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BART Patron Egress/Ingress Study: Use of Stairs and Escalators Between Platform and Concourse Levels

MATT du PLESSIS

ABSTRACT

The shorter headways planned for 1989-1990 and the increased patronage projected over the next 5 years caused concern about the capacities of the Bay Area Rapid Transit (BART) stations to handle exiting patron loads. A basic objective at BART has been that patrons from one train should be off the platform before the next train coming from the same direction arrives; that is, within the existing headway. To analyze the patron egress/ingress capacities of BART's stations, five parameters were considered: (a) the planned headways between trains, (b) the projected patronage at each station, (c) the availability of escalators, (d) the processing rates for the stairs and escalators, and (e) the number of patrons that can be expected to use the stairs. On the basis of these five parameters, a basic criterion was developed: The projected 95th percentile of peak patron loads during the exit rush 2 hours should be able to use the stairs and escalators to exit the platform within 2.25 min, even if one escalator is unavailable. Each station was analyzed under four conditions. The analysis revealed that nine stations would have problems in the 2.25-min time frame when one escalator is unavailable. Each of the nine stations was evaluated in detail, and preliminary recommendations were made for the number of escalators or stairs to add to the stations. To facilitate a decision on constructing an escalator or stairwell at each station, cost estimates should be obtained and considered in light of the indicated severity of potential egress/ingress problems.

The Bay Area Rapid Transit District (BART) will be experiencing significant changes by 1990. The new C-cars will be added to the fleet of revenue vehicles, and the Daly City extension track will have been constructed. At the same time, BART staff are planning to reduce headways between trains to 2.25 min in 1989, and patronage is projected to increase by 40 to 45 percent in the next 5 years. A critical issue for BART is the egress/ingress capacity of the stations under these conditions. Is there enough escalator and stairway capacity to handle projected volumes of patrons?

The manager of station operations asked management services to conduct an analysis of the egress/ingress capacity of the stations to determine (a) which stations, if any, would not be able to handle the projected patronage increases within the shorter headways; and (b) the estimated number of escalators or stairways needed to handle the increased load.

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The issue of additional faregates and other automatic fare collection (AFC) equipment was not considered a part of this study, but will be addressed by the AFC Study Committee.

Described in this paper is the analysis of the station egress/ingress capacities between the platform and concourse level only. The concourse-to-street-level capacities are not expected to be as critical as the platform-to-concourse capacities and were analyzed in a separate study.

The analysis described in this paper will demonstrate the method used to evaluate station egress/ingress capacities. The analysis was based on current patronage projections for 1989-1990. Based on this analysis, those stations that may have egress/ingress problems will be identified, and the number of escalators or stairwells recommended for adequate capacities under adverse conditions will be presented. The actual locations and cost estimates for installing escalators and stairs will be determined separately by design engineering staff.

To evaluate whether the escalator and stairway

capacity between the platform and concourse levels is adequate, five parameters must be considered:

1. Planned headways between trains,
2. Projected patronage at each station,
3. Availability of escalators,
4. Processing rates for the stairs and escalators, and
5. Number of patrons that can be expected to use the stairs.

PLANNED HEADWAYS

The BART District is planning to reduce the minimum scheduled headway between trains incrementally over the next 5 years. In early 1986 the minimum headway will be reduced from 3.75 min to 3.5 min. Further reductions will be made in each successive year until the headway is 2.25 min in 1989, if the necessary projects are completed on time. These minimum scheduled headways apply primarily to the downtown Oakland (K line) and San Francisco (M line) service. The headways on the suburban lines (R, C, and A lines) will be 4.5 min.

A basic objective is to have patrons off the platform before the next train arrives. Therefore, the time frames used to calculate each station's capacity were 2.25 min for the minimum headways for all lines and 2.25 or 4.5 min for the average headways, depending on the line. The consideration of the longer time frames provides a basis for determining the magnitude of the egress/ingress problem. However, the 2.25-min time period represents the desirable criterion for adequacy of capacity under minimum headways and for avoiding patron inconvenience in other cases. Also, the desire for equity on all lines favors using the 2.25-min criterion for the entire system.

PROJECTED PATRONAGE

The average weekday patronage for fiscal year 1988-1989 is projected to be 285,200, almost 40 percent greater than in 1983-1984. For individual stations the growth in exit-rush patronage during the commute periods varies from 3 to 25 percent. Twenty-four of BART's 34 stations have projected increases of less than 10 percent.

One important aspect of patron flow is that it fluctuates. High peaks are often followed by a low number of disembarking patrons. This fluctuation raises the issue of whether to design the system to handle the large peaks or to allow the patrons from the next train to encounter queues. For this analysis, the possibility of slight train delays causing a series of crowded trains led to a design criterion of having enough capacity to handle the 95th percentile of peak patron loads during the exit rush 2 hours. Thus, when the worst case occurs, patrons from the following train may encounter queues, but 95 percent of the time exiting patrons will have cleared the platform before the following train's arrival.

To determine the 95th percentile of peak patron loads in 1989-1990, current data were obtained for patrons alighting from trains and multiplied by the growth factors for each station--except for the downtown San Francisco stations. The heavily loaded trains from the East Bay are already at full capacity and have experienced little growth in recent years. However, the number of alighting patrons from West Bay trains was multipled by the station growth factors. The projected patronage figures are given in Table 1 for three of BART's five lines.

TABLE 1 Projected 95th Percentile of Peak Patron Loads During Exit Rush Two Hours in 1989-1990 by Station and Centroid

Station/Centroid	Projected Peak Patron Loads
C LINE	
Rockridge	140
Orinda	150
Lafayette	180
Walnut Creek	230
Pleasant Hill	320
Concord	500
K LINE	
12th Street - N	40
- C	100
- S	30
19th Street - N	170
- C	90
- S	40
MacArthur	160
M LINE	
Oakland West	90
Embarcadero - E	340
- W	440
Montgomery - E	320
- W	610
Powell - E	60
- W	220
Civic Center - E	130
- W	170
16th/Mission	90
24th/Mission	160
Glen Park	220
Balboa Park	200
Daly City	510

AVAILABILITY OF ESCALATORS

Of BART's 133 escalators, 81 of them connect the platform to the concourse level. The escalators can be out of service for one of three reasons: (a) preventive maintenance, (b) a malfunction, or (c) a major overhaul. Preventive maintenance is usually completed during the off-peak hours and therefore does not represent a major concern for this analysis. As for escalator overhauls, more than 80 escalators will be rehabilitated in the system during the next 3 years. The rehabilitation process should be completed before 1989, however.

The average availability of escalators at 6:00 a.m. on weekdays was as follows:

July	98.6 percent
August	95.6 percent
September	97.1 percent

According to Reliability Engineering staff, each escalator is available more than 95 percent of the time at 6:00 a.m. An analysis of the trouble incidents between July 1 and October 28 showed that the average amount of time an escalator is down is 5 hr

and 15 min. The range was from 1/2 hr to 37 hr. Inoperative escalators are required by BART's safety department to be blocked off so that patrons cannot use them.

The important consideration is that an escalator that goes out of service during the commute period could lead to a major problem when headways are 2.25 min. Also, the stations that are more than two stories underground should have one escalator operating in the up direction at all times. This means that during one of the commute periods (evening, generally), one escalator will be unavailable to transport patrons down to the platform. Therefore, the condition of one escalator being unavailable is included as part of the analysis to ensure adequate capacity under adverse conditions and/or to allow for one escalator operating in the reverse direction.

PROCESSING RATES--STAIRS AND ESCALATORS

The processing rates for stairs and escalators depend on the direction patrons are going on the stairs (up or down) or on the speed at which the escalator is operating, the width of the stairs or escalators, and the existence of a queue. The rate for going up a set of stairs is less than the rate for going down and, naturally, the faster an escalator is operating, the more patrons it will transport--up to a safe maximum.

The width of the stairs or escalators determines the number of lanes of pedestrian traffic that can be accommodated. The standard design width for stairs is 30 in. between handrails for one person and 52 in. for two persons. The stairs in the BART stations have two basic widths: approximately 4 ft or approximately 6 ft. In either case the stairs were found to accommodate two lanes of traffic. The 6-ft wide stairs provide additional space between two patrons using the stairs side by side, but not enough space to provide a third lane. The absence of a handrail also deters the development of a third lane. Therefore, all platform stairs except those at the North Berkeley station are assumed to have two lanes for pedestrian traffic. The stairs at the North Berkeley station are only 3 1/2 ft wide and are presumed to accommodate only one lane each. The number of stairwell lanes per station-centroid and the flow rates per station-centroid are given in Table 2 for three lines.

The flow rates given in Table 2 were based on National Fire Protection Association Code 130 (1) and confirmed by field observations. The flow rates

TABLE 2 Number of Stairwell Lanes Per Station-Centroid and Associated Flow Rates

Station/Centroid	Number of Stairwell Lanes	Exit Flow Rates (Patrons/Minute)	Entering Flow Rates (Patrons/Minute)
C LINE			
Rockridge	6	240	210
Orinda	4	160	140
Lafayette	4	160	140
Walnut Creek	2	80	70
Pleasant Hill	2	80	70
Concord	2	80	70
K LINE			
12th Street - N	2	70	80
- C	2	70	80
- S	2	70	80
19th Street - N	2	70	80
- C	2	70	80
- S	2	70	80
MacArthur	4	160	140
M LINE			
Oakland West	2	80	70
Embarcadero - E	4	140	160
- W	4	140	160
Montgomery - E	2	70	80
- W	6	210	240
Powell - E	2	70	80
- W	6	210	240
Civic Center - E	2	70	80
- W	2	70	80
16th/Mission	4	140	160
24th/Mission	4	140	160
Glen Park	2	70	80
Balboa Park	4	140	160
Daly City	2	80	70

per lane are 35 patrons/min for ascent and 40 patrons/min for descent. Thus, a two-lane stairway in an elevated station would process 80 exiting patrons/min, whereas in an underground station it would only handle 70 exiting patrons/min. A critical supposition in these processing rates for stairs is that all patrons are going in one direction; that is, no reverse pedestrian flow exists. Patrons attempting to use the stairs in the opposite direction will reduce the flow rates. If the reverse traffic is frequent enough, the number of available lanes must be reduced by one. Generally, the reverse flow in BART stations is not heavy enough to cause problems during the commute periods. However, to provide a simplified and consistent calculation of a station's processing capacity, the lower patron flow rates for going up a stairwell were used for calculating the stairs' capacity.

In the case of the escalators, the two operating speeds used in the BART District lead to two processing rates for each of the different width escalators. A nominal 48-in. escalator operating at a speed of 90 ft/min (fpm) has a capacity of 85 to 100 patrons/min when a queue exists. At a speed of 120 ft/min the capacity with a queue is 100 to 135 patrons/min. A nominal 30-in. escalator has flow rates of 60 to 75 patrons/min for the 90 ft/min speed and 75 to 100 for the 120 ft/min speed. For design purposes, the lower value of a range should be used; that is, 85 patrons/min and 100 patrons/min for the 48-in. escalator. These flow rates have been found to be reasonable based on field observations. It should also be noted that patrons walking on moving escalators do not add to the capacity of the escalators. Because all platform escalators have a 48-in. width and operate at 120 ft/min, their processing rate is therefore 100 patrons/min.

PATRON USE OF STAIRS

Several factors affect patrons' decisions to use the stairs instead of the escalators. Normally, a small percentage of patrons will always use the stairs no matter what the situation is. These patrons consider the use of stairs a form of physical exercise to help keep themselves in shape. Many patrons, however, will only use the stairs if one or more of the following conditions exist:

- Stairs are closer than an escalator and are going down,
- A large queue has formed at the escalator,
- Stairs are not too long or steep,
- Stairs are not too crowded, and
- Escalator is out of service and an alternative escalator is too far away.

Even in stations that have additional centroids, patrons tend not to use the other end of the station if their usual escalator is out of service. These patrons will wait for long periods to use the secondary escalator at their end of the station.

BART stations can be grouped into three basic categories: (a) elevated stations, (b) underground stations in which the platform is less than 24 ft below the concourse, and (c) underground stations in which the platform is more than 24 ft below the concourse.

For each of these three types of stations, patron behavior and service criterion will differ. The 24-ft criterion is based on American Public Transit Association (APTA) design guidelines for escalators in rapid transit facilities: backup "up" escalators should be considered where vertical rise exceeds 24 ft.

Elevated stations cause the least concern for patrons exiting from the platform. Observations in the field found that 40 to 60 percent of patrons will use the conveyance that is closest, either the stairs or the escalator. Therefore, stairs in elevated stations are presumed to be used to full capacity. Fortunately, 20 of BART's 34 stations are of the elevated type.

Seven of the underground stations have platforms that are less than 24 ft below the concourse level. In these stations patrons tend to use the escalators more than the stairs, but are not resistant to climbing the stairs, especially if an escalator is out of service or is operating in the opposite direction. Therefore, as with the elevated stations, stairs in underground stations with platforms less than 24 ft below the concourse are presumed to be used to full capacity.

The seven underground stations that have platforms of more than 24 ft below the concourse are all located in downtown Oakland and San Francisco and are the ones that require close scrutiny. Although most patrons may be willing to climb stairs that are one or two stories, they are hesitant to climb stairs that are more than two stories. The general pattern at the downtown stations for the majority of disembarking patrons is to use the escalator until an extremely large queue develops. Then patrons divert to the stairs until a queue develops for the stairs. The queue for the stairs is never as large as the queue for the escalator and dissipates long before the escalator queue does. So the stairs at the downtown stations are never used to the degree the escalators are. Therefore, a reduced use of the stairs' capacity was employed in the analysis of the downtown stations.

After sampling at the Embarcadero and Montgomery stations during the morning commute period it was found that the average percentage of patrons using the stairs was almost 9 percent, with all the escalators working. When one of two escalators in proximity was out of service, the average percentage during the morning commute period increased to slightly more than 20 percent, although there were specific instances in which 25 to 28 percent of the patrons used the stairs. To achieve these kinds of usage rates, the stairs were presumed to be used at 25 percent of capacity when all escalators are operating and 50 percent of capacity when one escalator is out of service. This could also be interpreted to mean that stairs are used to full capacity for 25 or 50 percent of the time that patrons are moving from the platform to the concourse level, as was observed during the survey of stations. For the stations or centroids with one stairwell and two escalators, this equates to 8 percent of the patrons using the stairs when both escalators are operating and 26 percent of the patrons using the stairs when only one escalator is operating. For centroids with more than one stairwell, the percentages are higher.

The condition of stairs being used at full capacity when one escalator is out of service will also be included in the analysis to show the maximum capacities of the downtown stations. However, the only circumstance for which patrons could be expected to fully use the stairs would be for evacuation purposes.

ANALYSIS

On the basis of the foregoing discussion, the analysis of potential egress/ingress problems will incorporate the following suppositions:

• A 2.25-mi design egress time should be used as a desirable objective for station capacity between trains and to avoid patron inconvenience.

• The projected 95th percentile of peak patron loads should be processed by a station's escalators or stairs, or both.

• To ensure adequate capacity under adverse conditions or to allow for one escalator operating in the reverse direction, one escalator should be presumed unavailable.

• To provide a simplified method for estimating a station's processing capacity, the lower patron flow rates for stairs should be used and a processing rate of 100 patrons/min should be used for escalators.

• Stairs in elevated stations and underground stations with platforms less than 24 ft below the concourse will be fully utilized; stairwells in other underground stations will experience reduced usages of only 25 percent when all escalators are operating and 50 percent when one escalator is out of service.

With all available escalators presumed to be operating in the same direction, an indication of stations that may have egress/ingress problems from the platform to the concourse level can be obtained by analyzing the capacity of the stairways and escalators under four conditions:

1. Maximum 2.25-min capacity. The optimum capacity with all escalators working and with normal patron use of stairs.
2. Desirable criterion. The 2.25-min capacity with one escalator unavailable and with normal patron use of stairs.
3. Basic criterion. The capacity under planned headway times with one escalator unavailable and with normal patron use of stairs.
4. Maximum design/capacity. The capacity under planned headway times with one escalator unavailable and with patrons assumed to use stairs to maximum capacity.

The capacities for the four conditions are listed in Table 3 for three of BART's five lines. Those capacities that are less than the projected 95th percentile of peak patron loads during exit rush 2 hours in 1989-1990 (see Table 1) are enclosed in

TABLE 3 Patron Flow Capacities by Station-Centroid

	(1)	(2)	(3)	(4)
	All Working	One Escalator Unavailable		
	2.25 Minute Capacity		Planned Headway Capacity	
Station/Centroid	Normal Patron Use of Stairs			Full Use
C LINE				
Rockridge	700	470		
Orinda	540	315		
Lafayette	540	315		
Walnut Creek	380	[160]	315	315
Pleasant Hill	380	[160]	[315]	[315]
Concord	610	[380]	765	765
K LINE				
12th Street - N	490	300		
- C	490	300		
- S	490	300		
19th Street - N	490	300		
- C	490	300		
- S	490	300		
MacArthur	765	540		
M LINE				
Oakland West	380	160		
Embarcadero - E	530	380		
- W	530	[380]	[380]	540
Montgomery - E	490	[300]	[300]	380
- W	790	690		
Powell - E	490	300		
- W	790	690		
Civic Center - E	490	300		
- W	490	300		
16th/Mission	540	315		
24th/Mission	540	315		
Glen Park	490	300		
Balboa Park	540	315		
Daly City (Ptfm. 3)	[380]	[160]	[160]	[160]

[ ] = Capacities that are less than the projected peak patron loads.

boxes. Nine stations throughout the whole BART system, six of which are given in Table 3, are indicated to have problems in the 2.25-min time frame when one escalator is unavailable. The problems range from occasional inconveniences to frequent bottlenecks. Each of the nine stations was evaluated in detail in the actual report. For this paper, only three of the stations are discussed in detail.

EMBARCADERO STATION

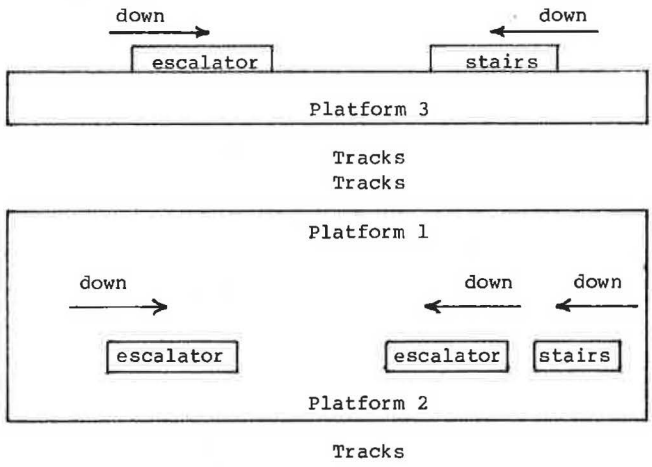
The Embarcadero underground station is one of the two busiest BART stations. The station's two centroids are mirror images, each having two escalators and two stairwells. During the morning commute, all the escalators are operated in the up direction to the concourse level.

The difficulty is that if one of the escalators goes out of service, queues could last longer than 2.25 min at the west centroid. Admittedly, increased use of the stairs by patrons could obviate the need for an additional escalator as shown by the lack of a box around the capacity in the last column of Table 3. Patron use would have to increase to almost one-half, however, when one escalator is out of service. As previously indicated, patrons are hesistant to climb the long stairs at the downtown stations, and only about one-fourth of the patrons can be expected to use the stairs. Furthermore, Embarcadero station experiences patron peaks of 1,000 or more. In those situations, and with one escalator unavailable, 60 percent of the patrons at the west centroid would have to use the stairs to avoid delays.

Patron's resistance to climbing the long stairs and the large peaks experienced by this station make it critical to have adequate capacities even when one escalator is out of service or unavailable. Therefore, a third escalator should be added to the west centroid. This backup escalator would again serve as a reverse flow escalator when all escalators are working.

DALY CITY STATION

The Daly City elevated station is the third busiest in the BART system. It has only one centroid, but it has two platforms with stairs and escalators distributed as shown below:



Currently, all trains use either platforms 1 or 2 at Daly City. Platform 3 is only used if trains are occupying both tracks at platforms 1 and 2 or some other problem exists. The plan for routing trains once the extension track is complete is to unload all patrons at platform 3, go into the extension area, and then return to the station to board patrons on platforms 1 or 2.

To handle the 95th percentile of patronage within the 2.25-min headway and with one escalator unavailable, platform 3 would need three stairways total, two more than it presently has. Extra capacity for the worst case patron loads could be achieved by adding two escalators instead of stairs. Otherwise, it may be necessary to devise an alternative plan for routing trains into the Daly City station when crowds develop on platform 3.

Another possible means of clearing platform 3 is to build a bridge from the platform to the parking structure across the street. This bridge could have faregates for exiting only and no addfares or vendors. Patrons would have to go down to the concourse level to use addfares or vendors. The installation of faregates on the platform level, however, could lead to fare evasion and equipment problems that would require having an agent on the platform. As for platforms 1 and 2, the two escalators and one stairwell would be adequate for the expected patron flow for boarding patrons even if one escalator were out of service.

PLEASANT HILL STATION

The Pleasant Hill station is elevated and is representative of most of the suburban stations in the BART system. It has the fifth largest projected peak patronage. Because of the parking problem at the Concord station, many patrons use the Pleasant Hill station as their embarkation point. This station also experiences peak patron loads that are almost as large as the ones at Concord.

The station has two platforms, each with one escalator and one set of stairs, that lead down to a common set of faregates. As is indicated by the boxed capacity figures in Table 3, patrons at this station would encounter queues if the escalator were unavailable. Even allowing for the greater headway time, the one stairwell at Pleasant Hill will not adequately handle the 95th percentile of peak patron loads, much less the larger peaks that can occur. But as indicated previously, the 2.25-min time frame should be the desirable criterion for evaluating the need for additional stairs or escalators in the case of alighting patrons. For the boarding situation in the morning commute, the longer headway time could be used. However, even with that allowance the Pleasant Hill station will have ingress problems if the one escalator goes out of service. Therefore, the need to install an escalator or stairwell at both platforms at the Pleasant Hill station should be given serious consideration.

Similar to the Concord station, Pleasant Hill is experiencing tremendous office development near the station. The potential increase in reverse patron flow at commute time increases the need for adding escalators or stairwells to both platforms.

CONCLUSIONS

On the basis of projected patronages for 1989-1990, BART will have nine stations that do not meet the following desirable criterion: the 95th percentile of projected peak patron loads should be able to use the stairs and escalators to exit the platform within 2.25 min, even if one escalator is unavailable.

The Daly City station will have the most critical problem because all trains will unload patrons at platform 3 only. Pleasant Hill is expected to have serious problems for both the morning and evening

commute periods, should the one escalator at each platform be out of service. The Embarcadero and Montgomery Street stations will have problems because of patron resistance to climbing the long stairs at these stations. The Concord, El Cerrito Del Norte, Walnut Creek, Union City, and Hayward stations could use an additional escalator or stairwell. However, with their current configurations, the longer headway times at these five stations would allow patrons to exit the platform before the next train arrives.

The recommendations for additional escalators or stairwells are as follows:

Station	Escalator or Stairwell Location
Daly City	Two at platform 3
Pleasant Hill	One at each platform
Embarcadero	One at the west centroid
Montgomery	One at the west centroid
Concord	One for its single platform
El Cerrito Del Norte	One at the east platform
Walnut Creek	One at the east platform
Union City	One at the west platform
Hayward	One at the west platform

To facilitate a decision on constructing an escalator or stairwell at each station, cost estimates should be obtained and considered in light of the indicated severity of potential egress/ingress problems.

A Microcomputer-Based Fare Collection Dependability Model

DAVID I. HEIMANN

ABSTRACT

With the increasing sophistication of fare collection structures and consequently of fare collection equipment, equipment reliability and cost are becoming increasingly important issues. Techniques have been developed to analyze the interrelationships among reliability, cost, and the ability of a fare collection system to deliver dependable service to passengers. These techniques, based on mainframe computers and an investigation of the steady-state performance of the system, evaluate the performance of a given system, analyze its sensitivity to changes, determine specifications necessary for a given level of performance, and make trade-offs between system parameters. Microcomputers are becoming progressively more powerful, inexpensive, and readily available. So that the analysis techniques can be used more easily by transit personnel and analysts, a fare collection dependability model has been developed to run in a user-interactive microcomputer environment. The model determines the likelihood of equipment failures affecting system operation during a peak period. If equipment failures cause insufficient capacity to adequately process passenger demand, the fare collection system is defined as "in trouble." The likelihood of trouble is called the "trouble rate," whereas the likelihood of adequate capacity is called "peak period dependability." The technical approach for the performance and cost aspects of the model is discussed, both the probabilistic basis and the computational methodology to minimize execution time. The software to enable the user to interactively operate the model is described, and instructions are provided for its use. A sample fare collection dependability analysis session, consisting of four runs, is also provided.

The collection of transit system fares has been receiving increased attention as fares rise and federal operating subsidies decrease. Transit authorities are becoming more concerned about ways to maximize revenue and minimize costs while providing equitable fare and reliable, convenient service for passengers. Fare collection methods have a significant impact on total transit costs, amount of revenue generated, and passenger service (1,2). Fare collection costs range from 7 to 31 percent of passenger revenue at rail transit systems, and revenues generated from fares can vary from 40 to 90 percent of total transit

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