the Office of Methods and Support, UMTA. The views expressed are ours and not necessarily those of the U.S. Department of Transportation.

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Automatic Vehicle Monitoring: Effective Technique for Transit System Management and Control

RICHARD W. LYLES AND MAURICE H. LANMAN III

In the context of searching for new approaches for efficient transportation system management and utilization, the Urban Mass Transportation Administration (UMTA) has funded a comprehensive demonstration of an automatic vehicle monitoring (AVM) system in Los Angeles. AVM coverage includes approximately 10 percent of the Southern California Rapid Transit District's (SCRTD) route miles and buses. The system is now operational, the AVM capabilities having been phased in over a year's time. Although the evaluation program on the part of UMTA and SCRTD continues, analysis of the impacts to date shows that benefits have accrued in several areas of transit system operations, including route scheduling and information management, improvement of day-to-day system reliability, rendezvous of scheduled and nonscheduled vehicles, and response to emergency situations.

The cost of providing public transportation service continues to increase due to the high price of energy, other increasing operation and maintenance costs, and the rising costs of building new system elements and/or replacing rolling stock. Thus, operators of public transportation systems, as well as federal, state, and local officials, are looking in earnest at techniques that enable better use of existing systems, and especially the use of buses that have the flexibility to accommodate geographically shifting passenger demand. Questions arise as to how the nation's bus fleets can be used more efficiently and effectively. One approach that is receiving increasing attention is the use of automatic vehicle monitoring (AVM).

In the above context, the Urban Mass Transportation Administration (UMTA) funded an AVM demonstration project in Los Angeles with the cooperation and participation of the Southern California Rapid Transit District (SCRTD). The basic purpose of the demonstration was to enable the evaluation of the effectiveness and efficiency achieved in bus system operation through use of the real-time monitoring and control capabilities of a fully operational AVM system. The project represents the first such comprehensive AVM implementation in the United States. The system was developed and installed by AVM Systems, Inc. (formerly a division of Gould, Inc.) and was operational in spring 1980. The Transportation Systems Center, UMTA, served as system manager for the project.

HISTORICAL DEVELOPMENT OF AVM

AVM is not a completely new concept (1), having been used in one form or another as early as 1935 in Chicago to check on streetcars and for buses in the 1940s. Information on headways was being collected automatically by 1955 in Pittsburgh, St. Louis, and Philadelphia, and optical scanning was being used in London in 1958 (2). However, in these early attempts, vehicles were not necessarily explicitly identified nor was there any attempt at real-time control by using the information that was obtained.

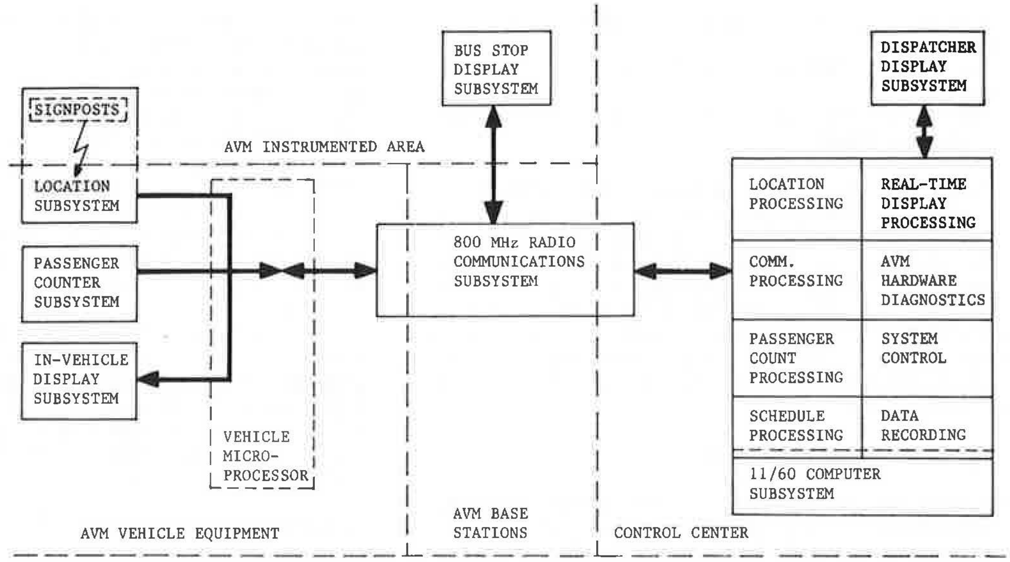
Currently, AVM is considered to be directed to real-time monitoring of vehicles (e.g., location) with the potential for exercising control as opposed to only identification. The basic components of the modern AVM system include the following (3, p. 202):

1. Vehicle locating and status monitoring devices,
2. Communications system, and
3. Central control facility.

Although AVM has demonstrated application in any operation that involves the coordination of fleets of vehicles (e.g., taxis, police cars), several recent experiments with transit operations are of immediate interest. Lukes and Shea (2) and Miller and Basham (4) describe an experiment in the early 1970s that focused on citywide AVM coverage for a small percentage of the Chicago Transit Authority's (CTA) rolling stock. The AVM-equipped buses were those providing "owl" service. Although problems with equipment and an apparent lack of execution of the control potential by CTA dispatchers hindered the experiment, conclusions were that use of AVM resulted in schedule and headway adherence that was at least as good as that achieved with manual control that, according to the authors, would have resulted in sufficient manpower savings to economically justify the system.

Bevilacqua and others (5) describe a more recent demonstration--the General Motors' transit information system (TIS) in cooperation with Cincinnati's Queen City Metro transit system. That system, while

Figure 1. System block diagram.



not an AVM system per se, produced data on passenger boardings, alightings, and bus travel times that were available on a bus trip or route-segment basis. Locations were established through the use of radio signposts and bus odometer readings. The principal difference between TIS and AVM is that information generated by the former is for off-line use (e.g., for trip scheduling and route planning) whereas AVM information is useful for real-time control as well. The authors concluded that TIS, if properly functioning, does appear to be economically viable for systemwide use in Cincinnati.

Another effort of note is being undertaken in Toronto, Ontario, Canada (6). The system installed on the Toronto Transit Commission property provides a continuous flow of information on vehicle location, schedule adherence, passenger loadings, and emergency status. In addition, options for further development include the capability to connect into the traffic-control system to provide priority signal phasing for transit vehicles and for voice response to passenger phone-in queries for current schedule and service information. The benefits realized in Toronto after a year of operation (1979-1980) included the identification of a 5-10 percent oversupply of buses on AVM-equipped routes and a 5-10 percent savings in operating costs. In addition, the off-line uses of data for scheduling and route planning were expected to make overall use of equipment more efficient as well as more responsive to the demand for service.

LOS ANGELES DEMONSTRATION PROJECT

The demonstration in Los Angeles is the second of a two-phase effort funded by UMTA. The first phase (7) was undertaken in Philadelphia during 1976-1977 and was concerned with identifying the subsystem for vehicle location to be used in phase 2. The original purposes of the second phase were identified by Symes (8, p. 236):

1. Conduct a thorough test and evaluation of a fully functional, area coverage, multiuser AVM system;
2. Quantify the benefits to transit and other users;
3. Advance the state of the art of AVM; and
4. Establish technical and economical bases for future deployments.

The demonstration is not, however, systemwide--4 of 214 routes were instrumented and about 200 of 2600 buses--overall about 10 percent of route miles and buses. The demonstration was, however, comprehensive as far as the four lines and an adjacent 54-mile^2 (random-route) area.

Key components of the Los Angeles system are the equipment on board each instrumented vehicle, the signposts for the location subsystem, and the central control and transmission facilities. The basic relations between all components of the system are shown in Figure 1.

Signposts

The signposts for the location system are small, low-power radio transmitters mounted on existing utility or lighting standards and located at intervals of approximately 900 ft along each of the four specified routes and at somewhat larger intervals over a 54-mile^2 area for control of random-route vehicles and ascertaining the locations of off-route vehicles. On-route buses can be typically located within 300 ft by extrapolation, based on the signal strength of two adjacent and sequential signposts, and within 500 ft in the random-route area.

In-Vehicle Equipment

The on-board equipment for the buses consists of the following:

1. Pressure-activated passenger-counter devices in the bus stairs,
2. Electronics for information storage and transmission,
3. An antenna mounted on the top of the bus, and
4. An in-vehicle display (IVD) for the driver.

Although the first three items are relatively self-explanatory as to purpose, the last requires further explanation. The main components of the IVD are a message status panel, a schedule indicator, and a system clock. The message status panel consists of 10 message lights that are lighted when appropriate and are otherwise blacked out. The message panel serves three functions:

1. To convey an automatic start message from the system computer to the driver when it is time for

him or her to pull out from a division garage or layover point,

2. To convey messages to the driver from the dispatcher, and
3. To inform the driver of the status of pending radio communications.

The dispatcher-to-driver messages indicated in 2 above are essentially responses to tactical (problem) situations identified by the dispatcher or automatically by the system. The available messages include such things as "observe schedule", which means observe the schedule indicator, and "schedule adjust", which indicates that a schedule adjustment, relative to the trip sheet, is in effect. The IVDs were only operational on buses on one of the lines as of summer 1981.

Central Control and Transmission

The central control element of the system is where the significant departures from typical transit operations occur. Although the existing SCRTD system was already equipped with two-way radios, had a covert crime alarm for the driver's use, and was computer assisted, location estimation for buses was still a manual procedure. With the availability of comprehensive real-time operational information, the control of daily operations is largely shifted to the dispatcher. The extent of the differences between operations with and without AVM is implicitly defined in the description of the dispatcher's control console and the AVM capabilities at his or her command. The dispatcher's control center has the following elements: two cathode-ray tube (CRT) displays for real-time monitoring of operations on individual transit routes and for calling up displays such as location and status for specified buses, listing of buses that share a specified problem (e.g., all those buses on a specified line that are operating behind schedule), roll-outs from a specified division, and so forth; a 45-function keyboard for controlling the displays; a standard typewriter keyboard; and the existing vehicle identification and voice communication equipment already being used by SCRTD.

Colorgraphics Display

The first of the two CRTs is the colorgraphics, and it has the following components: the display identification, an emergencies list, a tactical-situation list, and the graphics area.

The display identification specifies the transit-route or random-route map being displayed, the scale of the display (e.g., one of three levels of detail available for transit-route maps), and the system time. The emergencies list shows, by bus and run numbers, all AVM buses that currently have an active silent alarm.

The tactical-situation list consists of a set of 10 situations that are automatically identified by the system for any AVM bus on an AVM line without dispatcher intervention. If one or more buses fall into a tactical-situation category, then that category name is lighted on the display. Tactical situations include such things as very late, off-route, and not at layover, all arranged in a priority order.

In the graphics area, displays of various maps are actually seen. Each of the four instrumented routes can be displayed here at full, one-fifth, or one-tenth scale. Buses are indicated at each scale and each is identified and color coded. The identification includes type of bus (e.g., accessible), indicated by a symbol; branch and destination code; service class; run number; and passenger count or schedule deviation. The color codes are red, emergency; blue, early; green, on-time; yellow, late; purple, very late; and white, a non-AVM bus. Individual bus positions on the displays are updated approximately every 40 s by automatic radio polling of each bus or every 10 s when a emergency has been declared.

The transit-route maps are linearized versions of the actual routes with cross streets shown for reference. On these maps all buses on the route can be shown or only specified groups (e.g., only late buses).

In addition to the transit-route maps, random-route maps with actual street patterns can be displayed. On these maps random-route vehicles (e.g., supervisors' vehicles) can be located and a specified line can be overlaid or a specific bus located. The latter capability is especially useful in locating off-route buses.

Alphanumeric Display

The other CRT screen is the alphanumeric display, and it also has four sections: a 2-line work area, a 4-line bus data area, a 37-line general data area, and a 2-line communications area.

The work area is where the dispatcher "talks" to the system computer. For example, one of the function keys allows the dispatcher to get all currently available data on a specified bus. The dispatcher would press a function key labeled GET BUS DATA; the system would respond with a prompt (question) in the work area for the line, run, and bus numbers; the dispatcher would type in the appropriate response and transmit it to the system; and the system would display the data on the specified bus in the bus data area. All such information exchanges are carried out in the work area, although the actual result is displayed in one of several locations.

The bus data area is where all current information on a single specified bus can be displayed. This information includes line, run, and bus numbers; current operating status; passenger count; schedule deviation in minutes; schedule adjustment in effect, if any; schedule deviation at last time point; whether the schedule indicator in the bus is on or off; tactical information; whether a problem currently exists; the identification of the console that responded to the problem; and schedule information including current location and time, next layover location and estimated time of arrival, and scheduled departure time from the next layover. The fourth line of the bus data area can be accessed by the dispatcher and is for comments. Once the bus data is displayed, it can be updated by using another key that causes a special polling of that bus.

The general data area is the largest portion of the alphanumeric display and has several uses, such as listing schedule information about individual or specified groups of buses, listing all buses in a specified group (e.g., all late buses), listing schedule information for a bus or group of buses, and providing instructions or information about the use of the system or explicit function keys. Schedule information that can be called into the general data area includes a list of the next 20 starts from a specified location and on a specific line, a display of the complete schedule of a specified bus that shows all time points, and a schedule block for a given line, direction, and starting time.

Buses are grouped in numerous ways by the system and a listing of those buses can also be reviewed in the general data area. There are five different classes of groupings: service class (e.g., local), passenger load (e.g., overloaded), tactical situation, status (e.g., unassigned or out of division), and a miscellaneous class that includes such buses as those that are non-AVM but on AVM lines or those with active tactics in effect. In all, there are 31 different groups that can be specified. As indicated earlier, the system can also give the dispatcher assistance, e.g., the list of the 31 possible groups can be called up for review.

Dispatcher Capabilities and Other System Aspects

Although there are other functions that could be discussed, the basic types of AVM monitoring and display capabilities available for the dispatcher have been outlined. The dispatcher can (a) monitor the operation of all buses or a specified group on any given AVM line at one of several scales, (b) call up real-time information on any AVM-equipped bus and locate the bus, (c) review the available information on a specified group of buses, and (d) make out trouble reports. In addition, there is a specialized procedure for dealing more efficiently with active crime alarms (emergency situations).

Thus, the dispatcher has a comprehensive view of ongoing transit operations on the AVM lines, i.e., more comprehensive than could possibly be obtained in the past. Given that information, a significant opportunity exists for exercising real-time control over transit operations.

Before reviewing the effects of AVM to date, several other aspects of the system should be noted. First, there were additional capabilities in the system that were not fully operationalized during the demonstration. Foremost among these were the tactical keys on the dispatcher's control console. These keys would have afforded the dispatcher the opportunity to send specific drivers (or groups of drivers) nonverbal tactical messages via the message status panel on board each bus. As actually implemented, the dispatchers were encouraged to give such messages via the normal communications channel.

Another aspect of the system that was not actually implemented in the field was the bus stop display for use by waiting passengers. Although a small number of displays were operational, they were never actually used on any of the lines. Information from this display included time of arrival of the next bus, branch or destination of that bus, type of service offered, and time of day.

In addition to the real-time aspects of AVM that have just been reviewed, the system also provides data tapes of raw data for experimentation and extensive summary files for use in scheduling, route planning, and other information management functions. These latter products are not trivial and possibly provide enough benefits in and of themselves to justify system costs.

EXPERIMENTATION AND EVALUATION PROGRAM

Benefits to be derived from AVM capabilities fall into several categories and are accrued only over a period of time. Major categories include the immediate payoffs associated with the improved response to emergency situations, somewhat longer-term advantages in reworking schedules and other information management areas, and future beneficial shifts in demand for service in response to increased system operating efficiency, dependability, and reliability. Thus, the potential impacts and benefits of the AVM system being demonstrated in Los Angeles are not all measureable in the short term. For example, considering demand sensitivity, it is quite likely that if transit system operations (insofar as the AVM lines are concerned) improve in dependability and reliability there will be resultant changes in patronage. Such incremental changes will be difficult to isolate and measure on a systemwide basis, let alone for isolated lines, considering the impact of seasonal variations and the impacts of other exogenous factors (e.g., What is the impact of continuing energy shortages and/or high prices on transit patronage and how is it separated from the positive impacts of system improvements?).

The remainder of this discussion is concerned with the shorter-term effects of AVM in three principal areas: (a) scheduling changes as a result of AVM, (b) impacts on day-to-day system dependability and reliability in terms of schedule and running-time deviations, and (c) response to emergency situations that involve driver-activated crime alarms and the rendezvous of scheduled and nonscheduled vehicles.

Evaluation Approach and Problems

The basic approach to the evaluation, insofar as day-to-day system dependability and reliability were concerned, was to collect data on schedule deviation, running-time deviation, and several other variables (automatically) as AVM capabilities and control potential were phased in, which provided the basis for a rough before-and-after AVM comparison as well as a comparison with a control line that, although monitored by AVM, was not subject to real-time intervention. The data were typically aggregated into 31 two-week test periods in three different phases. Phase 1 data were collected by using AVM capabilities, although no system control was exercised. Phase 2 data were collected as the dispatchers were introduced to the system and its capabilities, although minimal real-time control was exercised. Phase 3 and 3A data were collected during the final test periods when the dispatchers had been trained and familiarized with the system and were being encouraged to exercise real-time control over system operations. As indicated, the phased-in AVM capability was undertaken on only three of four lines, the fourth being retained as an experimental control in an attempt to more accurately track seasonal and any other normal background variations in service levels.

In addition, the 62-week duration allowed for a moderate year-to-year comparison to be made (i.e, the first 10 weeks with the last 10). This sort of comparison was useful insofar as variations due to seasonal fluctuations in service and demand were minimized.

The ability to isolate and quantify specific improvements in ongoing system operations, as indicated above, proved to be more difficult than originally anticipated and stems from several sources. First, the impact of exogenous factors made it difficult to isolate the effects of real-time AVM system control; e.g., How are the AVM effects accurately separated from acknowledged seasonal fluctuations both in the demand for service and the ambient traffic congestion?

Second, and perhaps more importantly, there was some reluctance on the part of some SCRTD dispatchers to become actively involved in exercising the full extent of the available control capabilities; some were quite interested and adept at using the system and some were not. These differing attitudes led, in turn, to inconsistent application of AVM capabilities and little use of the more comprehensive forms of intervention (e.g., shifting buses to a problem area).

Third, during several test periods there were problems with system operation due either to system malfunction or other interruption in system communication. Even though such breakdowns were often not a problem with the system hardware or software per se (i.e., interruptions also came about as a result of experiments, software modifications, and other activities), they nonetheless reinforced any negative feelings dispatchers might have had about the system.

Problems of the last two types described above became less troublesome during the final weeks of data collection as the dispatchers became more accustomed to the system and other interruptions became less frequent. These improvements notwithstanding, the effects of AVM (either positive or negative) were difficult to isolate except when the effects of exogenous factors and the degree of dispatcher intervention could be accurately identified. (This was the case during the evaluation of the timeliness of the response to a crime alarm and in accomplishing the rendezvous of scheduled and nonscheduled vehicles.)

Scheduling Changes as Result of AVM

Given that only four SCRTD routes were subject to AVM control and that one of those was reserved for experimental control, the opportunities to make significant changes in schedules were somewhat limited. However, the information from the first two phases of AVM data collection did indicate that, for one line in particular, overall running times were consistently longer than scheduled. Thus, in the third phase running times were lengthened in one direction with a resultant improvement in the running-time deviation.

This sort of schedule improvement is important not only to the drivers who no longer have the frustration of always running late but also to passengers who can have more confidence in the schedule. The identification of such a problem in the schedule also highlights the comparative advantages of AVM data collection and information management. In order to review such data with the old system, considerable manual effort would have been required to collect it in the first place (e.g., by using mobile supervisors) and then additional effort for the processing. The AVM system, by way of contrast, produces such summary data as an element of normal system operation, thus making both the identification and solution of such problems straightforward and routine.

In late 1981, problems in transferring information from the AVM computer system to the machine used by SCRTD were overcome, and other summary information was being processed that had direct bearing on off-line scheduling and management of the system.

Increased System Reliability and Dependability

As indicated earlier, data were grouped into two-week test periods and by level of AVM control available. Other stratifications of the collected data included time period during the day (e.g., morning and evening rush hours), direction on the line, and type of service (local or limited). Furthermore, evaluation data were limited to those collected on weekdays, during good weather, and within identified segments of each line. Typically, measurements (e.g., of schedule deviation) were made at four time points along the segments (i.e., near the beginning, two in the middle of the segment, and the last near the end).

Principal dependent variables that were examined were schedule deviation and running-time variation. Total passenger loadings were also examined for correlation between service provided and demand and to check for seasonal fluctuations. Available statistics for data from a test period (for data from one segment in one direction and for one time period) included the distribution (11 cells) of all observations, the mean of those observations, the standard deviation, and the sample size.

The basic hypothesis that was tested was whether the availability (and presumed use) of AVM control capabilities had a positive effect on the service-related variables that were measured. Comparisons were made both for a given line (e.g., Was service better in phase 3 than it was in phase 1 for a given line, direction, or time-of-day combination?) and relative to what occurred on the control line.

The results, in general, indicated that the effects of using AVM real-time control capability were positive, although reliable estimates of the magnitudes of those effects could not be obtained. It had originally been expected that a relatively reliable estimate of the actual magnitude of the impact of using the AVM system would be obtained by comparing operation and performance on the various lines in both before-and-after (the exercise of AVM control) modes and by making comparisons between each line and the control line not subject to intervention by AVM-assisted dispatchers. Unfortunately, the fluctuations and inconsistencies in the performance on the control line over the 62-week period were such that straightforward use of the data obtained from this line for estimating the magnitude of background variation in performance and in rigorous use of the line as a normal baseline condition were rendered impossible. The data were, however, useful for describing general trends in performance.

Similarly, while there were some predictable variations in the statistics of the performance variables for the lines, other variations were inconsistent; e.g., while the schedule deviation at a point varied more toward the end of any line than at the start, statistical measures of schedule deviation were not consistently related to total passenger boardings at the same point. Again, the net result was to make estimation of the actual magnitudes of AVM effects unobtainable.

However, in spite of the problems outlined above, the overall trend of the findings supported an assertion that AVM system control did have a positive impact. Basically, each line except the control was subjected to three increasing levels of AVM control, and data were also collected during an initial configuration when no control capability was available. Statistical measures of performance were then compared for each sequential pair of configurations and between two 10-week periods during the initial and last configurations (the year-to-year comparison).

The results of the between-configuration and year-to-year comparisons showed that, in general, service performance on the AVM lines was more likely to improve than degrade over time with increasing AVM control, as compared with the control line where performance was more likely to degrade over time (and without the exercise of AVM control). The important year-to-year comparison showed that 62 percent of the statistical measures considered showed improvement in the second year for lines where AVM control was exercised, whereas on the control line only 38 percent of the measures improved. In addition, for the control line the best performance occurred during either year 1 or configuration 1 approximately 67 percent of the time, whereas for the lines subject to AVM control only 30 percent of the best performances occurred during those periods (indicating again that the best performance occurred during a period when AVM control was being exercised).

Table 1. Trends in performance.

Line	Configurations 1-2						Configurations 2-3						Configurations 3-3A						Year 1-2						Incident of Configuration 1 or Year 1 Lowest Overall (%)
	Improve		Degrade		Even		Improve		Degrade		Even		Improve		Degrade		Even		Improve		Degrade		Even		
	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent	
44[a]	3	7	39	87	3	7	27	60	16	36	2	4	17	38	25	56	3	7	17	38	27	60	1	2	67
41	10	50	10	50	0	0	9	45	9	45	2	10	8	40	7	35	5	25	12	60	8	40	0	0	35
89	6	25	13	54	5	21	7	29	15	63	2	8	16	67	5	21	3	13	7	29	11	46	6	25	58
83[b]	14	58	8	33	2	8	14	58	7	29	3	13	8	33	15	63	1	4	20	83	1	4	3	13	8
83[c]	11	50	8	36	3	14	12	55	8	36	2	9	15	68	6	27	1	5	17	77	3	14	2	9	18
All AVM[d]	41	46	39	43	10	11	42	47	39	43	9	10	47	52	33	37	10	11	56	62	23	26	11	12	30

Note: This is a summary that indicates general trends in statistical measures (e.g., standard deviation) of the performance variables (e.g., schedule deviation). Column entries show the actual number and percentage of measures improving, degrading, or where there was no change.

[a]Control line. [b]Local line. [c]Limited line. [d]Except line 44.

The statistical comparisons (e.g., Did the mean or standard deviation of schedule deviation vary significantly over the several AVM configurations?) were typically not particularly enlightening relative to making an estimate of the magnitude of the AVM effects. For example, in some instances a statistically significant change might be noted although operationally the actual value was quite small (e.g., What is the operational significance of 10-15 s of improvement on a run time of half an hour?). Similarly, while schedule deviation might improve on two different lines, the magnitude of the improvement might vary substantially between the two. For these and similar reasons, the overall AVM effects relative to performance variables were reviewed from a more qualitative point of view: Were the general trends on the AVM lines showing improvement or degradation of service, especially as compared to what was happening on the control line?

Table 1 provides a summary of the qualitative review of conditions on the lines. In general, the statistics (mean, standard deviation, and number of observations occurring in the extreme tail of the distribution) for the performance variables were examined on each line at several locations, and an indication was noted of whether there was improvement from one AVM configuration to the next and in the year-to-year comparison. In addition, a notation was made as to when (over the four configurations and of the two 10-week periods) the best performance occurred.

The entries in the table indicate how many of the statistics were improving, degrading, and where there was no change. The percent figures represent the appropriate percentage of the total number of measures considered in each instance. The far right column shows the percentage of instances when either year 1 or configuration 1 had the lowest value for all of the configurations or years. Thus, Table 1 facilitates direct comparison both among the lines and between each line and the control and provides a good overall picture of what occurred, in general, on the lines as they were subjected to increasing levels of AVM control.

The last line in the table provides an overall indication of how all lines subject to AVM control (lines 41, 89, and 83) compare as a group with line 44, where AVM was never used by the dispatchers. It can be seen that the general improvement was greater than that expected on the basis of what happened on the control line. Perhaps the most telling statistics were the year-to-year comparisons and the indication of when the best performance occurred early in the overall period--fully 62 percent of the measures showed improvement (year to year) on the AVM-assisted lines compared with only 38 percent on the control line, and the best performance was about twice as likely to occur during a period of AVM control.

Based on the examination of each of the transit lines individually as well as the overall trends, it can be concluded that AVM-assisted control capability does, in fact, represent a positive impact on the performance of the lines that were monitored.

It should again be emphasized that an estimate of the actual magnitude of the impact was impossible to make, given the available data and the level of analysis undertaken. Although the overall trend seems clear, the differential impacts from measure to measure and from line to line varied a great deal.

Response to Emergency Situations and Other Vehicle Rendezvous

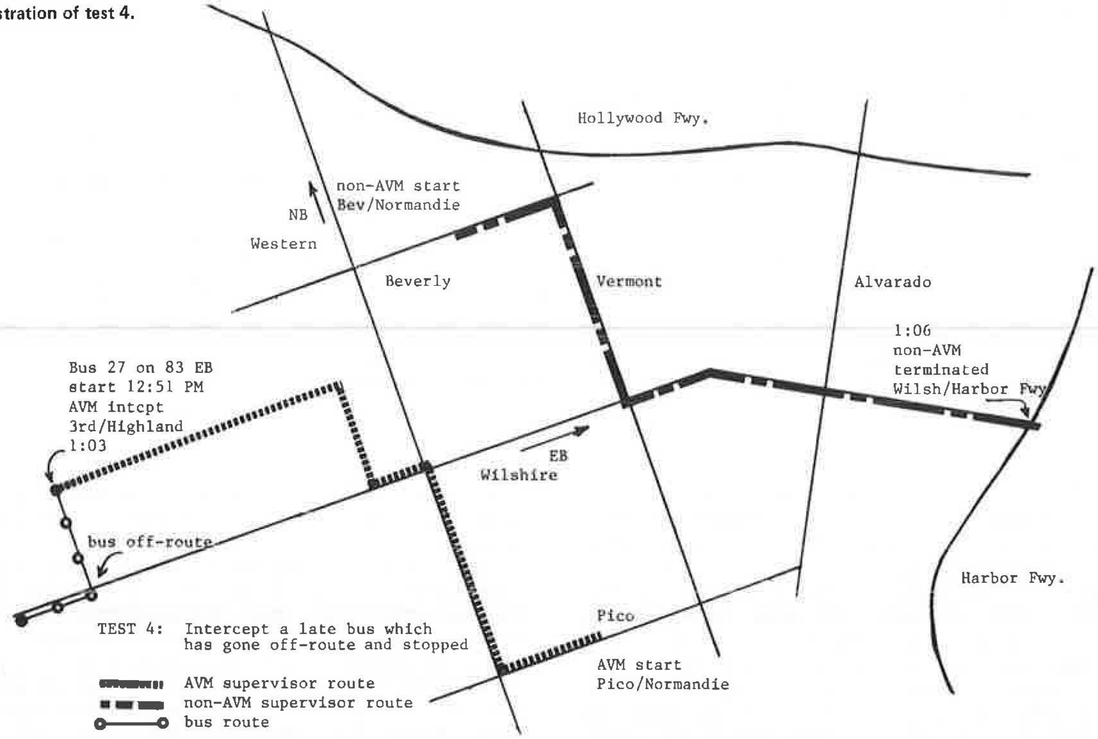
In contrast to the preceding discussion, the impacts of AVM control capability were quite significant and positive when the response to emergency situations and rendezvous of scheduled and nonscheduled vehicles were examined. In this latter examination, the situations were explicitly identified and the effects of background variation minimized.

Two separate types of operations were examined in five common experiment scenarios. The first type was responding to a driver-activated crime alarm [which is used when the driver feels that assistance is required (e.g., a robbery, a rowdy passenger)]. With the existing SCRTD system, the alarm is handled by a separate dispatcher who can automatically identify the bus but has to manually estimate its position based on the printed trip sheets. The dispatcher then identifies the nearest assistance (e.g., mobile supervisor) by using his or her radio and sends it to the bus. With the AVM system, the bus is automatically identified and its position can be determined by using the central control displays. By using another display, the nearest supervisor can also be identified and sent to the effected bus. When the alarm comes in, the system polling rate is increased so that movement of the involved bus can be more closely monitored.

The second type of situation was more general, which involves the rendezvous of a scheduled vehicle and an unscheduled one. Need for such a rendezvous might occur in several instances, such as a mobile supervisor taking material to a scheduled bus, replacing one bus on line with another, or affecting a transfer of passengers between a neighborhood-based demand-responsive van and a regularly scheduled line-haul bus.

In both types of situation, the question is how timely can the rendezvous be made. In the experiment scenarios, two supervisors starting from ap-

Figure 2. Illustration of test 4.



proximately equal distances from the bus to be intercepted were guided to interception, one via existing SCRTD procedures (i.e., manual approximation of the scheduled location of the bus) and one by using AVM capabilities. The supervisors had neither visual or radio contact with each other nor with the bus to be intercepted. The bus was temporarily assigned a real bus run number in each of the five scenarios.

The basic experiment procedure was common to all five scenarios and was as follows:

1. The two supervisors went to assigned locations;
2. The test bus was temporarily assigned a real bus run number and started from a previously assigned location;
3. After starting, the crime alarm on the test bus was activated and then was operated according to a previously defined script;
4. A non-AVM-assisted dispatcher guided one supervisor to the test bus while the AVM-assisted dispatcher guided the other; and
5. Each supervisor was tracked to the eventual point of interception (or test termination).

The five scenarios ranged from intercepting a scheduled bus moving on-route and on-time to intercepting a scheduled bus that was moving off-route, having been on-time when it left the route.

The comparison of the total response times and the search patterns of each supervisor illustrated the basic differences between the existing system and AVM capabilities. In summary, the five scenarios showed the following:

1. The supervisor receiving AVM information was always able to move more or less directly to the test bus without backtracking or making a false start in the wrong direction, which was not the case for the other supervisor [although the latter typically made the correct decision regarding where to attempt to intercept the bus based on available (manually obtained) information];
2. The directness of the routes taken by the AVM-assisted supervisor to intercept the test bus resulted in substantially lower response times (at a minimum, 30 percent less);
3. In two of the scenarios involving off-route buses, it appeared that the non-AVM-assisted supervisor might never make an interception--the supervisor was quite far from the bus with no indication of getting any closer; and
4. AVM-assisted response time did not seriously degrade even when the interception points were off-route.

Figure 2 illustrates one of the worst-case situations where the test bus was moving on-route but late when the crime alarm was activated, and then went off-route a short distance and stopped. The AVM-assisted supervisor received information that the bus was late as well as its location, then that the bus was off-route and where, then that it was stopped at a specific location, and intercepted it in about 12 min overall. The non-AVM-assisted supervisor received only the initial crime alarm report and standard time-point information from the schedule and proceeded to try to intercept the bus where it would have been had it been more or less on time. When the test was terminated, the latter supervisor was moving away from the test bus. This test, although admittedly a worst-case type of situation, is not unrealistic and serves to illustrate that with the current system, in all but the simplest instances, needed assistance can be searching blindly within a large area for a bus (and driver) in trouble.

SUMMARY

Although the evaluation of the AVM system being demonstrated and used in Los Angeles continues, the analysis discussed here has shown that there are considerable benefits to be accrued in several areas of ongoing transit system operations, including route scheduling and information management, improvement of day-to-day system reliability, rendezvous of scheduled and nonscheduled vehicles, and response to emergency situations. Although the day-to-day service improvements were quite difficult to separate from normal background variation, it seems clear that, at an absolute minimum, those operations did not degrade with AVM in place and positive results were obtained in several instances.

No attempt was made to place an absolute dollar value on the benefits noted, as several aspects are quite qualitative and their consideration beyond the scope of this evaluation; e.g., quantifying the value of increased rider confidence in on-time, or at least more predictable, transit performance. Although some of the benefits may be partly quantifiable in the long term (e.g., if increased confidence leads to increased patronage of the system), such data are not currently available or are subject to substantial error in approximation.

It is anticipated that future analysis will provide a more complete picture of the impact of day-to-day improvements that might be expected through exercising AVM control. For example, during the latter stages of the data-collection effort, dispatcher use of system capabilities became more consistent. Thus, subsequent analysis and comparison of results during this time period with those obtained more than a year ago will have the advantage of both the consistent use of AVM capabilities by the dispatchers and the opportunity to ignore some of the temporal (seasonal) variations.

It is also anticipated that as the SCRTD staff becomes more familiar with the types of data available from the system for route scheduling and so forth, greater advantage will be taken of those opportunities in a straightforward fashion (i.e., better scheduling for the instrumented lines) as well as in using the four lines for testing new strategies for controlling day-to-day operations that might be transferable to non-AVM lines.

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Comparing Fixed-Route and Flexible-Route Strategies for Intraurban Bus Transit

OLUSEGUN ADEBISI AND V.F. HURDLE

The usual fixed-route strategy is not the only possible strategy for operating intraurban bus transit. Among the alternatives are flexible-route strategies. This paper focuses on the problem of choosing between fixed-route and flexible-route strategies in order to optimize operations. A mathematical model is used to determine the optimum quantity of service that should be provided under each strategy so as to minimize the costs to operators and users. The quantity of service is characterized by the headways between buses and is given as a function of the average ridership rates, unit costs, and travel times. By comparing the optimum states for the two strategies, the conditions under which one strategy performs better than the other are derived. Findings from the latter are then used to derive a general methodology for comparing the strategies. The highlight of the proposed methodology is that the two strategies must be compared at the extremes of a typical day's ridership levels before one can ascertain whether operating exclusively with either strategy or jointly with both strategies will give the best results. The present study is, however, limited to very small service areas.

The current methodology for comparing fixed-route and flexible-route operating strategies of intraurban bus transit consists essentially of using cost-effectiveness curves (1,2). The cost of providing a preselected level of service is determined as a function of demand for each strategy. That level of demand for which the service cost is equal for the two strategies is referred to as the critical ridership rate. If the design ridership rate is less than the critical ridership rate, then a flexible-route strategy is considered to be more suitable than a fixed-route strategy, while a fixed-route strategy is more suitable where the design ridership rate exceeds the critical ridership rate.

However, the above method ignores the time-variant nature of transit ridership. Because only design demand is considered in the analysis, one cannot be certain that whichever strategy is chosen is actually superior to the other over all ranges of demand encountered on a typical day. Also, a prese-