$140 million as a rough but minimal approximation.

A summary of these costs is provided in Table 4. Clearly, there appears to be a justifiable need for additional regional rail commuter service.

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Assessment of Rail Automatic Fare-Collection Equipment Performance at Two European Transit Properties

JOSEPH M. MORRISSEY

The findings of an assessment of the performance of automatic fare-collection (AFC) equipment at two European transit properties—Tyne and Wear Transport Executive and Stuttgarter Strassenbahnen—are summarized. The properties operate in Newcastle, England, and Stuttgart, West Germany, respectively. Each has recently installed self-service ticket vendors and/or automatic gates that incorporate such new technologies as microprocessors, failure diagnostics, coin recycling, and needle printers. The analysis of the AFC equipment at each foreign property was based on a property evaluation plan (PEP) developed by Input Output Computer Services, Inc. The specific objectives of the assessment were to (a) apply the PEP to the two properties in order to assess AFC equipment performance; (b) assess any major performance differences between similar types of equipment, including equipment in use at U.S. rail transit properties; and (c) investigate innovative equipment techniques for possible use by U.S. transit properties. Analysis of performance results indicated that reliabilities for the European equipment were significantly greater than those for AFC equipment in service at Port Authority Transit Corporation, Illinois Central Gulf, Washington Metropolitan Area Transit Authority, and Metropolitan Atlanta Rapid Transit Authority. It is suggested that such state-of-the-art equipment could be used at some American transit properties. The net result could be increased maintenance productivity, enhanced unmanned station operation, and improved control of accounting data.

An assessment of automatic fare-collection (AFC) equipment performance was conducted at two European properties in accordance with procedures defined in the property evaluation plan (PEP) developed by Input Output Computer Services, Inc. (IOCS) (1). The properties examined were Tyne and Wear Transport Executive of Newcastle, England, and Stuttgarter Strassenbahnen of Stuttgart, West Germany. The assessments were conducted as part of the UMTA Rail Transit Fare Collection (RTFC) project. The UMTA RTFC project has identified a critical need for U.S. transit systems to develop improved AFC systems in order to improve operating efficiency, enhance control of receipts, and reduce labor and maintenance costs.

The two properties were selected because each has recently installed equipment that incorporates microprocessor technology, needlepoint printers, and coin recycling. Each assessment was based on data collected during an on-site survey and, where available, on transaction and failure data provided by each property.

OBJECTIVES

The objectives of the current study were threefold:

1. To apply the PEP to the two properties in order to assess AFC equipment performance;
2. To assess any major performance differences between similar types of equipment, including equipment in use at U.S. rail transit properties; and
3. To investigate innovative equipment techniques for possible use by U.S. transit properties.

DATA COLLECTION AND ANALYSIS

A data-collection plan was developed for each property in accordance with procedures described in the PEP. Each plan was designed to observe a sample of AFC equipment in service. Each plan called for data collection during peak hours for a 5-day period in July 1981.

Statistical analysis of performance measures consisted of chi-square and t-tests of proportions. The tests were used to determine whether a machine, or group of machines, exhibited a performance measure significantly different from that of another machine or group. Where significant differences did exist, failure distributions were examined in an effort to explain the differences.

Table 1. Summary of Tyne and Wear vendor reliabilities.

Period	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)
On-site data: July 13-17, 1981	19	0.999 789	4708	14 123
Property-supplied data				
April 1981	53	0.999 859	7087	503 169
May 1981	65	0.999 830	5882	647 021
May 1981[a]	53	0.999 954	6757	567 612
April-May 1981[a]	53	0.999 855	6908	1 070 781

[a]Excludes data on vendors at four new stations.

DEFINITIONS OF PERFORMANCE MEASURES

Reliability

Reliability is defined as the probability that AFC equipment or their major components or subsystems will successfully accomplish their functional task. In terms of the equipment observed at the two European properties, successful transactions were defined as follows: (a) ticket vendors--successful delivery of a ticket, and (b) automatic gates--successful admittance of a patron with a valid ticket or pass. In this report, reliability is expressed in three different ways:

1. As the probability of a successful transaction; i.e., R = (total transactions - total failures) ÷ total transactions;
2. As the mean number of transactions per failure (MTF); i.e., MTF = total transactions ÷ total failures; and
3. As the mean time between failures (MTBF); i.e., MTBF = total in-service time ÷ total failures.

For the computation of reliability measures, two sets of data were used. The first set was data that IOCS observers collected during on-site observations, where transaction, failure, and operating-time data were collected for each type of machine. The second set of data was that maintained by the property. For example, transaction data on equipment were provided that indicated tickets sold or patrons admitted or allowed to exit. Failure data were either in the form of permanent maintenance records for each machine or failure reports filed by technicians.

It is important to note that reliability measures based on property-maintained data are most often higher than reliabilities based on data collected by on-site observers. This situation occurs because maintenance records and failure reports do not record all jams and do not indicate how many times a machine failed to complete its mission before a failure was detected and corrected.

Availability

Availability is defined as the probability that AFC equipment will be operating satisfactorily at any point in time. Availability is calculated by dividing the total in-service time by the total operating time and converting the result into a percentage. Total operating time is comprised of (a) total in-service time (operating and available for service), and (b) total downtime (i.e., combined duration of all failures, including active repair time and response and logistic time). An example of logistic time is time spent going for parts. Availability (A) is expressed as follows: A = (total operating time - total downtime) ÷ total operating time.

Maintainability

Maintainability is defined as the time required to repair failures, and it is usually expressed as average downtime (ADT) and mean time to repair (MTTR). ADT is the more widely used measure and indicates the average time that AFC equipment will be out of service per failure. It is calculated as follows: ADT = total downtime ÷ total failures.

MTTR statistics are developed for hard failures that require action by a maintenance technician. Hard failures are defined in the PEP as failures that require an active repair time greater than 20 min or require component replacement. MTTR is based on the total downtime for all hard failures and the total number of hard failures. It is expressed as follows: MTTR = total downtime (hard failures only) ÷ total hard failures.

PROPERTY DESCRIPTIONS AND RESULTS

Tyne and Wear Metro

The Tyne and Wear Metro operates an integrated bus and rapid rail system that serves approximately 1.2 million people in Newcastle, England, and its surrounding communities. The Metro rail system opened in summer 1980 and will encompass 34 miles and have 41 stations when completed in 1983. As of July 1981, 14 miles and 18 stations were open, serving a weekly ridership of 180 000. Fares are based on the number of zones traveled.

The AFC system consists of 68 self-service vendors, 30 booking-office machines, and 89 passenger entry gates, of which 29 are fully accessible gates designed for handicapped passengers. The vendors and booking-office machines were manufactured by Crouzet of France. The cabinets and mechanical barriers of the gates were built by Cubic-Tiltman Langley, and the microprocessor-controlled magnetic ticket readers were manufactured by Crouzet.

The Tyne and Wear vendor incorporates a reprogrammable microprocessor, failure diagnostics, needlepoint printer, and coin-recycling subsystem. The machine accepts only coins (five types), and dispenses single magnetically encoded one-trip paper tickets of the Edmondson size (1.1875x2.625 in). The automatic gates can accept the tickets inserted in any of four possible orientations.

Equipment Performance: On-Site Data

Table 1 summarizes the reliabilities computed for Tyne and Wear vendors. The reliability of a sample of 19 vendors was measured at 4708 MTF based on more than 14 000 tickets vended. MTBF was measured at 71.7 h. The reliability of a sample of 16 gates was measured at 10 299 MTF based on more than 20 000 entries; the MTBF was 91.1 h.

Availability measures were also generated based on the on-site data. Vendor availability was 99.6 percent based on more than 215 h of machine operation. For the gates, availability was 99.8 percent based on more than 182 machine-h. ADT for both the gates and vendors was 13 min based on a relatively small number of failures. MTTR figures were not generated because no hard failures occurred.

Vendor failures were two ticket jams and a coin jam in the recycling subsystem. Only two gate failures occurred. One resulted from dirt and ticket dust that accumulated around a sensor in the ticket reader. The other was a ticket jam in the reader.

Table 2. Summary of SSB vendor reliabilities.

Period	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)	Comment
On-site data: July 27-31, 1981	10	0.999 451	1 821	5 464	
Property-supplied data					
1980	489	0.999 929	14 042	15 544 955	Technical failures only
January-June 1981	485	0.999 921	12 728	7 344 284	Technical failures only
January-June 1981	485	0.999 698	3 311	7 344 284	All failures
January-June 1981	485	0.999 856	6 948	7 344 284	Technical plus other selected failures (e.g., plugs and cables)

Equipment Performance: Property-Supplied Data

Reliability was also measured for vendors and their magnetic ticket issuer and reader subsystem based on property data from April and May, 1981. The system total reliability in April was 7087 MTF, whereas for May the MTF measure was 5882. The May figure included the performance of vendors at four new stations. When these machines were excluded, the May vendor reliability was 6757 MTF, a 5 percent decline that was not statistically significant. When the April and May figures were combined and the vendors at the new stations not considered, the reliability was 6908 MTF based on more than one million tickets sold.

For the magnetic ticket issuer and reader subsystem, the April reliability was 14 799 MTF for the 53 vendors in the Metro system. For the same machines, the May reliability was 13 844 MTF, a 7 percent decline that was not statistically significant. For the 53 vendors, the 2-month MTF measure for this subsystem was 14 277.

The failure data provided by the property were examined and distributions were generated. The distribution of 155 vendor failures for April and May by major subsystem affected was as follows: magnetic ticket issuer and reader, 48 percent; coin-recycling subsystem, 25 percent; coin selector, 10 percent; and logic, 3 percent. (The remaining 14 percent affected miscellaneous components.) Approximately 80 percent of the coin-acceptor failures were jams.

Stuttgarter Strassenbahnen

Stuttgarter Strassenbahnen (SSB) operates an extensive trolley and bus system that serves approximately two million people in Stuttgart, West Germany, and its surrounding communities. The SSB system comprises 10 trolley lines with 400 trolleys and 60 bus lines with 300 buses. Ridership on the SSB is approximately 400 000/workday. Fares are based on the number of zones traveled. A barrier-free system is used, whereby passengers are responsible for their own ticketing, and access to and from the system is not controlled except by random inspection.

The AFC system consists of approximately 490 self-service vendors and ticket cancellers. The vendors are located at every trolley stop and at high-passenger-volume bus stops. The vendors were manufactured by Autelca of Switzerland. They accept coins only (five types) and dispense single one-trip and multitrip paper tickets that are not magnetically encoded. Similar to the Tyne and Wear vendors, the machines incorporate a reprogrammable microprocessor, failure diagnostics, needlepoint printer, and coin recycling. The cancellers are located on each vehicle for use with the multitrip tickets.

Equipment Performance: On-Site Data

Table 2 summarizes the reliabilities computed for SSB vendors. The reliability of a sample of 10 vendors was measured at 1821 based on more than 5000 tickets vended. MTBF was measured at 45.3 h. Availability of the sampled equipment was almost 100 percent based on 136 machine-h of operation.

Equipment Performance: Property-Supplied Data

Extensive data were provided by the property, which included a summary of 18 months of transaction and failure data for the entire system. For 1980, failure data were available for technical failures only. For the first six months of 1981, data on all types of failures (e.g., vandalism and administrative failures) were available. (An example of an administrative failure is faulty ticket stock used in the machine.)

Reliability for the SSB system for 1980, based only on technical failures, was 14 042 MTF. Tickets vended exceeded 15 million. In the first six months of 1981, the systemwide MTF measure, based on technical failures, was 12 728. For the same period in 1980, the MTF measure was 13 080. The 10 percent decline was not found to be statistically significant.

Other systemwide reliability measures for the first six months of 1981 were generated based on various categories of failures. The reliability, based on all failures (including vandal-related), was 3311 MTF. The systemwide reliability of the needlepoint printers, based only on technical failures, was 32 497 MTF.

A distribution of technical failures for the first six months of 1981 was generated by the subsystem or component affected. The hierarchy of the 577 technical failures by major subsystem was as follows: needlepoint printer, 39 percent; coin-guiding plate, 16 percent; coin-recycling discs, 14 percent; coin acceptor, 9 percent; and logic, 6 percent. (The coin-guiding plate directs coins into the appropriate recycling disc.)

COMPARISON WITH EQUIPMENT USED AT U.S. TRANSIT PROPERTIES

The performance of the AFC equipment at Tyne and Wear and SSB were statistically compared with the performance of similar equipment in service at American transit properties. The American properties used in the comparison included Port Authority Transit Corporation (PATCO), Illinois Central Gulf (ICG), Washington Metropolitan Area Transit Authority (WMATA), and Metropolitan Atlanta Rapid Transit Authority (MARTA). Comparisons were made separately for figures generated from on-site and property data. Where significant differences in

Table 3. Comparison of vendor reliability based on on-site data.

Property	No. of Vendors	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	19	0.999 789	4708	14 123	3
SSB	10	0.999 451	1821	5 464	3
ICG	9	0.996 613	295	5 019	17
WMATA (pre-retrofit)	40	0.993 759	160	153 983	961
WMATA (retrofit A)	14	0.994 282	175	20 638	118
WMATA (retrofit B)	6	0.997 630	422	20 673	49

Table 4. Comparison of reliability of automatic gates based on on-site data.

Property	No. of Gates	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	16	0.999 903	10 299	20 597	2
ICG	28	0.999 781	4 570	86 842	19
WMATA (pre-retrofit	24	0.998 007	502	191 696	382
WMATA (retrofit A)	18	0.998 592	712	134 268	189
WMATA (retrofit B)	7	0.999 551	2 220	153 600	69
MARTA	26	0.999 425	1 740	106 122	61

performance were found, failure distributions were examined in an effort to explain the differences. Failures that were related to bill acceptors were not included in the assessment because the European machines do not incorporate the devices.

For the vendors, based on the on-site data, both the Tyne and Wear and SSB machines had MTF measures significantly greater than those for ICG and WMATA at the 95 percent confidence level. (Note that the American vendors dispense magnetically encoded farecards of the credit-card size.) As can be seen in Table 3, the WMATA measures included the reliabilities measured for two retrofit programs. An examination of performance differences based on failure data was not possible due to the low number of failures that occurred in the European machines.

The comparison based on property-supplied data had similar results. Both Tyne and Wear and SSB vendors had MTFs significantly greater than those for PATCO and ICG at the 95 percent confidence level, as seen from the table below:

Property	Reliability (R)	MTF	Sample Size (transactions)	Failures
Tyne and Wear	0.999 855	6908	1 070 781	155
SSB	0.999 761	4178	7 344 284	1758
PATCO	0.996 846	317	97 960	309
ICG	0.992 074	126	10 976	87

An examination of failures indicated that distributions were similar.

For automatic gates, the comparison was based only on the on-site data because property data for the Tyne and Wear gates were not available. The reliability for the Tyne and Wear sample was significantly greater than that for both the MARTA and WMATA gates, both preretrofit and postretrofit (Table 4). The performance of the European gates was also greater than that of the ICG gates. However, the difference was not found to be statistically significant.

Maintenance

This section presents summary descriptions of the maintenance organizations of the two European properties and two American properties, PATCO and ICG. In addition, the impact of maintenance on the performance differences between the European and American equipment is discussed.

As part of the original contract with Crouzet, Tyne and Wear was provided a one-year equipment warranty. The AFC maintenance organization comprises six electronic technicians and two engineers (i.e., senior technicians and a supervisor). Under a program initiated by Tyne and Wear, three of the technicians are Metro employees who are being trained to repair equipment after the warranty period is over.

Maintenance is divided into two levels. The first is on-site correction and routine preventive maintenance. The latter is carried out on gates and vendors about every six weeks in accordance with an extensive checklist of items. The second level consists of repairs and overhauls in the workshop.

When a gate or vendor goes out of service, a control center is automatically notified via a computerized remote-control indicator (RCI) system. The message sent to the center indicates whether the out-of-service condition is due to a technical failure. If so, a supervisor at the center informs a maintenance technician in the field by two-way radio.

The SSB AFC maintenance organization comprises 25 technical and maintenance support personnel located at a central workshop. During the day, there is a team of two technicians in the field who are in radio contact with the central facility. The field technicians make necessary minor adjustments (e.g., clearing paper jams in the printer or removing bent coins). In addition, for both preventive maintenance and major repair, the technicians replace components and subsystems and bring them back to the central workshop where more highly skilled personnel attend to the equipment. Several of the major subsystems, such as the printer, coin acceptor, and coin recycler, are replaced and preventively maintained about once a year. However, machines that experience extensive use usually have the printer replaced every six months.

The PATCO AFC maintenance organization consists of 10 people: 1 foreman, 8 electronic technicians, and 1 repairman. On weekdays during the daytime hours (including both morning and evening peak periods), there are two technicians in the field who respond to calls for repair from an operator in a monitoring center. One technician covers the Pennsylvania side and the other the New Jersey side of the system. (PATCO has 75 gates and 61 vendors in 13 stations. The vendors were placed into service in 1969 and the gates in 1975.)

The operator receives patron complaints and information concerning AFC equipment problems and contacts the appropriate technician. The technicians do repair work only. When finished with a job, they call the operator to let it be known that the repair has been done and inquire about another job. In some cases, these technicians will find and repair unreported failures.

In addition to the field technicians, the foreman, two electronic technicians, and the repairman work at a central shop facility. One of the technicians and the repairman do preventive maintenance and overhauls. The second technician does component repair, primarily on electronics and coin acceptors. At PATCO, vendors are not preventively main-

Table 5. Comparison of European and American AFC equipment performance and maintenance work loads.

Property	Vendors	Vendor MTF[a]	No. of Gates	Gate MTF[b]	No. of AFC Maintenance Personnel	AFC Equipment per Worker
Tyne and Wear	65	6908	89	10 299	9	17.1
SSB	485	4178	NA	NA	25	19.4
PATCO	61	317	75	5 907	10	13.6
ICG	112	126	169	4 570	19	14.8

Note: NA = not applicable.

[a]MTFs based on property data. [b]MTFs based on on-site data (except PATCO).

tained but are attended to on a repair basis. Gates, on the other hand, are preventively maintained on a fixed schedule by component.

The ICG AFC maintenance organization consists of 29 persons, 2 of whom are supervisors. This number includes a group of six field electronic technicians responsible for the upkeep of the passenger assistance line (PAL) equipment. (PAL is a central monitoring facility that provides patron assistance by closed-circuit television and a public-address system.) Another group of four electronic technicians work at the central workshop and do equipment rebuilding, redesign, and modification under a research and development program.

The remaining personnel do repair and preventive maintenance of vendors and gates and are assigned into one of four coverage areas, each with its own small shop. (ICG has 169 farecard-accepting gates and 112 vendors in 49 stations. The vendors and gates were installed between 1973 and 1976.)

On weekdays during daytime hours (including both morning and evening peak periods), there are either one or two electronic technicians covering each area. These workers are contacted by PAL operators who inform them of equipment problems. If not working on a repair, the technicians are preventively maintaining the equipment. (Gates and vendors are preventively maintained about once a week.) In rare instances where a bench is required, the technicians will bring a part back to a shop for repair.

At the central maintenance facility there are three electronic technicians assigned to do simple electrical and mechanical repairs. Sometimes these workers are dispatched to the field to handle additional work load.

Maintenance and Performance

The impact of maintenance on the performance differences between the European and American equipment was considered. With respect to reliability, this impact is difficult to quantitatively assess because of several important factors, such as the age and technology of the equipment in service, as well as maintenance policy, organization, and technician skill levels and work loads.

Nevertheless, a rough estimate of level of effort can be generated based on measures of equipment per maintenance personnel. These have been generated for Tyne and Wear, SSB, PATCO, and ICG and are given in Table 5 with corresponding reliability measures. (Note that the vendor MTFs are based on property data. The gate MTFs, with the exception of the PATCO figure, are based on on-site data.)

As can be seen in Table 5, SSB and Tyne and Wear have higher equipment per maintenance personnel ratios; i.e., in general, technicians and repairmen cover more machines, yet the reliabilities of the equipment were higher than both PATCO and ICG (significantly higher in the case of the vendors but not significantly higher for the gates). However, it is not possible, based on such limited data and the cautions presented above, to infer with any statistical confidence the predominant reason or reasons for this anomalous situation. In other words, it is just as likely that the significantly greater performance of the European equipment is due to equipment characteristics (i.e., state-of-the-art technology) than to maintenance policy, organization, or technician skill or level of effort. Common sense suggests that a mix of the factors is responsible, but isolating any of these is not possible based on limited data.

APPLICATION TO U.S. PROPERTIES

The state-of-the-art technology found in the Tyne and Wear and SSB equipment could enhance unmanned station operation and improve failure identification, repair productivity, and control of accounting data. For example, with a coin-recycling system, the vendors do not have to be regularly filled with coins as do the ICG vendors. Coupled with a high-capacity vault subsystem, this allows for longer periods of service without opening the machine.

The microprocessor technology provides capability in a number of areas: reprogramming of fares, failure diagnostics, and control of accounting data. Reprogramming of fares can be done quickly with the insertion of a new program in the logic. The program can be placed in the machine and set to trigger fare changes automatically on a given date.

The failure diagnostic capability provides a quick indication of the type of failure. This could enhance the productivity of equipment repairs because technicians would not have to spend much time isolating the problem. In addition, failure diagnostics can improve the recording of failures by providing technicians with clearly assignable failure categories.

For the accounting function, the machines can maintain an extensive array of accounting data for long periods or be programmed to deliver data to a central computer. If the latter capability is used, machine openings can be limited to vault pickups, ticket stock refills, and necessary maintenance actions.

For the older American AFC systems, such as ICG and PATCO, the coin-recycling and microprocessor technology could enhance system operation and efficiency. However, use of vendors such as those in service at Tyne and Wear would require the use of gates that accept the Edmondson-sized tickets.

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Effect of Crowding on Light Rail Passenger Boarding Times

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Passenger congestion may have important effects on passenger level of service and station stop or dwell times. In order to examine this concept, research on boarding and alighting times of passengers on light rail vehicles was conducted by sampling rush-hour operations on the Presidents' Conference Committee vehicles of the Massachusetts Bay Transportation Authority's (MBTA) Green Line, a high-volume, light rail subway-surface line. The boarding process is emphasized here, but similar treatment has been undertaken for alighting. Linear regression relations were calibrated between the number of passengers boarding per unit time and concurrent passenger counts (or densities) on board the vehicle and on the platform. These alternatively formulated models reflect the trends in the raw data that the boarding rates decline markedly under increasing congestion, especially as the space per standee falls below the often used nominal standee space level of 2.7 ft^2/standee and approaches crush-capacity density of 1.5 ft^2/standee. On the other hand, at freer circulation levels, these models provide predictions quite similar to predictions from constant-service-time models frequently formulated in earlier research. The modeling approach and subsequent results can be absorbed in future research and operational endeavors for MBTA, for other operating authorities, and for vehicle manufacturers in (a) quantifying the effects of passenger congestion on travel time and reliability, (b) permitting more refined simulation models of travel time, (c) providing a practical approach toward evaluation of realistic vehicle capacity through knowledge of circulation difficulties manifested in low boarding rates, (d) supporting short-term and low-cost operational measures to alleviate frequent problems of rush-hour service, and (e) planning new system or rolling stock requirements.

This paper is based on earlier research (1) and consists of an abridgment of coverage of that work. In particular, the emphasis given here is on the boarding process where only one of the vehicle doors is in use to process passengers who are queued to enter or exit the vehicle. The original work also covered the alighting process, as well as further treatment of multiple doors in processing passengers.

Congestion may have an important impact on station stop or dwell times. As passengers board, they must circulate on board to their respective resting positions to sit or stand. Passenger congestion may prevent passengers from circulating within the vehicle as freely as they would desire without interactions. One can term this relative freedom, or ability to circulate, as the circulation potential. Several authors (2-4) have found a reduction in flow rate, or the number passing through the doors in unit time, when standees are present; however, fluctuations in flow rate parametrically related to varying passenger densities (passengers per unit area of floor space) have not been established. Moreover, only limited attention has been given to studies of light or heavy rail systems or of bus transit corridors where high passenger densities are the rule rather than the exception. The focus of this study extends models of passenger service time--the dwell-time components related to boarding and alighting--to include high-density situations; subsequently, passenger service times in both high- and low-density situations are compared.

Indeed, actual circulation patterns on board the vehicle are difficult to quantify. Kraft (3), in his development of passenger vehicle interface (PVI), hypothesized that the manifestations of passenger-passenger and passenger-vehicle interface might be reflected in the rate at which groups of passengers enter or exit the vehicle. Possibly, low-circulation potential might be reflected in slower passenger service times--quantities that are relatively more amenable to measurement than circulation patterns themselves.

Experimental designs must be carefully chosen if results and conclusions are to be generic in nature. For example, boarding observations of vehicles with fare payment, which are typical of most of the previous studies, involve access to the vehicle, the fare payment itself, and access to the vehicle interior. However, time-consuming fare payments may confound any congestion effect due to access times.

In order to fill this research gap, and at the same time select an appropriate sampling frame, the Massachusetts Bay Transportation Authority's (MBTA) Green Line, a network of high-volume light rail routes that merge in the Central Subway, was selected as the site at which to investigate possible impacts of passenger-vehicle interaction on passenger service times under congested conditions. Several pertinent reasons accompanied the choice of the Green Line:

1. Long dwell times that constitute a high percentage of travel time (2);
2. High daily rush-hour passenger volumes (2);
3. Prepaid fares that eliminate the need to stop and pay on board;
4. MBTA's President's Conference Committee (PCC) fleet (the Boeing Standard Light Rail Vehicle fleet was not yet in operation at the time this study was initiated), which is an historical and well-used vehicle that is still in use there and elsewhere; and
5. Unique platform berth variations for comparative analysis when one, two, or three doors per vehicle are in use at a given station.

By expanding on Kraft's PVI dwell-time studies concept, this focused sampling frame, with several variables controlled, was used in producing a generic modeling approach for better understanding the effects of passenger congestion. Two proxy variables, observable or estimable from the platform, were selected to reflect circulation potential and level of service: passenger flow rates at the vehicle door, and the estimated passenger load volumes on board the vehicle, respectively. The latter are inversely proportional to standee densities.

After the data-collection phase of the study was completed, two modeling approaches were examined (each calibrated through linear regression) to predict the passenger service time on light rail vehi-