satisfactorily.

### 4.6.4 Addfare Machines

Add fare machine functions are as complex as that of a farecard vendor. The utilization rates are low, but high enough to cause problems. Table 4-12 below indicates the transactions for various machines at four of the WMATA Survey stations in a 6-month time period.

Table 4-12. Transactions by Equipment Type

| Equipment | Rosslyn | Silver Spring | Farragut West (18) | Farragut West (17) | Total |
|---|---|---|---|---|---|
| Farecard Vendor | 38,036 | 23,804 | 21,359 | 19.905 | 103,104 |
| Entry Gates | 106,048 | 68,079 | 78,889 | 57,258 | 310,274 |
| Exit Gates | 111,166 | 69,513 | 68,511 | 57,257 | 306,447 |
| Addfare Machine | 7,145 | 7,022 | 3.677 | 2,894 | 20,617 |
| % Buying Farecards | 35.8 | 34.9 | 27.0 | 34.7 | 33.2 |
| % Using Addfare M/C | 6.4 | 10.1 | 5.3 | 5.0 | 6.7 |

The data clearly shows that on an average over the 6 month period only 6.7% of the riders utilized the equipment. Equipment such as farecard vendors and addfare machines fail depending on the intensity of use. These machines also require the frequent attention of the station attendant to handle the high currency rejection rates of these machines.

The availability of the addfare machines can be increased by reducing the transactions performed by the machines. The 6.7 percent of the patrons who use the machine could be new users of the system who are not aware of exact fares. In a city like Washington, D.C., there will always be many tourists who will be new users of the system.

The fault tree analysis of the BART addfare machines shows that internal coin handling and ticket transports are major causes of machine failure (Figure 4-4). IBM equipment uses a separate change machine near the addfare machine to reduce the complexity of the addfare machine. Thus, bill validator problems for IBM machines are less frequent than those for Cubic machines. The changers used in association with IBM machines were not separately analyzed. The bill validator used in the IBM equipment is recognized as an early design inferior to the validator in the Cubic equipment.

A comparison of Cubic and IBM equipment shows that the IBM addfare machine had a reliability of 0.961 compared to 0.906 for the Cubic addfare machine. However, the Cubic machines perform more complex functions and do not use a separate changer.

The addfare machine data analyzed from the WMATA survey is shown in Table 4-13. The overall availability for these machines is 0.9588, with a MTBF of 1.959 rush hour hours, resulting in a failure for every 74.6 transactions. The soft failures had a low MTTR resulting in the higher availability. Almost 40 percent of these jams are due to farecards.

Improved reliability of the coin acceptors, bill validators and ticket transports used in addfare machines and other AFC equipment could result in a substantial increase in equipment availability.

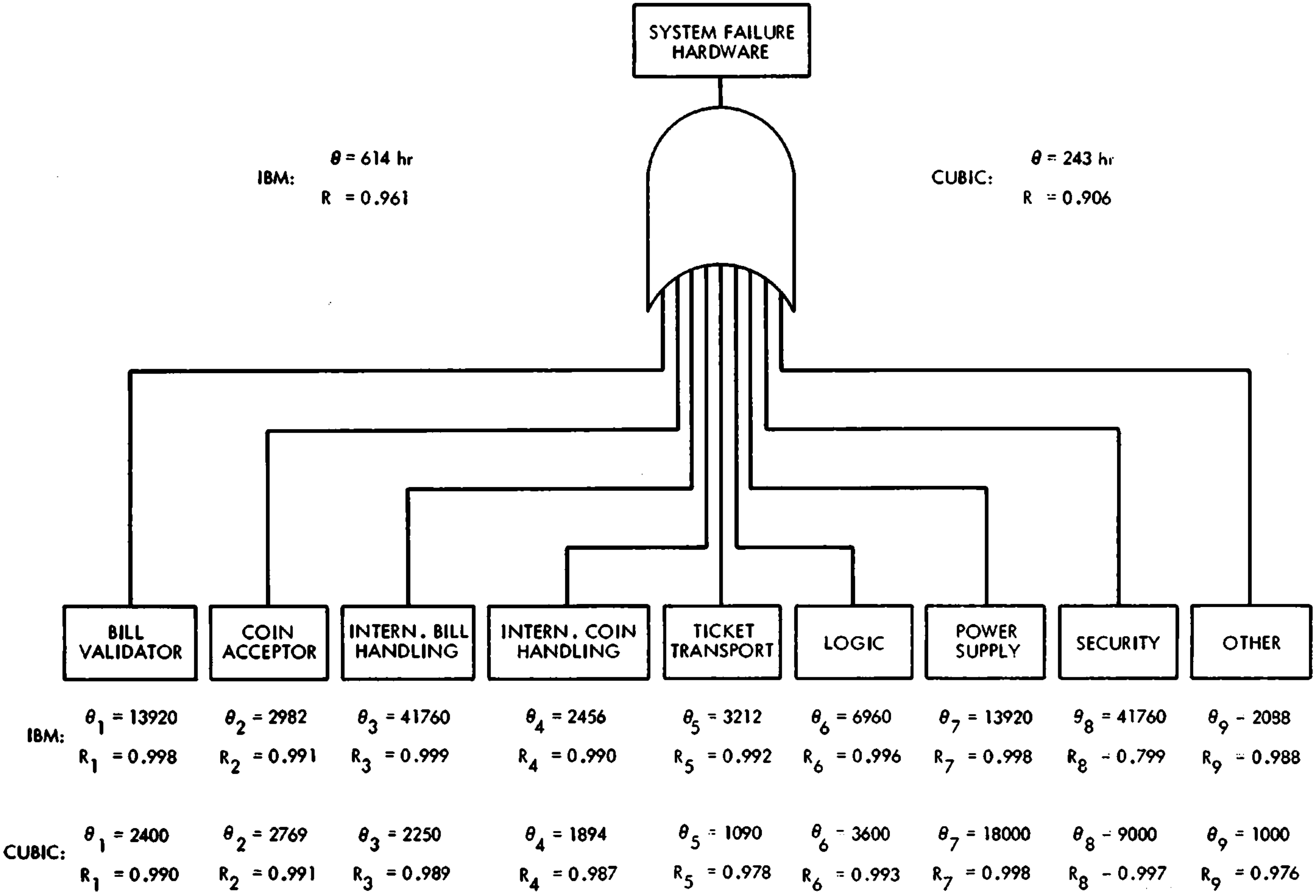


Figure 4-4. Fault Tree Analysis for Addfare Machines, BART (May 1979)

Table 4-13. WMATA Survey - Addfare Vendor Failures

| Type of Failure | Failures | MTBF hrs* | Transactions per Failure | Average MTTR hrs* | Availability |
|---|---|---|---|---|---|
| ALL | 340 | 1.959 | 74.6 | .0841 | 0.9588 |
| HARD | 111 | 6.000 | 228.5 | 0.1719 | 0.9721 |
| SOFT JAMS | 229 | 2.908 | 110.8 | .0333 | 0.9887 |
| FC Jams | 90 | 7.400 | 281.8 | .0333 | 0.9955 |
| Bill Jams | 63 | 10.57 | 402.6 | .0333 | 0.9969 |
| Coin Jams | 76 | 8.7632 | 333.7 | .0333 | 0.9962 |

No. of Machines: 13
Total No. of Transactions: 25,364
*Rush hour hours

It should be noted that the BART failure analyses were developed by summarizing technicians repair narratives as recorded on BART records. They only account for hardware failures. A considerable amount of jams and apparent failures could be caused by software deficiencies and would not be indicated by this type of analysis.

# 5. RELIABILITY AND MAINTAINABILITY

## 5.1 Reliability and Procurement

The performance of existing fare collection systems and analysis of their failures were discussed in earlier sections, and it is evident that their reliability is not optimum. If an operator were to purchase new equipment today to perform similar functions, must its performance be similar to existing equipment in service? This section will describe a method for obtaining more reliable equipment and the best performance out of existing equipment. Later sections will examine alternate design and operations improvements for the existing system, and different technological approaches to meet the performance objectives.

### 5.1.1 Background

Historically, reliability in transit and railroad equipment was assured by slow introduction of new technology, with close monitoring of new equipment and industry-wide acceptance only after there was no doubt of the equipment's performance. Major equipment advances were made especially in locomotives and in signal equipment.

By examining how these equipments were successfully introduced, lessons can be learned which can be applied to fare collection. The two important aspects to the problem are the business relationships between the railroad owner and the equipment suppliers and the process of introducing new equipment. From the business aspect, equipment introduction was a joint endeavor, with the staff of the supplier and owner working together to design, develop and validate new concepts to meet new needs. There was a sharing of resources, talents, risks and rewards.

For the introduction process, incremental deployment was built in. One new locomotive would be built, extensively tested and modified in operation or one small segment would be signalized, extensively tested and modified. Maturing of the concept took place over several years. Needed corrections were made before massive deployment took place.

Thus, these aspects - shared development and incremental deployment - were fundamental tenets of the industry.

### 5.1.2 A Perspective on Fare Collection Development

Fare collection and metering equipment followed a similar course to signal equipment and locomotives until the 60's. However, the market base was broader - bus, rail, amusement parks, supermarkets, etc. The requirements on the equipment were simple and could generally be satisfied by mechanical devices alone. However, in the last fifteen years, dramatic changes in requirements have taken place. Not only have variable fares been introduced in an attempt to more equitably allocate cost to the rider and to provide marketing alternatives, but the burden of information gathering was placed on the fare collection system. Much of the change was driven by optimistic expectations from technology proponents. There was virtually nothing that the computer couldn't do, or so they thought.

At first, major digital equipment firms showed interest in this new concept of fare collection. However, as it became clear that requirements on this equipment were unique and extremely demanding and there was little potential for a stable and sufficiently large market, they withdrew. But the variable fare and information gathering requirements necessitated the entry of a supplier with thorough knowledge of digital equipment.

In addition, the two major applications of distance-related AFC, BART and WMATA, were new transit systems that attempted to open on day one with novel equipment. The need to deliver a large volume of new equipment places a great burden on the equipment development process.

In both system-wide uses of the new generation of equipment, reliability remains a major concern. There are no apparent technical reasons why a reliable system cannot be provided to the transit industry. The failure has primarily been in not adhering to two tenets - shared development and incremental deployment. The new systems were procured en masse. However, a fixed price contract arrangement was used in both cases. A measure of whether or not a fixed price contract was reasonable can be obtained by reviewing the applicable sections of the Federal Procurement Regulations section 1-3.404-2 which states:

> "(a) Description. The firm fixed-price contract provides for a price which is not subject to any adjustment by reason of the cost experience of the contractor in the performance of the contract. This type of contract, when appropriately applied as set forth in this section 1-3.404-2, places maximum risk upon the contractor. Because the contractor assumes full responsibility, in the form of profits or losses, for all costs under or over the firm fixed price, he has a maximum profit incentive for effective cost control and contract performance. Use of the firm fixed-price contract imposes a minimum administrative burden on the contracting parties.
>
> (b) Application. The firm fixed-price contract is suitable for use in procurements when reasonably definite design or 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 the same or 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 the 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 which represents assumption of a reasonable proportion of the risks involved; or

(5) Any other reasonable basis for pricing can be used consistent with the purpose of this type of contract.

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." (Reference 13)

The two conditions necessary are reasonably definite design and performance specifications and a reasonable basis for price determination. Neither of these conditions existed at the time of the procurements. Much of the current reliability problem with the fare collection system is a result of buying the cheapest system using a fixed price contract. Of the three parts of the contractor performance - price, schedule, and performance - emphasis was placed on price.

But emphasis should have been placed on performance first, schedule second, and then price. Further, any effort now taken to remedy the reliability problems must emphasize those three in that order. This will require shared development with an industrial supplier and the property owner, and incremental deployment.

### 5.1.3 The Real Requirements

The real requirements on the fare collection system are still unspecified. In broad terms they appear to be:

(1) Number of operations between equipment failures must be increased at least an order of magnitude.

(2) Equipment must fail gracefully. For example, a machine should attempt to eject a worn or damaged farecard rather than require an attendant to remove it.

(3) The system of equipment at a station must be resilient; able to absorb failures without dramatic impact on station throughput.

(4) The primary task of collecting fares must not be jeopardized by information-gathering functions.

(5) Equipment should have self-checking functions and give failure warnings to maintenance staff.

(6) Soft failures such as card jams must be kept at a minimum or be clearable by the transit patron, or the equipment.

(7) Failure identification, isolation and correction must be streamlined. This includes use of diagnostic tools.

(8) Universal application across modes (rail and bus).

### 5.1.4 Designing for Reliability

Based on our review of equipment performance to date, a remedial design program for the properties is the first step to correction. This design program would select all or the most appropriate of the following techniques. Reliability, operability and maintainability goals, considering failure modes and their effect on equipment function and performance, would be developed. Functional requirements and performance goals would be established. Changed functional requirements would be categorized as critical, desirable, and optional. Stationary performance levels would be established for nominal and degraded situations.

Hardware design concepts would be reviewed, and nominal reliability and maintainability levels would be calculated for each configuration. This calculation would make use of statistical simulation tools to assess the impact of each part, component and subsystem on station throughput. Critical components and subsystems would be identified and durable design alternatives would be sought, then tested.

### 5.1.5 Achieving Relability Objectives

Developmental programs involving designs for reliability and prototype testing for innovative equipment will not by themselves achieve reliability. There is a rigorous method that must be followed to achieve reliability objectives. The mere statement of these objectives in a development or production procurement contract will not guarantee their fulfillment.

In both a development and production procurement, establishment of a reliability process and its continual enforcement are essential. Several of the more important elements are described below:

(1) Reliability and maintainability objectives must be clearly established. As noted earlier for fare collection equipment, this should include criteria on both hard and soft failures in terms of mean cycles between failures, mean time between failures, and mean time to repair. Failure conditions must also be defined.

(2) Reliability and maintainability analyses should be an integral part of the design.

(3) Testing of prototypes and the subsequent preproduction run should be conducted in a controlled field environment under realistic humidity and temperature conditions. Accelerated testing should be employed. Especially during the preproduction testing, it is essential to account for the cause of all failures and make appropriate corrections.

Controlled environment implies that a highly trained test engineer will keep excellent records on the field performance failures and corrections. It is very common for maintenance personnel, especially on new equipment, to repair the wrong component or even inadvertently cause other damage.

When making a repair, a second maintainer might have a different solution to the same problem. Every effort must be made to avoid these errors during initial testing.

Controlled field tests are excellent for identifying unanticipated problems. However, they can be expensive and time consuming. Once a problem has been identified, a fuller understanding of its cause and the viability of potential solutions can sometimes be achieved by laboratory tests. Engineering evaluations conducted in the laboratory of components and subsystems can also avoid problems that might otherwise be incorporated into a design or specification.

(4) During production, the manufacturer must verify that the parts purchased are good ones and that the final product is assembled correctly. A burn-in period for components with high infant mortality should be conducted.

(5) In the acceptance testing period, as well as the preproduction testing, the contractors' higher management must be involved in the failure analysis, review, and correction cycle. All failures should be explained.

(6) The equipment operator should have a product assurance manager who is responsible for ensuring that the process is faithfully enforced. Similarly the manufacturer should have a reliability manager and established company procedures for reliability and quality assurance.

## 5.2 Maintainability

Once the equipment has been accepted, it is the responsibility of the owner or a maintenance contractor to maintain it, during and after the warranty period. On any complex piece of equipment, it is advisable to keep accurate records indicating the failure frequencies and cause. Over a period of time, these will indicate problems with particular machines or components.

Since fare collection failures are closely related to use, failure analyses should include transaction information. As the machines age, service time, not transactions, will become a more significant measure for the non-mechanical, electronic components, and this data must be collected. This data base should be in a standardized form and easily accessible.

To predict age failures before they occur en masse, it is advisable to select several machines and give them accelerated use under careful observation.

Maintenance personnel should go through a thorough training program and be equipped with appropriate tools, manuals and spare parts. The maintenance data base should be used to plan a preventive maintenance program. In many areas of transit, the preventive maintenance effort is often four times as large as the corrective effort. Unfortunately these proportions aren't being approached with respect to recent automatic fare collection equipment.

The maintenance manuals supplied by automobile manufacturers could serve as a model to the minimal desired information in an automatic fare collection maintenance manual. A unit of AFC equipment could cost 3-5 times as much as an automobile, and one should expect an extensive manual. These manufacturers manuals should provide information on procuring, organizing and operating a primary maintenance facility (alignment, adjustment, change out and test routines), secondary maintenance facility (bench disassembly), recommended spare parts, and second sources or original manufacturer's data for purchase of spare parts.

Certain equipment may fail to perform so frequently that an investigation for design fixes may be warranted. Such an investigation would be greatly aided by a carefully kept data base of failure reports and analyses. If the data were not developed under controlled conditions, it might be best to select several pieces of equipment for operation, testing, and evaluation in a controlled scientific manner. Decisions for design retrofits would then be made on a solid foundation.

Even if the maintenance functions are contracted out, the operator should have personnel who have access to this data base, are thoroughly familiar with the equipment, are aware of maintenance schedules, and can adequately gauge the performance of the contractor. In the event that the operator decides to perform his own maintenance, these personnel would support the program.

Maintenance, by the operator, of complex fare collection equipment suspected of requiring design improvements should not be initiated lightly. BART staff expended great efforts when they took over maintenance from IBM of fare collection equipment, their staff had to be trained under fire. The operator who is concerned with service, might have more interest than a contractor in keeping the equipment functioning at high levels of availability and addressing long term problems. However, it should be possible to structure a maintenance contract with incentive payments for availability.

Some guidance might be developed by considering escalator maintenance in transit. Many operators provide their own maintenance. Several contract for maintenance from the manufacturers, at times with a fifteen year service contract based on unit costs with an inflation escalator (PATH contracts escalator maintenance, PATCO change makers are maintained by the manufacturer, and rented to PATCO). This provides an incentive for the manufacturer to design on a life cycle cost basis so that the equipment won't wear out in a few years.

The analogy is limited in that there is a wealth of operating experience on maintaining escalators, and the manufacturers are actively interested in promoting maintenance contracts. This condition doesn't exist in automatic fare collection, in that it is a newer and less prevalent technology.

Competition in maintenance or any contracting is an important factor. There are several escalator maintenance companies that are fully capable of undertaking a new contract on short notice. Again, the same does not apply for fare collection equipment. The operator has limited negotiating power when there is only one qualified contractor. It would be prudent in a contract maintenance operation to divide the system into several sections, with different contractors responsible for each. Operator maintenance at one of these sections would aid in gauging the contractors performance, provide a valuable learning experience for the equipment owner, and would be good insurance if one day a maintenance contract could not be negotiated.

As a closing note, it should be mentioned that comparative analyses are difficult to do when the data being used is not truly comparable. This can result from different collection methods, reporting forms, and even basic definitions of words such as "failure". The best way to insure effective comparative analyses in the future is to develop uniform, standardized data collection systems methods, definitions, and forms wherever possible.

## 5.3 Comparison of Performance Data from Vending and Transit Industry

A considerable amount of practical experience and data that have been developed in the vending industry could be useful to the transit industry. Normalized equipment performance characteristics, such as transactions per failure, can be compared. However, this must be done with caution. Several of the more important factors that inhibit a one-to-one correspondence are listed below.

(1) Institutional versus public environment - Vending machines are placed in institutional settings (company cafeterias, schools, hospitals) and public environments (airports, movie theaters, department stores). The experience of several vending machine service organizations indicates that the repair frequency is often four times greater for similar machines located in a public environment than in an institutional one. A transit situation would correspond more closely to the vending industry public environment.

(2) The arrival rate of customers at a vending machine is greater in a transit setting than in the usual vending industry setting. Some vending equipment may jam if a second customer inserts money before the internal machine processing of the previous customer's money is completed.

(3) Electrical power supply transients and stray ground currents may interfere with the operation of vending equipment in a transit environment.

(4) Exposure to weather, cold temperatures or sunlight can affect the performance of vending equipment usually used in a temperature controlled building, not readily available in a transit situation.

(5) Public vending environments often have more severe nuisance vandalism from small children (insertion of gum wrappers, popsicle sticks) than in a transit station which may be more closely supervised by station attendants or even closed circuit TV.

(6) The price of a vended ticket for transit (one ride or multi-ride) is often several times higher than the vend price in a coffee or candy machine. This requires insertion of more coins per vend in the acceptance and escrow mechanism. The probability of handling a defective coin that will cause a jam is increased as is the likelihood of a backup of coins behind a jammed one preventing use of the coin clear mechanism.

# 6. SYSTEMS EVALUATION MODEL

## 6.1 Availability Model

A model has been developed to relate the performance of individual pieces of equipment to station characteristics. The model consists of two stages. At the first stage, the average availability of a type of machine (e.g., ticket vendors) is used to calculate the probability that a given number of similar machines in a bank of machines in parallel operation will be available for patron use.

The second stage of the model is a queueing model for multiple servers, which yields probabilities of waiting time, average queue lengths, average time in the system, etc.

Use of a two-stage model greatly simplifies the analytical description, while relating two of the major processes occurring during station operations. These are the out-of-service condition of one or several AFC machines and the subsequent increase in arrival rates and queues at the operating equipment.

Such an analysis may be used as a tool to see the effect of availability on equipment performance at stations and throughout the system. By relating system-wide performance to equipment reliability and maintainability, it can serve as a useful guide in developing equipment performance objectives. Ideally, a simulation model would have permitted a better characterization of the equipment performance at a station, but this could not be developed because of time constraints. Queueing models in general are subject to certain limitations but can still yield valuable insight into the effect of availability on station operation. One of the limitations is that in field use passengers will preferentially use certain machines over others, often despite there being a short queue. The model used in this section assumes that as queue lengths grow, passengers will use the machine with the shorter queue.

The probability p, that a given machine is available for service at any instance in time, is called availability and is defined as

$$\text{Availability} = \frac{\text{MTBF}}{\text{MTBF+MTTR}} \qquad \text{(Reference 14)}$$

where MTBF is the mean time between failures and MTTR is the mean time to repair the equipment. By use of the appropriate service rate for the period under consideration, availability can also be expressed in terms of mean transactions between failures.

Availability takes into account the maintenance of the machine. Thus, if a failed machine is quickly put back into service through improved maintenance procedures or assignments, a higher availability will result.

The probability that a specific number of machines in a bank of machines will be available for use at a given moment can be calculated by using the binomial distribution.

Thus, if p is the probability that a machine is available for use (its availability), the probability that x machines out of a bank of n machines will be available is:

$$\frac{n!}{x!\,(n-x)!}\; p^{x}\,(1-p)^{n-x}$$

Using the number of machines in use at Rosslyn station as an example, the model was utilized to calculate the probability that various numbers of machines in the bank will be operable . These probabilities were calculated for the availability based on WMATA data and also for values of availability of 0.85, 0.90, 0.95, and 0.975 (Tables 6-1, 6-2 and 6-3).

For example, if the average availability of farecard vendors at Rosslyn is .903 (which was based on rush hour data from WMATA), the probability is

.01008 that exactly six of them will be operating and four will not. This represents about 1% of the time. The probability that two or more of the machines will not be working is .1871 + .0536 + .0101 + .0013 + ... = .25. As the availability of a typical machine increases, the probability of all the machines in the group being available also increases, and the probability of several of the machines being down decreases.

In an effort to acquire further insight into the effect of machine availability on overall system performance, a probability model was developed to derive the expected number of stations in the system which would have 2 or more inoperable machines of the same type.

In other words, a "station failure" was defined to be the situation where 2 or more ticket vendors would be inoperable, where 2 or more gates would be inoperable in the same direction, or where 2 or more addfare machines would be inoperable.

Table 6-1: Probability That Exactly a of the Farecard Vendors Will Be Operable

Farecard Vendor - 10 Machines

Availability per Machine*

| | | (Current) .903** | .85 | .90 | .95 | .975 |
|---|---|---|---|---|---|---|
| | 0 | - | - | - | - | - |
| | 1 | - | - | - | - | - |
| | 2 | - | - | - | - | - |
| | 3 | - | - | - | - | - |
| | 4 | - | - | - | - | - |
| a | 5 | .0013 | .00849 | .00149 | .0006 | $2x10^{-6}$ |
| | 6 | .01008 | .04010 | .01116 | .00096 | .00007 |
| | 7 | .05362 | .12983 | .05740 | .01048 | .00157 |
| | 8 | .18718 | .27590 | .19371 | .07463 | .02297 |
| | 9 | .38722 | .34743 | .38742 | .31512 | .19906 |
| | 10 | .36048 | .19687 | .34868 | .59874 | .77633 |
| | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*Values less than $10^{-3}$ not shown

**Current availability

## Table 6-2: Probability That Exactly a of the Gates Will Be Operable

Gates - 9 gates

Availability per Machine

| | | .85 | .90 | .95 | .975 |
|---|---|---|---|---|---|
| | 0 | - | - | - | - |
| | 1 | - | - | - | - |
| | 2 | - | - | - | - |
| | 3 | - | - | - | - |
| a | 4 | .00499 | .00083 | .00002 | 1x10$^{-6}$ |
| | 5 | .02830 | .00744 | .00049 | .00004 |
| | 6 | .10692 | .04464 | .00661 | .00113 |
| | 7 | .25967 | .17219 | .05717 | .01885 |
| | 8 | .36786 | .38742 | .28853 | .18375 |
| | 9 | .23162 | .38742 | .64717 | .79624 |
| | | 1.00 | 1.00 | 1.00 | 1.00 |

## Table 6-3: Probability That Exactly a of the Addfares Will Be Operable

Binomial Probabilities - Rosslyn Station

Addfare Vendor - 2 machines

Availability per machine

| | | .85 | .90 | .95 | .953* | .975 |
|---|---|---|---|---|---|---|
| | 0 | .02250 | .01000 | .00250 | .00221 | .00063 |
| a | 1 | .25500 | .18000 | .09500 | .08958 | .04875 |
| | 2 | .72250 | .81000 | .90250 | .90821 | .95063 |
| | | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

*Current availability

This was taken as a condition that transit management would want to avoid. Two machines down of the same type could quickly lead to overloading the remaining machines, long lines and an angry public. The condition of no machine failures during the time period of interest is one that the present equipment does not even approach. Station failures could be avoided by installing extra machines, but there are more effective solutions.

A 34 station system similar to BART was postulated in Table 6-4.

Table 6-4. Hypothetical System Configuration

| | Number of Stations | Number of Ticket Vendors per Station | Number of Gates per Station | Number of Addfare Machines per Station |
|---|---|---|---|---|
| | 6 | 3 | 2 | 2 |
| | 9 | 5 | 4 | 2 |
| | 8 | 8 | 6 | 2 |
| | 6 | 10 | 8 | 4 |
| | 3 | 12 | 10 | 4 |
| | 2 | 20 | 20 | 4 |
| Total | 34 | 263 | 214 | 90 |

Based on the hypothesized level of equipment availability(.85, .90 and .95), the expected number of station failures from farecard vendors at a random moment of time would be 10.6, 6.2 and 2.1 respectively (Table 6-5). The expected number of station failures from gates would be 8, 4.6 and 1.5 respectively. The expected number of station failures from addfare machines would be 1.7, 0.8 and 0.2.

Table 6-5. Instantaneous Station Failures-Hypothetical 32 Station System

| Station Failures | A=.85 | A=.90 | A=.95 |
|---|---|---|---|
| Farecard Vendors | 10.6 | 6.2 | 2.7 |
| Gates | 8. | 4.6 | 1.5 |
| Addfare | 1.7 | .8 | .2 |

In other words, with a .90 availability level for all three machine types, an observer viewing the system at a random moment would expect to find about 6 stations with 2 or more farecard vendors inoperable, about 5 stations wiht 2 or more gates inoperable, and about 1 station with 2 or more addfare machines inoperable.

Examination of even this model for the hypothetical case indicates the importance of high reliability levels. The number of station failures increase at a rate very much faster than the rate of decline of equipment availability.

Subsequent work can and should include the development of a more sophisticated mathematical model to answer the question, based on machine availability, of how many station failures can be expected in a time interval (e.g. rush hour, 8 hour shift). This could lead to an optimization of maintenance manpower allocation which in turn would lead to reduced maintenance times and increased availability. This process would lead to the improvement of overall system efficiency and lower operational cost. The relationship of the failure and transaction rates should also be considered.

## 6.2 Queueing Model

Knowing the number of station failures is a first approximation of the performance of the total system. It is possible to have conditions that would lead to numerous public complaints even if several or all of the machines are working. A queueing model can develop more detailed information about these conditions.

A method for estimating queues at fare machines is illustrated using the data from the Rosslyn Station.

The number of machines, their incidence of failure, the time it takes for them to be repaired, passenger processing rates, and passenger arrival rates are all factors which affect queue length.

A standard multiple server queueing model was used for illustration. (Reference 15). Such a model can be combined with the results of the equipment availability model to indicate expected queue lengths and waiting times with varying numbers of machines in working order.

Such a model can provide the following type of information at each station:

(1) The average number of customers in the queue

(2) The average number of customers in the system

(3) The average waiting time in the queue

(4) The average flow time through the system

(5) The probability of waiting longer than t seconds.

Peak hour arrival rate data used in these models was supplied by the WMATA financial planning staff for the Rosslyn Station. The peak hour flows were found to be about 3800 patrons/hour, with the most critical condition occuring when 260 patrons alight from an arriving train. Because of the need to clear the platform in 2 minutes, this arrival rate was used to estimate the impact of equipment availability on queueing.

The equipment at Rosslyn Station consists of the following:

10 farecard vendors
9 entry/exit gates
2 addfare machines

The following tables offer illustrative examples for Rosslyn Station using the queueing model. Results were not supplied when fewer than 7 farecard vendors or 6 gates were operable since the model shows that the queues would increase without bound. Also, the model was not applied to the addfare vendors due to lack of arrival rate and service rate data.

### 6.2.1 Farecard Vendors

To estimate customers for farecard vendors, it was assumed that 15% of the patrons arriving at the station would buy a farecard during the peak hour. The mean service time for farecard vendors was assumed to be 20 seconds. The results of the model are displayed in Table 6-6. The model indicated that very long queues could be expected at Rosslyn farecard vendors when 4 or more of the 10 machines are out of order. Current availability (.903) based on survey data shows that the probability that 4 or more of the 10 machines will be out of order is about 1%. Depending upon the ability of the station attendant to clear the jams, up to 15 people could be waiting to buy farecards.

The queueing statistics for 7 or more machines working are shown in Table 6-6. When 7 machines are working the average waiting time is 30 seconds, which is not a desirable condition. However, the conditions are quite acceptable when 8 or more machines are in working order. The probability that 3 machines will be out of order is about 5% during the peak hour.

### 6.2.2 Entry/Exit Gates

The mean service time for Cubic gates is about 2 seconds (30/minute). The WMATA staff indicated an average processing rate of about 22 customers per minute (.36 patrons/sec). Using the arrival rate of 260 customers in 2 minutes, the results of queueing model for Rosslyn Station are summarized in Table 6-7.

Table 6-6: Farecard Vendors - Queueing Model

| | | No. of Machines Operating | | | |
|---|---|---|---|---|---|
| | | 7 | 8 | 9 | 10 |
| Average queue length | | 9.82 | 2.04 | .71 | .28 |
| Average # in system | | 16.30 | 8.52 | 7.19 | 6.76 |
| Average queue waiting time (sec) | | 30.03 | 6.31 | 2.02 | .86 |
| Average flowtime (sec) | | 50.03 | 26.31 | 22.2 | 20.86 |
| | seconds | | | | |
| The probability that a patron will wait more than ___ seconds to use a machine. | 60 | .17 | .01 | * | * |
| | 30 | .36 | .05 | .01 | * |
| | 15 | .53 | .15 | .04 | .01 |
| | 10 | .61 | .22 | .08 | .03 |
| | 5 | .69 | .33 | .15 | .06 |
| | 3 | .73 | .38 | .19 | .09 |
| | 2 | .75 | .41 | .22 | .11 |
| | 1 | .77 | .44 | .24 | .13 |

Service time = .05 customers/sec

Arrival Rate = .325 customers/sec (15% of 260 patrons/2 minutes (peak condition))

*Negligible

The queueing model indicated that ever-increasing queues could be expected when 6 or less than 6 gates are operational. Based on the binomial distribution, this situation occurs with the existing equipment +5% of the time (A=.90).

With six gates in working order, there are at least 32 customers standing in lines. The mean time spent in the queue is about 15 seconds. The model also shows that the probability of a customer waiting for at least 30 seconds is 15%. Exactly six gates in working order would occur approximately 4% of the time for the indicated availabilities.

Table 6-7 Gates Queueing Model

| | | No. of Machines Operating | | | |
|---|---|---|---|---|---|
| | | 6 | 7 | 8 | 9 |
| Average queue length | | 32.35 | 2.79 | .86 | .32 |
| Average # in system | | 38.18 | 8.63 | 6.69 | 6.15 |
| Average queue waiting time (sec) | | 15.40 | 1.33 | .41 | .15 |
| Average flowtime (sec) | | 18.18 | 4.11 | 3.19 | 2.93 |
| | seconds | | | | |
| The probability that a patron will wait more than ___ seconds to use a machine | 60 | .03 | * | * | * |
| | 30 | .15 | * | * | * |
| | 15 | .38 | 1x10$^{-3}$ | * | * |
| | 10 | .51 | .01 | * | * |
| | 5 | .68 | .07 | .01 | * |
| | 3 | .77 | .16 | .03 | .01 |
| | 2 | .82 | .24 | .07 | .02 |
| | 1 | .87 | .37 | .15 | .05 |

Service Time = 0.36 customers/sec

Arrival rate = 2.10 customers/sec

---

*Negligible

The queueing situation is more relaxed when 7 or more of the 9 machines are in working order, with less than 3 customers on an average, waiting to be processed.

These models show the type of operation that can be expected with varying levels of availability and, therefore, establish a planning tool for assessing the magnitude of the effect of a change in machine availability. Studies of this kind can be done, tailored to individual stations and various availability levels.

# 7. EVALUATION OF RELIABILITY IMPACTS OF ALTERNATE FARE COLLECTION SYSTEMS

## 7.1 Introduction

Rail transit operators periodically review the impact of fare collection equipment modifications and alternatives. Models are required to assist in the evaluation of these improvements. The previous chapter developed a method for estimating queue lengths at fare collection equipment when two units of a bank of similar units are temporarily out of service. This section will consider the interaction of passengers with each element of the total fare collection system configuration. A general evaluation model will be developed for alternatives under investigation that calculates an equipment maintenance cost index and the probability that a passenger will encounter an equipment-caused delay. The model requires five inputs: (1) system flow charts describing the sequence of fare collection processing stages as passengers pass through the station and the relative activity at each stage (as in Figures 3-1 - 3-4), (2) the reliability of individual units of equipment in terms of transactions per failure, (3) total number of passengers processed per hour, (4) the response time to correct equipment malfunctions, and (5) whether the station is attended or unattended.

The evaluation method will be used to compare several different fare collection systems, as if implemented on a hypothetical transit system. The systems will be compared for capital costs and the outputs previously noted. The alternatives evaluated will be for equipment that could implement three types of fare structure: flat, zone, and graduated distance related.

The revenue implications of the fare collection systems and associated fare structures will not be considered, since they were beyond the scope of this study. A thorough analysis of these issues would require knowledge of the trip distribution by length, origin-destination and time of day, and the effect of fare level on ridership. There are other issues relating to fare collection that must be considered by a transit agency in addition to the passenger delay, operating costs, and revenue generated. These include compatibility of the rail transit fare system with the local bus fare system, the flexibility of the system in effectuating pricing changes, the simplicity of the system and its ability to be understood by the general public, the equitability of the fares charged to passenger subsets, and the relationship of the fare system to any subsidy agreements between local governments and the transit agency. This chapter provides a tool that will aid in one aspect of the fare collection alternate improvements analysis; the evaluation of the reliability impacts of alternate fare collection systems. It will also aid planners of new systems in setting reliability objectives.

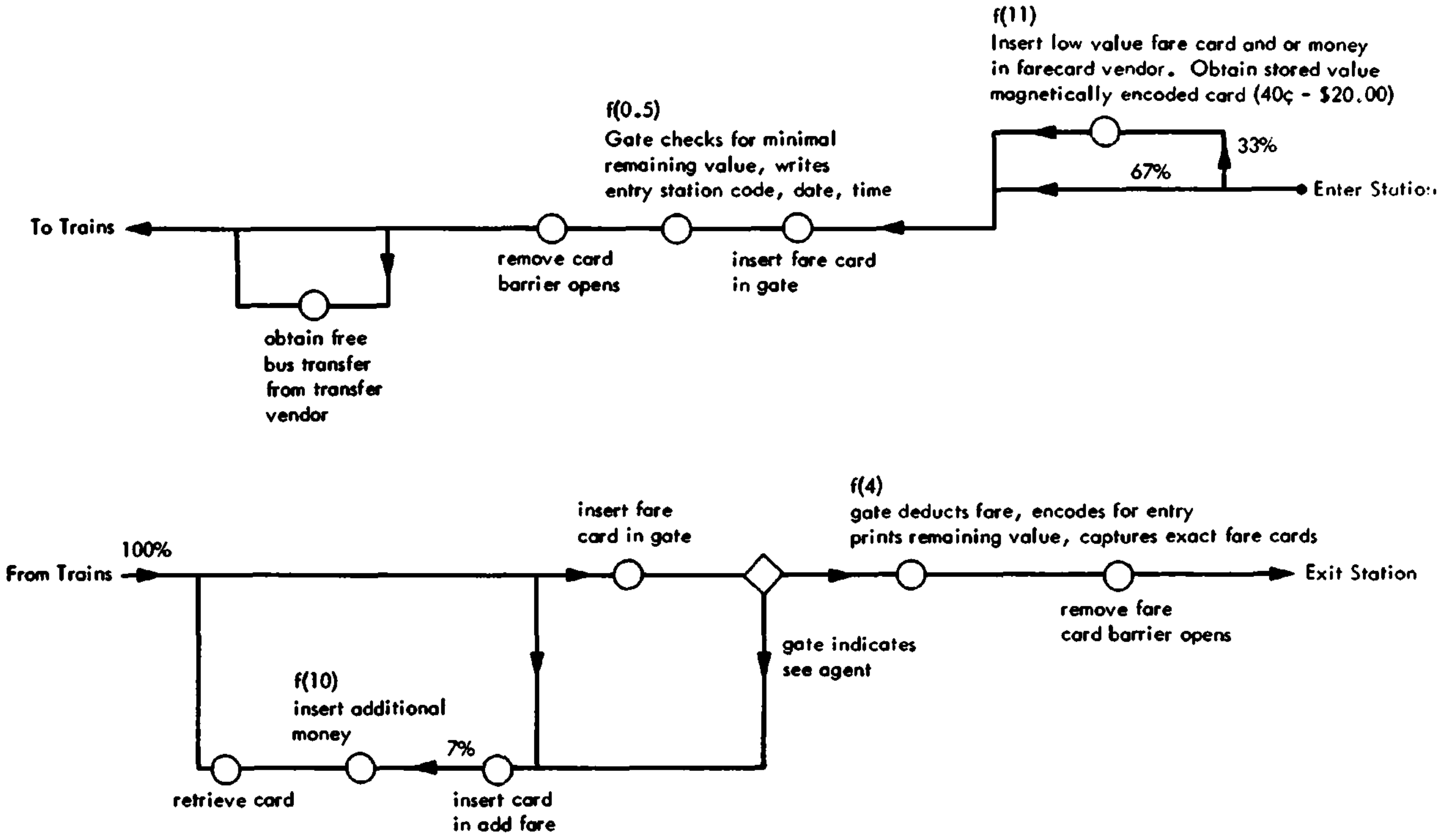
## 7.2 General Method for Evaluating Operating Cost and Impact on Passenger Flows of Fare Collection Equipment

A method will be developed for describing the operation of various fare collection systems. It will be used to estimate the relationship of the fare collection system to capital costs, maintenance costs, passenger flows and delays, and level of station manning. As part of the analysis, it will be necessary to develop estimates of the effect of variations in fare structure on individual equipment activity.

Seven alternate systems will be examined. They are described in a series of flow charts. The first chart, Figure 7-1, represents the passenger flows into and out of a typical station. The small circles are symbols for the performance of an operation. The percentages represent the portion of passengers following various lines of the flow chart.

The next six charts are modifications of the first. Each contains a failure rate printed above each of the operations. For example, f(11) appearing above the farecard vendors indicates that the present vendors fail (hard and soft) at a rate of 11 failures per 1000 transactions. The initial flow and failure rates are derived from surveys conducted at several transit systems.

By using the passenger flow distribution and failure rates, one can calculate the expected failures per 1000 passengers into and out of a station, as well as several other system descriptors. These are equal to the sum over all the system elements of the products of the reliability rates and the percent of passengers utilizing that system element.



Combined failures per 1000 passengers = 9.11

f(n) - failures per 1000 transactions

Figure 7-1 Baseline System - Graduated Fare

## Baseline System

For the baseline system the total number of failures per station are:

$$F_{\text{total}/\frac{1000}{\text{passengers}}} = .33(11) + .67(0) + 1.0(.5) + 1.07(4) + .07(10) = 9.11$$

This failure frequency can be used to compare the reliability and to estimate the relative maintenance costs of alternate systems. Previous surveys indicate that the ratio of hard to soft failures varies between 5/1 and 3/1. A hard failure requires replacement or adjustment of a part, usually by a technician. A soft failure requires the clearing of a farecard or money jam, usually by the station attendant. With sufficient data the soft to hard failure ratio could be derived for each type of fare collection machine. As an approximation, a uniform ratio of 4/1 will be assumed. Knowing the annual maintenance costs and the preventive maintenance costs, the cost per hard failure can be derived. It is assumed that there is no actual cash cost per soft failure. Hence, the failure frequency can be used by itself to estimate relative maintenance costs for alternate systems.

The failure frequency can also be used as an input to develop the availability of individual units and banks of similar unit equipment.

Availability can be defined as: (Reference 14)

$$\text{Availability} = \frac{\text{Mean Time Between Failures (MTBF)}}{\text{Mean Time to Repair (MTTR)} + \text{MTBF}}$$

The MTBF can be derived from the failures per transactions, when the passenger arrival rates are known. For example, a typical WMATA station might serve 9000 passengers per day, 71% of these in the four and one half peak hours or 1400 passengers per peak hour. If these are assumed to be distributed uniformly among 10 fare gates, the service load would be 140 passengers per gate per hour. Using the exit gate failure rate of 4 failures per 1000 transactions leads to:

$$\text{MTBF}_{\text{exit gate}} = \left[\frac{1}{140} \quad \text{(hours/transaction)}\right]\left[\frac{1000}{4} \quad \text{transactions/failure}\right]$$
$$= 1.79 \text{ hours}$$

The MTTR can be calculated by knowing the repair time and relative frequency of hard and soft failures. If a station attendant is present, a soft failure (jam) can usually be repaired in 5 minutes or .083 hours. Most hard failures require an adjustment or a module replacement, either of which can usually be accomplished by a technician within 15 minutes. If the system is one in which the technician is assigned by repair service zones and can respond to calls within 15 minutes, the repair time for a hard failure would be 30 minutes or .5 hour. The combined repair time would be:

$$\underset{\text{(attended stations)}}{\text{MTRR}} = \frac{1(.5) + 4\ (.083)}{5} = .13 \text{ hours}$$

The individual gate availability would be:

$$A = \frac{1.79}{1.79 + .13} = 93\%$$

This number indicates that under the given service rates, failure rates, and repair times, whenever a passenger approaches any exit gate during the peak period, he can expect it to be in service 93% of the time.

The same method can be used to demonstrate the effect on availability of unattended stations. If it now requires a telephone call to obtain station assistance, the repair time for soft failures might increase to 20 minutes. The combined repair time would be:

$$\underset{\text{(unattended stations)}}{\text{MTRR}} = \frac{1(.5) + 4\ (.33)}{5} = .37 \text{ hours}$$

The gate availability would be:

$$A = \frac{1.79}{1.79 + .37} = 83\%$$

This number indicates the difficulty of operating unattended stations with equipment without high levels of reliability.

The availability of a typical unit of equipment can be used to develop another valuable descriptor of the system, the incidence of simultaneous failures of two or more units of the same type of equipment. A station is usually supplied with enough equipment to avoid long passenger queues even if one unit of the equipment is temporarily out of service. A serious delay condition may develop if two or more units are simultaneously out of service. A delay condition will be defined as occurring whenever two or more units of the same type of equipment are out of service at the same time.

The binominal probability distribution can be used to predict the incidence of two or more simultaneous failures, where machine availability is taken as the probability of success. (Reference 15)

Tables of this distribution are available in many references. For the case of 10 fare gates, with unit availabilities of .93, the probability of two or more of the 10 gates simultaneously being unavailable is .15. The group availability for this condition will be defined as 1-.15 or .85.

A similar type calculation can be made for each type of fare collection equipment that passengers use; ticket vendors, entry gates, addfares and exit gates. The incidence of simultaneous failure for each type of equipment can be used with the passenger flow charts to determine the incidence of delay conditions. This number should correlate well with the incidence of delay that a passenger might encounter in a particular fare collection system and can be used to compare alternate systems. It should be noted that the delay represents lost time for the patron who first encounters the equipment malfunction plus the lost time of following patrons who are slowed by the higher activity on the functioning units.

The individual availabilities for a typical station with the baseline system, and a passenger arrival rate of 1400 per hour are given in Table 7-1.

Table 7-1. Baseline System - Individual and Group Equipment Availability

| Equipment | Quantity per Station | Failures/1000 Transactions | % Passengers Using Machine | MTBF (hr) | Unit** Avail. | Group** Avail. |
|---|---|---|---|---|---|---|
| Farecard Vendors | 10 | 11 | 33 | 1.968 | .94 | .88 |
| Entry Gates | 10 | .5 | 100 | 14.28 | .99 | .996 |
| Addfare | 3 | 10 | 7 | 3.06 | .96 | .995 |
| Exit Gates | 10 | 4 | 107* | 1.67 | .93 | .85 |

Flow rate = 1400 Passengers/hr

MTTR = .13 hr

* - Assuming That Those Using the Addfare Machine Use the Gates Twice.

** - Assuming Station is Attended (Group Availability = Less Than 2 Units).

The last column in the table represents the group availability for a bank of machines as previously defined; that is the probability that less than 2 of that type of machine will be simultaneously out of service. This was assumed to correlate with the probability of the passenger not being delayed when using the equipment. The probability of his being delayed will be 1 minus the group availability. Therefore, the probability of a passenger encountering a delay condition as he passes through the station would be:

$$P\ (\text{Delay}) = .33(.12) + 1.00(.004) + .07(.005) + 1.07(.15) = .20$$

This indicates that one out of five passengers are expected to encounter a delay related to the failure of the equipment.

The last number, P, (Delay) can be used to compare alternate systems. The lower this number, the better.

The delay condition only gives an indication of the frequency of delays, it does not give the actual magnitude of delays. This can be estimated by using multi-server queueing tables developed for conditions of one to several of the services being out of service. For example, it can be shown (Section 6) that at a station equipped with five farecard vendors, if two of the vendors were out of service the average queue waiting time would be six seconds. If three were out of service, the average queue waiting time would be 30 seconds.

The delay condition can be used to compare alternative systems, although a more precise, but time consuming method would be to calculate the actual queue length when different numbers of machines are out of service, and weigh the queue lengths by the appropriate group availability.

The alternatives considered in this study were conducted at large, active stations with many units of similar equipment. The effect of varying the activity is non-linear. For example, if only five farecard vendors were needed at a less active station instead of 10 (constant service rate), the group availability would be increased by a factor of approximately three. However, in a queueing sitution, two out of five machines being unavailable is many times more severe than two out of 10 machines being down.

When a station is unattended, the availability figures lead to a probability of experiencing a delay of .76, implying that 3 out of 4 people would encounter a delay caused by equipment malfunctions.

Table 7-2 Probability for Equipment Caused Delay
(Baseline - Unattended Station)

| Equipment | Quantity per Station | Failures/1000 Transactions | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Farecard Vendors | 10 | 11 | 33 | 1.94 | .84 | .51 |
| Entry Gates | .0 | .5 | 100 | 14.28 | .975 | .975 |
| Addfare | 3 | 10 | 7 | 3.06 | .89 | .966 |
| Exit Gates | 10 | 4 | 107 | 1.79 | .83 | .47 |

$$P(\text{delay}) = .33(.49) + 1(.025) + .07(.034) + 1.07(.53) = .76$$

The next section performs similar calculations and describes the essential features for each alternative.

Another important characteristic is the capital cost of each alternative. For the baseline system, a typical station would have the following equipment.

Table 7-3 Capital Costs - Baseline

| Equipment | Quantity | Cost/Unit | Total |
|---|---|---|---|
| Farecard Vendors | 10 | $30,000 | $300,000 |
| Entry Gates | 2 | 19,000 | 38,000 |
| Reversible Gates | 9 | 28,000 | 252,000 |
| Exit Gates | 2 | 19,000 | 38,000 |
| Addfare | 3 | 30,000 | 90,000 |
| Data Acquisition and Display System (DADS) | 1 | 14,000 | 14,000 |
|  |  |  | $694,000 |

## 7.3 Description of Alternatives

### 7.3.1 Improved Transport and Coin Acceptor

The first alternative investigated (Figure 7-2) is an improved baseline system achieved by replacing the coin acceptors in the vendors and addfares, the transport in the gates and the ticket vendor with improved models.

It will be assumed that the coin acceptor and card transport improvements lead to an 80% reduction in gate failure rates and a 90% reduction in failure rates of the farecard transport mechanism in the vendor and the addfare. Since these subsystems account for about 25% of vendor failures (Section 4.5), this means an overall failure rate reduction of only 40%. This leads to new failure rates of 7 and 6 for the vendor and addfare respectively. The entry and exit gate failure rates are similarly reduced to 0.1 and 0.8 failures per thousand respectively.

These reliability rates are processed in the manner described in the preceding section to derive the various system descriptors. The new combined failure rate per 1000 passengers is 3.7.

Table 7-4 Probability of Delay for Baseline Attended Station - Improved Transport and Coin Acceptor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Farecard Vendors | 10 | 7 | 33 | 3.06 | .96 | .942 |
| Entry Gates | 10 | .1 | 100 | 71.43 | .998 | .999 |
| Addfare | 3 | 6 | 7 | 17.01 | .992 | .999 |
| Exit Gates | 10 | .8 | 107 | 8.34 | .985 | .991 |

$$P(\text{delay}) = .33(.058) + 1.00(.001) + .07(.001) + 1.07(.009) = .03$$

Table 7-5 Probability of Delay for Baseline Unattended Station - Improved Transport and Coin Acceptor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Farecard Vendors | 10 | 7 | 33 | 3.06 | .89 | .70 |
| Entry Gates | 10 | .1 | 100 | 71.43 | .995 | .999 |
| Addfare | 3 | 6 | 7 | 17.01 | .979 | .999 |
| Exit Gates | 10 | .8 | 107 | 8.34 | .958 | .937 |

$$P(\text{delay}) = .33(.30) + 1(.001) + .07(.001) + 1.07(.063) = .17$$

No estimate is presented of the capital cost of these improvements.

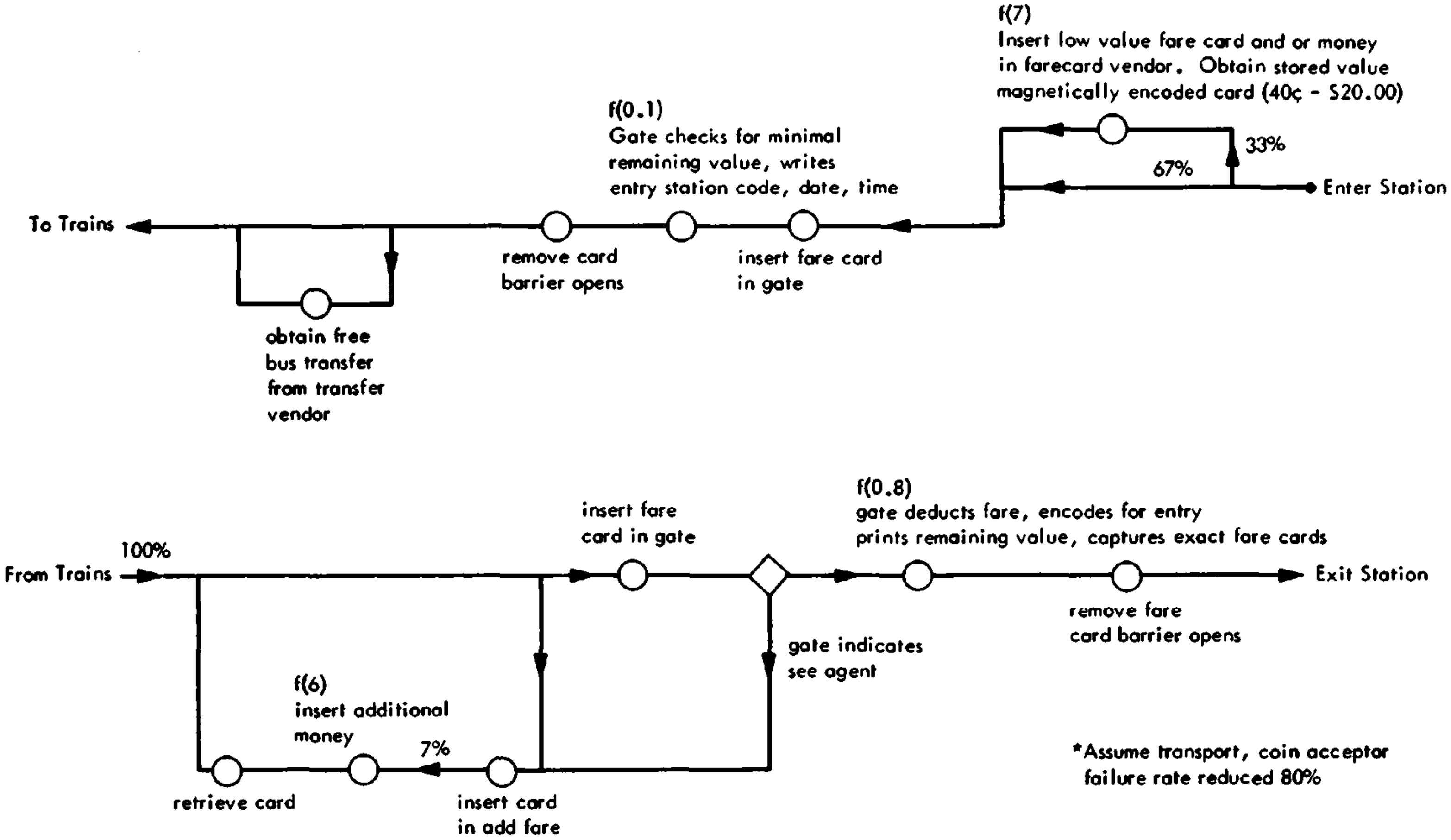
### 7.3.2 $1 and $5 Fast Vendors

Figure 7-3 is a flow chart showing the impact of installing $1 and $5 fast vendors in addition to the previous improvement. Fast vendors sell pre-encoded farecards at one or two price levels, whereas the multi-price vendor will encode and print a farecard for any value between 40¢ and $20.

There are two divergent philosophies about the use of fast vendors. One is that their increased reliability would increase passenger use of higher value farecards, and reduce all vendor failures and transit agency farecard costs. The other is that many riders would only buy a one or two ride ticket under any circumstance and that they should be processed with equipment as simple and reliable as possible.

### 7.3.2.1 Estimate of Effect of Fast Vendors on Activity of Multi-Priced Vendor and Addfare

In order to estimate equipment use levels, the results of queued passenger surveys were reviewed. Assume that a sample survey of 260 passengers was conducted. The sample size is too small to yield precise results but it can give general directions. The percentage of persons who take less than 10 trips per week will be compared to the percentage of passengers who purchase single or round trip tickets.

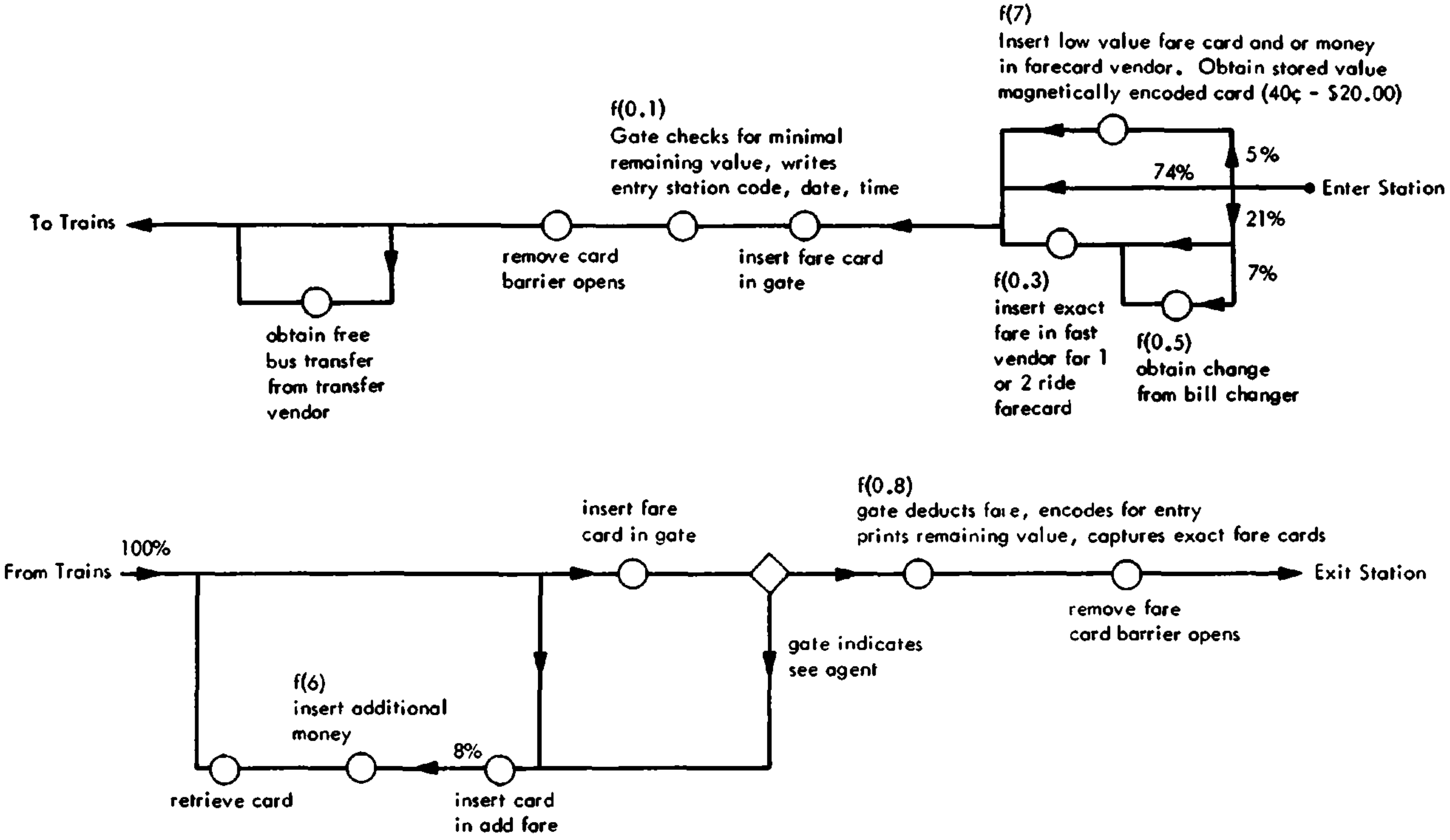


*Assume transport, coin acceptor failure rate reduced 80%

Combined failures per 1000 passengers = 3.69

f(n) - failures per 1000 transactions

Figure 7-2 Baseline System - Improved Ticket Transport and Coin Acceptor



Combined failures per 1000 passengers = 1.89

f(n) - failures per 1000 transactions

Figure 7-3 Baseline System - Improved Ticket Transport and Coin Acceptor Plus $1 and $5 Fast Vendor

Table 7-6 Trip Frequency

| Trips per Week | Average | Number of Persons | % of Persons | Number of Trips | % of Trips |
|---|---|---|---|---|---|
| 0-4 | 2.5 | 68 | 26 | 170 | 8 |
| 5-9 | 7 | 40 | 15 | 280 | 14 |
| 10 | 10 | 130 | 50 | 1300 | 63 |
| 11 or more | 14 | 22 | 8 | 308 | 15 |
| | | 260 | 100 | 2058 | 100 |

Table 7-7 Farecard Vendor Activity-Baseline

| Farecard Value Purchased | % Persons | % Passengers Using Farecard Vendor | Adjusted % Pass. Using Vendor | Adjusted % Persons |
|---|---|---|---|---|
| Single Trip | 21 | 21 | 17 | 17 |
| Round Trip | 29 | 15 | 12 | 24 |
| Less Than $5 | 15 | 1 | 1 | 21 |
| More Than $5 | 35 | 3 | 3 | 38 |
| | 100 | 40 | 33 | 100 |

In the third column in the preceding table, the first two values correspond to the farecard vendor activity for the first two classes of farecard sales. (They are calculated by dividing the second column value by the number of trips per sale). Their sum is 36%, but if it were assumed that all remaining trips were taken with high value farecards for 10 or more average trips, they would account for 4% more sales and a total vendor activity of 40%.

This figure does not correspond with data collected by WMATA at six stations during rush hours over a six month period which as reported on the first flow chart, indicates that 33% of passengers, not 40%, utilize the farecard vendors. This discrepancy is most likely due to the small size of the passenger survey samples. It does indicate the insensitivity of the analysis to the assumption concerning the use of the high value forecasts. The fourth column adjusts the passenger survey to correspond to the larger set of statistics on farecard vendor activity. It is calculated by arbitrarily reducing the first two values by 7%. The last column is adjusted to account for 100% of the passengers.

Comparing the above two tables indicates that only 22% of trips are taken by persons who travel less than 10 times per week while 41% of passengers purchase a one- or two-ride farecard. If the farecard vendors had extremely high reliability and a small bonus were offered for buying higher value farecards, it might be expected that only 22% instead of 41% of farecards would be sold for single rides or round trips, and 78% of trips would be taken on high value farecards.

These numbers can be compared to the experiences of other transit systems, such as PATCO. PATCO reports that 40% of their riders purchase a 10-ride ticket from a news vendor while 60% purchase one or two ride tickets. The following table presents this information in a similar format to the preceding tables:

Table 7-8 Multi-Ride Ticket Sales (PATCO)

| PATCO Tickets Purchased | % Passengers | Number Trips | % Trips |
|---|---|---|---|
| One or Two Ride | 60 | 90 | 18 |
| 10-Ride | 40 | 400 | 82 |
| | | 490 | 100 |

PATCO is primarily a commuter line. It has fewer regular trips than WMATA and its patrons are likely to have a higher income and be less resistant to investing in a 10-trip ticket than WMATA patrons.

The International Union of Public Transport reported in 1973 on the use of multiple journey tickets among their bus transit system members. (Reference 16) The results are summarized in the following table.

Table 7-9 Multi-Ride Ticket Sales - European Surface Transit

| % of Trips Using a Multiple Journey Ticket | Number of Transit Systems |
|---|---|
| 90-94 | 2 |
| 80-90 | 5 |
| 70-80 | 7 |
| 60-70 | 10 |
| 50-60 | 6 |
| 40-50 | 13 |
| 30-40 | 7 |
| 20-30 | 3 |
| 10-20 | 4 |
| 1-10 | 8 |
| | 65 |

It is evident that it is infrequent for more than 70% of passengers to take part in a high value farecard program even if a small discount is offered. In other words, it is rare to reduce the number of passengers who purchase one or two ride tickets to less than 30%.

Presently only 33% of WMATA passengers use a farecard vendor on each trip. The reduction caused by the fast vendors can now be estimated. The following table considers the number of farecard vendor transactions for various passengers. It is based on the assumption that the percentage of persons buying one or two ride tickets can be reduced from the current 41% to 30%.

Table 7-10 Farecard Vendor Activity With 30% of Passengers Purchasing One- or Two-Ride Farecards

| Number of Trips per Farecard Purchased | % Riders | % Passengers Using Farecard Vendor |
|---|---|---|
| 1 | 12 | 12 |
| 2 | 18 | 9 |
| | 30 | 21 |
| 14 | 70 | 5 |
| | 100% | 26% |

The table assumes that at least 30%, instead of the former 41%, of passengers now buy a one or two ride farecard (with no discounts to reduce low-value sales further), and that the proportion between one and two ride cards remains constant. Then, these sales would account for 21% of the passengers who use the vendor. If the average purchase for all remaining passengers is a farecard for 14 trips, then an additional 5% of passengers would utilize the vendors for a total of 26%. The effect of the fast vendor would be to reduce vendor activity from 33% to 26% of passengers entering a station. Reducing vendor activity to 26% increases the portion of passengers who proceed directly to the gates from 67% to 74%.

The impact of the $1 and $5 fast vendor will not only be a slight increase in the sale of high valued farecards and diversion of activity to the fast vendors. It will also cause an increase in the use of the addfare machine. The same September 1978 WMATA survey contains information that can be used to estimate this effect. The usual fare paid by passengers as reported by the survey is:

Table 7-11 Multiples of Passenger Fare to Equal Ticket Value - Fine Fare Structure

| Fare | Number Persons | Exact Multiples of Fare to Reach $1 or $5 |
|---|---|---|
| $.20 | 3 | 5 |
| .40 | 32 | x* |
| .45 | 102 | x |
| .50 | 63 | 2,10 |
| .55 | 11 | x |
| .60 | 2 | x |
| .65 | 3 | x |
| .75 | 9 | x |
| .80 | 24 | x |
| .85 | 2 | x |
| .90 | 4 | x |
| .95 | 3 | x |
| | 258 | |

*Indicates when the addfare machine must be used.

The last column is a measure of the utility that this system presents to a regular commuter who wants to consume the entire value on his farecard. For example, passengers whose regular fare is 45¢ might use a $5 farecard for eleven 45¢ trips. The remaining 5¢ would not be enough to pay for a twelfth trip without use of the addfare or farecard vendor to increase the value of the farecard. If the initial value of the farecard was an exact multiple of the fare, there would be no remaining value after completing these eleven trips, and the farecard would be discarded.

It is evident that only 66 out of the 258 passengers surveyed (24%) could be assured of using a fast vendor, without at a later date being compelled to use the addfare. Therefore, the use of fast vendors would not be as high as expected and the use of the addfare machine would be increased substantially.

WMATA could modify its fare structure to reduce this problem. One illustrative example which rounds many fares by a 10¢ maximum to 50¢ or $1 follows.

Table 7-12 Multiples of Passenger Fare to Equal Ticket Value - Rounded Fare Structure

| Fare | Shifted Number Persons | Multiples of Fare to Reach $1 or $5 |
|---|---|---|
| $.20 | 3 | 5 |
| .40 | -- | x |
| .45 | -- | x |
| .50 | 210 | 2,10 |
| .55 | -- | x |
| .60 | -- | x |
| .65 | 3 | x |
| .75 | 9 | x |
| .80 | 24 | x |
| .85 | 2 | x |
| .90 |  | x |
| .95 | -- | x |
| 1.00 | 7 | 1,5 |
|  | 258 |  |

Now, 217 out of 256 passengers (84%) could effectively avail themselves of the fast vendor. This more than triples the fast vendor's practicality and substantially curtails the use of the addfare machine.

It would be expected that for convenience, unavailability of the multi-price vendors, or changes in travel plans, the frequency of use of the addfare would increase. Assuming that of the 16% of passengers who could not effectively use the fast vendors, one third of them do use it, then addfare usage would increase from 7% to 12%.

### 7.3.2.2 Probability of Delay Calculations

The reliability of the fast vendors must be estimated. Experience with simple, fast vendors used for the Michigan State Lottery indicates that most failures on these devices are due to jams in the bill validator. These devices use an accordion type feed system, sell only exact price tickets and do not return change. A reliability corresponding to that of a coin changer: one failure per 2000 transactions will be assumed.

With the revised reliability and flows, a combined failure rate can be calculated for the station.

$$\text{Failures per 1000 passengers} = .05(7) + .21(.5) + .74(0) + 1.00(.1) + .12(6) + 1.12(.8) = 2.17$$

Availability and delay information are summarized as follows:

Table 7-13 Probability of Delay - Improved Attended Baseline Plus $1 and $5 Fast Vendor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (Normal) | 3 | 7 | 5 | 20.41 | .994 | .999 |
| Vendor (Fast) | 7 | .5 | 21 | 68.03 | .998 | .999 |
| Entry Gate | 10 | .1 | 100 | 71.43 | .998 | .999 |
| Addfare | 3 | 6 | 12 | 4.96 | .974 | .998 |
| Exit Gate | 10 | .8 | 112 | 7.97 | .984 | .989 |

$$P(\text{delay}) = .05(.001) + .21(.001) + 1(.001) + .12(.002) + 1.12(.011) = .014$$

Table 7-14 Probability of Delay - Improved Unattended Baseline Plus $1 and $5 Fast Vendor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (normal) | 3 | 7 | 5 | 20.41 | .982 | .999 |
| Vendor (fast) | 7 | .5 | 21 | 68.03 | .995 | .999 |
| Entry Gate | 10 | .1 | 100 | 71.43 | .995 | .999 |
| Addfare | 3 | 6 | 12 | 4.96 | .931 | .986 |
| Exit Gate | 10 | .8 | 112 | 7.97 | .956 | .931 |

$$P(\text{delay}) = .05(.001) + .21(.001) + 1(.001) + .12(.014) + 1.12(0.69) = .08$$

Use of a $1 or $5 fast vendor even with a restructuring of the fare structure would result in a minimal reduction in failures per 1000 passengers at a station because of the increased activity on the addfare. Any benefits gained are due to active use of the more reliable fast vendor rather than a large reduction in farecard vendor activity.

The capital cost of the fast vendor depends on the model selected. For the purposes of this analysis, it will be assumed that vendors costing $3000 per unit will be purchased.

If two thirds of the multi-price vendors are replaced by fast vendors, 7 fast vendors would be required per typical station.

Fast Vendor Capital Cost = 7 x $3000 = $21,000 per station.

### 7.3.3 One and Two Ride Fast Vendor

The next flow chart (Figure 7-4) is based on the improved coin-accepters and transport and fast vendors that sell one or two ride tickets instead of $1 or $5 tickets. The vendors will be of the exact fare type and to facilitate their use for varied fares a bank of bill changers would be installed at a nearby location in the stations.

If seven fast vendors are installed in each station, and each can sell tickets of two different values, then enough differently priced tickets could be sold to accommodate almost all of passenger demand. To assure availability or to accommodate high volume, more than one machine can be assigned to sell certain value tickets.

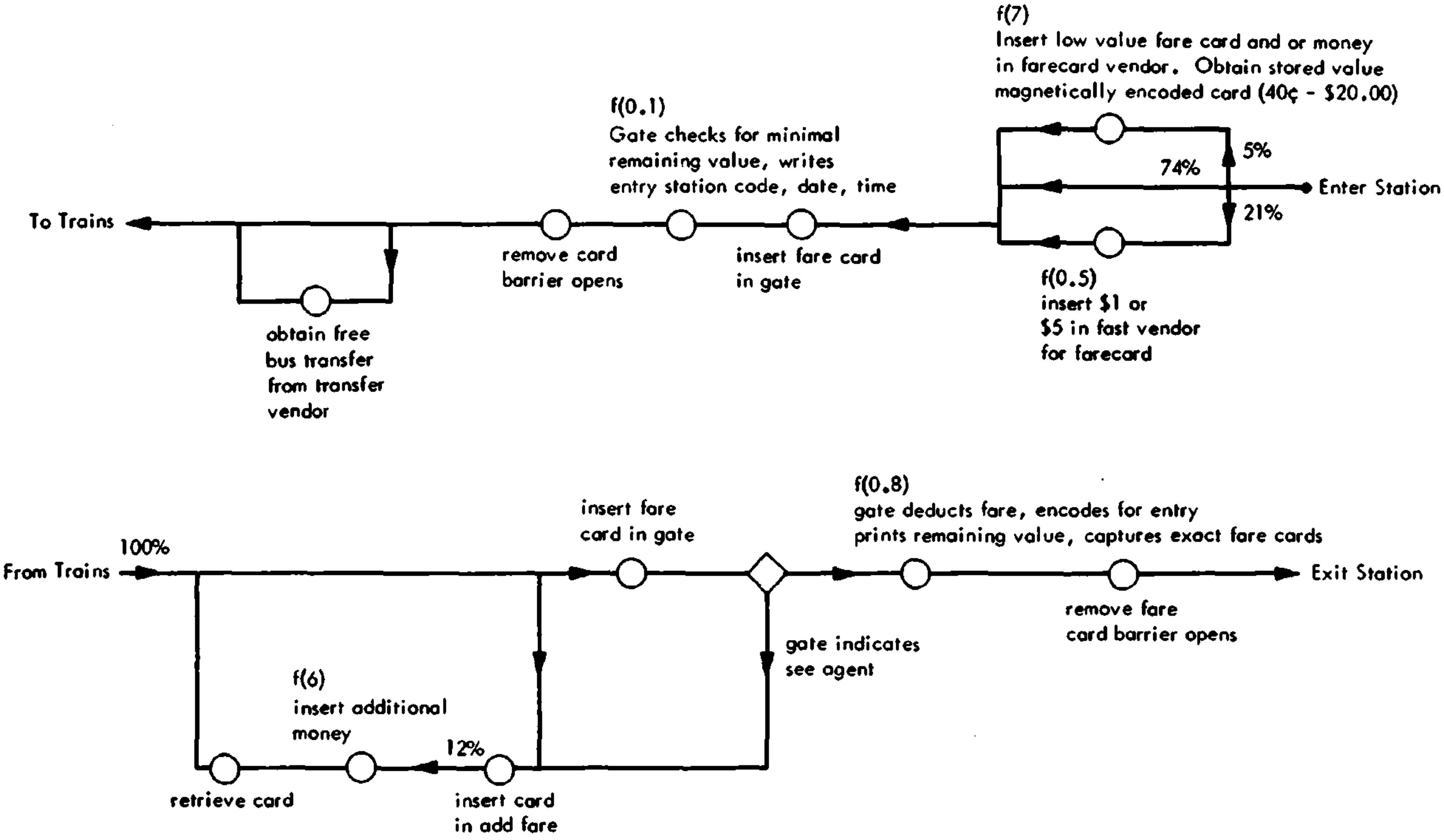
A fast farecard vendor should accept several types of coin. One model on the market presently accepts only quarters. The manufacturer should be able to add a multi-coin feature at little additional cost, for an order of the appropriate quantity.

Corresponding to PATCO statistics, it was assumed that approximately one third of passengers who utilize a fast vendor would require the use of a bill changer. Since bill changers will be available, they could also be used to vend $1 coins for a $5 bill. If this option is selected, the reliability of the fast vendors would increase since fewer bills would be utilized, and the reliability of the bill changer would also increase since $5 bills are generally less worn than $1 bills.

Figure 7-4 indicates a bill changer reliability of 0.5 failures per 1000, which corresponds to the PATCO experience. The fast vendor reliability is 0.3 per thousand on the assumption that half the fares would be paid by bills and coins and half by coins only. Table 3-4 reports that European ticket vendors achieve reliabilities of over 5000 transactions per failure. This is due in part to their accepting coins only, and the circulation of high value coins. The flow chart assumes a slight increase in the use of the addfare, but not as much as for the $1 and $5 fast card vendors.

The combined failures per 1000 passengers are now reduced to 1.89, a small additional improvement over the $1 and $5 fast vendor.

Availability and delay information are summarized in Tables 7-15 and 7-16.



Combined failures per 1000 passengers = 2.17

f(n) - failures per 1000 transactions

Figure 7-4 Baseline System - Improved Ticket Transport and Coin Acceptor Plus One or Two Ride Fast Vendor

## Table 7-15 Probability of Delay - Improved Attended Baseline Plus One or Two Ride Fast Vendor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (normal) | 3 | 7 | 5 | 20.41 | .994 | .999 |
| Fast Vendor | 7 | .3 | 21 | 113.38 | .999 | .999 |
| Bill Changer | 6 | .5 | 7 | 204.08 | .999 | .999 |
| Entry Gate | 10 | .1 | 100 | 71.43 | .998 | .999 |
| Addfare | 3 | 6 | 8 | 14.88 | .991 | .999 |
| Exit Gate | 10 | .8 | 108 | 8.27 | .985 | .991 |

P(delay) = (.001)(.05 + .21 + .07 + 1 + .08) + .009(1.08) = .011

## Table 7-16 Probability of Delay - Improved Unattended Baseline Plus One or Two Ride Fast Vendor

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (normal) | 3 | 7 | 5 | 20.41 | .982 | .999 |
| Fast Vendor | 7 | .3 | 21 | 113.38 | .997 | .999 |
| Bill Changer | 6 | .5 | 7 | 204.08 | .998 | .999 |
| Entry Gate | 10 | .1 | 100 | 71.43 | .995 | .999 |
| Addfare | 3 | 6 | 8 | 14.88 | .976 | .998 |
| Exit Gate | 10 | .8 | 108 | 8.27 | .957 | .934 |

P(delay) = (.001)(.05 + .21 + .07 + 1) + .002(.08) + .066(1.08) = .073

Utilizing 6 bill changers, the capital cost per station would be approximately:

Table 7-17 Capital Costs - One or Two Ride Fast Vendor

| Equipment | Quantity | Unit/Cost | Cost |
|---|---|---|---|
| Fast Vendor | 7 | $3000 | $21,000 |
| Bill Changer | 6 | $2000 | $12,000 |
| | | | $33,000 |

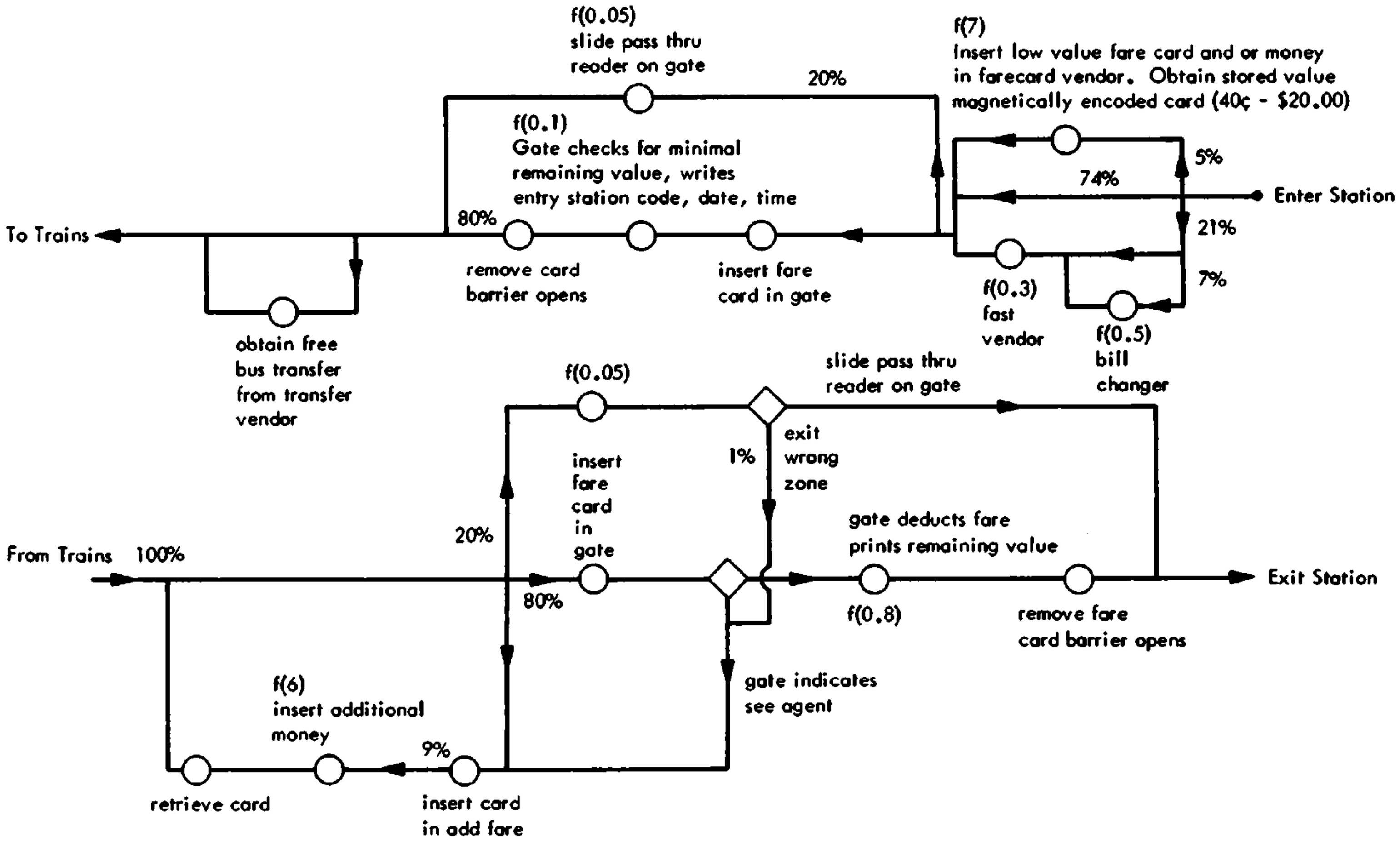
## 7.3.4 Monthly Pass, One and Two Ride Fast Vendor, Improved Transport and Coin Acceptor

The impact of the previous improvements plus a monthly pass is described in the next flow chart, Figure 7-5.

The pass would be plastic coated, time dated, and used in conjunction with a slide-through reader. No writing would be done on the pass. Since it must be compatible with the existing graduated fare structure, it will be assumed that a limited zone system (3-5 zones) would be established for passengers only. Several types of passes, at different prices, would be sold and used by passengers only for travel between two specific zones.

A monthly pass would be expensive and a high market penetration would not be expected. Forty percent of PATCO passengers purchase a weekly 10-ride ticket. Slightly over 10% of MARTA's bus and rail passengers purchase the recently introduced monthly pass. This analysis will assume that 20% of the passengers would purchase a monthly pass. It is assumed that the monthly pass would be sold through the farecard vendors, preferably through a fast vendor that accepts $5 and $1 bills.

The reliability of the slide-thru readers are expected to be high and a value of one failure per 20,000 transactions or 0.05 failures per thousand is used.



Combined failures per 1000 passengers = 1.80

f(n) - failures per 1000 transactions

Figure 7-5 Baseline System - Improved Ticket Transport and Coin Acceptor, One and Two Ride Fast Vendor Plus Monthly Pass

Upon exit, some pass holders will, because of a change in plans during transit, forgetfulness, or error, attempt to exit at a station for which their particular pass is invalid. It is assumed that 1% of passengers would fall into this category.

A method to process these patrons must be developed. The one assumed for the purposes of this analysis is as follows. After his card was rejected by the exit gate slide-thru reader, or on his own, the passenger would request assistance from the station attendant. The patron would fill out and sign a form stating his entry station, name, and address. The attendant would check identification and then hand the patron a pre-encoded exit pass for the zone of the specified entry station. The patron would insert the exit pass with the difference owed in the addfare and it would be validated for use in the exit gate. The central office would file and tabulate these forms. A patron who repeatedly abused this procedure could be billed or charged with theft of services if appropriate.

The combined failures per 1000 passengers for the monthly pass system would be 1.79, another slight improvement. The pass system is a major public convenience, and could be used to accomodate special groups such as the handicapped and students. It should have a significant impact on queue lengths at exit gates.

Availability and delay information follow.

Table 7-18 Probability of Delay - Improved Attended Baseline, One or Two Ride Fast Vendor Plus Monthly Pass

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (Normal) | 3 | 6 | 5 | 20.91 | .982 | .999 |
| Fast Vendor | 7 | .3 | 21 | 113.38 | .997 | .999 |
| Bill Changer | 6 | .5 | 7 | 204.08 | .998 | .999 |
| Pass Reader Entry Gate | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Entry Gate (Normal) | 8* | .1 | 72* | 99.21 | .999 | .999 |
| Addfare | 3 | 6 | 9 | 13.23 | .990 | .999 |
| Pass reader exit gate | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Exit Gate (Normal) | 8* | .8 | 72* | 12.40 | .989 | .997 |

P(delay) = (.001)(.05 + .21 + .07 + .28 + .72 + .09 + .28) + (.003)(.72) = .004

*Two of the ten machines accept both passes and coins or tokens. Twenty percent of the passengers with passes enter these two. It must be assumed that some passengers (8%) use the coin or token acceptor mode at these two turnstiles. The presumed loading is 9% at each of the eight non-pass machines and 4% at each of the pass machines.

Table 7-19 Probability of Delay - Improved Unattended Baseline, One or Two Ride Fast Vendor Plus Monthly Pass

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Vendor (Normal) | 3 | 6 | 5 | 23.81 | .985 | .999 |
| Fast Vendor | 7 | .3 | 21 | 113.38 | .997 | .998 |
| Bill Changer | 6 | .5 | 7 | 204.08 | .998 | .999 |
| Pass Reader Entry Gate | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Entry Gate (Normal) | 8* | .1 | 72* | 99.21 | .996 | .999 |
| Addfare | 3 | 6 | 9 | 13.23 | .973 | .998 |
| Pass Reader Exit Gate | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Exit Gate (Normal) | 8* | .8 | 72* | 12.40 | .971 | .979 |

P(delay) = .05(.001) + .21(.002) + .07(.001) + .28(.001) +.72(.001)
+.09(.002) + .28(.001) + .72(.021) = .017

* - See previous table.

The equipment cost per station is:

Capital Cost - Pass Reader

| Equipment | Quantity per Station | Unit/Cost | Cost |
|---|---|---|---|
| Pass Reader | 4 | $2000 | $8000 |

### 7.3.5 Zone Fare-Pay on Entry Turnstile

Large increases in reliability at little additional equipment cost could be achieved by the alternative of using flat fare turnstiles to implement a one or two zone fare structure.

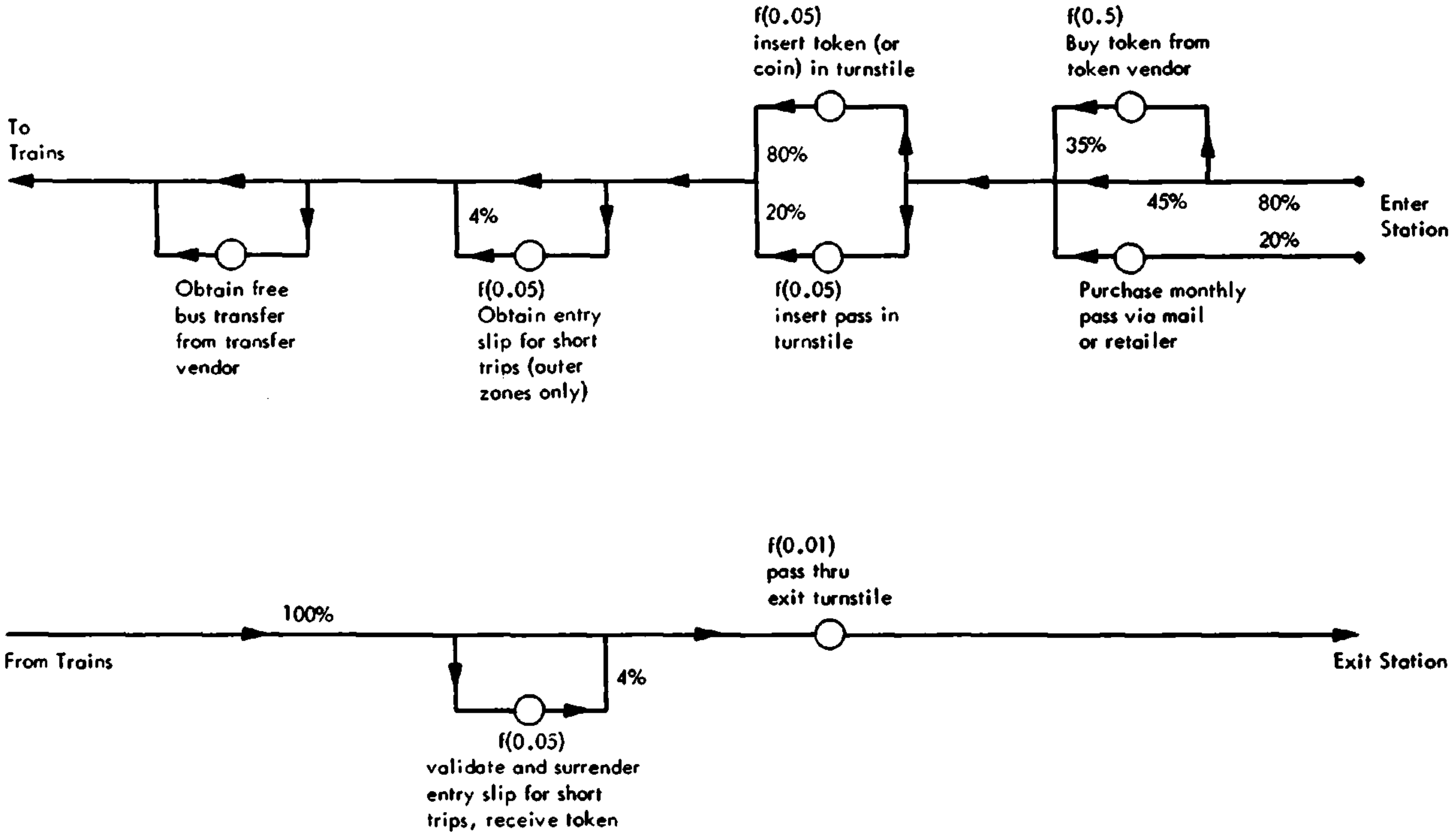
Three zones could be established and a different entry fee charged in each zone. The assumption is that most trips are radially-oriented commutation trips. The longer, round-trip commutation journey would be charged a higher fee than a central city, intra-zone trip.

The system achieves many of the revenue benefits of a graduated fare structure but uses very simple equipment and does not require the tracking of the entry and exit stations for each passenger.

The alternative described (Figure 7-6) assumes very reliable turnstiles accepting tokens at a failure rate of 0.05 per thousand transactions. Coin-accepting turnstiles are less reliable today but could probably be sufficiently improved by use of electronic coin validators. Token vendors will be provided and would function at the same reliability as bill changers. Experience indicates that approximately one-third of passengers would utilize the token vendor.

The reliability rate chosen, f(.05), is between that of the best coin-accepting turnstile, (PATH, f(.11)), and of a token-accepting turnstile, (NYCTA, f(.025)) for which we have data. This alternative does not distinguish between the use of coin-accepting or token-accepting turnstiles. The reliability of each of these units is significantly higher than the reliability of a bill changer. In this alternative it is the bill changer that is the weakest link in the system and the use of of coin or token-accepting turnstiles does not have a major effect on the combined system reliability.

A system for monthly passes would be included. It could use a slide-thru reader similar to that described in the previous section or a conductive ink type canceller. The reliability of each is high.



Combined failures per 1000 passengers = 0.20

f(n) - failures per 1000 transactions

Figure 7-6 Zone Fare, Pay on Entry

Turnstiles can be purchased that can charge different fares at peak and off-peak hours. They are presently several times more expensive and also somewhat less reliable than the single level, token accepting turnstile.

Turnstiles that charge different fares at different times can be used to charge a higher fare to some longer-distance passengers. As noted in Section 3.6, trip length is much shorter during the off-peak hours then in the peak. It is also likely that a very high proportion of these short, off-peak trips are taken in the downtown area. Therefore, this type of turnstile inherently charges a higher fare to the longer trip when it is used to implement a fare structure with reduced off-peak fares, and a higher fare to the outer to inner zone trips than to the intra-inner zone trips.

These turnstiles offer a great deal of flexibility, with daily off-peak and even weekend fares. Inclusion of this option should be considered in any program involving turnstiles.

The implementation of lower, off-peak fares could cause some complication with a monthly pass program. If the pass were a stored ride type, not time dated, unlimited use, some provision would be required to distinguish between the two ride values.

The greatest obstacle to implementation of a zone fare structure is the inequity it causes for short trips, especially those that originate in the outer zones. A simple procedure can be developed to solve this problem, if as for many systems, only approximately 4% of passengers would have a trip ending in an outer zone and of a length less than 3 miles. These are the passengers who require special handling.

They would utilize a piece of equipment yet to be built, called a short trip credit dispenser, (STCD). Two STCD's would be located at each bank of turnstiles. Upon entry a passenger could, upon request, receive a machine-readable, paper hole punched, entry slip. It would be encoded with the entry station, date and time. At an exiting station, the passenger would insert the entry slip into the STCD. If the slip indicated that the entry station and time were within the established bounds, it would vend a token.

The passenger would use this token on his return journey, and his net round trip fare would be greatly reduced. Vending a token is preferred over a coin since it offers less incentive for patron abuse.

The reliability of this system should be within the same range as the machine used to dispense and read punched hole transfers, in use on the Montreal transit system, 20,000 transactions per failure, f(.01). Although they have yet to be built, it will be assumed that the STCD can be purchased in volume for $10,000 per unit.

A system for selling the monthly passes must be established. The flow chart assumes that these very high value farecards would be sold by mail, by retail outlets, or through employers. However, if the vendor sold passes, only an additional 1% of passengers would use the farecard vendor. With such a low flow rate, its effect on the combined systems reliability would be minimal if this form of sale were utilized. The combined failures per 1000 passengers for this alternative is 0.20.

The number of turnstiles utilized would be the same as the existing number of fare gates. Turnstiles have a higher passenger flow rate than fare gates and fewer would be required. However, since they are relatively inexpensive and the space is available, an equal number might as well be used. For a station that has not been constructed yet, reducing the number of turnstiles and construction cost should be considered. Availability and delay information follow.

## Table 7-20 Probability of Delay - Attended, Zone Fare, Pay on Entry

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Token Vendor | 8 | .5 | 35 | 40.82 | .997 | .999 |
| Turnstile (Pass Reader and Coin or Token Acceptor) | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Turnstile (Coin or Token Acceptor Only) | 8* | .05 | 72* | 198.41 | .999 | .999 |
| Entry Slip Dispenser | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Entry Slip Validator | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Exit Turnstile | 10 | .01 | 100 | 714.29 | .999 | .999 |

P(delay) = .001(1 + .04 + .04 + .72 + .28 + .35) = .00243

*See previous table

## Table 7-21 Probability of Delay - Unattended, Zone Fare, Pay on Entry

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Token Vendor | 8 | .5 | 35 | 40.82 | .991 | .998 |
| Turnstile (Pass Reader and Coin or Token Acceptor) | 2* | .05 | 28* | 510.20 | .999 | .999 |
| Turnstile (Coin or Token Acceptor Only) | 8* | .05 | 72* | 198.41 | .998 | .999 |
| Entry Slip Dispenser | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Entry Slip Validator | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Exit Turnstile | 10 | .01 | 100 | 714.29 | .999 | .999 |

P(delay) = .002(.35) + .001(2.02) = .00070 + .00202 = .00272

Table 7-22 Equipment Capital Cost - Zone Fare, Pay on Entry

| Equipment | Quantity per Station | Cost | Total |
|---|---|---|---|
| Turnstiles Entry | 10 | $ 3,000 | $30,000 |
| Turnstiles Exit | 10 | $ 1,000 | $10,000 |
| Short Trip Credit Dispenser | 2 | $10,000 | $20,000 |
| | | | $60,000 |

### 7.3.6 Zone Fare-Pay on Entry and Exit (Outer Zones Only)

A system with zoned fares paid on entry leads to a high difference in fares between different zones in order to maintain the same revenue as a graduated fare structure. If this difference is great enough, it could cause undesireable alterations in passenger travel behavior. Passengers might ride a bus several additional miles to reach a subway station in a lower fare inner zone, then return in the evening to the more outlying station.

If fares were collected on exit in addition to entry, the difference in fare level at adjacent zones would be reduced by half. The next flow chart, Figure 7-7 illustrates such a system. It is the same as the pay-on-entry system, except for the additional exit turnstiles.

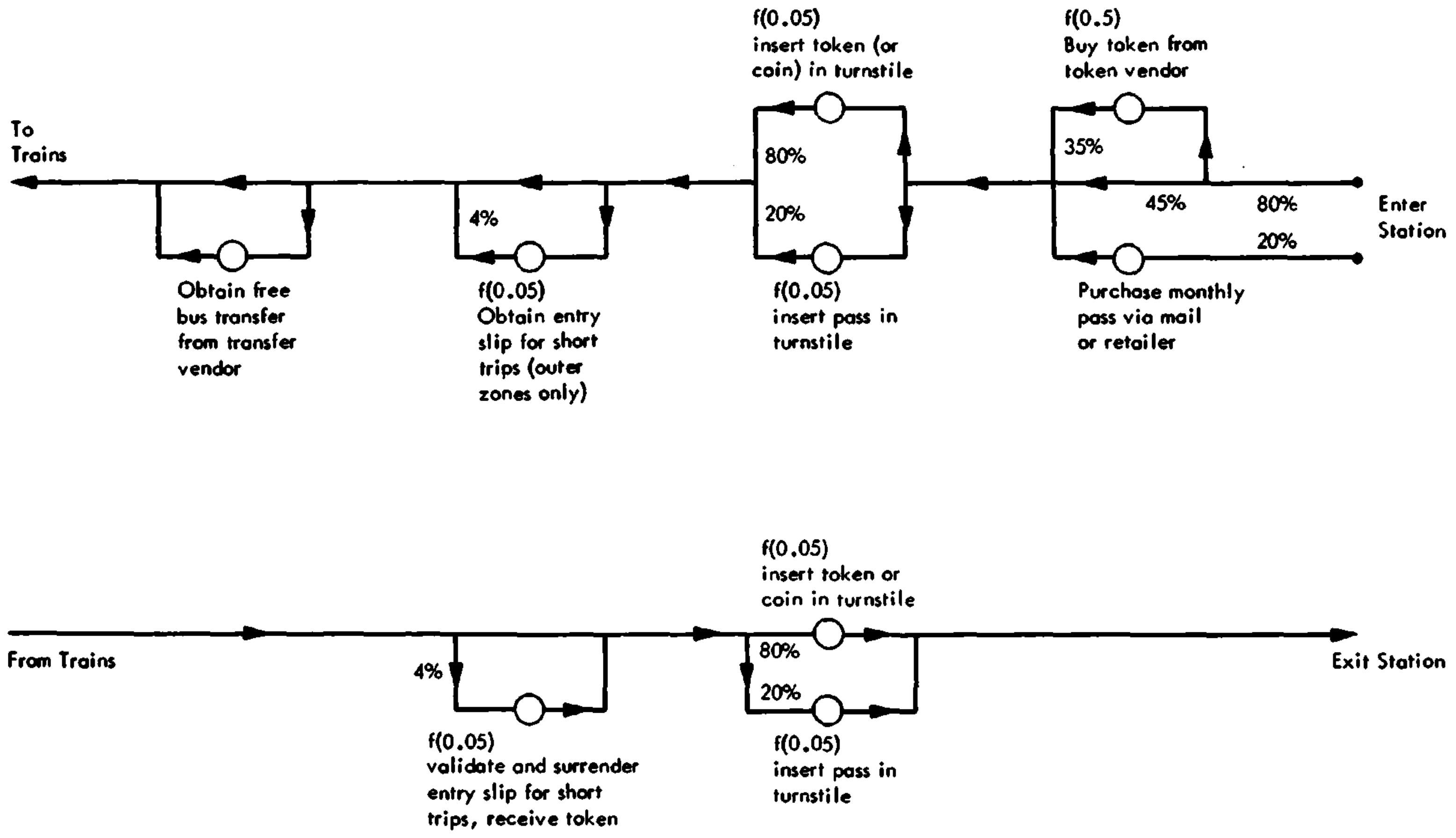
Collecting a fare on exit is a more critical operation than on entry. Passengers arrive at the turnstiles at a much higher rate when exiting from a train then when entering the station. Higher processing rate, token accepting instead of coin accepting turnstiles would lead to shorter queues at exit gates and are assumed to be used in this alternative. The combined failures per 1000 passengers for this alternative is .24.

A bank of 10 turnstiles would be used in the typical station at entry and exit. Presently, token-accepting turnstiles that accept a fare in both the entry and exit direction are not manufactured. They could be supplied if ordered in sufficient quantity. Availability and delay information follow.

Table 7-23 Probability of Delay, Attended, Zone Fare, Pay on Entry and Exit

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Token Vendor | 8 | .5 | 35 | 40.82 | .997 | .999 |
| Turnstile (Pass Reader and Coin or Token Acceptor) | 2 | .05 | 28 | 510.20 | .999 | .999 |
| Turnstile (Coin or Token Acceptor Only) | 8 | .05 | 72 | 198.41 | .999 | .999 |
| Entry Slip Dispenser | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Entry Slip Validator | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Exit Turnstile (Pass Reader and Coin or Token Acceptor) | 2 | .05 | 28 | 510.20 | .999 | .999 |
| Exit Turnstile (Coin or Token Acceptor Only) | 8 | .05 | 72 | 198.41 | .999 | .999 |

P(delay) = ..001(.35 +.28 +.72 +.04 +.04 +.28 +.72) = .00237



Combined failures per 1000 passengers = 0.24

f(n) - failures per 1000 transactions

Figure 7-7 Zone Fare, Pay on Entry and Exit (Outer Zones)

Table 7-24 Probability of Delay - Unattended, Zone Fare, Pay on Entry and Exit

| Equipment | Quantity per Station | Failures/1000 Transactions% | % Passengers Using Machine | MTBF (hr) | Unit Avail. | Group Avail. |
|---|---|---|---|---|---|---|
| Token Vendor | 8 | .5 | 35 | 40.82 | .991 | .998 |
| Turnstile (pass reader and coin or token acceptor) | 2 | .05 | 28 | 510.20 | .999 | .999 |
| Turnstile (coin or token acceptor only) | 8 | .05 | 72 | 198.41 | .998 | .999 |
| Entry Slip Dispenser | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Entry Slip Validator | 2 | .05 | 4.2 | 3401.36 | .999 | .999 |
| Exit Turnstile (pass reader and coin or token acceptor) | 2 | .05 | 28 | 510.20 | .999 | .999 |
| Exit Turnstile (coin or token acceptor only | 8 | .05 | 72 | 198.41 | .998 | .999 |

P(delay) = .002(.35) + .001(2.08) = .00278

Table 7-25 Capital Cost - Zone Fare, Pay on Entry and Exit

| Equipment | Quantity | Unit Price | Total |
|---|---|---|---|
| Entry Turnstiles | 10 | $3,000 | $30,000 |
| Exit Turnstiles | 10 | $3,000 | $30,000 |
| Short Trip Credit Dispensers | 2 | $10,000 | $20,000 |
| | | | $80,000 |

An interesting modification to the zone pay on entry and exit system is described below, but not examined in detail. Two zones would be established, an inner and outer. At all times in the inner zone, passengers would pay a uniform fee to enter, but none to exit. In the outer zone, the same would apply except for the evening rush hour. At this time, patrons entering would pay a nominal or zero fee while all those exiting would pay a uniform fee. Such a system would require the use of coin or token accepting turnstiles that could vary the required fare by time of day. This fare structure would be advantageous when a large proportion of short distance intra outer zone riders are expected. For a round trip, they would be charged the same fare or slightly above that of all other short-distance riders on the system. Longer distance riders would still be charged a higher fare. The need for special equipment to refund money or rides to short distance inter- or intra-zonal travelers is diminished.

## 7.4 Summary of Comparisons

The results of the preceding analysis are summarized in the table below. For the baseline system and each of the six alternatives, it lists several system descriptions which describe the effectiveness of the fare collection system at a typical station.

Table 7-26 Effectiveness of Alternative Improvements

| Alternative | Capital Cost/Station | Failures per 1000 Passengers | Probability Passenger Experiencing Equipment Delay: Attended Station | Probability Passenger Experiencing Equipment Delay: Unattended Station |
|---|---|---|---|---|
| (1) Baseline (Graduated Fare) | $694,000 | 9.11 | .20 | .76 |
| (2) Plus Improved Transport, Coin Acceptor ((1) + (2)) | $694,000+ | 3.70 | .03 | .17 |
| (3) Plus $1 and $5 Fast Vendor ((1) + (2) + (3)) | $715,000 | 2.17 | .014 | .08 |
| Or | | | | |
| (4) Plus One and Two Ride Fast Vendor ((1)+(2)+(4)) | $726,000 | 1.89 | .011 | .073 |
| (5) Plus Monthly Pass ((1)+(2)+(4)+(5)) | $734,000 | 1.79 | .004 | .019 |
| (6) Zone Fare, Pay on Entry | 60,000 | .24 | .002 | .003 |
| (7) Zone Fare, Pay on Entry and Exit | 80,000 | .29 | .002 | .003 |

The first column lists the capital cost per station. For the existing baseline system, it is $694,000. A system with 50 stations would require $35,000,000 of equipment of this type. The alternatives that modify the baseline would require the additional capital investment indicated for existing stations. Newer stations would require a full set of new equipment, less these which could be transferred from existing stations (e.g. vendors). Unfortunately, a capital cost figure for alternative 1 is not available but is believed to be of the same order of magnitude as the remaining alternatives.

The second column indicates the expected number of both hard and soft equipment failures (jams) that would occur at a station for every 1000 passengers. The third and fourth columns indicate the minimum probability that a passenger would encounter a delay as he travels through a station. A value for both the attended and unattended stations is presented. The probability of delay is based on the incidence of two or more pieces of similar types of equipment being out of service at the same time. This would be a good estimate of severe delays. However, delays due to peak loading can also occur even if all the equipment is operating or only one unit is down.

The failures per 1000 passenger transactions are also an index of the maintenance effort required to keep the system operating. Hence, this table provides a means for comparing both the capital and maintenance costs of alternate systems. Estimates have been made of over $100,000 annually per station for some transit systems. This is a large enough value to make it an important factor in any decision.

The probability of a passenger delay occuring is strongly related to the time in which a machine can be brought back into service after it jams. This analysis assumed that the mean time to repair a failure would be .13 hours in an attended station and .37 hours in an unattended station.

Considering the large number of passengers processed each day, it would be desirable to have as low a probability of delay as feasible. Even if the probability of delay were only 0.01, nearly 100 persons per day per station would be delayed. Alternative 4, which has this value of delay probability, would require a corresponding servicing of 17 machine failures per day at a station.

It is apparent that only alternatives 5, 6, and 7 offer any hope of maintaining delay levels at attended stations within reasonable bounds. All three of these alternatives have probabilities of delay of .004 or less. This is an improvement over the baseline by a factor of 50.

The table also indicates the high sensitivity of delay probability to equipment reliability. The rate of decrease of delays is many times greater than the rate of decrease of failures per 1000 passengers. Review of the previous tables in this section will indicate that to achieve these low levels of delay, an equipment availability of at least 99% is required.

None of the listed alternatives require the station attendant to handle large volumes of money. They would be required to handle single $1 or $5 bills when they clear jams. Each of these alternatives would operate more effectively if, as part of their normal functions, revenue collection agents cleared jammed bills and coins.

There are many factors that must be considered by the transit operator in selecting a fare collection system. This analysis has considered some of the more important ones - equipment, capital and operating costs, passenger delays, and station manning. Others that have not been considered are: revenue collection costs, security from robbery and fraud, the effectiveness of the system in charging the proper fare to each rider, the fare level, and impact on ridership.

Another important issue is ease of implementation. Each of the improvements to the baseline system requires only that the one machine being modified be taken out of service at any time. Little inconvenience to the public should result. Replacement of the baseline system by turnstiles could also be accomplished with little inconvenience. A bank of turnstiles would be placed in front of a bank of gates. Electrical connections would be made and they could operate immediately. Overnight or over a weekend, the present gates would be deactivated and the turnstiles activated. One by one gates would be removed and each turnstile moved several feet into the former gate location. Depending on the turnstile purchased, its cost could be so much lower than that of the existing gates that any effort to salvage parts from the gates would not be justified.

The transit agency is faced with a complex political, social, and technical problem; selecting a fare collection system. This section has provided analytical tools that aid in these tasks. This is only an initial but important step. A more comprehensive analysis would investigate other attributes and the process of weighting these attributes under uncertainity. The final decision must be made by the operator who is aware of many special local restraints.

# 8. FARE COLLECTION DEVELOPMENT NEEDS

There are several fare collection problems that apply to all transit systems while others apply only to a few. In general, all agencies want to keep collection costs down and revenues high. Problems with coin acceptors and bill validators, such as their frequent jamming, wear, and accepting foreign coins and slugs affects nearly every transit system. These devices are used in changemakers, token sellers or as subsystems of vendors and turnstiles.

New versions of these devices are continually being developed for the vending industry. Some of these improvements may be directly applicable to transit, others may require some incentive for the manufacturer to modify the equipment to serve the small transit market (e.g., higher value coin escrows on electronic coin changers). Redesign of some items may be required to meet transit requirements such as low rejection rates of worn bills.

There is a need for an organized testing program of these devices in transit situations. Operating agencies are usually very cooperative in conducting such tests. The information developed should be analyzed and exchanged. If at that point it is determined that the new commercial models do not meet the needs of transit, then a development program for a transit version of these devices may be initiated.

Properties are finding increased public pressure for special fares, which their equipment designed for flat fares, cannot handle. They often process student fares, senior citizen and handicapped fares, monthly passes, off-peak fares and weekend fares in a manual makeshift manner. As the volume grows, these exceptions are becoming more expensive to process. An automatic system to process these fares that complements, not replaces, the existing system is needed. The Massachusetts Bay Transportation Authority is testing a promising system that utilizes a reader for magnetically encoded monthly passes.

Security for station agents and passengers is a problem. Agents who process large volumes of money are robbery targets. Closed circuit television does not function well in dimly lit stations with columns, has low resolution, and requires a human monitor to constantly watch a myriad of TV screens.

The data presented in this report indicates that the reliability of recent designs of automatic fare collection equipment must be improved several-fold. Their security from fraud, internal and external, must also be improved and be achieved in a manner that does not significantly reduce reliability.

A first step toward achieving improved reliability would be a program of controlled tests to precisely determine the causes of frequent failures of automatic stored value and stored ride fare collection systems. This should be done in conjunction with operators, manufacturers, and independent analysts and should use a standardized data collection method. This would be followed by a series of tests of design retrofits. There is need for a verified multiagency fare collection reliability information exchange.

Reassessment of the concept of using magnetically encoded cards as the ticket medium is worthy of consideration. The recent experience with magnetically encoded farecards has not been satisfactory. This does not imply that those systems if properly specified and developed could not be made to work. However, satisfactory, less expensive alternatives may exist that perform the same function. A clear rationale for the decision to develop the stored value, magnetic encoded card system could not be found in the literature.

Reassessment should include alternate approaches to transport design. Systematics, Piscataway, NJ, in support of the UMTA bus program, has developed a straight line transport in which the card moves in, then out. Holding the card stationary and moving the magnetic heads should also be examined. Early literature on automated fare collection cites the development of both linear and rotary ticket transports. "The rotary transport comprises a continuously rotating wheel with a belt which retains the ticket in contact with the wheel during its passage through the device, and magnetic read and write heads must be placed at suitable positions around the path of the ticket in line with the circumference of the driving wheel."(Reference 16) A preference for linear transports is indicated. Although it was recognized as more likely to jam than a rotary transport, the expected passenger throughput was higher since the ticket was returned to the passenger downstream rather than at the same location. Cubic has developed an improved transport that could be retrofitted onto existing equipment. It utilizes improved software to reduce jams and takes advantage of the high signal-to-noise ratios of certain types of farecard magnetic tape to increase the tolerance on magnetic head adjustments. Any ticket transport program should evaluate the use of non-contact printers.

Present AFC magnetic coding techniques repeat the information several times as a check for errors. This leads to a higher bit density, a requirement for greater precision in the adjustment of the magnetic heads and increased error generation. The use of error detection and correction codes could reduce errors without repeating the stored information. The lower bit density on the magnetic tape should greatly increase reliability and reduce the need for mechanical adjustments. Correction codes are regularly used in many information transmission systems.

Tickets with encoding in electrically conductive inks, punched holes, or visible characters readable by both machines and humans, offer many possibilities. Some of these concepts are already in practice as in the Almex card canceller, certain parking lot pass gates, and at supermarket counters. With minimal modification, several of these devices could be adapted to implement a zone fare structure.

The design of ticket vendors should also be examined. Several European manufacturers produce vendors that sell magnetically encoded tickets from a roll or a fan fold (accordion stacking). This eliminates many of the problems associated with the hopper feeding thin paper or plastic tickets. U.S. manufacturers produce machines that are being used to vend single price lottery tickets from a roll or fan fold. Their reliability is high. Use of a carrier strip would permit these vendors to be used in conjunction with existing magnetically encoded farecards. The European manufacturers also include recirculating coin changers, and gates that prevent a passenger from inserting a second coin until the first has cleared without jamming. The utility of the dollar escrow must also be evaluated.

The banking industry is developing concepts that could have application in transit. The use of electronics funds transfer could reduce many of the worn money problems. The cost of this service must be considered, however. Use of more sophisticated coding techniques could greatly reduce the possibility of counterfeit cards.

Farecard design is an area that could have a large impact on system performance. By varying surface textures, coatings, and shapes, card jam rates may be significantly reduced. Present farecards are thin and have smooth surfaces. When stacked in a hopper, air pressure can cause them to stick together.

A hidden cost is money counting and accounting. Methods to reduce the costs of these functions are needed. Recent vendor designs have tried to reduce the workload in the central counting room by having the vendor perform a stacking function. The value of this policy should be examined, in light of added costs of vendor reliability. Equipment to aid in the processing of large volumes of money is also required.

As in the rest of the transit industry, procedures or equipment designs to perform a function vary from one agency to another. Increased standardization might lower the costs of new equipment. Less ambitious fare collection specifications might permit greater use at lower costs for upgraded products originally developed for the vending industry. Efforts to develop equipment specifications that could be used by several operators should be pursued.

The transit industry has varying attitudes toward retailers selling farecards for a sales commission. Several systems use it very successfully to lower activity on their less reliable fare collection equipment. Other systems are reluctant to take this approach. The farecard vending machines at BART and WMATA have the capability of selling higher-valued tickets at a discount, although this feature has never been utilized. There are claims that this might discriminate against lower income passengers. A clear understanding of these issues could lead to reduced collection costs or at least the elimination of a function from the equipment specification that will never be used.

Very few transit systems have developed an automated technique for issuing transfers between rail and bus. For other than systems using magnetically encoded tickets or automated techniques, the process of issuing the transfer is an expensive and time delaying procedure. Several transit systems have expressed interest in the development of a rail to bus transfer. Commuter railroads have been charging distance-related fares for many years, and offer the potential for a successful demonstration of self service fare collection techniques.

The cost of the fare collection system is a hidden element of the construction costs of new rail transit lines. Huge increases in station costs are due to the need to provide fare collection mezzanines. Investigation of techniques to reduce these costs are warranted. Fare collection represents between 7% and 31% of revenues collected. Operators might obtain large cost savings from research and development leading to more effective systems.

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