PART 1

Management

Service-Quality Monitoring for High-Frequency Transit Lines

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Over the past 2 years the Massachusetts Bay Transportation Authority (MBTA) has been developing ways to monitor service quality on high-frequency rail transit lines. The approaches taken to measuring service quality and displaying relevant information in real time to system controllers who have the responsibility to take ameliorative action are discussed. The resulting system has been implemented for the rail rapid transit and light rail lines of MBTA, focusing on accurately monitoring the passenger waiting time at key points in the network. This approach is particularly attractive for older rail systems and high-frequency bus lines that are not equipped with automatic vehicle location (AVL) systems and may also be extended to form a comprehensive service-quality monitoring system when AVL systems are installed.

The problem of monitoring service quality on high-frequency transit lines and a system that has been developed and implemented at the Massachusetts Bay Transportation Authority (MBTA) over the past 2 years are described. The aim of this paper is to show how, even in old transit systems that are heavily constrained in terms of capital and new technology, systems can be developed that effectively measure (in real time) important components of service quality. As it exists now, the MBTA system is limited to monitoring headways at critical points on the rail transit lines. As newer and more reliable automatic vehicle identification (AVI) and automatic vehicle location (AVL) systems are introduced, the scope of the service-quality monitoring system can be expanded.

The general problem of service-quality measurement on high-frequency transit lines is also discussed emphasizing passenger waiting time. Subsequently, the focus is on the MBTA system, with a description of the hardware and software currently in use, and presentation of the results of the monitoring process. Finally, there is a brief discussion of the potential for expansion of this type of service-quality monitoring system.

SERVICE-QUALITY MONITORING

Monitoring transit service quality is important in at least three respects. First, as part of operations control, monitoring service in real time is the essential basis for dealing with incipient problems before they become serious. For this it is necessary to capture and display relevant information in a form that a controller can readily assimilate and respond to. Second, it is necessary to record significant incidents that harm service quality so that they can be investigated and, where possible, steps can be taken to prevent their recurrence. Third, it is important to measure service quality over time so that the results of changes in the operations plan or in operations control procedures can be measured. Such service-quality measures can also be used for setting annual objectives and for reporting to governance and oversight boards.

Service quality has many dimensions, some of which depend on the design of the service and others, on operational performance. For example, number of transfers required, access distance and time, and fare are all facets of service quality, that are determined by service design (*1*). Other aspects such as waiting time, riding time, reliability, and comfort are affected by actual operations and by the service design (*2*). In this paper we are most interested in these latter aspects of service quality because they should be more amenable to improvement in the short run without major capital investments or planning initiatives.

It is also likely to be less expensive and more efficient to focus on measures of service quality that are based on vehicle observations (and passenger counts) rather than on passenger interviews. It is certainly possible to obtain richer information on service quality through passenger interviews, but it is not a realistic basis for a continuous service-quality monitoring program. However, it is important to undertake passenger surveys periodically to ensure that the proxy measures being used daily are consistent with true passenger perceptions of service quality. Measuring service quality using data that principally rely on observations of vehicles makes it difficult to estimate service quality for individual passengers, but this is not the real aim of such a monitoring system. Realistic aims might be

- To measure average service quality,
- To compare actual service quality with an ideal standard, and
- To measure the percentage of passengers receiving good (and bad) service.

All of these are possible for one or more aspects of service quality, provided at least one of the following automated detection systems is in use: automatic vehicle detection (AVD), AVI, or automatic passenger counters (APCs). Service-quality measures could also be based on manual data collec-

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tion techniques, such as point checks on a high-frequency bus route, but the objective of monitoring system performance in real time requires automated vehicle monitoring. Each of these three approaches to automated monitoring is discussed with the corresponding facets of service quality that can be measured.

Automatic Vehicle Detection

An AVD system is the minimal basis for doing any automated service-quality monitoring and severely limits what can be monitored. Such a system simply registers the passage of a vehicle at a point in the network and transmits this signal to the control center for processing, but it provides no identification or other information on the vehicle. Thus, although headways at detection points can be deduced, there is no ability to determine travel time for a particular vehicle between detectors on a line. AVD systems exist on many older rail networks, such as MBTA's, but they would never be installed as new technology because AVI systems provide better information for essentially the same cost. For AVD-equipped systems, information is available on individual headways. This information can be used to estimate expected (average) passenger waiting time at detector locations. This process will be explored in the context of the MBTA system later.

Automatic Vehicle Identification

AVI systems provide a unique vehicle identifier and detection. A distinction might be made between AVI technology, defined as providing vehicle passage times at selected points within the network, and AVL systems, which provide more continuous information on vehicle locations (*3*). This distinction might be important in some aspects of real-time control (i.e., in an emergency response situation) but for many other aspects of operations control and for service-quality monitoring it is less important. Specifically, real-time operations-control actions are likely to be appropriate only at limited points in the network and service-quality measures must also be aggregated in some way to be meaningful.

With AVI data it is possible to measure travel times between points on the service network and estimate waiting times at specific points. However, with AVI it is still not possible to measure directly anything related to passenger crowding on board vehicles. For this purpose, APC systems are also required.

Automatic Passenger Counters

APC systems provide counts of passengers on board vehicles at any point on a route (*4*). To date, APC systems have been used for off-line planning and scheduling purposes rather than as part of a real-time operations control system. However, there is potential to integrate APCs into AVI (AVL) systems to provide passenger load information in real time. Clearly, there would be significant additional costs in this because all of the vehicles would have to be APC-equipped, rather than just a sample of about 10 percent, which is currently the rule for APC systems used to support operations planning. Two alternatives exist, and they still retain some of the benefits of having passenger count information. First, the vehicle operator could be asked to input approximate passenger load information manually. This approach is used at the Toronto Transit Commission (TTC) to provide real-time load data for its comprehensive bus service monitoring system. Second, the central computer could estimate passenger loads on the basis of real-time headway data and information on passenger flow rates. This method is used at San Francisco Bay Area Rapid Transit (BART), for example, where complete data are provided on passenger entries and exits, as well as train arrivals and departures by clock time for every station.

The main advantage of APC-type data is that passenger load–related information can be incorporated into service-quality monitoring. Such measures could include standing and crush load conditions and estimates of denied passenger boardings.

Waiting-Time Measures for High-Frequency Transit Lines

The focus here is service quality on high-frequency transit services, which will be defined to have mean headways of 10 min or less. This frequency is characteristic of most urban rail systems and many bus routes in the inner portions of major cities, particularly in peak periods. On these short headway routes, it is generally assumed that passengers arrive at transit stops independent of the timetable. At longer headways, of course, an increasing proportion of passengers arrive at stops at times designed on the timetable to minimize their expected wait, that is, they try to arrive just before the transit vehicle arrives (*5*). In the latter case good service quality will usually be achieved by improving on-time performance—by minimizing the difference between scheduled and actual vehicle arrival times (but avoiding early arrivals)—but this is less appropriate for high-frequency service. Abkowitz et al. and Henderson et al. (*2,6*) provide good reviews of service quality indexes for high-frequency transit services.

For randomly arriving passengers at a constant mean arrival rate, it has been shown (*5,7*) that the expected passenger waiting time is given by

$$\bar{w} = \frac{\bar{h}}{2}[1 + \mathrm{cov}^2(h)] \tag{1}$$

where

$\bar{w}$ = mean passenger waiting time,
$\bar{h}$ = mean headway, and
$\mathrm{cov}(h)$ = coefficient of variation of headway, that is, standard deviation divided by mean headway.

If all headways are identical, $\mathrm{cov}(h) = 0$ and the mean wait time is simply half the mean headway, but as the standard deviation of headway increases, so does the mean passenger waiting time.

Equation 1 provides a simple and direct means to estimate passenger wait times given only AVD data. It must be stated that this is predicted on an assumed constant average rate of passenger arrivals—which will seldom be the case; but even with somewhat variable passenger arrival rates, this measure is likely to be a reasonably good representation of mean passenger waiting time. To account for highly variable passenger arrival rates, a better estimate could be obtained by using prior data on average passenger arrival rates in Equation 2.

$$\overline{w_p} = \frac{1}{2} \sum_{i=1}^{n} h_i^2 \times p_i \Big/ \sum_{i=1}^{n} h_i \times p_i \qquad (2)$$

where

$\overline{w_p}$ = mean (passenger-weighted) passenger waiting time,
h_i = headway of ith vehicle, for each of n consecutive vehicle trips, and
p_i = mean passenger arrival rate during h_i.

Theoretically $\overline{w_p}$ is a better measure of passenger waiting time for the average passenger, but it depends on having reasonably accurate data on passenger arrival rates over small time intervals. For the MBTA system and other older rail systems, current data of this type are unlikely to be available, and therefore Equation 1 with an assumed constant passenger arrival rate will be used for this analysis. To minimize errors associated with this assumption, time periods used for computing passenger wait time should be small (i.e., a peak period rather than a complete day).

Two other types of measure are useful supplements to the mean passenger waiting time: excess passenger wait time and passenger wait time percentages. Excess passenger wait time has been used by London Transport to capture service reliability and it is useful for comparing service quality across routes with quite different headways (*8*). It is the difference between the actual expected wait time and the expected wait time that would result if there were perfect schedule adherence. Thus, excess passenger wait time is given by

$$EWT = \overline{w} - \frac{\overline{h_s}}{2}[1 + \mathrm{cov}^2(h_s)] \qquad (3)$$

where

EWT = excess passenger wait time,
$\overline{h_s}$ = mean scheduled headway, and
$\mathrm{cov}(h_s)$ = coefficient of variation of scheduled headway.

For any period in which the scheduled headway is constant, EWT is simply the mean passenger waiting time minus half the scheduled headway. In some cases, particularly for longer periods, the scheduled headway will vary and thus the coefficient of variation for scheduled headway will be nonzero.

Finally, it would be valuable to measure the portion of passengers who receive good (and bad) service using passenger wait time percentages. In a high-frequency service with randomly arriving passengers, ideally everyone would be served within a maximum wait of one scheduled headway. This can be approximated by the total time within one scheduled headway of a vehicle arrival, expressed as a percentage of the total time. This should be as close to 100 percent as possible. At the other end of the spectrum, bad service may be defined as the total time for which the next vehicle arrival is more than two scheduled headways away, again expressed as a percentage of the total time. Ideally this percentage should be zero.

These three measures provide a concise, but comprehensive, characterization of passenger waiting time within the constraints of an AVD-type detection system.

MBTA SERVICE-QUALITY MONITORING SYSTEM

MBTA is responsible for the delivery of public transportation services for metropolitan Boston, which encompasses 78 cities and towns. MBTA offers bus, light rail, heavy rail, commuter rail, commuter boat, and paratransit service for a daily ridership of 650,000 passengers. More than 60 percent of these passengers are served by urban rail transit, which consists of the Green, Red, Orange, and Blue lines. The Green Line is a four-branch, low-platform, overhead catenary, light rail system that operates as streetcars in mixed traffic and on exclusive rights-of-way on some surface branches and also in the common downtown subway. The Red, Orange, and Blue lines are all high-platform, third-rail rapid transit operations.

The signal and control systems vary enormously among these rail lines:

- The Green Line has an absolute block signal (ABS) system. All interlockings are controlled by vehicle operators as they approach the switch and call their route. There is no centralized signal control and only a rudimentary monitoring capability. An AVI system is now being installed that will automate the route selection function and provide more information to the control center in real time.
- The Red Line is centrally dispatched by a controller working with three tower persons in the control center. The line uses ABS traffic control rules and relies on automatic train operation (ATO) for speed control. There is a rudimentary and obsolete AVI system on the Red Line.
- The Orange Line uses centralized traffic control rules and is controlled by a dispatcher at the control center who works with a towerman at the maintenance yard. There is an ATO system that exercises speed-control functions and a very limited AVI system.
- The Blue Line is an ABS system with interlockings controlled from a tower at the maintenance and storage facility. There are no Blue Line monitoring or control facilities in the control center.

With such a mix of signal and control systems there has been no easy way to monitor, manage, and measure performance of the rail transit lines on a common basis.

Historical Context

Traditionally, operations effectiveness was measured with a software application known as Thruput, which compared the actual and scheduled numbers of trains passing detectors during half-hour periods. All data were hand-entered into the computer at half-hour intervals. Thruput provided an estimate of the quantity of service provided at each location but was not sensitive to the distribution of trains over each half-hour interval, and therefore did not reflect the passenger's perception of service quality.

The new Passenger Waiting Time application was designed to allow for more detailed measurement and rigorous analysis of schedule adherence from the Thruput locations by recording the actual times that trains passed these points and comparing actual and scheduled headways. As train detection signals are received, the system performs three functions:

- Maintains a real-time monitor showing system status (last train observed, next train due, delay status, Thruput tally) at each location;
- Prepares half-hourly reports showing all significant delays and the Thruput counts for each period; and
- Calculates periodic service-quality summary statistics.

The Passenger Waiting Time system is a set of computer programs that run on a PC-DOS local area network (LAN) supported by a programmable controller (a UMAC) that monitors the field detectors. The system logs the passage of trains by each detector and provides a continuous real-time color-coded display of scheduled versus actual performance at each location. Each half-hour the system produces a report showing significant delays detected and the Thruput tally for each location. At the end of each rush hour and each day, standard reports summarize passenger service-quality measures. The overall system architecture is shown in Figure 1; each of the critical elements is described briefly.

Automatic Vehicle Detection

Figure 2 shows the MBTA rail network with the 29 detector locations marked. The 13 Green Line detectors are suspended from the catenary and activated by each car's pantograph, and 16 rapid transit detectors are wired to signal block relays that indicate track occupancy. Each detector is linked to a separate input port on the programmable controller in the control center. The controller has a 64K microprocessor that runs a simple BASIC program in a continuous loop, polling the input ports and posting any observations to an output array with port identifier and the exact time of the observation.

Real-Time Monitor

The controller is polled every 12 sec by the application program that runs on an IBM PS/2 Model 55SX. The real-time monitor then

- Posts new observations to a data file for later batch reporting;
- Compares the latest observations for each detector with a headway schedule array to detect operating anomalies (trains too close together or too far apart);
- Updates its screen output arrays to show new observations; and
- Refreshes its screen display to reflect new data received and the progress of already-identified delays (see Figure 3).

The video display is modeled after an airport arrivals-and-departures board and is color-coded to reflect the colors of MBTA's four rail transit lines. Conditions such as delays and trains following too closely (hot) are flagged and highlighted. When a train is 2 min overdue, a message indicating this delay is displayed for that location. As passengers continue to wait, the delay message is incremented. If the delay grows to 10 min the affected portion of the display flashes until the delay is alleviated.

Auxiliary Monitors

The real-time monitor drives a series of auxiliary monitors in the control center as follows

- 13-in. monitors are in each dispatcher's work area, in the public address announcer's cubicle, and in the office of the superintendent of the control center.
- 26-in. monitors are suspended from the ceiling in the control center, oriented so that one is visible from any location in the room.

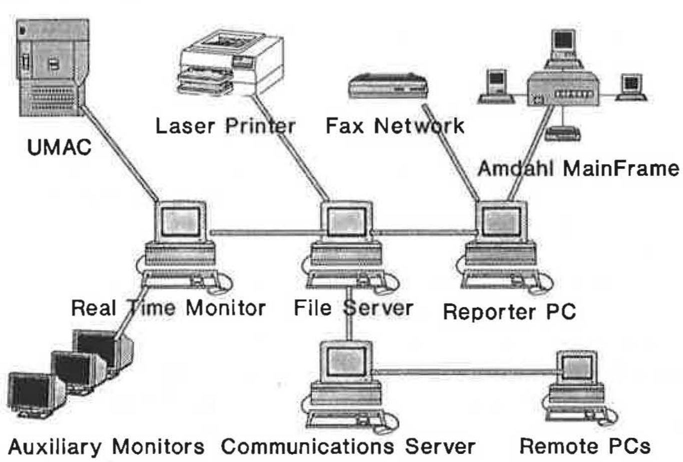

FIGURE 1 System architecture.

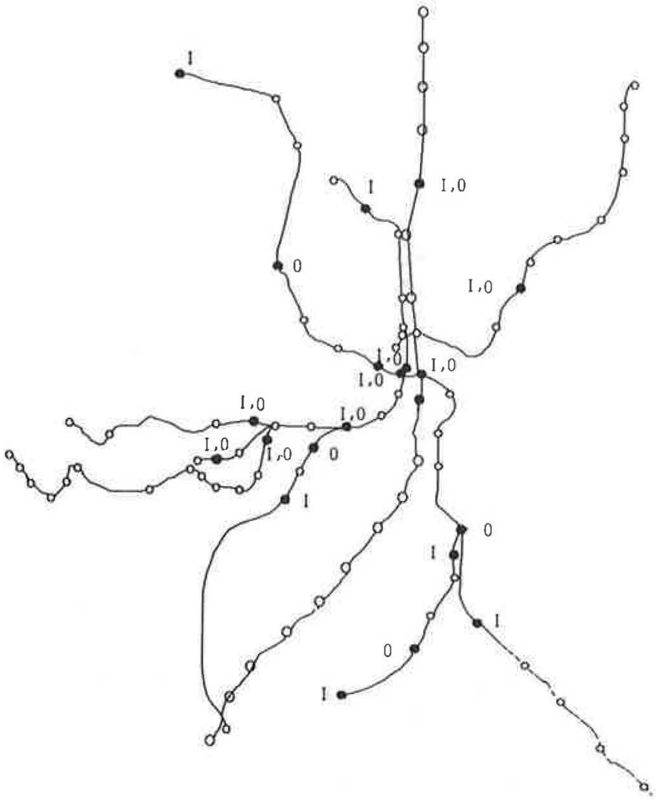

FIGURE 2 MBTA rail detector map.

The auxiliary monitors are used to identify delays, guide disruption relief work (announcements, extra trains, short turns, etc.), and monitor service conditions. There is also a dedicated direct line between the control center and the headquarters of the MBTA Transportation Department in another building in downtown Boston. The transportation department's remote node drives three additional auxiliary monitors that monitor system status.

When the new Green Line AVI system is fully operational, this new input will replace the obsolete detectors currently in use.

Data Reporting

In a typical weekday the system processes more than 7,000 observations from the field detectors. Two types of report have been developed to summarize these data for management and performance monitoring: operating reports are used by transit operating staff to provide operating statistics and highlight anomalies (delays) for review or investigation, and summary reports are used by planners, senior executives, and external constituencies to summarize customer service statistics.

Operating Reports

Every half-hour a report is printed showing Thruput performance for the last period and the previous six periods (see Figure 4). As noted previously, the Thruput measure simply compares the number of trains passing a detector to the number scheduled within that half-hour period. The Thruput component facilitates the transition from the old performance measurement system to the new system and it also lists all delays greater than 5 min that have occurred in the last half-hour.

Every half-hour there is an automatic upload of all trips and delays observed to the MBTA's mainframe on-line system. Each delay has a cause coded by the controller to facilitate subsequent investigation and reporting. A series of on-line reports on the trip and delay data are available when users specify their own data selection and sorting criteria. Reports are printed in users' offices at field locations.

In addition to the mainframe facilities, a fax board is integrated into the LAN for the distribution of reports. This

Massachusetts Bay Transportation Authority
Passenger Waiting Time Monitoring System
08:54:49

Monday 02-18-1991
Service Type SAT

INBOUND						OUTBOUND					
Location	Thruput Sch	Thruput Act	Last Trip	Next Trip		Location	Thruput Sch	Thruput Act	Last Trip	Next Trip	
No Quincy	2	2	8:41	8:54		JFK/Brntre	2	2	8:51	9:04	
Savin Hill	2	2	8:50	9:03		JFK/Ashmnt	2	2	8:47	9:00	
Downtown	4	4	8:54	9:00		Downtown	4	4	8:52	8:59	
Charles St	5	3	8:49	8:56		**Charles St**	**5**	**3**	**8:42**	**8:50**	**D>5**
Alewife	4	3	8:48	8:54		**Harvard**	**4**	**3**	**8:41**	**8:49**	**D>6**
Maverick	**4**	**5**	**8:53**	**9:00**	**HOT**	Maverick	4	5	8:49	8:57	
Mattapan	3	3	8:48	9:00		Ashmont	4	2	8:46	8:54	
Fenway	4	2	8:52	9:02		Fenway	3	2	8:45	8:55	
St Marys	4	3	8:49	8:57		St Marys	3	2	8:52	9:02	
Blandford	4	3	8:46	8:53		Blandford	4	5	8:52	8:59	
Northeastn	3	3	8:51	9:01		Prudential	3	2	8:45	8:55	
Arlington	14	12	8:54	8:55		Arlington	14	11	8:43	8:54	
Science Pk	3	3	8:51	9:01							
Chinatown	3	2	8:50	9:00		Chinatown	3	2	8:51	9:02	
Community	2	2	8:53	9:04		Community	2	2	8:45	8:57	

FIGURE 3 Real-time monitor sample display.

Massachusetts Bay Transportation Authority FRI 02-29-1991
Passenger Waiting Time Monitoring System 12:30:12
Half Hourly Thruput & Delay Report

INBOUND

	Period Starting: 12:00				Previous Variances					
Location	Sch	Act	Var	Pct	11:30	11:00	10:30	10:00	9:30	9:00
Maverick	4	3	-1	75	1	0	-1	0	1	0
Arborway	6	4	-2	66	1	1	0	0	0	0
Boston Col	6	6	0	100	0	0	2	-1	-1	0
Cleveland	6	5	-1	83	0	0	0	0	0	0
Green Core	24	19	-5	79	2	3	0	1	-2	3
Lechmere	6	5	-1	66	0	0	0	0	0	0
Mattapan	4	4	0	100	0	1	-1	0	0	0
Riverside	6	5	-1	83	0	-1	0	-1	0	0
Forest Hls	4	4	0	100	0	0	0	0	0	0
Oak Grove	4	3	-1	75	1	0	1	-1	0	0
Ashmont	3	3	0	100	0	0	0	0	0	0
Braintree	2	2	0	100	0	0	0	0	0	0
Alewife	5	5	0	100	0	0	0	0	0	0
Portal Bea	5	5	0	100	0	0	0	0	0	0
Downtown	5	5	0	100	0	0	-2	+1	+1	-2

FIGURE 4 Sample half-hour report.

facility is used to send the half-hour delay and Thruput summary to the chief transportation officer. Daily delay reports are automatically compiled and faxed to district offices each night at the close of service.

Currently, the supervisors of the light rail lines systematically investigate all delays of more than 10 min. Reports are targeted to reflect the scope of individual inspectors' service areas and duty hours, and it appears this program is working effectively to reduce long delays on the Green Line.

Summary Reports

The summary reports differ radically from the operating reports in that they statistically abstract the operating data to serve as proxies for the customer's perspective on the service. Summary reports are prepared three times a day: 8:30 a.m. (for morning peak period), 5:30 p.m. (for afternoon peak period), and 1:30 a.m. (for the complete day). The same statistics are presented in each of these reports; only the reporting period and format differ. For each branch of the four rail lines, the three statistics introduced in the earlier section on service-quality monitoring are computed and displayed for the two peak periods and the full day. These statistics—mean passenger wait time, excess passenger wait time, and passenger wait time percentages—provide a sufficient level of detail to assess the day's service. The summary sheet of the daily performance report is shown in Figure 5. The example day shows fairly typical service, with the exception of the Orange Line afternoon peak.

Summary statistics are distributed automatically by fax; they are also available on the mainframe in an on-line database used for rapid retrieval, ad hoc reporting, trend analyses, and archival purposes. The trend analysis not only provides data on whether passenger wait times are improving or declining, but it also provides a sense of scale to measure an individual day's performance. Figure 6 shows examples of trend analysis for the passenger wait time percentages and excess wait time for the Orange Line in the p.m. peak period for FY 1991.

Limitations of Existing System

The new rail service monitoring system makes use of existing operational data but summarizes it in a statistical form that approximates the customer's perspective (wait time) instead of the operator's (Thruput). This system is a major advance over the previous Thruput system, but it is still subject to some important limitations and incorporates several key assumptions. Probably the most significant limitation is that it measures only the passenger waiting time aspect of service quality, which is certainly one of the most important components of service quality but not the only one. As is discussed in the following section, implementing an AVI system to replace the AVD system will allow other facets of service quality to be monitored.

Given this limitation, several other assumptions are required for the service-quality measures to be accurate:

1. All trains detected are in normal revenue service. Trains that are dead-heading out of service because of mechanical problems or in express service will also be detected just as any train in normal revenue service. However, passengers will be unable to board them because they will pass through the station without stopping.
2. Enough space is always available on board any train to accommodate anyone waiting for service (i.e., there are no denied boardings).
3. Any passenger waiting at a station can board any train, regardless of final destination. This does not account for branching network structures and short-run trips, both of which exist in the MBTA rail system.

Violation of any of these assumptions means that the waiting time measures will underestimate true passenger waiting

Massachusetts Bay Transportation Authority
Daily Passenger Waiting Time Summary
2 6 91

PEAK PERIOD

AM Inbound							PM Outbound				
			% Psgr Waiting							% Psgr Waiting	
Sched Hdwy	Obsrvd Wait	Excess Wait	< 1 Hdwy	> 2 Hdwy	Line	Branch	Sched Hdwy	Obsrvd Wait	Excess Wait	< 1 Hdwy	> 2 Hdwy
8:34	4:31	0:09	90.6		Red	Braintree	8:34	4:24	0:00	88.6	
8:31	4:25	0:03	94.0		Red	Ashmont	8:38	4:53	0:27	86.7	
4:22	2:33	0:18	85.4		Red	Alewife	4:16	2:42	0:31	81.4	2.6
4:46	2:44	0:21	85.5	1	Org	Oak Grove	5:18	4:42	1:54	75.3	11.5
5:07	3:03	0:23	86.5	1	Org	Forest Hls	5:18	4:29	1:39	70.7	11
3:30	2:18	0:24	86.3	0.2	Blu	All Service	3:23	2:16	0:21	85.4	0.2
5:11	3:34	0:53	81.7	5.9	Grn	Boston Col	5:20	3:37	0:49	81.6	3.7
6:04	3:07	0:00	92.5		Grn	Cleveland	5:57	3:43	0:42	82.2	1.6
3:28	2:31	0:47	72.0	4.3	Grn	Riverside	4:05	3:44	1:41	60.5	9.4
8:42	4:37	0:09	91.7		Grn	Arborway	8:08	4:30	0:25	87.6	0.1
1:37	1:07	0:18	77.2	7.1	Grn	Green Core	1:41	1:11	0:20	75.4	6.5
4:37	2:38	0:06	89.0	1.6	Grn	Mattapan	4:21	2:38	0:25	80.2	

FULL DAY

Inbound							Outbound				
			% Psgr Waiting							% Psgr Waiting	
Sched Hdwy	Obsrvd Wait	Excess Wait	< 1 Hdwy	> 2 Hdwy	Line	Branch	Sched Hdwy	Obsrvd Wait	Excess Wait	< 1 Hdwy	> 2 Hdwy
10:40	6:13	0:40	89.9	2.1	Red	Braintree	10:34	5:58	0:31	87.5	0.7
10:41	5:42	0:09	94.0	0.1	Red	Ashmont	10:37	5:52	0:23	88.0	0.5
5:18	2:57	0:12	88.6	0.4	Red	Alewife	5:21	3:29	0:40	79.3	1.8
7:28	4:58	0:37	85.5	1.4	Org	Oak Grove	7:26	4:56	0:39	86.0	2.2
7:26	4:53	0:36	86.8	1.9	Org	Forest Hls	7:28	5:14	0:53	81.9	2
5:54	4:10	0:26	88.8	0.1	Blu	All Service	5:57	4:19	0:32	86.0	0.3
6:19	4:17	0:46	80.2	3.2	Grn	Boston Col	6:21	4:40	1:04	76.1	3.2
6:31	4:06	0:36	83.4	1.2	Grn	Cleveland	6:31	4:16	0:43	79.9	1.4
6:13	4:31	0:45	79.9	1.9	Grn	Riverside	6:08	5:03	1:16	76.6	6.6
8:52	4:56	0:26	87.7	0.2	Grn	Arborway	8:51	5:00	0:30	87.6	0.4
1:46	1:36	0:34	67.1	11.3	Grn	Green Core	1:44	1:35	0:39	68.1	11
6:57	4:26	0:11	92.9	0.3	Grn	Mattapan	6:57	4:29	0:14	87.7	0.5

FIGURE 5 Sample daily summary report.

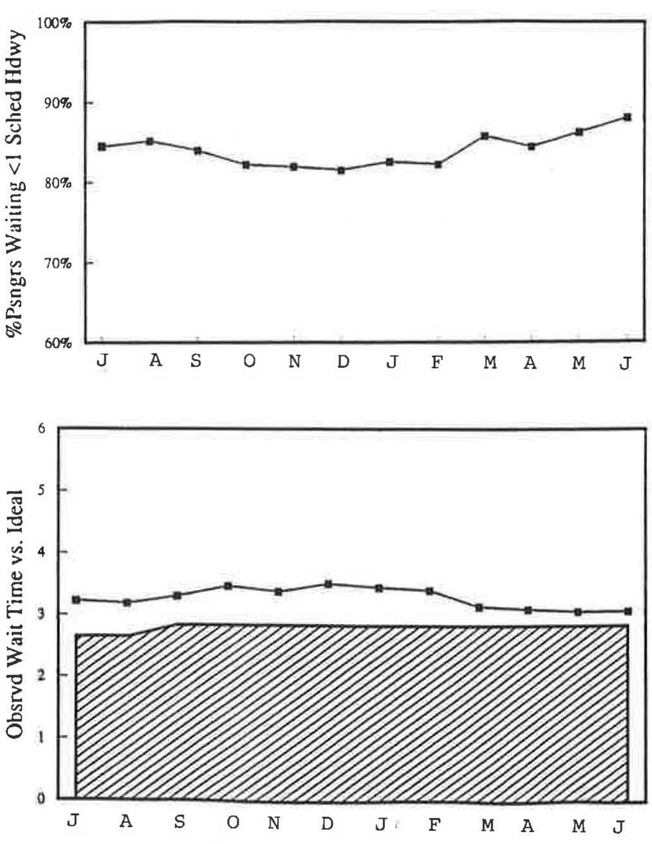

FIGURE 6 Passenger waiting time (*top*) and excess wait time (*bottom*) for Orange Line, p.m. peak period FY91.

times. With an AVI system, each of these problems can be overcome, directly or indirectly.

A final assumption is that the headway distribution observed at a detector is representative of the headway distribution along that segment of the line. This assumption will not always be true; its validity depends on the location of the detectors. In general, the variance of headway increases with distance from the terminus, so detectors located at or near the start of a line tend to underestimate mean passenger wait times on the line as a whole (*9,10*). To minimize this type of bias, if there are only a small number of detectors, they should be located at about the midpoint of the line in terms of cumulative boardings. Alternatively, more detectors can be installed along the line.

Practical Results

The new monitoring system for passenger waiting time was implemented at relatively low cost. Because the system was designed to use the existing hardware for train detection, the initial capital cost of the system consisted primarily of personal computers, color monitors, printers, and communications boards, for a total cost of approximately $35,000. Additional labor costs of $65,000 were incurred to refine the monitoring software and to correct errors in the existing detection equipment. The on-going operating cost of the system is about the same as the Thruput system that it replaced.

The real-time monitoring system and daily reports were tested for 6 months in 1990 before going live July 1, 1990. MBTA managers, while enthusiastic about the passenger orientation of the new system, were initially uncomfortable with the wait-time statistics, because they were not as intuitive as

Thruput data. Once managers began to understand the statistics, action was taken to respond to problems indicated on the real-time system and delays shown in the reporting system were investigated.

The impact of the monitoring system on service quality is difficult to gauge. As noted, the passenger's wait is just one component of a trip. After the first year of monitoring, the percentage of passengers waiting less than one scheduled headway for service has increased by almost two percentage points across the system. There has also been a major reduction in the incidence of delays of more than 5 min. However, no customer surveys have been taken to see if this level of improvement is significant, given the other factors affecting service quality.

Overall, the new system has resulted in a better understanding of the quality of service and in a modest improvement in service, even though it was implemented in a short time at a relatively low cost. To continue to make improvements and to create a more customer-based monitoring system, a higher-cost AVI system would be required.

MORE COMPREHENSIVE SERVICE-QUALITY MONITORING

With AVI systems for vehicle detection, the concept of service-quality monitoring presented earlier can be extended to reflect travel time as well as wait time. A difficulty in this case will be selecting a manageable set of measures from the overwhelming number of options. Using the passenger wait time measures as a guide, the following questions must be addressed:

1. Which origin-destination pairs should be included?
2. Should measures be developed for both ride time and total time?
3. What thresholds should be used for establishing good and bad service?

Any location equipped with an AVI detector is a candidate origin or destination, but even with a small number of detectors on a line, the number of possible origin-destination pairs quickly becomes unmanageable. A reasonable approach is to include the origin-destination pairs that have the highest passenger volumes, with a limit of perhaps four per line in the summary report. It should also be possible to access service-quality data readily on any other origin-destination pair.

Service measures should be calculated separately for wait, ride, and total times. Separate measures for total time are desirable because marginally acceptable wait and ride times may result, if combined, in unacceptably long total times. The computation of ride time measures are independent of the associated wait times, whereas the total time measures are based on the combined headway and ride times for each vehicle.

Finally, there is the issue of thresholds for good and bad service. The ride time equivalent of the scheduled headway is the scheduled vehicle running time between a given origin-destination pair. Commensurate measures of good service would be that the ride time was less than or equal to the scheduled running time, and the total time less than or equal to the sum of the scheduled headway and scheduled running time. A threshold for bad service is more difficult to define. One way to define bad service would be to use one scheduled headway beyond the scheduled running time as the threshold. Another definition would use a percentage of the scheduled running time (e.g., 120 percent of running time). For the sake

Wait Time

Line	O-D Pair	Sched Hdwy	Obsrvd Wait	Excess Wait	% Pass Waiting < 1 Hdwy	% Pass Waiting > 2 Hdwy
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

Ride Time (RTime)

Line	O-D Pair	Sched RTime	Obsrvd RTime	Excess RTime	% Pass Riding < Sched RTime	% Pass Riding > (Sched RTime + 1 Hdwy)
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

Total Time (TTime)

Line	O-D Pair	Total TTime	Obsrvd TTime	Excess TTime	% Pass TTime < (Sched RTime + 1 Hdwy)	% Pass TTime > (Sched RTime + 2 Hdwy)
	$O\text{-}D_1$					
	$O\text{-}D_2$					
	$O\text{-}D_3$					

FIGURE 7 Service quality report format.

of simplicity and consistency, using the scheduled headway as a reference is suggested, even though it will tend to set a hard-to-meet standard for long trips on very short headway services.

Figure 7 shows a format for a service-quality report for a single line. A couple of points are worth emphasizing about this figure. First, the scheduled running time is assumed to be the time that passengers expect when they plan a trip. If it is systematically different from the mean ride time, this will show up in the excess ride time measure, and large differences may suggest that the scheduled running time needs adjustment. Second, the ideal total time is the sum of the wait time under scheduled train operations and the scheduled running time, not the sum of the scheduled headway and the scheduled running time.

At this stage the proposed comprehensive service-quality report is just that—a proposal. When AVI systems are installed, it will, no doubt, be modified in light of operational experience, as has the passenger wait time monitoring system at MBTA. Other measures of service quality could be added if APC data were also available, or if passenger flow rates and loads could be estimated with a reasonable amount of reliability from prior system data collection.

This level of detail in service-quality monitoring can be achieved, given the existing data in transit systems such as TTC and BART. However, for an older system to gain the benefits of a more detailed service-quality monitoring system, a major commitment to new automatic detection equipment is necessary.

CONCLUSION

The passenger wait time system implemented for the urban rail lines of MBTA has shown that with crude (in fact, obsolete) train detectors, and without major capital investment, reasonable measures of service quality for passenger waiting time for service can be estimated. The resulting system provides a real-time monitoring capability that is being used in controlling MBTA rail services and providing measures of service quality that can be compared across lines as well as over time. Service measures, which are applicable to any high-frequency transit line, when passengers arrivals can reasonably be assumed independent of the schedule, include expected passenger wait times, differences between actual and ideal service quality, and the percentages of passengers who receive good and bad service. As AVI systems are implemented, at MBTA and elsewhere, the scope of the service-quality monitoring system can be expanded to cover ride and total times as well as wait times.

Thus, transit operators can be more aware of service quality in both planning and operations control by using readily available operations data more effectively. One important result may be a reduction in the difference between operational performance as measured by the transit operator and that experienced by the passenger.

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