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A Socioeconomic Impact Assessment of the Los Angeles Automatic Vehicle Monitoring (AVM) Demonstration

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October 1982
Final Report

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Office of Technical Assistance
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The demonstration showed the AVM technology to be mature for use in transit systems, but also very dependent on the skill and commitment of affected transit personnel. Dispatcher control actions were successful in reducing the number of buses running ahead of schedule. Separate experiments showed that real-time AVM data expedites the location and interception of buses in an emergency, thus increasing transit security. The independent automatic passenger counting subsystem, as implemented during the assessment period, did not yield sufficient accuracy to fully meet the expectations of the schedulers and planners, but they generally considered the AVM data output well suited to realize savings through more efficient scheduling.

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PREFACE

This report summarizes the results of a socioeconomic impact assessment of the Los Angeles Automatic Vehicle Monitoring (AVM) Demonstration. The primary goal of the demonstration was to estimate the extent to which the expected benefits of AVM (i.e., improvements in level-of-service, security, and management information) were realized and are realizable.

The Urban Mass Transportation Administration of the U.S. Department of Transportation was the sponsor of the Los Angeles AVM Demonstration. Responsibility for systems management and the assessment of the impacts of the demonstration rested with the Transportation Systems Center (TSC), Research and Special Programs Administration, U.S. Department of Transportation. John Durham was the UMTA evaluation manager, except for a brief period in 1980 when Ron Nawrocki substituted for him. Michael Wolfe was the TSC impact assessment manager until April 1981; at that time, Dr Arthur Priver assumed that role. Kenneth Bray was the TSC on-site project manager at SCRTD in Los Angeles.

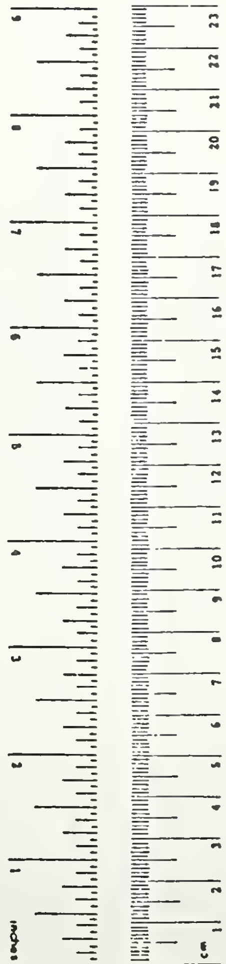
The socioeconomic impact assessment of the demonstration done by SYSTAN, Inc., was carried out principally by Douglas Daetz and Marlies Bebendorf. Roy Lave provided overall guidance, and David Whitman contributed technical assistance. Juliet McNally assisted in the processing of control route data, which had been collected by Juarez & Associates.

SYSTAN, Inc., wishes to express its gratitude to the many individuals and organizations that cooperated with the evaluation effort. Special thanks go to Allan Styffe, SCRTD's AVM coordinator, to Maurice Lanman III of AVM Systems, Inc. (formerly Gould, Inc., Information Identification Division), and to Betty Juarez of Juarez & Associates, Inc. The helpful and patient guidance and feedback of the UMTA and TSC personnel monitoring and managing the demonstration are very gratefully acknowledged.

METRIC CONVERSION FACTORS

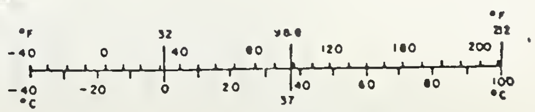
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

Searching for new ways to increase operating efficiency and ridership, several public transit systems in the United States and abroad have started to employ a radio-based technology known as automatic vehicle monitoring (AVM). An AVM system uses location, communication, and data processing subsystems to monitor the locations of appropriately equipped vehicles operating within the area served by the system. A passenger-counting subsystem may also be incorporated so as to provide detailed data on boardings, alightings, and vehicle loads. Vehicle locations -- and, if applicable, passenger loads -- can be displayed to dispatchers on schematic route maps for use in managing the equipped fleet's operation. In addition, the location (and passenger) information can be recorded for later analysis by the transit system's planners and schedulers.

The benefits that may be derived from the use of AVM systems depend upon both the specific capabilities built into a particular system and the type and vigor of application. The applications and associated potential benefits of a "full" AVM system[1] for fixed-route transit include:

- Real-time control of bus operations
  - improved on-time service
  - more predictable service
  - reduced bus bunching, resulting in more even loadings of passengers on vehicles
- Security (Emergency Vehicle Location)
  - increased passenger and driver safety
- Generation of management information
  - more complete, up-to-date, and accurate information about running times and passenger loads

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[1] Here a "full" AVM system is understood to be an AVM system that, in addition to providing current information on vehicle locations, counts passengers, incorporates silent alarm signaling, and offers real-time video display for dispatchers of the location, schedule deviation, and passenger load of each AVM-equipped vehicle.

- reduced volume and cost of data collected manually
- reduced number of personnel for a given amount of service
- more efficient and effective planning and scheduling.

In order to investigate and document the actual performance of a full AVM system under field conditions, the Urban Mass Transportation Administration (UMTA) of the U.S. Department of Transportation (USDOT) sponsored an AVM demonstration in Los Angeles. This demonstration, which was managed by the USDOT's Transportation Systems Center (TSC), lasted from September 1977 to September 1981.[2] Some of UMTA/TSC's specific objectives for the AVM demonstration were to:

- observe how a large transit property reacts and adjusts to AVM;
- gain insights into the general and site-specific factors that determine the benefits and costs of AVM; and
- estimate the extent to which the expected benefits of AVM were realized and are realizable by the host transit property.

In the Los Angeles AVM demonstration, 200 buses (out of about 2,800) operated by the Southern California Rapid Transit District (SCRTD) were outfitted with AVM equipment, including passenger counters.[3] Four of SCRTD's approximately 220 routes were selected for the testing of the AVM system. Signpost transmitters -- the roadside elements of the location subsystem -- were placed along the four routes and throughout a 54-square mile primary AVM service area in central Los Angeles so that both buses and SCRTD supervisor cars (i.e., random-route vehicles) could be monitored. The central station equipment consisted of a computer and a dispatcher console with input keyboard and cathode-ray-tube (CRT) screens for displaying schedule information and color-coded bus status information.

From April 1980 to June 1981, data pertaining to schedule adherence and ridership on the four SCRTD test routes was automatically tabulated by the AVM system. Additional information relating to implementation, security, and service issues, as well as management information and economics, was compiled by the contractor designated by TSC to assess

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[2] After the end of the demonstration, the test system was kept in operation by the Southern California Rapid Transit District.

[3] These buses were already equipped with a radio-based silent alarm system before the demonstration.

the impacts of the demonstration.[4]

The effectiveness of real-time control efforts, responses to silent alarm calls, and the use of management information was somewhat limited in the Los Angeles demonstration due in part to the fact that AVM was implemented on only a very small part of SCRTD's system.[5] Therefore, the following summaries of key findings and conclusions will incorporate supplementary information gained from other AVM implementations.

Implementation Experience

Dispatchers, drivers, planners, and managers affected by the AVM system were generally in favor of the new technology and the options it offered to their respective areas of work. Among the four groups, AVM dispatchers were the most skeptical. They experienced an increase in their workload, and about one-third of them remained doubtful with regard to the effectiveness of real-time control actions. Two-thirds of the drivers said they liked the AVM system, especially the possibilities it offered for improving driver security and for controlling drivers who run ahead of schedule, but some drivers resented being "watched". Planners and scheduling staff were very positive about the opportunities connected with AVM-generated operating data. After learning more about the attitudes and expectations of the various managers and groups of employees affected by or involved with AVM, SCRTD top management shifted its main emphasis among the areas of AVM impact from real-time control to security and management information benefits.

It became obvious in the course of the demonstration that a continuous management commitment and a reorientation of the staff toward the requirements and rewards of operating an AVM system are required in order to realize the system's full range of benefits. Proper selection and adequate training of AVM dispatchers are crucial for successful real-time control. Fundamental to the achievement of all AVM benefits is the cooperation of those responsible for the consistent assignment of AVM-equipped buses to AVM routes, the correct and timely entry of bus assignment data into the computer-aided radio system, and the maintenance of AVM buses and equipment. A high level of skill and enthusiasm among planners and schedulers is equally important.

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[4] The assessment contractor was SYSTAN, Inc., with the collaboration of Juarez & Associates, Inc. (Los Angeles).

[5] The full realization of security benefits requires the coverage of the complete geographical area and vehicle fleet to avoid problems on non-equipped buses or buses taken off-route. The benefits of real-time control and management information can only be maximized for a set of AVM routes that function as a complete (sub)system, within which buses can be allocated efficiently.

Real-time Control Impacts

During the demonstration, a number of factors within and beyond the control of project participants limited the effectiveness expected of AVM's real-time control potential.[6] Among the changes in schedule adherence that could be observed in the demonstration was a decline in the percentage of early buses on AVM routes (e.g., from 6% to 3% on Route 41, and from 9% to 5% on Route 83 Local). At the same time, the share of late buses increased slightly, but in most cases there was a net increase in the percentage of buses within 3 minutes of schedule. The overall change (aggregated over the three dispatcher-controlled AVM routes) in the mean schedule deviation and the standard deviation of schedule deviation was only on the order of six to ten seconds of improvement. No substantial change could be shown in the distribution of passenger loadings among buses.

Security Benefits

The data regularly recorded in connection with both AVM and non-AVM silent alarm calls did not permit a reliable analysis of AVM's security benefits. Therefore, some bus-interception experiments were conducted toward the end of the demonstration. In those experiments, the information provided by the AVM system was markedly superior to estimates of vehicle location based on schedule information. Buses signaling an emergency with the silent alarm were located and intercepted faster with the help of AVM data, especially when running off-schedule and/or off-route.

Management Information for Planning and Scheduling

During the demonstration no substantial scheduling changes based on AVM data were implemented, so the economic benefits of AVM management information were never really tested in Los Angeles. However, AVM capability in this area was demonstrated in Cincinnati, where scheduling changes were made based on AVM data. It is expected that savings in operating costs can be realized if analysis of AVM data shows where cutbacks in scheduled vehicle-hours can be made, e.g., by increasing headways where low demand permits or by decreasing layover/recovery times. Other savings may be possible through more appropriate allocations of running times, or by a more precise adaptation of service to demand conditions (e.g., by season, day-of-week, or time-of-day).

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[6] Apart from being a partial (4-route) implementation as discussed above, the Los Angeles test of AVM was limited by a low level of real-time control activity on the part of some AVM dispatchers, missing bus data in the system, and downtime of the computer system in the early phases of the program.

Costs of an AVM System

The capital costs of an AVM system consist of the investment in in-vehicle equipment, stationary equipment, and system software. On a 200-vehicle basis, capital costs for the entire system are estimated to be about $10,000 per bus (based on 1980/81 cost information). In-vehicle equipment accounts for approximately 70% of this amount. The major cost items among off-vehicle equipment are the central processor ($125,000 plus up to $70,000 for preparation and installation), the display consoles ($30,000), the radio base stations ($10,000 plus $1,000 for installation), and the signpost transmitters ($200-500 each installed). The costs for system software can range from $120,000 to $1 million.

The operating costs are largely generated by the computer and communication systems, although maintenance of the on-bus equipment is also a factor. The hardware-related share is about $60,000 per year; total operating costs amount to about $100,000 per year, which is about $500 per bus per year.

Other AVM Experience

As shown in Exhibit 1 (using the stages as defined by ECOPLAN), more than thirty implementations of AVM or AVM-related systems have been made since 1958 when the first Automatic Vehicle Location system was tested in London. After a gap of eleven years, in 1969, AVM activities began again with tests in Chicago and Hamburg, West Germany; both of these cities have a form of AVM operational today. During the early seventies interest in AVM expanded more rapidly abroad, especially in Europe, than in the United States.

AVM activity in the United States has picked up in the past five years. In 1977-78 an information-gathering system akin to AVM (TIS -- Transit Information System)[7] was tested in Cincinnati (Queen City Metro); reductions of 8% in the (platform) bus-hours of the test routes were realized as a result of schedule changes made on the basis of TIS data. Beginning in 1977, the New York City Transit Authority (NYCTA) undertook an AVM demonstration involving more than 200 buses on 12 routes operating out of the Queens Village depot; since late 1980, when NYCTA's AVM system became operational, dispatchers have exerted real-time control by calling (and writing up) early drivers, with the result that early buses were fewer (late buses were more numerous) and more buses ran within 3 minutes of schedule.

Abroad, recent AVM demonstrations very similar to the Los Angeles AVM demonstration have been conducted in Toronto, Canada, and Stockholm, Sweden. In both cities, favorable, though not large, changes in

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[7] This name was coined by the system's developers at the Transportation Systems Center of the General Motors Corporation. The TIS recorded data on time-at-stop and passenger loads, but the data was not available in real-time.

Exhibit 1

AVM Deployments : An International Overview*

City/Country	Year Initiated	Original Target	Number of Vehicles	Current Status
STAGE I PROJECTS — "The Trial Run"				
London, U.K.	1958	Simple AVL	240	Life Expired (1974)
Hamburg, FRG	1969	Limited AVM	165	Active/Expanding
Chicago, U.S.A.	1969	AVM Test	570	Full fleet EVL
Zurich, Switzerland	1969	Limited AVM	70	Active/Expanding
Paris, France	1973	1-Line AVM Test	35	Test Terminated (1976)
Bristol, U.K.	1973	1-Line AVM Test	100	Withdrawn (1974)
London, U.K.	1973	1-Line AVM Test	44	Test Concluded (1979)
Tokyo, Japan	1973	1-Line AVM Test	75	Test Completed
Nottingham, U.K.	1973	Limited AVI	8	Not Expanded
STAGE II PROJECTS — "The Demo Stage"				
Toulouse, France	1974	AVM Test	16	Terminated
Nagoya, Japan	1974	1-Line AVM Test	17	Completed
Dublin, Ireland	1974	AVM Demonstration	100	Active
Toronto, Canada	1974	AVM Demonstration	100	Expansion Planned
Besançon, France	1974	AVM Demonstration	60	Active
Brescia, Italy	1976	Phased AVM Demo	90	Demo suspended
Cincinnati, U.S.A.	1976	TIS Demonstration	30	Terminated
Berne, Switzerland	1976	AVM Pilot	12	Expanding
Stockholm, Sweden	1977	AVM Pilot	60	Evaluation
Friedrichshafen, FRG	1977	DRT + AVM	12	Active Demonstration
Graz, Austria	1977	Full AVM	90	Active
Mississauga, Canada	1977	AVL + Info System	35	Active/Expanding
London, U.K.	1978	AVM Demonstration	50	Small Pilot Project
Wunstorf, FRG	1978	DRT + AVM	5	Active Demonstration
Strasbourg, France	1978	Phased AVM Demo	60	Active/Expanding
Darmstadt, FRG	1979	AVM Pilot	56	Active
Rome, Italy	1979	AVM Pilot	37	Successful Pilot/Expanding
Regensburg, FRG	1979	AVM Pilot	15	In Process
STAGE III PROJECTS — "The Breakthrough"				
Hannover, FRG	1980	AVM + DRT Demo	15	Being Tested
Wiesbaden, FRG	1980	AVM Pilot	25	Being Deployed
Augsburg, FRG	1980	AVM Pilot	25	Being Deployed
Los Angeles, U.S.A.	1980	AVM Demonstration	200	Active
Melbourne, Australia	1980	AVM Demonstration	60	Initial Stages
Johannesburg, S.A.	1980	AVM Pilot	20-30	Initial Stages
Basel, Switzerland	1980	Full AVM	Ca. 100	Active
Salzburg, Austria	1980	Full AVM	Ca. 100	Active
Nancy, France	1981	Full AVM Demo	220	Being Deployed
Caen, France	1981/82	Full AVM Demo	—	Initial Stages
Anguilleme, France	1981/82	Full AVM Demo	—	Initial Stages

Legend:
- AVL Automatic Vehicle Location
- EVL Emergency Vehicle Location
- DRT Demand-Responsive Transit
- AVI Automatic Vehicle Information
- TIS Transit Information System

*Adapted from tables prepared by ECOPLAN, Paris, France, 1981.

schedule adherence were associated with the use of dispatcher control of instrumented lines, and in Toronto, analysis of AVM data and controller (dispatcher) experience led to a reduction in midday buses (from 6 to 5 and 4 to 3) on two of the six test routes. Several West German cities (e.g., Hamburg and Darmstadt) and Zurich, Switzerland, operate AVM systems that are no longer considered in the "test" stage. Collectively, the AVM experience in the various cities both complements and confirms the Los Angeles experience.

Conclusions

The AVM demonstration in Los Angeles was successful in that it achieved its objective of investigating the performance of an AVM system within the framework of a large transit property. Many of the results of the demonstration may be considered transferable to other transit properties because they have in fact been observed in different AVM implementations. Among the factors to be considered by transit operators planning to use an AVM system are:

- Personnel impacts. Usually younger dispatchers accept the new technology more readily than more senior ones. Attitudes of bus drivers are mixed but mostly positive. Planning and scheduling staff must be skilled and committed to the project to fully realize AVM's management information benefits; in this respect, initially there may be a need for additional programming support to develop the computer software (programs) that produces the management information.

- Real-time control impacts. Improvements can be expected when controlling early buses. More late buses may result, but overall a net gain of buses within 3 minutes of schedule is achievable. The extent of these impacts depends largely on policy decisions and the level of dispatcher activity. Utilization of AVM to recover from line disruptions (i.e., overloading, detours) is intuitively valuable, but not amenable to statistical analysis since it cannot be determined how bad the disrupted service would have been without AVM.

- Security impacts. For security purposes, the AVM system should include the entire vehicle fleet and service area to avoid problems with buses that are not AVM-equipped or are taken off-route. Experiments and actual cases showed that real-time AVM data expedites the location and interception of buses.

- Management information benefits. No management information system was operational in Los Angeles. However, the demonstrations of a Transit Information System in Cincinnati and a Communication and Information System (basically a full AVM system) in Toronto suggest that 3%-5% reductions in vehicle-hours system-wide are realizable using AVM (passenger counter and location) data to achieve more efficient schedules without reducing the level of service provided to passengers. The extent of the benefits is, however, partially dependent on how efficient the existing schedules are.

- Technology. At this stage of development, the AVM technology appears to be mature for use in transit systems. With the exception of the passenger counter mats, which are presently in use in Los Angeles, the system does not appear to pose any unusual maintenance problems.

- Costs. For a full AVM system like the one employed in the Los Angeles demonstration, capital costs for the entire system are estimated to be about $10,000 per bus on a 200-vehicle basis; the additional AVM operating cost is expected to run about $500 per bus per year. Annualized, the total system cost per bus adds up to approximately $2,100 (or about $6 per bus per day), assuming a 10-year life of the hardware and a 10-percent interest rate.

Site-specific factors can increase or decrease the chances for a cost-effective implementation of AVM at other sites. The following points describe some general aspects that a transit system should consider in evaluating the advantages or benefits of AVM as applied to its own situation:

- AVM has been shown to operate effectively in different transit modes. The first vehicle location technology was developed for rail transport and depended on electrical (wire) circuits for transmission of information. Today's AVM systems are more flexible (portable) because they use radio waves for transmission of information; hence they can be used with buses, and with combinations of rail vehicles and buses (as in Darmstadt, West Germany).

- The more successful implementations involve complete transit systems, or at least operationally complete (independent) subsystems of the overall transit system.

- It appears to be advantageous if a transit system does not rotate dispatcher assignments frequently, because high turnover of dispatchers assigned to the AVM system introduces discontinuities and means repeated training periods.

- When considering the purchase of an AVM system, transit management should try to assess whether there is at least 2%-3% of slack in their operations that could be eliminated with AVM in order to balance the additional cost. The experience of two transit districts that have tested AVM-like information systems (viz., Toronto and Cincinnati) suggests that increases in productivity on the order of 3-5% or more may generally be possible.

Apart from passenger counting systems, for which implementation experience is limited, AVM technology is well developed. AVM's benefits depend almost entirely on why and how it is put to use. In Chicago, AVM was introduced solely for security reasons; New York City, however, has a major interest in real-time control. Transit managers can choose the area(s) of benefit they want to emphasize and build up an AVM system matching those priorities. Once installed, the crucial factor associated with realizing the full potential of AVM benefits seems to be the continuous effort invested by management and staff.

1. INTRODUCTION

1.1 AUTOMATIC VEHICLE MONITORING (AVM)

A number of transit systems both in the United States and abroad have started to employ a radio-based technology for monitoring the location and operating status of transit vehicles. The term now most commonly used in the U.S. to refer to such a system is "Automatic Vehicle Monitoring", or "AVM". While the first operational test of an elementary AVM system was conducted in London (U.K.) in 1958, rapid improvement in AVM technology and a surge in the number of test implementations of AVM did not occur until the mid-1970's.

An AVM system can be viewed as having three subsystems: location, communication, and data processing and software. The location subsystem generates the signal or transmission that is processed and converted to locational information. The communication subsystem transmits this raw data from the location subsystem in the field to a central facility where it is processed. The data-processing and software subsystem computes and processes the information for immediate and/or later use, and displays the information to dispatchers, drivers, users, and so forth. Thus, the major function of an AVM system is to determine and display the current location and direction of movement of each active vehicle (e.g., transit bus) within the region covered by the system. A passenger-counting subsystem may also be incorporated so as to provide stop-by-stop data on boardings, alightings, and vehicle loads.

The information collected by an AVM system can be used by transit operators to derive the following benefits:

- Real-time control of bus operations. In a fixed-route bus system, current information about vehicle locations is used to indicate to a dispatcher the buses that are deviating from their schedules. By radio, the dispatcher can then direct the respective bus drivers to take corrective actions. These actions can result in more predictable service and reduced bus bunching, and eventually in more even passenger loadings on buses and shorter wait times at bus stops.

- Security of passengers and drivers. An AVM system can be combined with a silent alarm radio system on the buses. If a crime occurs on a bus, a driver may switch on a silent alarm that notifies the control room that assistance is needed without arousing attention on board the bus. The dispatcher can then direct the police to the exact location of the bus. Without AVM, the dispatcher has to estimate the bus's probable location along the route and the police may have to search for the bus, thereby reducing the speed of their response.

- Management information for planning and scheduling. In addition to generating a complete record of schedule reliability at each timepoint, AVM can be used to calculate actual run times for either an entire route or segments of the route. This information would allow the scheduling department to construct schedules that more accurately reflect the actual run time experience. Also, by knowing the degree of variation in route running time, the schedulers can minimize the required layover time at the ends of routes. Coordinated with automatic passenger-counting equipment, AVM can provide detailed transit ridership data as well. An overview of the data items available from a full AVM system (i.e., one including silent alarm and passenger-counting systems) and their areas of benefit is shown in Exhibit 1.1.

1.2 THE LOS ANGELES AVM DEMONSTRATION

This report describes the Los Angeles Automatic Vehicle Monitoring (AVM) Demonstration and provides an assessment of its socioeconomic impacts. The demonstration itself, which began in September 1977 (data collection started in April 1980) and ended in September 1981 (see Exhibit 1.5), was sponsored by the Urban Mass Transportation Administration (UMTA) and managed by the Transportation Systems Center (TSC). All but the last three months of the demonstration are covered by the impact assessment,[1] which was performed under the guidance of TSC.

The assessment of the socioeconomic impacts of the demonstration examined the three main areas in which SCRTD anticipated benefits from AVM: real-time (tactical) control of bus operations, emergency response and security, and management information for planning and scheduling. In addition, certain aspects of project implementation were examined, particularly those aspects dealing with the involvement of and effect on the host transit organization and its members. Furthermore, for purposes of dealing with the transferability of results, the assessment findings for the application of AVM in Los Angeles are also discussed in relation to AVM experience in other cities in the U.S. and abroad.

1.2.1 Demonstration Setting

The Southern California Rapid Transit District (SCRTD) was created in 1964 from the old Los Angeles Metropolitan Transit Authority (MTA). SCRTD provides ninety percent of all public transit services to 185 cities and communities in 2,280 square miles of the Greater Los Angeles area south of the San Gabriel Mountains. Approximately 2,800 buses are used to provide service on some 220 routes that range in length from as

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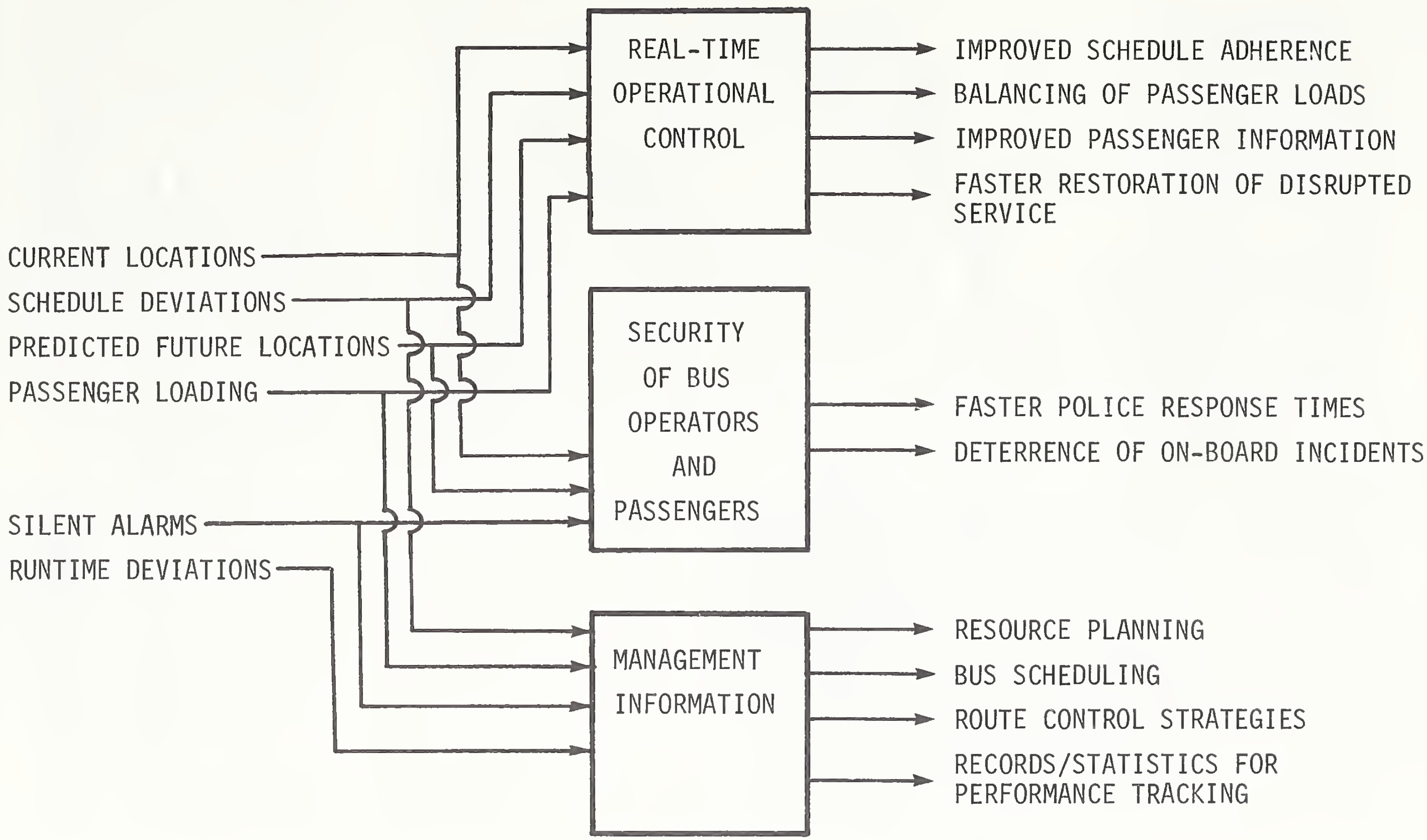
[1] Demonstration data generated after June 19, 1981 was not considered.

EXHIBIT 1.1

AVM DATA AND ITS USES



short as one mile to as long as 76 miles. During peak hours, about 2,000 buses are in revenue service.

SCRTD is the nation's third largest urban mass transit system, but the nation's largest all-bus transit system. On a typical weekday, there are as many as 1.4 million passenger boardings, or between 500,000 and 600,000 daily riders. In 1980, 390 million passenger trips were made on the system, 16% more than in 1979. Even so, SCRTD carries only about 5 percent of the commuters in Greater Los Angeles. In 1980, total operating costs were approximately $300 million, of which about two-fifths was covered by fares. The almost $200 million shortfall in farebox revenue in 1980 was funded by a combination of local, state (mostly sales tax), and federal subsidies.

1.2.2 Scope of the Los Angeles Demonstration

The Los Angeles AVM demonstration dealt primarily with the monitoring and control of fixed-route buses. The Transportation Systems Center selected four of SCRTD's approximately 200 routes to comprise the fixed-route application of AVM. These AVM test routes (41, 44, 83, and 89), with weekday headways ranging from 3 to 12 minutes, were selected to represent a cross-section of the types of routes SCRTD and other U.S. transit properties operate. All are local routes except the Line 83, which provides local and limited bus service along the Wilshire Boulevard corridor. Line 83 is by far the most heavily traveled line in the RTD system, with some 60,000 boardings per day. As shown in Exhibit 1.2, the AVM test routes are located in downtown Los Angeles and the western sector of greater Los Angeles out through Westwood to the ocean.

Besides the monitoring of buses on four routes, supervisor cars were monitored within a primary AVM service area of 54 square miles. The primary area, which coincides with SCRTD's supervisory districts 1 through 5, includes the Los Angeles central business district (CBD), comprising about six square miles, and an adjacent 48-square mile area largely northwest of the CBD.

The AVM system hardware was provided by the Information Identification Division of Gould, Inc., and its subcontractors. An overview of this system is shown in Exhibit 1.3. The Gould location subsystem is a broad-signpost system in which battery-powered signposts mounted on electroliers (light poles) transmit unique digital location codes that are detected by receivers installed in vehicles. The radiation fields of adjacent signposts overlap so that vehicle location is determined by the relative intensities of the transmissions detected by a vehicle's receiver. The locational data recorded by the AVM system can be used to continuously provide current operational data and/or instructions to dispatchers, drivers, and transit users.

To monitor buses along the fixed routes, signposts were placed about five to the mile along each route. To monitor flexible route

Exhibit 1.2

MAP OF AVM ROUTES

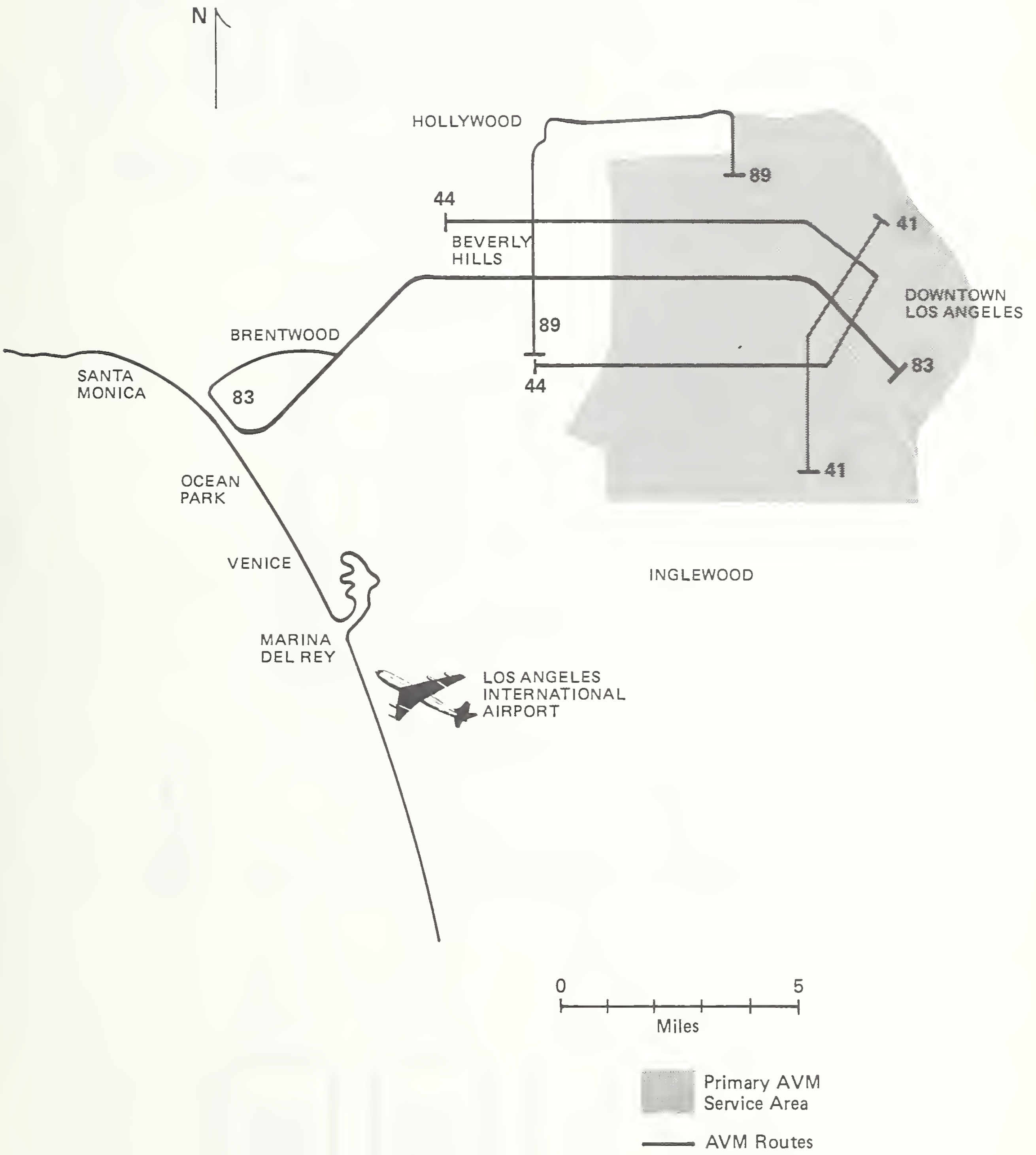
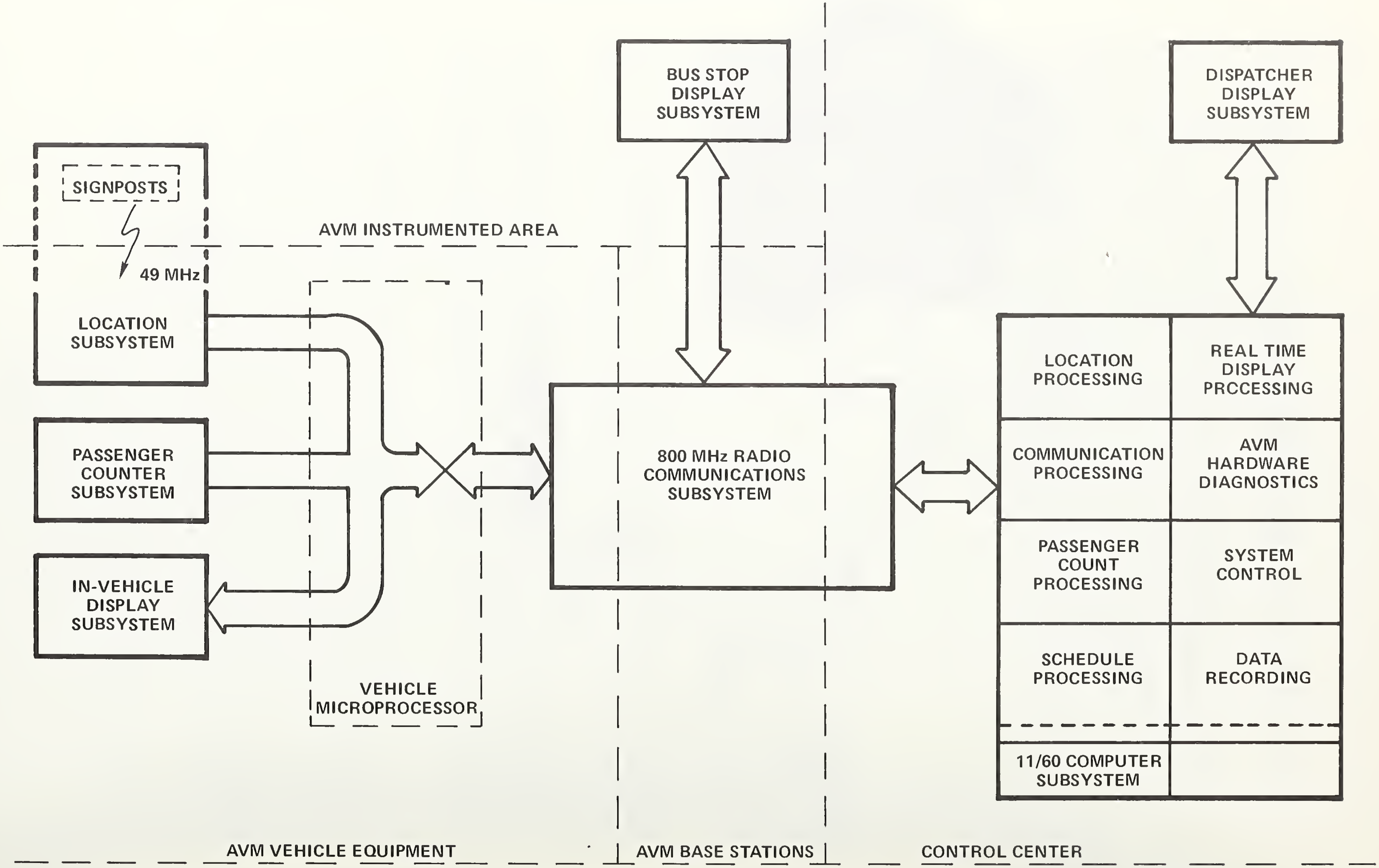


Exhibit 1.3

BLOCK DIAGRAM OF AVM SYSTEM



Adaptation of Figure 1.2, *AVM System Description,* Volume I (April 1981), Gould, Inc. (Information Identification Division) vehicles in the primary service area, signposts were placed in a grid pattern at intervals of approximately 2,000 feet. AVM equipment was installed in 200 buses[2] and 6 random-route SCRTD supervisor cars. Passenger counters were developed by a Gould subcontractor and were tested on Fort Worth buses prior to their use in Los Angeles. The system finally adopted uses treadle-type mats on two steps of a bus's entrance and exit stairwells to measure the direction and count the number of boarding and alighting passengers. The passenger-count data is transmitted with the signpost code data each time the central AVM computer polls a bus for current-status information.

In the control room, dispatchers have the capability of determining the location of any bus on an AVM route. They can see from a color graphic display if any buses are operating significantly off schedule, and they are immediately notified if a bus goes off route or if a silent alarm signal is activated.

During the final test period -- from May 18, 1981 onward -- in-vehicle displays (IVD's) were in operation on most of the buses assigned to Route 41. These display units have a digital clock, a schedule meter, and a message status panel. The clock shows the driver the official time, and the needle on the schedule meter automatically and continuously indicates to the driver whether he or she is early, on time, late, or very late. The system can also automatically activate message lights on the message status panel.

The AVM demonstration in Los Angeles had originally been planned as a "Multi-User AVM Demonstration" in order to explore the potential economies of shared use of certain AVM equipment (e.g., signpost transmitters) and perhaps system software. Initial planning envisioned the participation of both the Southern California Rapid Transit District (SCRTD) and the Los Angeles Police Department (LAPD); this particular multi-user combination would also have provided the opportunity to assess AVM's impact on police response time to buses that had activated silent alarms. However, the Los Angeles Police Department was not able to obtain funding for its participation, so only SCRTD participated in the demonstration. In addition, the four "bus stop displays" designed to provide transit users (or potential users) with up-to-the-minute estimates of bus arrival times were not publicly deployed. Corresponding reductions in the initially planned scope of the impact assessment were made.

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[2] 150 standard GMC buses, 33 lift-equipped AM General buses, and 17 MAN articulated buses.

1.2.3 Demonstration Participants and General Project Organization

The Los Angeles AVM demonstration was sponsored by the Office of Bus and Paratransit Technology of the Urban Mass Transportation Administration, U.S. Department of Transportation (see Exhibit 1.4). The host transit property was the Southern California Rapid Transit District (SCRTD). UMTA delegated responsibility for system design, implementation, and technical evaluation to the Transportation Systems Center (TSC), a research organization within the Department of Transportation. TSC contracted with Gould Inc., Information Identification Division (hereinafter often referred to simply as Gould[3]), to design and install the AVM system at SCRTD, to develop operational procedures for its use, and to collect data to be used in the assessment of the AVM system. Wilson-Hill Associates was retained by TSC to support the AVM training of SCRTD dispatchers, to evaluate human factor aspects of the AVM dispatching console, and to study the general level of AVM dispatcher activity and the kinds and frequency of real-time control actions taken by each dispatcher. In addition, MITRE Corporation was contracted with by UMTA to provide technical support to SCRTD for the development of a management information system (MIS).

In 1978, UMTA's Office of Socio-Economic and Special Projects contracted with SYSTAN, Inc., to develop a plan for an independent socioeconomic evaluation of the AVM demonstration.[4] Subsequently, in 1979, Juarez & Associates and SYSTAN were contracted with by UMTA to collect and assemble data for an adequate baseline description for the Los Angeles AVM demonstration.[5] Then, in 1980, SYSTAN and Juarez & Associates were contracted with by TSC to perform a socioeconomic impact assessment of the demonstration.

The American Public Transit Association (APTA), while not actually a participant in the Los Angeles AVM Demonstration, formed a subcommittee on AVM to follow the progress of AVM in general and the Los Angeles AVM Demonstration in particular. The APTA Automatic Vehicle Monitoring Subcommittee, whose parent was the Bus Technology Committee,

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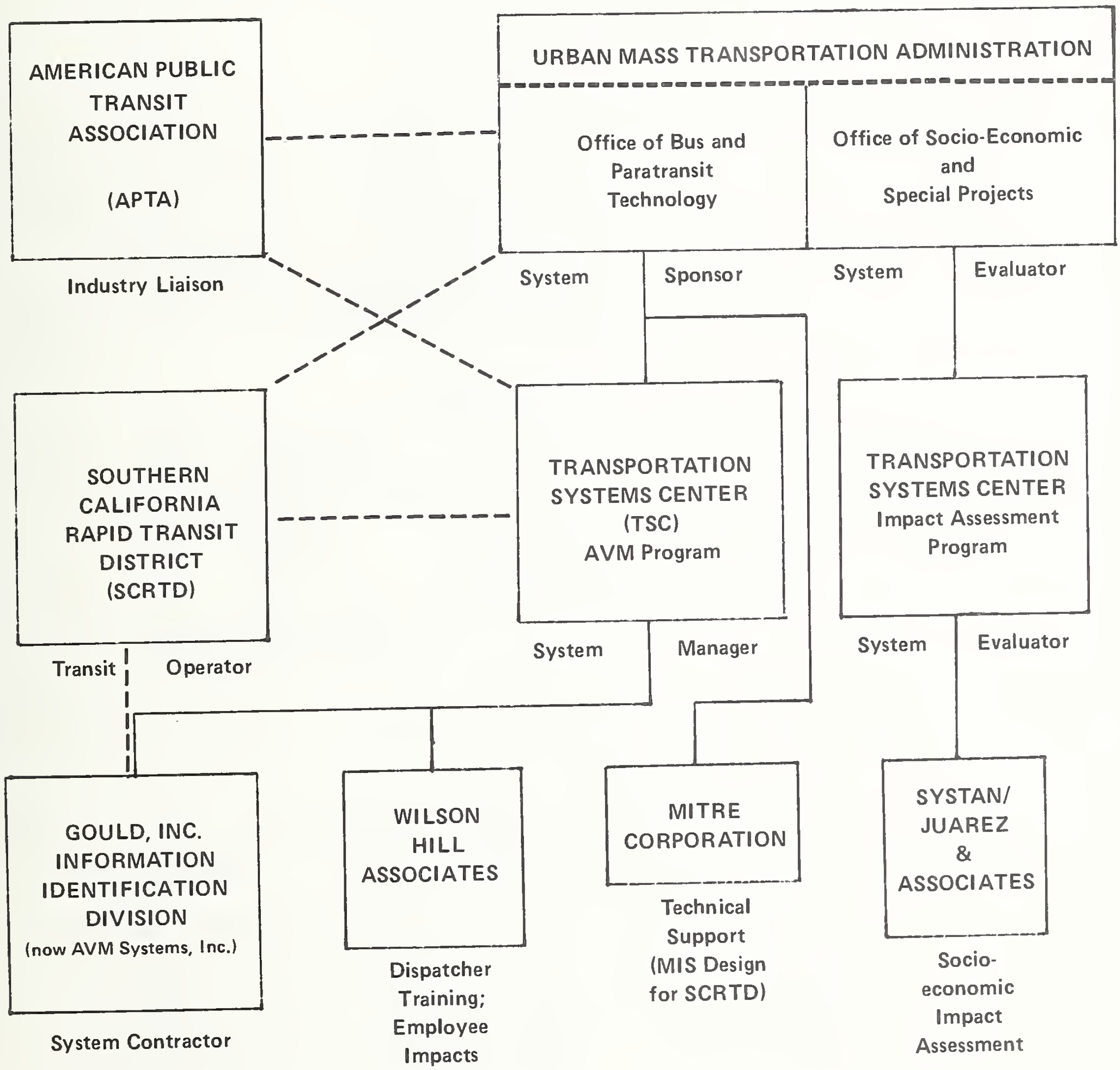
[3] Toward the end of the demonstration, in June 1981, Gould, Inc. sold its Information Identification Division to a group that incorporated itself as AVM Systems Inc.

[4] SYSTAN, Inc., <u>A Plan to Conduct a Socioeconomic Evaluation of the Los Angeles Automatic Vehicle Monitoring (AVM) Demonstration</u>, Los Altos, California, July 1978 (prepared for the U.S. Department of Transportation, Urban Mass Transportation Administration, under contract DOT-UT-60011T).

[5] Juarez and Associates, Inc., and SYSTAN, Inc., <u>Baseline Conditions Report for a Socioeconomic Impact Assessment of the Los Angeles Automatic Vehicle Monitoring Demonstration</u> (Report No. DOT-UT-90039-81-1), Los Angeles and Los Altos, California, May 1981 (prepared for the U.S. Department of Transportation, Urban Mass Transportation Administration, under contract DOT-UT-90039).

Exhibit 1.4

ORGANIZATIONS INVOLVED IN
THE LOS ANGELES AVM DEMONSTRATION



consisted of an APTA staff advisor and representatives of six transit districts with AVM or AVM-related experience or interest.[6] This AVM subcommittee held a series of five meetings (with financial assistance from UMTA) during the time the demonstration was in progress. The first meeting was at TSC (Cambridge, Mass.), the second at Gould, Inc. (Fort Worth, Texas), and the last three at SCRTD (Los Angeles). Representatives of all major parties involved in the Los Angeles demonstration generally attended these meetings both to share the latest AVM status reports with the APTA subcommittee members and to listen to the questions, comments, and reports on AVM experience offered by the subcommittee members.

1.2.4 Demonstration Budget

The Los Angeles AVM Demonstration -- Phase II of UMTA's AVM program -- had an initial total budget of $7,438,000 to be spent over a six-year period beginning in 1977. However, the length of Phase II of the demonstration was shortened from six years to four due to greater expenditures in the first three years than had been anticipated. The final budget for the AVM demonstration in Los Angeles was approximately $9,828,000. Funds were allocated as follows:

Gould Inc., Information Identification Division (System Contractor)	$7,004,000	(71%)
TSC Support	1,952,000	(20%)
SCRTD Support	450,000	(5%)
APTA Support	45,000	(.5%)
Technical Support (MITRE Corporation)	135,000	(1%)
Evaluation (SYSTAN/Juarez & Assoc.)	242,000	(2%)
TOTAL	$9,828,000	(100%)

1.2.5 Demonstration Chronology

Exhibit 1.5 presents a chronology of the Los Angeles AVM demonstration. The post-system-installation period of the demonstration is viewed for impact assessment purposes as having three phases:

Baseline Period	April 14, 1980 - September 14, 1980
Start-up Period	Sept. 15, 1980 - March 13, 1981
Test Period	March 16, 1981 - June 19, 1981

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[6] In addition to SCRTD, the transit districts represented were the Chicago Transit Authority, New York City Transit Authority, Seattle METRO, City of Cincinnati (and Queen City Metro), and the St. Paul (Minnesota) Metropolitan Transit Commission.

Exhibit 1.5

CHRONOLOGY OF THE LOS ANGELES AVM DEMONSTRATION

DATE	DEMONSTRATION EVENTS
	System Development and Installation
1977-1979	Hardware development by Gould, Inc. (Information Identification Division)
June 1979	Final selection of AVM test routes
August 1979	Installation of AVM computer equipment at SCRTD
December 4, 1979	Briefing concerning the AVM demonstration given to officials of the drivers' and mechanics' union
January 1980	Installation of AVM hardware on 200 buses completed. Software to track 200 vehicles completed.
March-April 1980	Installation of signpost transmitters completed. Shake-down period for automatic data collection.
	Baseline Data Collection
April 14, 1980	Automatic collection of evaluation data began for all four AVM routes
August 11-28, 1980	Two-week training sessions for the first six AVM dispatchers (familiarization continued through September 14, 1980)
	Start of Dispatcher Control of AVM Routes
September 15, 1980	Start of real-time control activities on AVM test routes 41, 83, and 89
December 10-21, 1980	Training sessions for two new AVM dispatchers
December 21, 1980	Two new AVM dispatchers assigned to weekday duties
	Final Test Period
March 16, 1981	Start of final test period
March 25, 1981	One new AVM dispatcher assigned to weekday afternoon duties
May 18, 1981	Start of use of in-vehicle displays on Route 41 buses
June 19, 1981	Last day of data collection for purposes of the impact assessment
September 1981	End of demonstration

1.3 GUIDE FOR THE READER

This summary report documents the demonstration implementation process of the Los Angeles AVM demonstration (Chapter 2) and presents results obtained in the analysis of each of the major AVM impact areas -- real-time control of bus operations (Chapter 3), emergency response and security (Chapter 4), and management information for planning and scheduling (Chapter 5). Experience gained in previous implementations of AVM systems in other transit organizations is described in Chapter 6. The final chapter summarizes the key findings concerning the AVM demonstration in Los Angeles, and presents the overall conclusions pertaining to the transferability of the results to other AVM users.

Several data sources have been used to support the impact assessment. SCRTD collected and compiled data regarding passenger wait times, emergency response times and crimes, and provided schedule information, statistical digests, and economic data. Information about the implementation process and other issues was derived from interviews and numerous conversations with SCRTD managers, surveys conducted among AVM-route drivers and dispatchers, and from studies by Wilson Hill Associates documenting AVM dispatcher training and performance. Schedule adherence and ridership data was collected and compiled for the AVM test routes by Gould, Inc., and for the control routes by Juarez and Associates, Inc. Traffic volume counts were obtained from the City of Los Angeles, Department of Transportation. Further information was gained in conversations with the TSC on-site manager of the AVM demonstration at SCRTD and the TSC evaluation manager.

2. IMPLEMENTATION ISSUES

2.1 ORGANIZATIONAL CONSIDERATIONS

The implementation of the AVM system at SCRTD was a complex undertaking requiring a high degree of organization and coordination within SCRTD. It also required consistent day-to-day management to coordinate the actions of the different organizations involved in the demonstration and to ensure adherence to the demonstration schedule as far as possible. In view of these requirements, a full-time project manager was clearly necessary.

Usually the host transit organization appoints one of its own employees to manage a demonstration project. However, because of the complex and technical nature of the project, SCRTD and TSC decided to place a technically-trained TSC on-site manager to be responsible for daily follow-through at SCRTD. The assignment of a TSC on-site manager was specifically warranted due to characteristics of the AVM demonstration in Los Angeles. First, the AVM system was a completely new technology for SCRTD; it required the installation of many different kinds of wayside, in-vehicle and central equipment. Therefore, many complex technical, procedural, and managerial aspects had to be coordinated at a certain level of detail. This task required a manager with up-to-date technical training, preferably with experience in real-time computer control. Second, in a situation where the employment of an additional professional person for a certain project becomes necessary, a transit operator may often find it difficult to make a permanent commitment by hiring new staff. Thus, the appointment of an on-site manager with experience in all aspects of the project -- a person who could be responsible for day-to-day management and coordination without representing an addition to the transit district's permanent staff -- appeared to be the most appropriate way to deal with the organizational aspects of the AVM demonstration.

2.2 MANAGEMENT ATTITUDE CHANGES DURING THE DEMONSTRATION

The previous section described the substantial degree of organization and cooperation at the managerial level at SCRTD that was required for a successful implementation of the AVM system. This organizational effort would hardly have been possible without a positive attitude toward AVM on the part of the managers affected by the AVM demonstration. To examine whether managers connected special hopes or expectations with AVM and whether those were met in the course of the demonstration, interviews with the managers of different SCRTD departments were conducted in November 1980, and June 1981. The topics addressed in these interviews covered the managers' perceptions regarding the various areas of AVM impact as well as the question of whether the AVM system should be expanded at SCRTD after the end of the demonstration period.

Comparing the responses of the first and second round of interviews, one finds that the overall positive attitudes seem to have remained largely unchanged, although some disappointment was expressed about different objectives of the demonstration that had not been fully realized by June, 1981. This experience caused a remarkable shift in the emphasis put on the different areas impacted by AVM. By the end of the demonstration, SCRTD management was principally interested in security and management information aspects, as they perceived limits to the amount of improvement in on-time service that could be achieved through real-time control. Most respondents were looking forward to the first AVM management reports; and disappointment was expressed only in connection with the malfunctioning of the passenger counter treadle mats which were in operation at the time. Many managers suggested that for the sake of enhanced security alone the AVM system should be extended, at least covering the city's high-crime area and the most crime-ridden routes. Exhibit 2.1 provides a synopsis of the interview responses of each manager for each of the AVM-related issues discussed in the following chapters.

2.3 DRIVER AND DISPATCHER ATTITUDES

2.3.1 Driver and Dispatcher Training and Assignment

The issue of the selection and special training of AVM dispatchers turned out to be of considerable importance in the assessment of AVM's effectiveness and potential. Unless drivers have in-vehicle displays, dispatchers are the first to put real-time information provided by the AVM system into active use.

Drivers and dispatchers were not assigned to AVM duty by management, but they obtained their assignments through SCRTD's normal bidding process: usually once every quarter, drivers and dispatchers are permitted to bid the shifts they want to work (drivers also bid route and run); once a year, drivers have the additional option of bidding for assignment to a different operating division. The outcomes of the bidding process are largely determined by the relative seniority of each driver or dispatcher.

For the drivers, the initial AVM equipment on buses did not cause any substantive changes in their work. After dispatchers were assigned to monitor and control the AVM routes, the drivers on those routes had to expect that they might be contacted by the AVM dispatcher relative to schedule deviations or service conditions, but they also knew that the dispatcher would be able to determine the location of their bus if it was in an emergency situation. AVM-training for the drivers consisted mostly of a short introduction about AVM and its effect on driver/dispatcher communication, and, much later in the demonstration (May 1981), a special short information session explaining the use of the in-vehicle display to drivers on Route 41.

Exhibit 2.1
VIEWPOINTS OF SCRTD MANAGERS CONCERNING AVM

AVM-Related Issues / SCRTD Departments	Main Interest and Global Attitude	Economic Aspects	Management Information	Security Aspects	Real-Time Control Aspects	Expansion of the AVM System
TRANSIT POLICE	Security — Attitude still very favorable	Security improvements considered to justify costs	AVM data considered useful in schedule planning	AVM seen to have tremendous potential to improve security	Improvements in schedule adherence expected to enhance security	Systemwide expansion favored for security reasons
MANAGEMENT INFORMATION SYSTEMS	Management Information — Attitude still positive	Cost-effectiveness expected through scheduling improvements	AVM data considered to have tremendous value	Positive impression of AVM's security aspects	Doubtful attitude about real-time control impacts	Expansion to high-crime routes or rotation among routes desirable
PLANNING DEPARTMENT	Management Information — Attitude still very favorable	Cost-effectiveness expected once required data is being generated	AVM data expected to be even more useful with passenger counters working	No statement	Improvements seen in spacing of buses (more uniform headways)	Rotation among lines desirable
INSTRUCTION DEPARTMENT	Schedule Adherence — Attitude still positive	Cost-effectiveness expected once schedule adherence is improved	AVM data expected to be useful in schedule planning and passenger loading	AVM expected to improve driver and passenger security	Better schedule adherence expected	Expansion considered to improve security
MAINTENANCE AND EQUIPMENT	Economic Aspects — Attitude rather negative than indefinite	Probably not cost-effective under present economic conditions	Doubts expressed about the helpfulness of AVM data	AVM's security benefits seen as overrated	Limitations to effectiveness seen (traffic)	No expansion within budget limitations
DISPATCHING CENTER	Security — Attitude still positive	No statement	No statement	Security considered AVM's best long-term benefit	Limitations to effectiveness seen (traffic)	Expansion to high-crime routes
OPERATIONS (RESPONDENT 1)	Security — Attitude still very favorable	No statement	Savings in operating costs expected with better scheduling	AVM's impact on security considered of great value	Control impacts seen as limited by uncontrollable factors (traffic)	Rotation among lines desirable
OPERATIONS (RESPONDENT 2)	Security — Attitude still indefinite	No statement	Savings in operating costs expected with better scheduling	Security a highlight of the AVM system	Benefits seen as still to be proved	No statement
ADMINISTRATION	Security — Attitude still very favorable	Security improvements considered to justify costs	Data expected to be useful for scheduling	AVM's security benefits seen as undisputed	No statement	Systemwide expansion, but at least to high-crime routes
SCHEDULING (RESPONDENT 1)	Management Information — Attitude still very favorable	Cost-effectiveness expected through scheduling improvements	Substantial potential seen in use of AVM data for scheduling	Security considered to warrant AVM systemwide	More dispatcher action necessary to realize effects	Systemwide expansion for security and data collection
SCHEDULING (RESPONDENT 2)	Management Information — Attitude still positive	Cost-effectiveness expected through scheduling improvements	AVM data will enable better long-range analysis	Security improvement considered one of AVM's main successes	Real-time control believed to be possible	Systemwide expansion needed to enhance security
TELECOMMUNICATIONS	Maintenance — Present attitude indefinite	No statement	No advantage seen without working passenger counters	AVM not considered to make a difference	No statement	No statement
ALL — DEPARTMENT SUMMARY	Security — Positive attitude	AVM economical because of security and scheduling	AVM data seen as valuable information for scheduling	Security benefits considered proven	Limits seen to the effectiveness of real-time control	Expansion to high-crime routes minimal

For the AVM dispatchers, however, the AVM system brought about changes in the shift schedule and major innovations of technology and working style.

Before the first bidding process in which AVM shifts were included (late summer 1980, for the September "shake-up"), all dispatchers potentially eligible to bid the AVM shifts were given a half to one hour introduction to AVM at the AVM console. However, it appeared that in this first and also in the successive shift shake-ups for dispatcher changes[1] the decision about bidding AVM shifts was not only based on the dispatchers' interest in the new technology, but also depended as well on the attractiveness of the AVM shift timings. Most non-AVM shifts include night and weekend duty, whereas the two main AVM shifts were basically day-time shifts (5AM-1PM and 1PM-9PM) with weekends free (duty only Monday through Friday). Thus, the principal AVM shifts were attractive even to dispatchers who were not very enthusiastic about using the AVM system. Consequently, the dispatcher control exercised on the AVM routes was characterized by variability among dispatchers in willingness to use the AVM system, and a generally low level of real-time control actions. The reference test period of the demonstration can therefore not be considered to be representative of the highest degree of impact on schedule adherence that can be achieved with the AVM system.

The training of AVM dispatchers was naturally more time-consuming than that of drivers. The first six dispatchers who had bid AVM shifts started their two-week training sessions on August 11, 1980. These introductory sessions used lecture-scripts, charts, slides and the manufacturer's manual for the AVM dispatching console as training materials. The manual proved to be a very effective reference for the dispatchers, although it was not in complete agreement with the AVM system as it operated at that time. Similar but shorter introductions at the AVM console were given to the respective new AVM dispatchers in December 1980, and March 1981. By then some concern had developed with respect to the low level of use of tactical control actions. Initially, training sessions had focused on the use of the new technology, but not on the choice between different control strategies. As a consequence, dispatchers had difficulties with diagnosing tactical situations and deciding on an appropriate sequence of actions.[2] Therefore, all AVM dispatchers were given on-the-job training sessions on tactics in March, 1981. The key emphasis in these sessions was put on maintaining the required headways between buses by concentrating on early and late buses, and interventions at the end of the route to enable the driver to depart from the next layover on time. These guidelines, however, do not reflect the full potential for tactical actions provided by the AVM

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[1] Shake-ups on September 14 and December 23, 1980 and June 14, 1981; one change in March, 1981 due to a senior dispatcher returning from sick leave.

[2] For a description of possible tactical situations and responses, see Section 3.1.

system.

2.3.2 Dispatcher Attitude Changes during the Demonstration

In order to gain more evidence about how AVM dispatchers felt regarding their work at the AVM console, and how their attitudes changed with increasing AVM experience, two rounds of surveys of dispatcher opinions were conducted in January and June, 1981. Each time, surveys were distributed through SCRTD, to all dispatchers with AVM exposure. The results are shown in detail in Exhibit A.1 in Appendix A.

A comparison of the two sets of survey responses allows the following conclusions: In general, the attitudes shown in the surveys vary strongly from dispatcher to dispatcher. Apart from the aversion toward the AVM system expressed by one of the dispatchers, none of the others viewed AVM as making their work more difficult. On the contrary, they all saw high potential in AVM as far as improved service was concerned, and expected the system to be accepted by bus operators. The only doubts were voiced in connection with AVM's potential for possible increasing ridership and cost-effectiveness. The majority of AVM dispatchers seemed to be generally in favor of the AVM system. This attitude, however, is not inconsistent with the low level of dispatcher control actions referred to by SCRTD managers (see Section 2.2). Instead, it indicates that this lack of activity was probably due more to the limited extent to which specific tactical responses had been developed and proven effective, than to disapproval of AVM on the part of dispatchers in general.

2.3.3 Driver Attitude Changes during the Demonstration

From the beginning of the demonstration, SCRTD managers had been very concerned about the drivers' possible reactions to real-time control actions by dispatchers. It was felt that drivers might perceive AVM as a surveillance tool and resent its implementation. Therefore, care was taken to inform the drivers and the labor unions about AVM's beneficial effects, such as enhanced security and assistance to the driver to maintain on-time service. In order to examine the drivers' perceptions of the AVM system and the degree of cooperation they were willing to show, surveys among drivers were conducted through SCRTD twice during the demonstration.

For the first survey in December, 1980, thirty AVM-route drivers with line-instructor status (ten from each of the three divisions with AVM buses) were given survey forms. All but five of these drivers returned completed surveys. It appears, however, that their more responsible status, together with the "optional" request to sign the survey with name and badge number, might have resulted in a survey outcome that was not necessarily representative of all drivers on the AVM routes. Therefore, in the second round of surveys in June, 1981, the questionnaires were distributed among a large and more randomly picked sample of AVM-bus drivers (20 out of each AVM division).

The following overall differences in attitudes toward AVM can be derived from the two sets of surveys, whose results are presented in detail in Exhibit A.2 in Appendix A. Many drivers commented on their main hopes related to AVM control. In both surveys, the majority of drivers focused on the importance of slowing down irresponsible drivers who run ahead of schedule (closely following the previous bus) in order to deal with as few passengers as possible and have long layover times. In the second survey, however, some drivers already complained that they saw no effect of AVM on those "sharp drivers." Some drivers also expressed their frustration about the directions given by the AVM dispatcher, which caused them to run late. Sometimes they had to keep a constant distance behind the leading bus (which was running late) or in some cases they were discouraged from building up time reserves between earlier stops in the run which they knew they would need later in the same run to reach their layover point on time. On the other hand, some drivers reported good experiences with the AVM system, e.g., in their opinion the spacing of buses had been improved, and their fellow-drivers seemed to be more responsible. Those drivers who had had experience with in-vehicle displays had divided opinions about their usefulness, probably due to the short time (about three weeks) they had been operating before the survey was conducted. In general, drivers did not appear too averse to the AVM system, but there were obviously a number of them who did not change their previous behavior very much in spite of dispatcher monitoring and control actions.

3. REAL-TIME CONTROL IMPACTS

3.1 INTRODUCTION

One of the major benefits expected from a transit operator's use of an AVM system is an improvement in the level of service offered to transit users without an increase (and perhaps with a decrease) in the material and human resources required. For the impact assessment of the demonstration, four indicators were chosen to examine the impacts of real-time control: schedule adherence, passenger wait time, passenger loadings, and the distribution of headways between buses.

Data describing schedule adherence and passenger loadings on the AVM routes were collected automatically by the AVM system. Gould started collecting this data on the four AVM routes in mid-March 1980. At that time only the leaders of the drivers' and mechanics' unions had been briefed on the AVM system and the demonstration project; no widespread diffusion of information concerning the AVM demonstration had been made by SCRTD to bus drivers, and no dispatchers had been assigned to work at the AVM console. In order to collect baseline data, the AVM system was operated in a passive, data-recording mode only for the first six months (i.e., March 17 - September 14, 1980). The managers of the demonstration felt, therefore, that the data collected prior to September 15, 1980, could be considered "uncontaminated" baseline data. From September 15, 1980 onwards, dispatchers exercised real-time control on AVM routes 41, 83, and 89. SCRTD announcement of the AVM project was made to employees in the September 3, 1980 edition of SCRTD's in-house newspaper, Headway. Automatic data collection on all four AVM routes continued unchanged to the end of the demonstration. The following table summarizes the AVM data collection schedule.

DEMONSTRATION COLLECTION AND PROCESSING OF AVM DATA		PERIODS DEFINED FOR DATA ANALYSIS	
Pre-Control Data Collection	March 17, 1980 – Sept. 14, 1980	July 21, 1980 – Sept. 14, 1980	Reference Baseline Period
Period of Real-Time Control	Sept. 15, 1980 – June 19, 1981	Sept. 15, 1980 – Dec. 20, 1980	First Start-Up Period
		Dec. 21, 1980 – March 15, 1981	Second Start-Up Period
		March 16, 1981 – June 19, 1981	Reference Test Period

Data pertaining to passenger wait times had to be collected manually. The wait-time data was recorded by checkers placed at one or two stops on the routes.

Naturally, the results of the analysis of real-time control impacts depend strongly on the amount and kind of dispatcher activity that occurred during the demonstration. AVM-related actions taken by AVM dispatchers generally dealt with four types of situations:[1]

- System errors. These were failures in hardware or software, such as a false silent alarm, an erroneous "late pull out" message, or a "hangup" of the AVM console keyboard.

- Coordination failures. These resulted from a lack of coordination between two or more groups at SCRTD, such as when a division dispatcher failed to enter a bus's route and run into the computer as the bus left the division.

- Disputed situations. In these cases there was a disagreement between the dispatcher and the bus operator concerning the status of bus operation, such as whether or not a bus was running early or had left a stop on time.

- Tactical situations. These were actual cases that required real-time control actions by the dispatcher, such as an early or a late bus.

During the demonstration, the time dispatchers could devote to real-time control measures was limited due to the fact that non-tactical AVM situations and activities not related to AVM accounted for almost 50% of their actions. These circumstances were most restrictive during peak periods.

Among the actual tactical situations, there were seven main problem areas that SCRTD dispatchers addressed using the AVM system: buses pulling out late from the division yard, early buses, late buses, stopped buses, overloaded buses, no bus found on route, and an emergency (silent alarm signal). Of these, early and late buses accounted for almost half of the cases examined by AVM dispatchers. Overall, the practice of contacting and instructing the bus operator was used extensively in most tactical situations. This approach reflects an emphasis on rather passive real-time control strategies. A reason for this behavior may be the fact that there was little consensus with regard to the "best" tactics to be utilized from case to case. As discussed above (see Section 2.3.1), the AVM dispatchers received training in the response to a tactical situation. However, this training was rather rudimentary, because there had been no high level of

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[1] Wilson Hill Associates, <u>Assessment of the Impact of Automatic Vehicle Monitoring on Bus Dispatchers</u> (Final Report), Boston, Mass., September 1981 (prepared for the U.S. Department of Transportation, Urban Mass Transportation Administration, under contract DTRS-57-80-C-00042).

development concerning the question of the most appropriate tactical response to each real-world trouble situation. Consequently, a week of discussions about real-time control actions in March/April 1981 revealed that there was no consensus among dispatchers as to which response to choose for specific situations, although they all followed the guidelines provided in Gould's manual developed for the control console.

This uncertainty about the proper use of real-time control tactics appears to be the main reason for a generally lower level of control activity than expected by the AVM project management. Other factors contributing to this situation were the high proportion of non-tactical problem situations requiring the dispatcher's attention (see above), and the fact that quite a few AVM dispatchers seem to have chosen the AVM-assignment because of its convenient shift schedule rather than because of a positive attitude toward the system.[2] A consequence of the low level of real-time control efforts is that the results gained from the data affected by dispatcher action can only be interpreted as suggestive, and certainly not as the best that real-time control might achieve. This limitation is important for the understanding of the following chapters in this report.

The balance of this chapter presents the results of the assessment of impacts related to real-time control. The specific topics addressed, in order, are the weekly variation and overall changes in schedule adherence, the effect of in-vehicle displays, and the changes in schedule adherence on the control routes. Exhibit 3.1 explains the abbreviations used for bus stops and defines the time blocks -- AM, Mid 1, Mid 2, and PM -- that are referred to in the material that follows.

3.2 PROFILES OF VARIATION IN SCHEDULE ADHERENCE ON AVM ROUTES

One of the most important objectives of using AVM in fixed-route transit systems is to improve schedule adherence. The graphical profiles shown in Exhibits 3.2 through 3.5 provide a first overview of the pattern over time of schedule deviations on AVM routes throughout the demonstration. On each profile, means and sample standard deviations of schedule deviation are plotted week-by-week for three bus stops in each direction, for the period from April 14, 1980 to June 19, 1981. Thus, each exhibit shows how schedule deviation on one of the AVM routes developed over the course of the demonstration during either the morning or afternoon peak. Additional figures of the same kind are presented in Exhibits A.3 through A.8 in Appendix A. Data for the first midday period turned out to be very similar to AM data, and midday 2 data resembled the PM peak, which is the reason for restricting the presentation of midday data mostly to the summary tables.

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[2] See Section 2.3.1 for details about the assignment process.

Exhibit 3.1

LIST OF ABBREVIATIONS FOR BUS STOPS AND TIME BLOCKS

AVM ROUTES

ROUTE 41

SBARB/FGROA	Santa Barbara Avenue & Figueroa Street
ALVRD/PICO	Alvarado Street & Pico Blvd.
ALVRD/SIXTH	Alvarado Street & Sixth Street
MONT/LBRTY	Montana Street & Liberty Street

ROUTE 44

ADAMS/LBREA	Adams Blvd. & La Brea Avenue
OLYMP/HILL	Olympic Blvd. & Hill Street
BVRLY/WSTRN	Beverly Blvd. & Western Avenue
BVRLY/LCNGA	Beverly Blvd. & La Cienega Blvd.
SMNCA/CANON	Santa Monica Blvd. & Canon Drive

ROUTE 83 (LOCAL AND LIMITED)

WILSH/WSTWD	Wilshire Blvd. & Westwood Blvd.
WILSH/FRFAX	Wilshire Blvd. & Fairfax Avenue
WILSH/WSTRN	Wilshire Blvd. & Western Avenue
7TH/MAPLE	Seventh Street & Maple Avenue

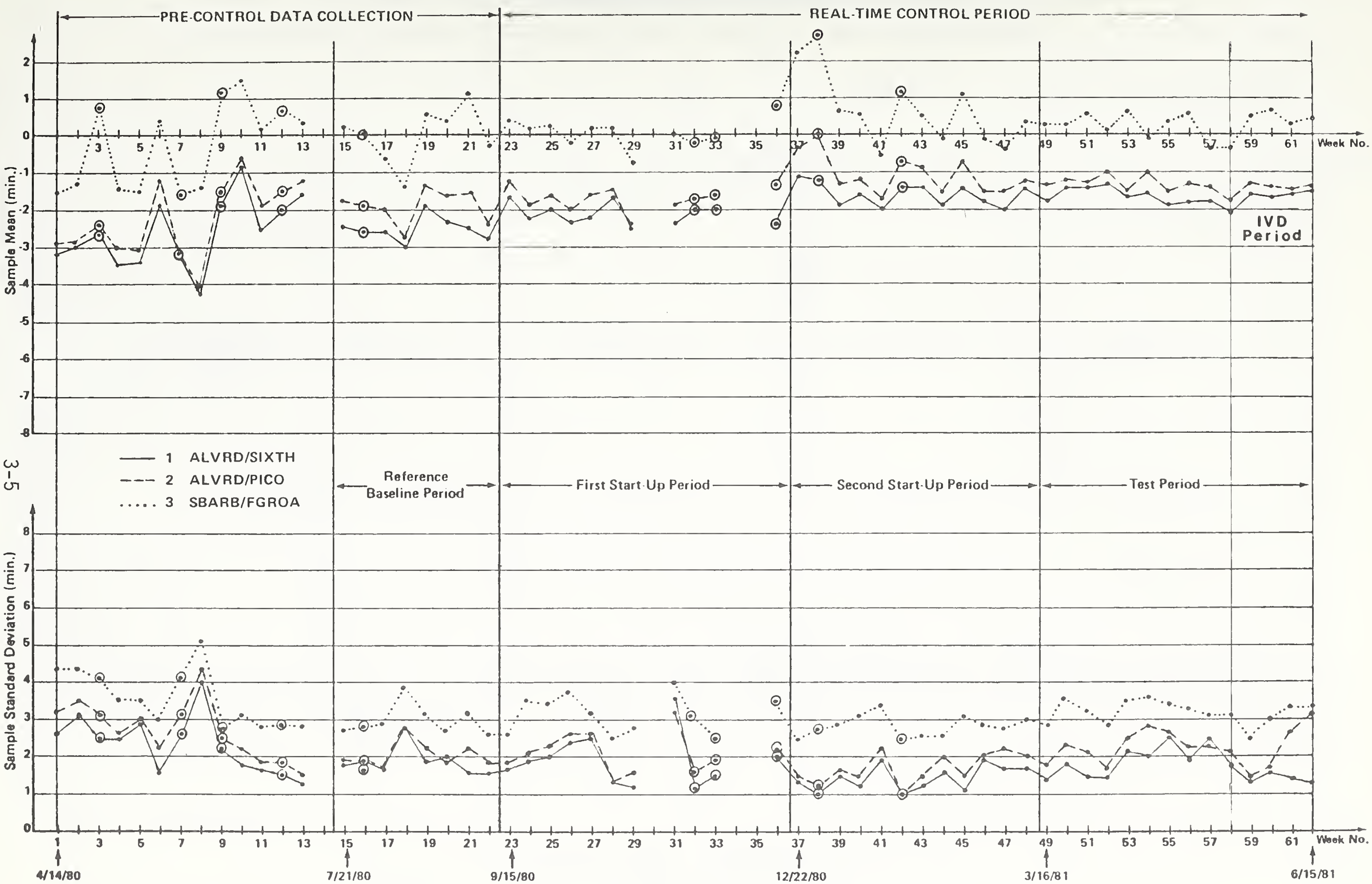
ROUTE 89

ADAMS/WASH	Adams Blvd. & Washington Blvd.
FRFAX/WILSH	Fairfax Avenue & Wilshire Blvd.
FRFAX/SMNCA	Fairfax Avenue & Santa Monica Blvd.
HWOOD/VINE	Hollywood Blvd. & Vine Street

TIME BLOCKS

A.M.	6:00 A.M.-8:30 A.M.
MID 1, MIDDAY 1	8:30 A.M.-1:00 P.M.
MID 2, MIDDAY 2	1:00 P.M. -3:30 P.M.
PM	3:30 P.M. -6:00 P.M.

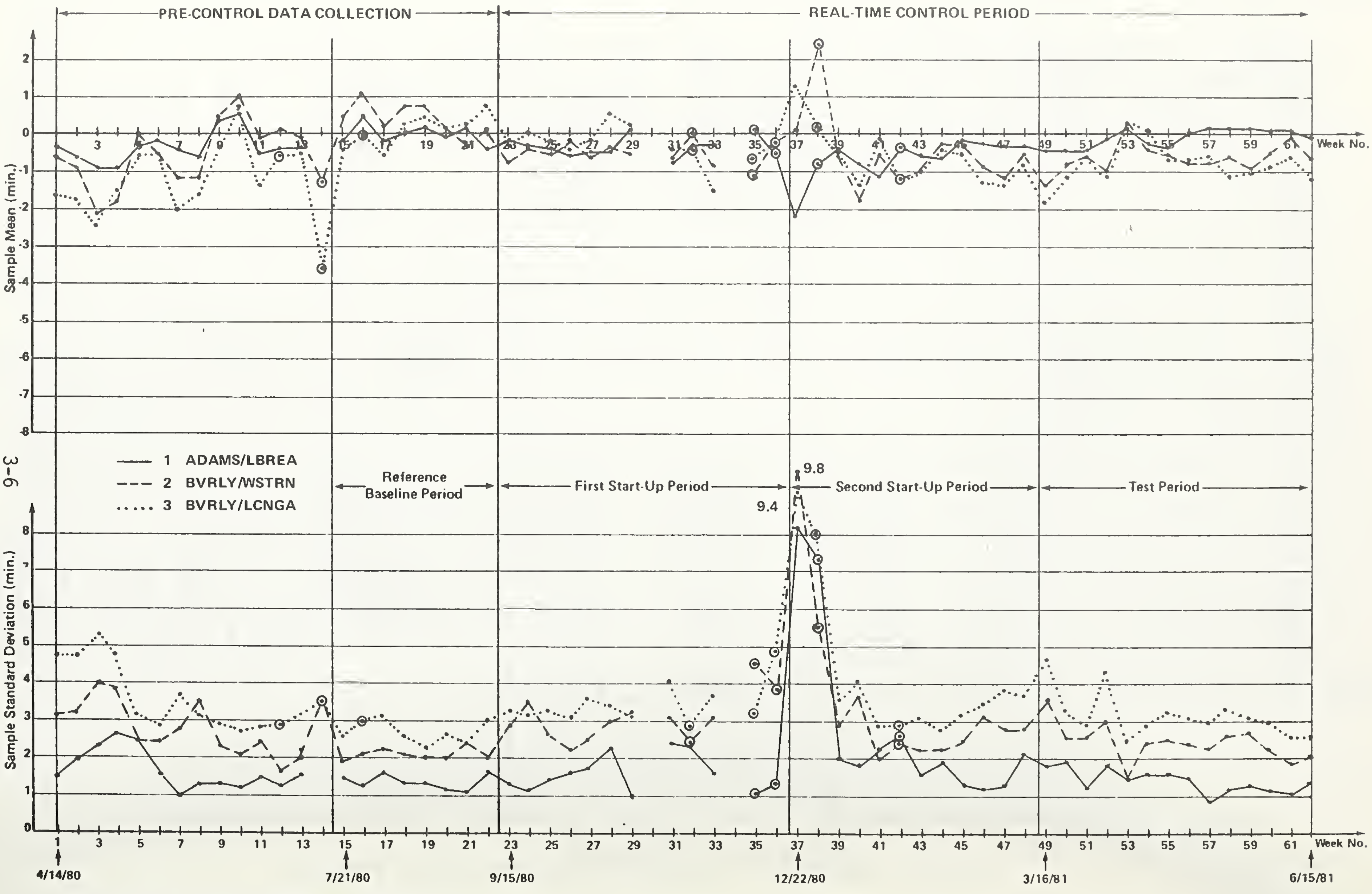
Exhibit 3.2. WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 41
(SOUTHBOUND – A.M. BLOCK)



Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

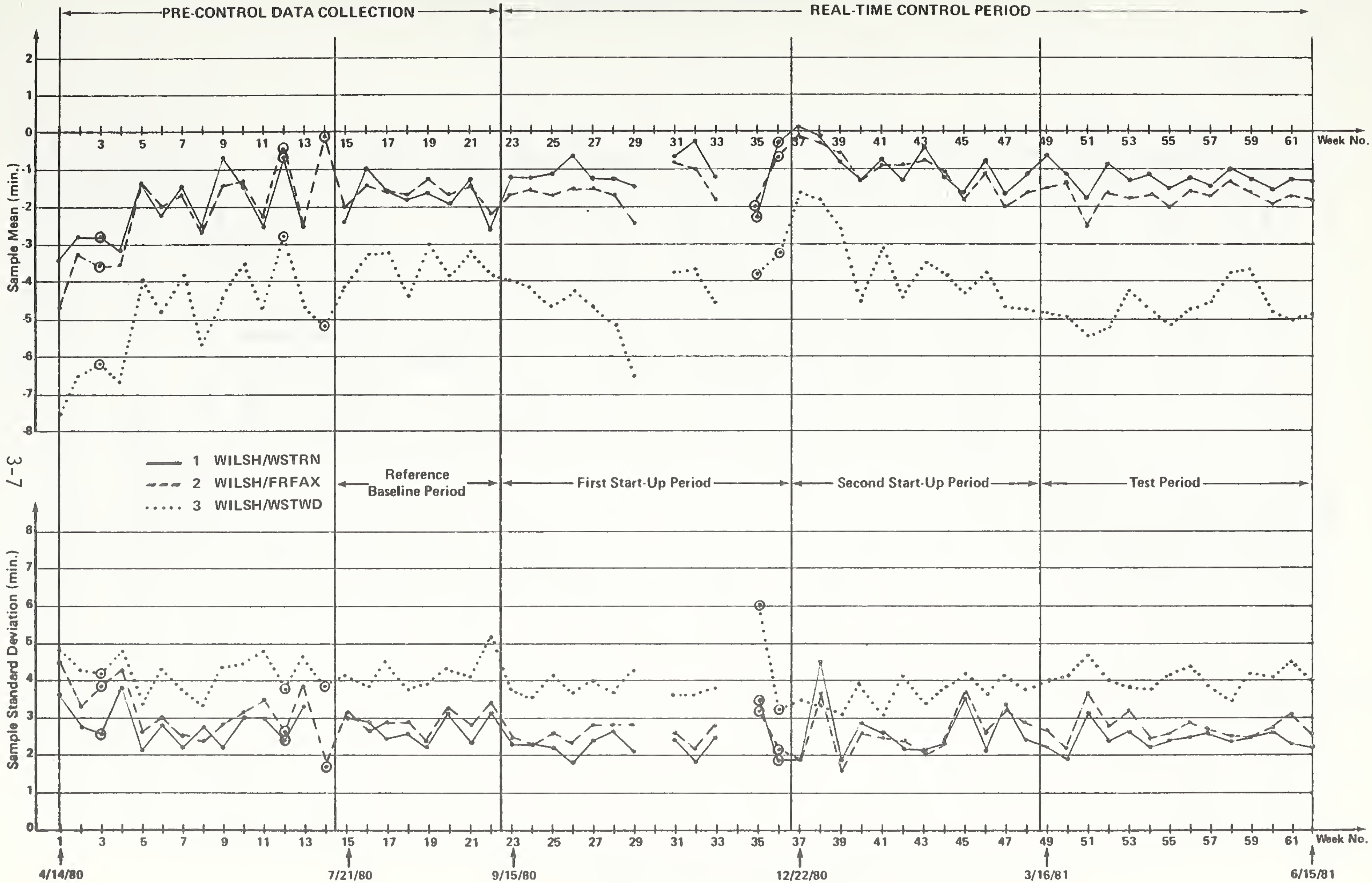
Exhibit 3.3

WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 44
(NORTHBOUND – A.M. BLOCK)



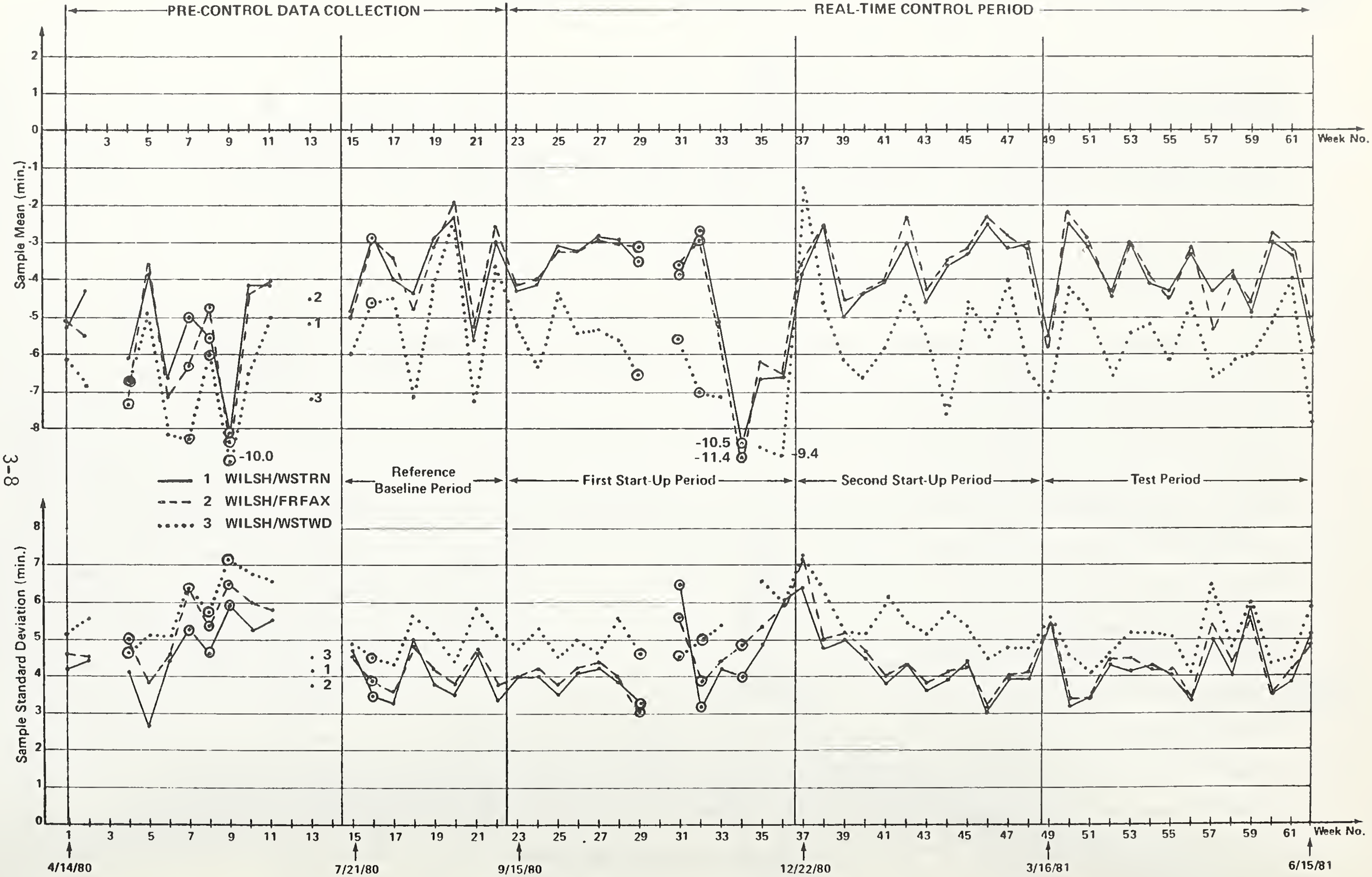
Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit 3.4 – WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 83 LOCAL (WESTBOUND – A.M. BLOCK)



Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit 3.5 — WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 83 LIMITED (WESTBOUND — P.M. BLOCK)



Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Before an interpretation of the profile graphs can be attempted, some of the limitations regarding the availability of (accurate) data have to be considered:

- Some weekly data points are missing or are based on extremely small sample sizes (largely due to planned and unplanned downtime of the AVM computer).[3]

- Some data points seem to differ substantially from the average trend. Several factors account for this discontinuity:

  - holiday traffic (Thanksgiving, Christmas, New Year),

  - possibly the use of outdated bus schedules in April through June, 1980, and the last two weeks in January, 1981,

  - missing and/or incorrect bus assignments at the division yard.

Of all these problems, the last one was the most serious. If the assignment of a bus is not entered into the AVM computer when the bus leaves the yard for its run, no data can be calculated for it.

Upon examining the weekly profiles for each of the AVM routes, one's general impression is likely to be that very little change in schedule adherence took place on the AVM routes over the course of the demonstration. Nevertheless, some degree of change occurred in various individual cases, both during and after the total period of pre-control data collection (April 14 to September 14, 1980):

- During the period of pre-control data collection, the mean schedule deviations (and to a lesser extent, standard deviations of schedule deviations) calculated from data generated by the AVM system became smaller in a few cases, e.g. on Route 41 and Route 83. This change in the direction of improvement appears to be attributable to some extent to two factors:

  - a resolving of the problem of wrong and missing assignments of buses (see immediately above), and

  - the informal diffusion of information about the AVM demonstration among drivers. Drivers may have become aware of being monitored, especially on such a small route as 41, and they may have improved their performance simply because they knew they were the object of attention (the well-known Hawthorne effect) or because they wished to avoid disciplinary measures.[4]

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[3] For purposes of the demonstration, no backup computer was deemed necessary.

[4] During the demonstration, though, no disciplinary action at all was taken against drivers in order not to jeopardize their acceptance of the AVM system.

- Following the profiles of weekly variation from left to right from the reference baseline to the test period, one notes some apparent changes over time on some of the routes:

  - the average schedule deviation on Route 41 (Southbound) appears improved in the AM block by almost one minute at Alvarado/Sixth (Stop 1, near the first third of the line) and by about one-half minute at Alvarado/Pico (Stop 2, near the second third of the line); in the PM block the only change apparent from the profile is at Santa Barbara/Figueroa (Stop 3, end of the line), where on average buses ended their runs less early.

  - the average schedule deviation on Route 44 (Northbound), which was not exposed to dispatcher real-time control, in the AM block showed a shift at Stops 2 and 3 (Beverly/Western and Beverly/La Cienega, respectively) from a fraction of a minute early to a fraction of a minute late; in the PM block, the average schedule deviation at Stop 1 (Adams/La Brea) showed about a 0.4-minute shift closer to on-time performance, at Stop 2 a shift to running later with higher variability, and at Stop 3 a shift from early to late (as with Route 41) and an increase of about 1 minute in the standard deviation of schedule deviation.

  - the average schedule deviation on Route 83 Limited (Westbound) in the AM time block shows an upward jump of about one minute at stops 1 and 2 (7th/Maple and Wilshire/Fairfax, respectively) after week 29; this change from an average of about 2 minutes late to an average close to one minute late appears to be the result of a schedule change on November 9 that added one minute to the running time from the Maple St. yard to 7th and Maple. Toward the end of the assessment period, however, the schedule deviation curve exhibits a drift back toward 2 minutes late.

As this week-by-week presentation of changes in schedule deviation could not reveal any overall trend for the demonstration, numerical summaries for the baseline, start-up, and test periods are discussed in the next section.

3.3 OVERALL CHANGES IN SCHEDULE ADHERENCE ON AVM ROUTES

Comparing data aggregated for each of the four demonstration periods eliminates some of the confusing variability present in daily and weekly data, but still the results are only indications of changes, not convincing proof.

The arrow diagram of Exhibit 3.6 shows graphically the changes in means and standard deviations of schedule deviation -- averaged over three stops and both directions -- for each AVM route between the reference baseline (pre-control) and reference test periods. Arrows turned upward indicate improvements in schedule adherence, arrows turned

Exhibit 3.6

SCHEDULE DEVIATION ON AVM ROUTES: COMPARISON BETWEEN THE BASELINE AND TEST PERIODS

	A.M.		MIDDAY 1		MIDDAY 2		P.M.	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Route 41	B: –1.13 T: –0.81 ▴	B: 2.23 T: 2.11 •	B: –1.62 T: –1.00 ▲	B: 2.51 T: 2.09 ▲	B: –1.17 T: –1.22 •	B: 2.24 T: 2.19 •	B: –1.37 T: –1.78 ▼	B: 2.74 T: 2.66 •
Route 44	B: 0.04 T: –0.35 ▾	B: 2.19 T: 2.34 •	B: –0.98 T: –0.53 ▲	B: 3.26 T: 3.03 ▴	B: –0.46 T: –0.81 ▾	B: 2.93 T: 3.54 ▼	B: –0.50 T: –1.17 ▼	B: 3.12 T: 3.99 ⯆
Route 83 Local	B: –1.09 T: –1.46 ▾	B: 2.76 T: 2.78 •	B: –2.45 T: –2.22 ▴	B: 3.74 T: 3.48 ▴	B: –2.78 T: –1.54 ⯅	B: 4.19 T: 3.86 ▴	B: –2.11 T: –2.34 ▾	B: 4.37 T: 3.94 ▲
Route 83 Limited	B: –1.81 T: –2.09 ▾	B: 3.13 T: 2.75 ▴					B: –3.74 T: –3.53 ▴	B: 4.39 T: 4.09 ▴
Route 89	B: –0.07 T: –0.65 ▼	B: 1.71 T: 1.80 •	B: –0.80 T: –1.18 ▾	B: 2.55 T: 2.41 •	B: –0.59 T: –1.44 ⯆	B: 2.52 T: 2.82 ▾	B: –0.48 T: –0.78 ▾	B: 2.50 T: 2.41 •

Legend:

Improvement		Deterioration
•	No change	•
▴	0.2 < 0.4 min.	▾
▲	0.4 < 0.7 min.	▼
⯅	> 0.7 min.	⯆

B: Baseline value (in min.)

T: Test value (in min.)

All respective sample sizes are larger than 1,200 cases downward stand for deteriorations. Any change of less than 0.2 minutes (12 seconds) was defined as "no change" in view of data round-off to tenths of a minute and the general level of data inaccuracy. As becomes evident from the exhibit, most of the changes between the reference baseline and test periods stayed within a range of 0.2 to 0.4 minutes, or 12 to 24 seconds. The only change of more than 1 minute occurred on Route 83 Local in the Midday 2 period, where average schedule deviation improved from -2.78 to -1.54 minutes. Overall, Routes 44 (the uncontrolled AVM route) and 89 showed generally worse adherence to schedule in the test period, whereas Routes 41 and 83 seem to have improved during the same period.

Schedule adherence, however, cannot be examined in isolation. The degree of schedule deviation at any point along the route depends - apart from general conditions - on the schedule deviation with which a driver leaves the last layover point, and on the running time provided in the schedule. On the average, buses in the test period started their run about 0.2 to 0.5 minutes less late, but only Route 89 showed an average increase in lateness at the first timepoint. The scheduled running time was only changed in three instances: one minute was added to southbound runs on Route 44, and to westbound runs on Route 83 in the afternoon; four minutes in total running time were added to Route 83 Limited in the westbound direction during the morning. This 4-minute change is the only scheduling change with a visible effect on schedule deviation by the end of the run where average lateness decreased by 1.4 minutes. About two-thirds of the added running time, then, was used up during the run. Thus, comparisons of schedule deviations in this chapter should be viewed as net results of different factors coming together, rather than pure effects of real-time control.

Supplementary information to these global results is given in Exhibit 3.7 which differentiates between directions and the morning (i.e., AM plus MIDDAY 1) and afternoon (i.e., MIDDAY 2 plus PM) blocks, and gives additional data describing the two start-up periods. Aggregate results for the three routes subject to dispatcher control (41, 83 and 89) are shown at the bottom of the exhibit.

Based on this table, a number of observations can be made:

- In general, schedule adherence deteriorates on all AVM routes during the progression of the day (from A.M. to P.M.).
- On Route 41, the difference in schedule adherence between the two directions of the route, seems to be linked to rush-hour traffic patterns. On the other routes, however, schedule adherence is usually worse in one direction throughout the day (e.g., westbound for Route 83, southbound for Routes 44 and 89).
- As far as the development in the course of the demonstration is concerned, there is no apparent and continuous trend toward improvement. The global baseline-test difference of 0.07 minutes (4.2 seconds) greater average lateness and a decrease in standard deviation of schedule deviation by 0.1 minute (6 seconds) are

Exhibit 3.7

EVOLUTION OF SCHEDULE DEVIATION ON AVM ROUTES

	Demonstration Period							
	Baseline		Start-up 1		Start-up 2		Test	
	$\bar{x}$*	s*	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Route 41								
A.M.*** Northbound	−1.59**	2.30	−1.55	2.03	−1.15	1.97	−1.04	1.91
A.M.*** Southbound	−1.28	2.51	−1.26	2.36	−0.86	2.18	−0.83	2.28
P.M. Northbound	−1.27	2.40	−1.27	2.12	−1.60	2.68	−1.31	2.28
P.M. Southbound	−1.26	2.58	−1.70	2.61	−1.86	2.74	−1.68	2.57
Route 44								
A.M. Northbound	−0.55	2.92	−0.63	3.21	−0.47	2.90	−0.36	2.82
A.M. Southbound	−0.41	2.65	−0.74	2.84	−0.63	2.63	−0.53	2.61
P.M. Northbound	−0.44	2.91	−1.17	3.68	−0.69	3.73	−0.96	3.77
P.M. Southbound	−0.52	3.13	−1.41	3.86	−1.18	3.83	−1.05	3.81
Route 83 Loc.								
A.M. Eastbound	−0.53	2.86	−0.58	2.68	−0.79	2.85	−0.83	2.79
A.M. Westbound	−3.68	4.07	−3.00	3.54	−2.99	3.82	−3.26	3.79
P.M. Eastbound	−1.80	4.02	−1.07	3.46	−0.24	3.56	−0.28	3.45
P.M. Westbound	−3.41	4.47	−3.13	4.08	−2.98	3.94	−3.43	4.30
Route 83 Ltd.								
A.M. Eastbound	−0.06	2.46	−0.64	2.27	−0.60	2.11	−0.57	2.07
A.M. Westbound	−2.94	3.49	−3.26	3.44	−2.81	3.32	−3.09	3.12
P.M. Eastbound	−3.44	4.07	−3.17	3.80	−1.97	3.11	−2.57	3.57
P.M. Westbound	−3.99	4.64	−4.77	4.83	−4.56	4.52	−4.43	4.51
Route 89								
A.M. Northbound	−0.21	2.27	−0.65	2.14	−0.91	2.18	−0.70	2.26
A.M. Southbound	−0.78	2.22	−1.17	2.13	−1.48	2.33	−1.27	2.16
P.M. Northbound	−0.50	2.37	−0.98	2.59	−1.11	2.64	−0.96	2.59
P.M. Southbound	−0.58	2.66	−1.11	2.67	−1.41	2.83	−1.28	2.66
Rts. 41,83,89								
A.M.	−1.49	2.96	−1.53	2.74	−1.57	2.87	−1.59	2.82
P.M.	−1.89	3.53	−1.96	3.38	−1.80	3.39	−1.86	3.42
All Day	−1.63 (n=35,995)	3.17	−1.70 (n=52,464)	3.01	−1.66 (n=49,036)	3.09	−1.70 (n=86,438)	3.07

*$\bar{x}$ = Mean schedule deviations; s = standard deviation of schedule deviation.

**In minutes; all sample sizes larger than 700 cases

***In this exhibit only: A.M. = A.M. + MID 1, P.M. = P.M. + MID 2 statistically significant, but these differences cannot be interpreted either as due to AVM or as an operationally "significant" change in the level of service on this set of AVM routes.

However, comparing the period-to-period changes by route, there seems to be a connection between changes in schedule adherence and the amount of dispatcher action allocated to the specific route in each period. Generally, dispatchers were faced by different kinds of problem situations in the morning and afternoon shifts: the morning shifts were characterized by AVM system errors and RTD coordination failures (resulting in "late pull out" and "no bus" problems), whereas the afternoon dispatchers had to deal primarily with tactical situations ("early" and "late" buses). Also, dispatchers had to resolve different problem situations for each of the three controlled routes, and devoted markedly different amounts of time to each among them:[5]

Route	% of Dispatcher Action Received	Major Problem Areas
41	5%	Late Pull Out Stopped Bus
83	77%	Early Bus Late Bus
89	18%	Early Bus Late Bus Emergency

The problems occurring on Route 41 are mainly caused by system errors and lack of coordination in the morning block, and it appears that the morning dispatchers could effectively correct these situations, as schedule adherence improved on Route 41 during the AM block (both in means and standard deviations). The afternoon dispatchers concentrated mainly on the tactical situations developing on Route 83 -- obviously successfully with regard to eastbound buses, but without apparent influence on westbound buses. Routes 41 and 89 showed the same decline in schedule adherence during the afternoon. The reasons for the varying degrees of success associated with either coordination or tactical situations (i.e., "late pull out" versus "early/late buses") seems to lie in the way in which dispatchers respond to early or late buses. First, dispatchers have different personal priorities regarding the decision whether to put more emphasis on contacting early or late buses. Second, dispatchers differ according to their definition of when a bus is early or late enough to require a control action. It seems that, on the average, dispatchers contacted the bus driver when a bus was running about 4 minutes ahead of schedule, or about 16 minutes late. Among individual dispatchers, the mean lateness of buses contacted for being late ranged from 10 to 20 minutes. Once a bus is so far off schedule,

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[5] Data obtained from Wilson Hill Associates, op. cit.

however, the tactical response of contacting and instructing the driver to discharge passengers only, can not be expected to remedy the situation completely within the same run.

These findings suggest that the results of the baseline-test comparisons of means and standard deviations of schedule deviation have to be interpreted in the light of the degree of dispatcher action addressed to each tactical situation. The "late-pull-out" problems characteristic of Route 41 in the morning could apparently be resolved, but the average lateness of buses running in the afternoon increased in most cases.

Similar individual trends as observed among the overall data points can be seen in a week-by-week analysis of the means and standard deviations of schedule deviation. However, these changes did not reveal any overall trend for the demonstration period and are therefore not included in this presentation.

Means and standard deviations do not tell the entire story, however. Additional insights into what happened on AVM routes are gained by investigating the distribution of schedule deviations. Exhibits 3.8 through 3.10 and A.9 and A.10 in Appendix A present the percentages of early, on-time (within 3 minutes of schedule),[6] and late buses along the AVM routes in both the baseline and test periods, grouped by time of day (AM or PM), direction, and bus stop. For each individual route, the shifts in the distribution of early, late and on-time buses between the baseline and test periods can be summarized as follows:

- On Route 41, fewer buses ran early northbound in the morning, and in both directions in the evening. The relative number of late buses decreased among southbound buses in the morning, but it increased in the afternoon, especially among southbound buses. This pattern explains the improvement of schedule adherence observed for the morning block, and the slight deterioration observed for the afternoon.

- On Route 44, the uncontrolled AVM route, a similar trend can be observed: generally fewer buses more than 3 minutes early, and more buses over 3 minutes late. Exceptions to this rule are buses at the beginning of the line in the PM peak period, where the opposite shift to more early and fewer late buses occurred.

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[6] Although for the AVM displays a bus was indicated as on time (green indicator) if it was not more than 3 minutes late or more than 2 minutes early, the data available for analysis was summarized by two-minute intervals with odd-numbered boundaries (e.g., 1 to 3 minutes early, between 1 min. early and 1 min. late, and 1 to 3 minutes late).

Exhibit 3.8

COMPARISON BETWEEN BASELINE AND TEST PERIODS OF THE PERCENT OF BUSES EARLY, ON-TIME, AND LATE: ROUTE 41

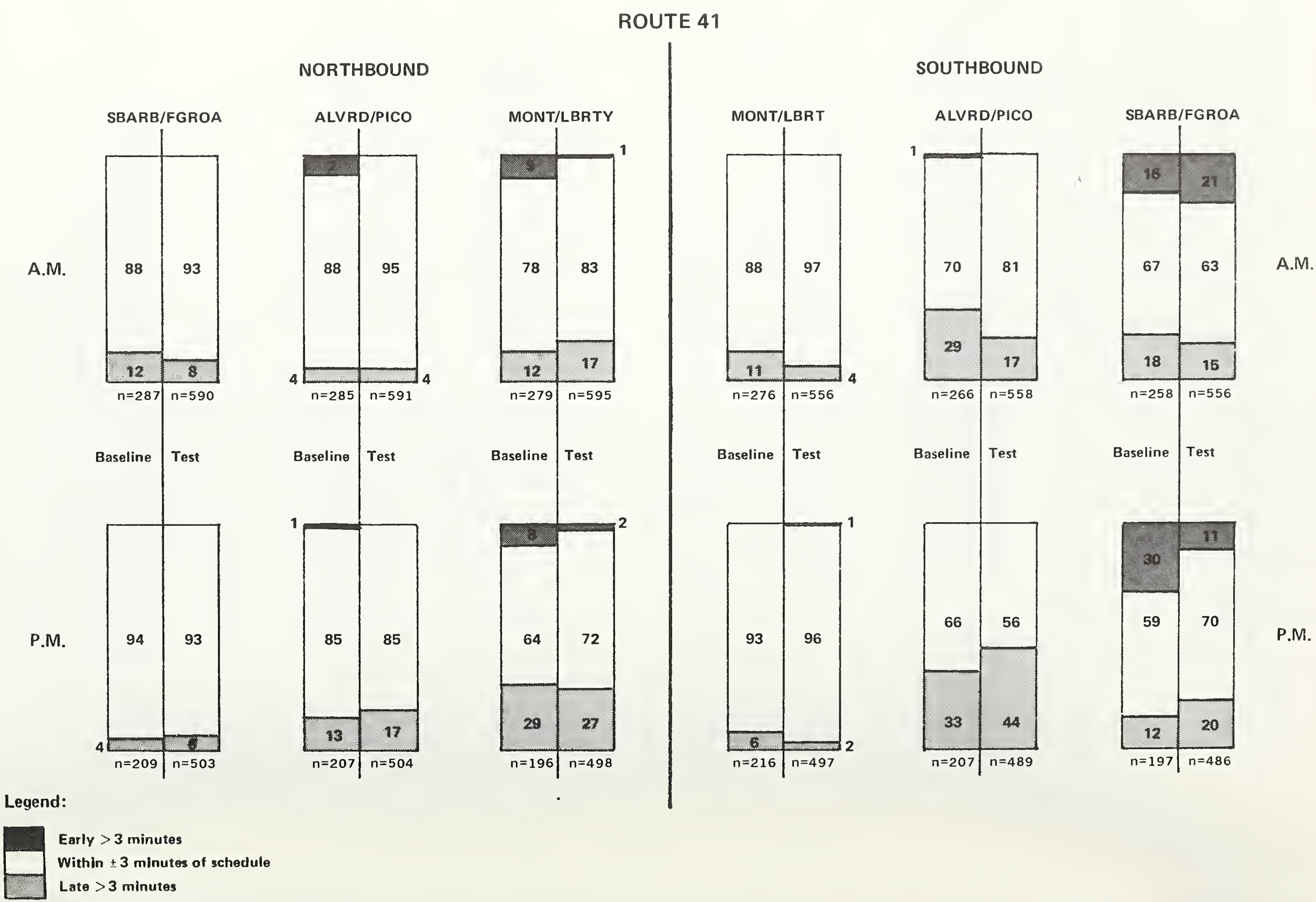


Exhibit 3.9

COMPARISON BETWEEN BASELINE AND TEST PERIODS OF THE PERCENT OF BUSES EARLY, ON-TIME, AND LATE: ROUTE 44

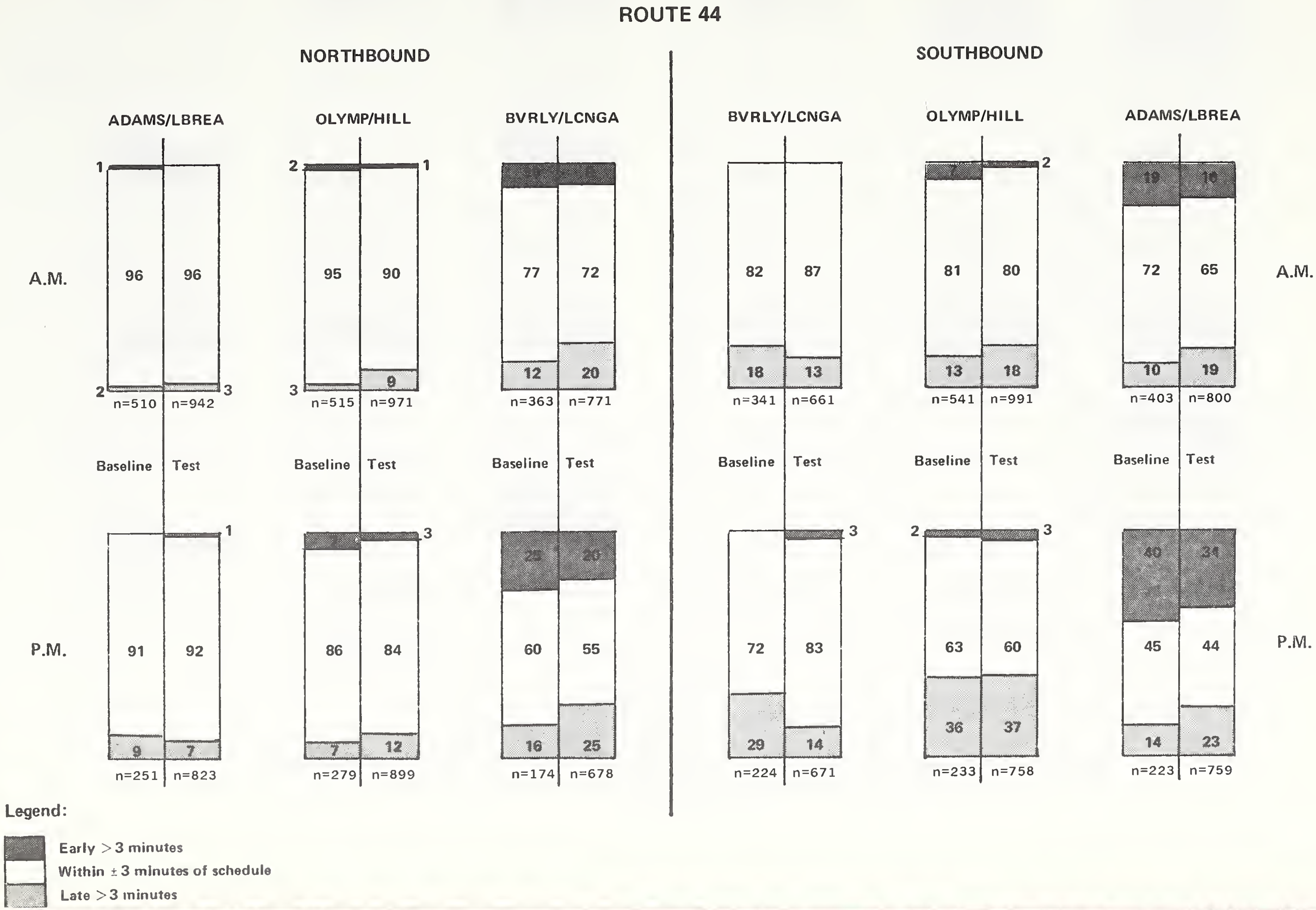
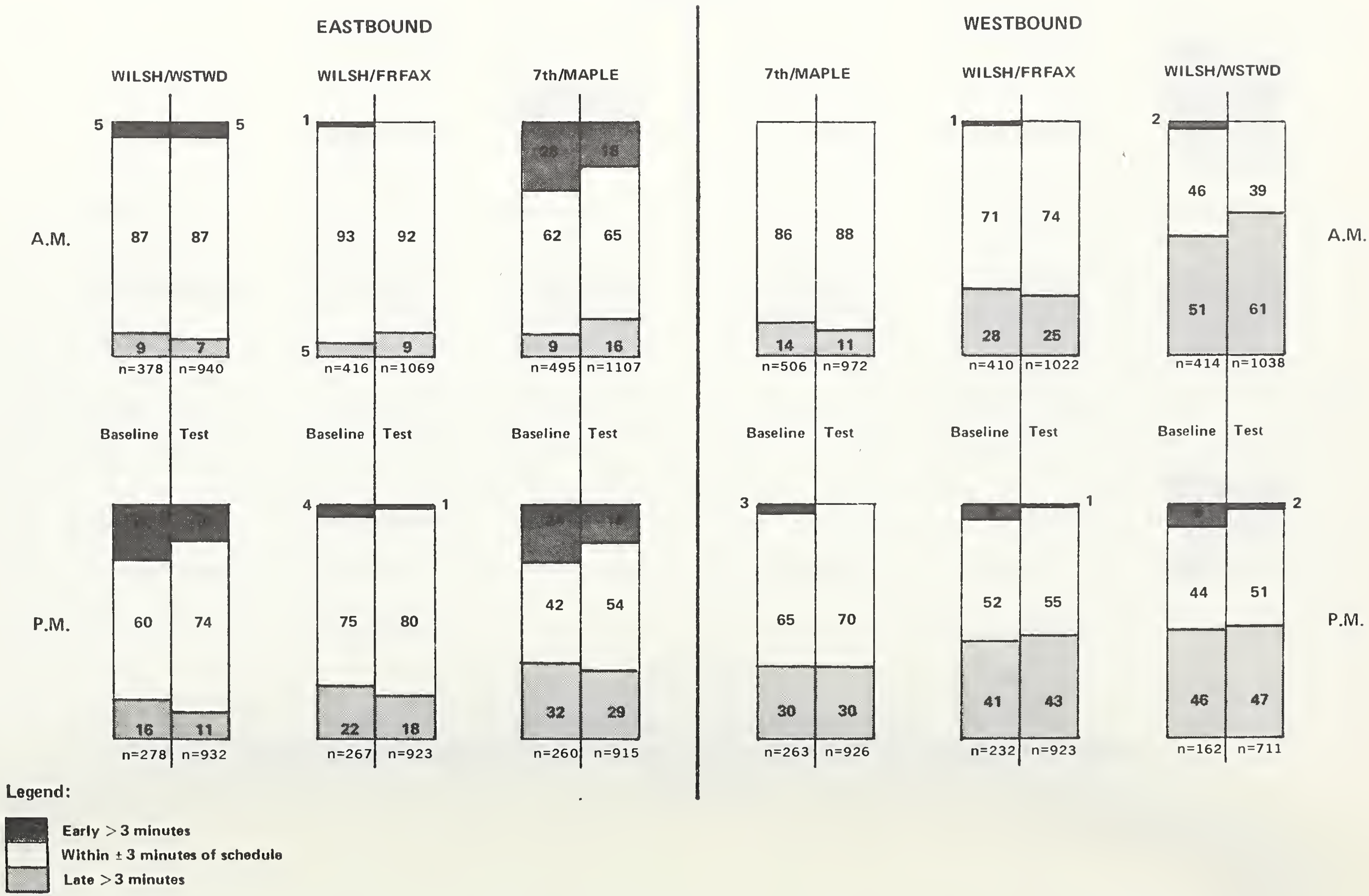


Exhibit 3.10

COMPARISON BETWEEN BASELINE AND TEST PERIODS OF THE PERCENT OF BUSES EARLY, ON-TIME, AND LATE: ROUTE 83 LOCAL



- Among local buses on Route 83, the overall distribution changed toward a larger share of on-time buses (at 9 out of the 12 places for which data was compared). The percentage of early buses declined throughout the route. The share of late buses generally increased in the morning, whereas it decreased among eastbound buses and remained almost constant for westbound buses in the afternoon. This development is consistent with the improvement of schedule adherence observed for eastbound buses in the PM block, and the increased lateness of buses in the same direction during the morning blocks.

- The results for Route 83 Limited reveal the same shifts as described for Route 83 Local. Considering the remarkably low share of on-time buses at the end of the line (at the eastern end, 42% in the afternoon, and at the western end, 25% in the morning and 33% in the afternoon), it seems that traffic conditions and other factors can hardly be overcome by real-time control on this route (an adjustment of scheduled running times would seem to be indicated).

- In most of the cases presented for Route 89, the percentage of early buses declined, with a parallel increase in the share of late buses, leaving the number of buses running on-time largely unchanged. Consequently, the mean values of schedule deviation shifted downward to increased lateness.

Thus, the general trend on all AVM routes appears to consist of late buses replacing early buses in the distribution, causing the overall level of schedule adherence to shift toward increased lateness. This trend was not followed in some cases, e.g., on Route 83 in the afternoon (especially for eastbound buses) and on Route 41 in the morning. Considered together with earlier findings in this section, the results for Route 41 and 83 seem to indicate an effect of dispatcher control actions.

The extent to which overall schedule adherence improved on AVM routes as a result of the use of the AVM system was not sufficient to induce measurable secondary effects. The analyses of headway distribution ("bus bunching"), passenger loading, and passenger wait times at bus stops did not reveal consistent and significant changes and are thus not included in this presentation.

3.4 EFFECT OF IN-VEHICLE DISPLAYS

An in-vehicle display (IVD) unit consists of a digital clock, a schedule meter, and a message status panel (recall Section 1.3.2). The clock shows the official "system time", and the needle on the schedule meter indicates to the driver automatically and continuously whether he or she is early, on time, or late.

The actual evaluation period for the in-vehicle display units (in the following referred to as the "IVD period") was five weeks (May 18, 1981 to June 19, 1981), and not all buses assigned to Route 41 were IVD-equipped during that time. Therefore, only little experience could be gathered about the effects of IVDs on driver performance.

In Exhibits A.11 and A.12 in Appendix A, schedule deviations on Route 41 are presented for both the pre-IVD phase (March 16, 1981 to May 8, 1981) and the IVD phase (May 18, 1981 to June 19, 1981) of the reference test period. Separate graphs for each of the four time blocks (AM, Midday 1, Midday 2, PM) show the means and standard deviations of schedule deviation at each of four bus stops for both directions along Route 41.

Comparing the values of means and standard deviations of schedule deviation for the pre-IVD and IVD periods, one can observe some substantial improvements (changes at a 5% or better level of statistical significance were usually on the order of 0.5 to 1.0 minute). There were only six significant changes in the means of schedule deviation, most of them recorded for northbound buses in the Midday 1 and PM blocks. The changes in standard deviations of schedule deviation were by far more pronounced. For northbound buses, standard deviations decreased in almost all instances (only two exceptions). For southbound buses, improvements could be observed very early in the route during the AM and PM blocks, and rather toward the middle and end of the route during the Midday blocks.

One possible explanation for this improvement in the standard deviations of schedule deviations is that after the activation of the IVDs most of the drivers were consistently adjusting their driving to the same time, i.e., SCRTD system time, by using the digital clock in the IVD instead of their watches. In the second AVM driver surveys, almost half of all drivers with IVD-experience mentioned that they considered it helpful to use the IVD clocks with correct line time. However, one driver mentioned that the periodic time checks -- in which a dispatcher announces the correct system time on the bus radio once every 30 minutes -- kept him on system time just as well as the IVD, which might be generally the case for most drivers.

Another explanation for the greater stability of schedule deviations is suggested by the results of the same pre-IVD-period versus IVD-period comparison of Route 44 data. Schedule deviations on Route 44, which was not controlled by dispatchers or by IVD's, improved as well, especially in the morning time blocks (not as much in the afternoon). This development parallel to the changes on Route 41 suggests that some seasonal or other factors unrelated to AVM may have caused the observed tendencies at least in part.

To supplement these global findings with more detailed data, a separate analysis was conducted for buses running in the AM time block. Run by run, the schedule deviations for all northbound Route 41-buses monitored by the AVM system were tabulated for the entire IVD period. In this category, a total of 235 buses was observed, with 179 of them

(76%) equipped with an IVD. Thus, during the IVD evaluation period, on average, each driver was assigned an IVD bus about three out four times. In the analysis, some tentative trends became evident:

- On average, IVD-equipped buses started more on time (probably with the help of the "start" message the IVD gives at the beginning of the line), then did not run as far ahead of schedule between the first and second stops (probably due to the "wait" message for early buses), and ultimately fell further behind schedule toward the end of the line, as they lacked some of the time reserves they used to build up before the second stop.

- Drivers were affected by the IVD in different ways. Some drivers completed their run later than before, which may reflect a strong concern about running early. Others were obviously more anxious not to fall behind schedule, s their runs ended up early instead of late as before. Some drivers managed to maintain better on-time service.

In general, no final conclusion about the potential cost-effectiveness of in-vehicle display units can be drawn.[7] There seem to be some trends related to requirements of the route, the behavior of individual drivers, or seasonality and other factors, but the period of IVD-use during the demonstration period was not long enough to determine the validity of these trends.

3.5 COMPARISON OF CHANGES IN SCHEDULE ADHERENCE BETWEEN AVM AND CONTROL ROUTES

The initial evaluation plan developed by SYSTAN, Inc.,[8] specified the collection of schedule-adherence and passenger-load data on control routes selected to match as closely as possible the demonstration AVM routes. Four control routes (84, 4, 91, and 94) were selected as matches to the AVM routes in terms of general location, configuration, length of route, direction (e.g., north-south, or east-west), headway,

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[7] It does appear clear, however, that a dashboard clock displaying the correct system time would be a generally accepted and positive factor for bus operations.

[8] SYSTAN, Inc., 1978, op. cit.

and number of buses.[9] Exhibit A.13 in Appendix A shows the locations of the control routes in relation to the AVM routes.

The control routes were checked twice during the demonstration -- before and after AVM was used for real-time control -- to determine if factors unrelated to AVM were influencing the demonstration's results. Schedule adherence and passenger load data for buses on the four control routes had to be collected manually. Since having an observer on-board runs the risk of influencing the driver's behavior, observation by checkers stationed at bus stops was chosen as the means to gather the data. Checkers positioned at three timepoints along each route recorded the route, bus number, run number, bus departure time, and the estimated number of passengers on board for buses running in both directions.

The baseline data for the four control routes was collected weekdays from 7:00 AM to 6:00 PM during the period April 15 - May 2, 1980. Test period monitoring was conducted during the time from April 20 - May 8, 1981, a week later than in the preceding year to avoid distortions caused by Easter traffic. As before, data was collected on weekdays only, from 7:00 AM to 6:00 PM (on some days until 7:00 PM to gather additional afternoon peak data).

The global results of the analysis of schedule deviations on control routes were compared with AVM-route data for comparable two-week periods (see Exhibit A.14 in Appendix A). On the four control routes, schedule adherence worsened between mid-spring 1980 and mid-spring 1981: mean schedule deviation went from -1.28 minutes to -1.89 minutes, and the standard deviation of schedule deviation increased from 3.13 minutes to 3.45 minutes.[10] On the AVM routes (both controlled and uncontrolled), schedule adherence remained about the same during the 1980 and 1981 two-week periods: no significant changes in mean schedule deviation and standard deviation of schedule deviation were observed.

To interpret these schedule adherence results, i.e., the lack of change on AVM routes and a noticeable worsening on control routes, one must take into account two changes in conditions between the 1980 (before) and the 1981 (after) measurements: 1) new "RTS II" buses were placed in service on the control routes only a few weeks before the 1981 measurement period, and 2) weekday traffic volumes between 7:00 a.m. and 6:00 p.m. in April/May 1981 averaged 3% higher on AVM routes (even including a 9% decrease on the uncontrolled route, Route 44) and 4% lower on control routes than in January 1980.

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[9] A detailed comparison of AVM and control routes with respect to these criteria as well as bus frequencies and peak passenger loadings is presented in Exhibits 5.6 and 5.7 in Juarez & Associates, Inc., and SYSTAN, Inc., op. cit.

[10] As checkers indicated special problems during the data collection on Route 4, a separate analysis was conducted for Routes 84, 91 and 94 combined, leading to identical conclusions (at the same level of statistical significance).

Had new buses not been introduced on the control routes, the stability of AVM-route schedule adherence measures in the face of slightly heavier traffic and the deterioration in control-route schedule adherence measures despite slightly lighter traffic could possibly be considered a demonstration of a positive real-time-control impact of the use of the AVM system. The unanticipated change in buses on the control routes, however, raises a serious challenge to such an inference. If mechanical problems and other difficulties commonly experienced when new vehicles are placed in service (e.g., drivers having to get accustomed to the operating characteristics of the new vehicles) were largely responsible for the observed increase in average lateness and average variability of bus arrival times on control routes, then the before (1980) and after (1981) control-route data are not comparable, and hence one cannot argue that "no change" on the AVM routes represents an improvement over what might have been expected if AVM had not been applied on the routes.

4. EMERGENCY RESPONSE TIME AND SECURITY ISSUES

4.1 SILENT ALARM PROCEDURES

When a crime or disturbance takes place on board a bus, the driver usually seeks to notify the SCRTD dispatching center to ask for assistance. If the situation on the bus is perceived to be sufficiently non-threatening, the driver can use the bus's two-way radio (on a "priority" transmission) to request help by voice, specifying the location of the bus at the same time. However, if the incident is such that the driver might not want to or be able to make an audible radio call, then he or she can discretely activate a silent alarm that will be received at the dispatching center.

This silent alarm feature can be implemented independent of an AVM system. In Los Angeles, all SCRTD buses, not just those equipped with AVM, have a silent alarm. Activation of the silent alarm on an SCRTD bus has the following effects: the head sign on the bus changes from route information to the message "Emergency! Call Police"; emergency flashers on top of the bus are turned on; the radio is switched off to all dispatcher-to-driver communication; and the bus number, route number, and scheduled run number are displayed on the dispatcher CRT screen in the downtown control center.

If the bus activating an alarm is not an AVM-equipped bus, the dispatcher responsible for silent alarm calls immediately consults the appropriate schedule to estimate the calling bus's probable location, notifies SCRTD's supervisors or transit police, and calls the appropriate police department. Bus drivers are advised to call back as soon as the situation is cleared.

Under these procedures, considerable uncertainty in estimating a bus's location may arise when an emergency signal is received from a non-AVM bus that is either off-schedule, off-route, or supposed to have completed its run. In the first two cases, the dispatcher will unknowingly direct assistance to a wrong location (the estimated on-route, on-schedule position). In the third case, the division yard must be checked to determine if the bus has returned or left again, or if the alarm was triggered accidentally by someone servicing or cleaning the bus.

It follows from the preceding description that pinpointing the location of a bus in trouble is the crucial element in a dispatcher's response to an emergency call. Important time can be lost if those sent to assist the bus must search for it. With the AVM system, a bus's last reported location can be read off the dispatcher's display at once, together with additional information (e.g., if the bus is stopped or moving, on or off route, ahead of or behind schedule, or at layover).

As the locations of supervisor cars are known as well, the closest vehicle can be dispatched to intercept the bus. While a supervisor (or police agent) is en route to a troubled bus, the dispatcher can provide the supervisor (or police agent) with updated location information (if the bus is still in an area having signpost transmitters).

If an AVM-equipped bus has completed its run and has returned to a division yard, then it is automatically deassigned and logged out of the AVM system. Thus, if a silent alarm is received from a bus that has returned to a division yard, the AVM system will indicate this location by showing the bus's status as "not assigned".

4.2 BUS INTERCEPTION EXPERIMENTS

The time period between an SCRTD driver's first perception of an emergency situation and the arrival of assistance at the troubled vehicle is called "total response time". It consists of three components: the time it takes the driver to contact the SCRTD dispatcher, the time needed by the dispatcher to determine the bus's location and to dispatch assistance, and finally, the time required by the assisting vehicle to intercept the bus. Considering the reliability of the location information provided by the AVM system, it was expected that AVM would be capable of reducing the last two elements of total response time considerably. However, a precise statistical investigation of this issue was rendered impossible, because the only records documenting emergency situations -- the "Trouble Report Forms" submitted by SCRTD dispatchers -- do generally not allow a correct reconstruction of response times.

Considering the importance attributed to AVM's impact on transit security, other data sources were sought for analysis. During the week of June 8, 1981, a set of "bus interception experiments" were conducted in Los Angeles to demonstrate AVM's potential for shortening response times.[1] To make the experimentation effort as informative as possible, five different test situations were designed:

- bus moving on-route and on-time;
- bus moving on-route and late;
- bus stopped on-route and late when stopped;
- bus stopped off-route and late when it left the route; and

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[1] See Lyles, Richard W., AVM Benefits Emergency Situations and Other Types of Vehicle Interceptions -- Experiment Results, Richard Lyles Associates, Bangor, Maine, June 1981 (prepared for AVM Systems Inc., Fort Worth, Texas, under USDOT/UMTA Contract DTRS57-81-C-00086).

- bus moving off-route and on-time when it left the route.

Each of the five tests involved one bus and two supervisor cars. The test bus was assigned an actual run number on Route 83 (Wilshire Blvd.). The supervisor cars, one to be guided by the AVM dispatcher on duty and the other to be directed by the non-AVM dispatcher assigned to handle silent alarms, were pre-positioned equidistant from (about one mile) and on opposite sides (north and south) of Wilshire Boulevard before each test began. Once the test bus had started its run following a predetermined plan, the driver activated the silent alarm. Upon receipt of the alarm in the dispatching center, the non-AVM dispatcher provided the supervisor assigned to him with the "traditional" information (i.e., the estimated location at the time of activation of the alarm), whereas the AVM dispatcher gave his assigned supervisor the location information shown on the AVM displays. Both supervisors tried to intercept the test bus within the shortest time possible.

> The overall results of the experiments were the following: AVM capabilities provided a real and consistent advantage over the current SCRTD system and procedures in responding to a bus with an active SAS [silent alarm signal] (and the more general problem of accomplishing a rendezvous of scheduled and RR [random-route] vehicles). This advantage was demonstrated in the following ways in the five test situations:
>
> 1. The AVM-assisted supervisor was always able to move directly to the SAS vehicle as opposed to the other supervisor who often made incorrect decisions relative to where to intercept (although logical based on his available information).
>
> 2. The AVM-assisted supervisor always intercepted the SAS vehicle in a shorter elapsed time than did the non-assisted supervisor.
>
> 3. AVM-assisted response times did not seriously degrade even when the interception points were off-route.[2]

It is interesting to note that an unplanned bus interception test occurred only a few days before the planned tests described above were carried out. In the last week of May, 1981, a run on Route 75 (not an AVM route, but one which operated in an area with AVM signposts) was assigned an AVM-equipped bus. When a silent alarm from that bus was received at the dispatching center, the dispatcher at the AVM console immediately located the bus using the AVM map display and relayed to the Los Angeles Police Department the location information. A police car sent to assist arrived at the bus within a very few minutes. Although it turned out that there was no emergency (accidental activation), RTD

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[2] Lyles, op. cit., page 4.

staff were extremely pleased with the speed with which the bus was located by the AVM dispatcher and by police.

Thus, it seems to be convincingly demonstrated that AVM-assisted response times are potentially shorter than those achieved without the help of an AVM system. However, this examination leaves open the question of whether response times can be made sufficiently shorter using AVM to result in a higher apprehension rate of those who commit crimes or create disturbances on buses, and, eventually, fewer crimes on buses.

4.3 PASSENGER AND DRIVER SECURITY

In 1980, SCRTD crime reports recorded an overall 17% increase in transit crime over 1979. Assaults with a deadly weapon had increased by 77.7%, and robberies by 55.5%. This substantial growth in transit crime and serious concern among drivers on crime-targeted routes made passenger and driver security a priority issue for SCRTD management.

In mid-October 1980, just one month after AVM dispatchers began monitoring AVM lines, SCRTD launched an intensified anti-crime campaign. As part of that program,

- drivers were permitted to arm themselves with a mace-like chemical spray device for protection,
- additional off-duty law enforcement officers were hired as undercover agents to ride buses along crime-ridden routes, and
- a pilot program to test surveillance cameras inside buses was initiated.

The increase in arrests and decrease in on-board assaults and robberies that followed the institution of these measures caused the Los Angeles County Board of Supervisors, which had financed the hiring of police officers, to approve a second grant in March 1981 to continue the effort.

Given the new security program, it was impossible to determine the extent to which the AVM system may have contributed to the reduction in the number of serious incidents on AVM routes during the same period.

5. ECONOMIC AND EFFICIENCY ISSUES

5.1 INTRODUCTION

Public transit operators are presently recovering considerably less from fares than the cost of each bus-hour or bus-mile of service, and the public appears to be neither in a mood to increase the rate (or amount) of subsidy or to pay considerably higher fares. Faced with such realities, U.S. transit properties must find ways of "doing more with less,"[1] i.e., improving service while increasing operating efficiencies. It is in this context, then, that AVM and AVM-related systems must be evaluated to determine if they are economically viable tools for the times.

Unfortunately, it is difficult at this point to deal with the economic and efficiency issues of Automatic Vehicle Monitoring in general. First, there is not just one AVM system; there are several major types and even more minor variations on the theme, depending mostly on the main purpose of the implementation (real-time control, security, and/or collection of operating data). This presentation focuses on the specific type of AVM system that was tested in Los Angeles.

Another level of differentiation concerns the specific technology employed for each function. Alternative technologies exist for vehicle location, passenger-counting, and data collection. An estimate of the cost of a system can only be made when many parameters are set, e.g., the area or the number of route-miles to be covered, the number of vehicles to be monitored, the required polling frequency, the number of radio channels available for transmitting voice communications and data, the accuracy desired on vehicle location and passenger counts, and the types of data needed in real-time.

Second, the partial-system nature of the Los Angeles application of AVM, together with the shortness of the demonstration eliminated the possibility of empirically observing most of the postulated productivity benefits of AVM shown in Exhibit 5.1. The Los Angeles AVM demonstration touched only the tip of the iceberg (shaded area in the Exhibit). Hence, much of the discussion in this chapter must remain in the "potential" tense.

Since the present task was assessment of AVM impacts and not a cost-benefit study geared toward the making of a choice among specific alternatives, the likely benefits and costs of AVM-related and non-AVM

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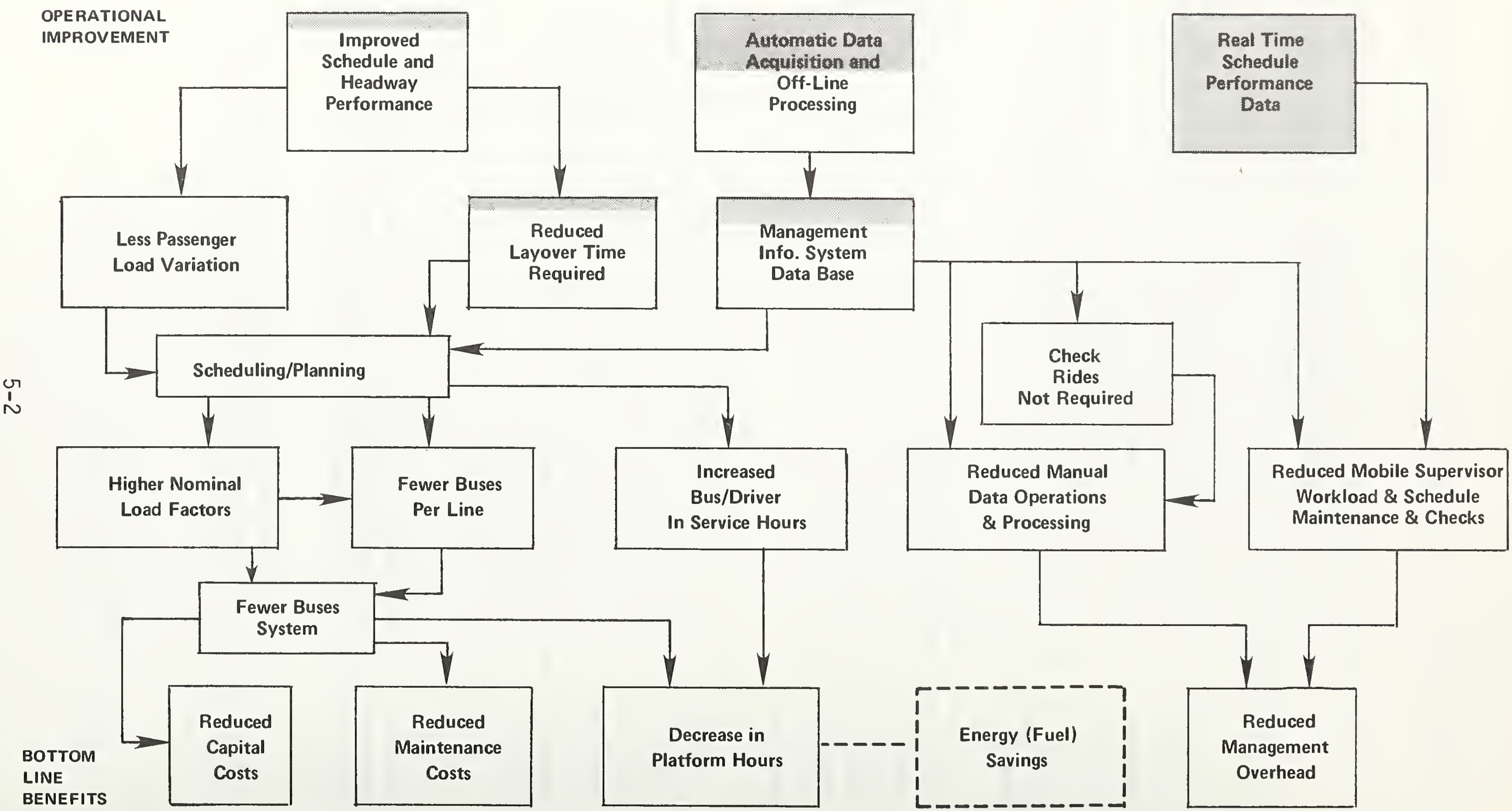
[1] A phrase that is the trademark of American engineer R. Buckminster Fuller.

Exhibit 5.1

DIAGRAMMATIC SCENARIO OF EXPECTED AVM ECONOMIC BENEFITS



NOTE: Source of basic diagram is presumed to be Gould, Inc., Information Identification Division.
Shaded areas represent benefits demonstrated to date in the Los Angeles AVM Demonstration.

alternatives for improving schedule adherence, increasing ridership, reducing operating costs, and improving driver and passenger security have not been compared.[2] Therefore, in the following sections on AVM costs, effects on productivity, implications for changes in operating costs and revenues, and overall economic viability, AVM is considered only in comparison to the "continue present methods" alternative.

5.2 THE COSTS OF AN AVM SYSTEM

5.2.1 Capital Costs

The capital costs of an AVM system consist of the investment in on-vehicle equipment, stationary equipment, and system software. Installation costs connected with these items are also considered capital costs. Assuming that each transit vehicle already has a suitable multi-channel radio for two-way voice communication, the on-vehicle equipment required includes a radio interface module to give the radio a digital communication capability (for data transmission), a signpost receiver subsystem, and a microprocessor; if applicable in a particular case, the on-board hardware may also include a passenger-counting system, a special odometer, an in-vehicle display, and/or a system for temporary storage of data. The stationary equipment includes wayside equipment (signpost transmitters), base stations, central computer, and display console(s). The system software, of course, is what makes everything work together; without it there is no useful output.

Almost all AVM projects completed to date, besides being different from each other, have included development costs, so costs from these demonstration projects do not provide a reasonable guide to what it would cost a transit property today to buy a non-developmental system. However, SCRTD's recent capital grant application to UMTA, in which support was asked for a $2.2 million project to equip 100 additional buses with AVM and give "any route" coverage capability, provides some guidance on the hardware capital costs. The amount budgeted for bus equipment (including odometers, passenger counters and digital radios, but excluding voice radios) is $700,000, or $7,000 per bus. The SCRTD proposal does not help, however, with respect to stationary-equipment and software capital costs, because the project involves the retrofit of 200 existing AVM buses, a complete redesign of the system software used in the Los Angeles AVM Demonstration (to convert from a broad-signpost

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[2] Some of the non-AVM alternatives are use of street supervisors ("transit line coordinators" in San Francisco), training programs for drivers and supervisors (including human relations and stress management), better maintenance of coaches and their equipment, dedicated or preference lanes for transit vehicles, vehicle-triggered signal priority at intersections, bus intercom systems that permit the dispatcher to speak or listen to passengers, and police (both uniformed and undercover) aboard buses and along transit routes.

system to a sharp-signpost-plus-odometer system and to generalize the software for "any-route" capability), and the development of substantial MIS software. However, a rule of thumb offered by a supplier of AVM systems is that the total capital cost for a new AVM system is twice the bus hardware cost (here the cost of a digital radio is excluded and systems involving 150 buses or more are assumed).

Exhibit 5.2 shows current "ballpark" estimates for the unit capital costs of the main components of an AVM system. Multiplying these unit costs by the number of items of each type in a particular application would give a crude estimate of the total system cost. Of course, the unit prices for some items - like signposts and odometers - vary with the volume of purchase, and the software price depends on the complexity of the functions desired, and the extent to which it must be customized to suit the transit property.

The net effect of putting together all the capital costs for an AVM system with real-time control and passenger-counting capability (but no in-vehicle displays) is a current (1980/81) estimate of $10,000 per bus. As a ballpark figure, this number is confirmed by current estimates from the Toronto Transit Commission and the Hamburg (West Germany) Transit Authority.

5.2.2 Operating and Maintenance Costs

Exhibit 5.3 presents the best information available at this time for the "steady-state" operating and maintenance costs of the Los Angeles 200-bus AVM system. In round numbers, the total annual operating cost is $100,000, or $500 per bus for 200 buses.

It should be noted that the total operating cost is quite insensitive to the number of buses, as only the item for "maintenance of AVM equipment" is a function of the number of buses. At SCRTD maintenance records kept by the Telecommunications Department showed that over the six-month period from January through June, 1981, an average of 52 hours per month was spent in field and shop maintenance for the AVM equipment (including bus radios). Thus, the average maintenance time per bus has been a surprisingly low one-quarter hour per month (or 3 hours per year). Not included in these maintenance figures, however, is the time to change passenger-counting mats in the buses; changes to later-generation passenger-counting mats were done as part of the developmental program of the demonstration.

Exhibit 5.2

ESTIMATED UNIT CAPITAL COSTS FOR AVM SYSTEM COMPONENTS

STATIONARY EQUIPMENT	UNIT COST[1]
Radio Base Station[2]	$ 10,000
Central Processor (e.g., PDP-11/70 computer)	$125,000
Display Console[3]	$ 30,000
Signpost Transmitter[4]	$200-$500 (installed)
[Bus-stop Display Unit]	
ON-VEHICLE EQUIPMENT	
[Digital radio][5] Single Channel	[$1,500]
Radio Interface Module	$2,000
AVM Microprocessor	$1,000
Signpost Receiver Board	$ 500
Passenger-Counting Subsystem	$3,000
[Odometer][4]	[$150-$250 installed]
[In-Vehicle Display Unit]	[$1,500-$2,000]
SYSTEM SOFTWARE	$120,000-$1,000,000
INSTALLATION	
Computer room preparation[6]	$70,000
Computer	$ 1,000
Base Station	$ 1,000
On-Vehicle Equipment	$ 400 per vehicle

[1] 1980/81 estimates.

[2] Part probably chargeable to regular voice communications system

[3] Perhaps $20,000 chargeable to regular voice radio communication system

[4] Price depends greatly on the number purchased

[5] If a multi-channel radio adequate for both data transmission and voice communication is not already present on buses, then a suitable radio would have to be purchased.

[6] Estimate from Bevilacqua, et. al., *Evaluation of the Cincinnati Transit Information Systems (TIS)* (Report No. UMTA-MA-06-0060-79-1).

Exhibit 5.3

AVM OPERATING AND MAINTENANCE COSTS – LOS ANGELES SYSTEM

Basic Cost Elements	Total Annual Cost[1]	Annual Cost per Bus
Computer maintenance ($1962/mo.)	$23,544	$117.72
Versatec Line Printer ($78.00/mo.)	935	4.68
Base station leases (2 @ $180/mo.)	4,320	21.60
Leased telephone lines (2 @ $190/mo.)	4,560	22.80
Magnetic computer tapes (1/day @ $10)	3,650	18.07
Utilities (electricity) [estimated][2]	6,000	30.00
Maintenance of AVM equipment (52 hrs/mo. @ $27/hr)	16,848	84.24
Hardware related subtotal	$59,857	$299.11
Management cost [minimum] (half-time system controller: salary and fringes @ $21,000 +50% overhead)	$31,500	$157.50
Subtotal	$91,357	$456.79
G&A @ 6.4%	5,847	29.23
	$97,204	$486.02

Unknown costs
- Software maintenance
- Additional dispatcher hours

[1] For 200-bus fleet.

[2] Principally computer and air-conditioning in computer room. $6000 was the estimate made for the Cincinnati TIS installation.

5.2.3 Total Annualized Costs

If one annualizes the capital costs of AVM, one can add the obtained value to the annual operating costs to get an equivalent total annual cost. Taking the estimated system capital cost per bus, \$10,000, and assuming a 10% discount rate and a 10-year system life (a rule of 10's!), one finds that the equivalent uniform annual cost of AVM is \$1,627 per bus.

Adding the \$1,600 annualized capital cost per bus to the \$500 annual operating cost per bus, one obtains \$2,100 as the estimated total annual cost per bus. For a 200-bus system, this amount multiplies up to a \$420,000 annual cost (present value using 10% interest and 10-year life is \$2.6 million).

5.3 IMPACTS OF AVM ON PRODUCTIVITY AND PROCEDURES

5.3.1 The Management Information System (MIS) at SCRTD

At the present time SCRTD is developing its own Management Information System (MIS) software for processing of the data recorded by the AVM system. SCRTD has been assisted in this effort by the MITRE Corporation, which prepared a detailed design for an MIS.[3] The data files planned for the MIS at SCRTD include: a tracked-bus file, an ordered-bus-stop file, a trouble-report (CS-10) file, and a trip file. Among the possible management reports are: daily exception reports (i.e., based on user-defined thresholds for schedule deviation and load factor), daily trouble reports, running-time reports, ridership reports, schedule deviation reports, layover reports, and UMTA Section 15 reports. Implementation of the MIS design has been delayed by a shortage of computer programming resources within SCRTD. The actual benefits of AVM data for this Management Information system were never fully tested in Los Angeles. However, it is possible to describe the potential contributions of AVM (as in the following subsections) based on the data which were available during the demonstration.

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[3] Ludwick, John S., Jr., Detailed Design for a MIS for the Southern California Rapid Transit District, The MITRE Corporation (Metrek Division), McLean, Virginia, October 1980 (prepared for the Urban Mass Transportation Administration, Office of Technology Development and Deployment, under Contract No. DOT-UT-90006).

5.3.2 Planning and Scheduling

Transit properties throughout the U.S. are currently encountering a continuing demand for service that is not accompanied by a parallel development of farebox revenues and subsidies. Under these circumstances, reliable and complete data on service conditions has become an indispensable tool for transit managers in their endeavor to use their highly constrained resources productively.

Traditionally, data describing run times, ridership, and fares is collected by on-board checkers. In a large system like SCRTD, however, which operates about 220 routes with approximately 2000 buses on the road during peak hours, manual checking is not as advantageous as automatic data collection by an AVM system. Several arguments support this point:

- AVM data can be collected continuously -- 24 hours a day, 7 days a week -- and thus can be more complete than data collected by checkers. Without an AVM system, a transit district can only afford to have checkers collect data for one or a few days per year per route, so planners cannot be sure whether the data represents long-term averages or is strongly influenced by particularities or atypical occurrences on the day of a check.

- AVM data is machine-readable and can be processed directly. Therefore, AVM data can be available for analysis within a few days after collection, whereas printouts derived from manually collected data are often ready for use by schedulers only after 6 to 12 months.

- AVM data is more consistent. All data points are derived in the same manner and oriented to the same reference time.

- AVM data is more detailed. Each individual bus is tracked during its entire run, which permits the analysis of any desired grouping across runs or time.

Thus, except for fare data, which would still have to be collected manually, AVM-generated data potentially offers a quantity and quality of data that permits true statistical analysis. The principle present limitation to analysis for the Los Angeles system that should eventually be overcome is the reliability of passenger counts.

From the raw data collected by the AVM system, a management information system can calculate values for such variables as: schedule deviation, total run time per trip, run-time variation by route segment, passengers on board, total boardings per trip, passengers boarding and alighting by stop, maximum passengers on board, number of standees and standee time, passenger-miles, passenger-hours, bus-miles, bus-hours, bus trips, layover time. To date, the first six items on this list are available in Gould's printouts of AVM data.

Properly used by the planning and scheduling departments of transit operators, this wealth of information can yield numerous benefits. Some of these benefits are quantifiable and others are qualitative; some benefits accrue immediately, while others are only reaped after a year or more. Primarily, these benefits can be realized in two steps: one, the improvement of schedules based on run-time and ridership information, and two, a translation of these productivity gains into cost savings and/or revenue gains for the transit property. The following types of schedule changes seem feasible considering AVM experience to date:

- running time adjustments,
- planning efficient layover times,
- changes in headways,
- changes resulting in smoother passenger loadings and fewer standees,
- appropriate summer/winter/weekend schedules,
- changes in response to performance indicators.

These and other potential schedule improvements realizable through the use of AVM data in planning and scheduling can gain effectiveness when supplemented with real-time control. Once dispatchers manage to control day-to-day variations, schedules would need to provide less slack time to account for the uncertainties of traffic and other infrequent delays. On this basis, it may be possible to construct new schedules with shorter running and layover times. Headways are another area that might benefit from interactions between scheduling and real-time control. If headway variation (bus bunching) can be controlled by AVM dispatchers, headways can be scheduled to be longer without increasing the average wait times of passengers (compare Section 4.3 above).

Apart from generating more efficient schedules, the planning and scheduling department can use AVM-system data to:

- evaluate effects of schedule adjustments within a short period of time,
- give feedback on their performance to individual drivers, and
- facilitate major improvements in manual data collection methods. With a large base of AVM data available, various sampling procedures for manual data collection can be tested to determine which data is the most reliable.

The changes and improvements in the approach to scheduling described so far result in numerous benefits to both passengers and transit operators. Passengers may experience higher service reliability based on realistic schedules, shorter trip times, and more comfortable rides due to a more regular availability of seats. Transit operators may realize increases in vehicle productivity based on schedule improvements, which can result in a reduction of vehicles and drivers in cases where the original combination of route length, headways, and slack permits it.[4] The next section -- dealing with cost and revenue implications -- will examine the magnitude of AVM-induced cost decreases and/or revenue increases required to render an AVM project economically self-sufficient.

5.3.3 Control Room Operations

It was expected at the outset of the demonstration that AVM dispatchers might discover unforeseen uses of the AVM system, thus increasing the effectiveness of control room operations. To date, these expectations have not been fulfilled. Two general observations, however, were made concerning the productivity and procedures of dispatching with the AVM system.

The experience at SCRTD and elsewhere (e.g., Toronto) suggests that the maximum number of vehicles that an AVM dispatcher can actively monitor and effectively control is about eighty, or perhaps up to 100 under optimal circumstances of low rates of vehicle breakdown, on-board incidents, and schedule deviations.[5] By comparison, at SCRTD a non-AVM dispatcher, who only responds to driver calls, can easily cover the approximately 200 vehicles assigned to the radio channel that he or she is assigned to monitor.

Second, observations of AVM dispatchers indicated that a higher frequency and better use of real-time control options might be made by assigning AVM dispatchers in teams of two during the peak periods. Thus, the principal AVM dispatcher on duty could be assisted during a peak period by a second dispatcher-analyst at another console who would concentrate on locating schedule adherence, headway, and passenger loading problems and recommend appropriate tactical actions to the lead dispatcher. Under these conditions, the lead dispatcher has more time to contact the respective operators and deal with non-tactical situations.

Whether one reduces the number of buses per dispatcher or uses a tandem team approach, effective real-time control using an AVM system appears to require more dispatchers than two-way voice communication

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[4] This issue is examined further in the following subsection (6.3.3).

[5] In New York, AVM dispatchers control up to 200 buses, but they call drivers of early buses only.

systems. However, the extent to which additional dispatchers may be required cannot be determined until the scope of incremental AVM-related dispatcher activities is more clearly defined.

5.4 COST AND REVENUE IMPLICATIONS OF AVM

Any one or a combination of the following AVM benefits might recover the costs of implementing and operating an AVM system: (1) reduced number of data collectors, (2) fewer buses required for a given level of service, and (3) increased ridership. The next three subsections look at each of these areas independently.

5.4.1 Transit Data Collection and Analysis

The Service Analysis and Scheduling Department at SCRTD currently operates with a total annual budget of close to $4 million, which supports a staff of about 110. Approximately half of this budget is spent on data collection and processing. For data collection tasks, 35 checkers are employed to conduct on-board checks for running times, ridership, and types of fares paid. Several coders and seven keypunchers are paid for data entry; 33 schedule makers and schedule analysts eventually work with the data.

If an AVM system covers a sufficiently large percentage of a transit district's routes (even if on a rotational basis), cost reductions can be expected in the areas of manual data collection and data entry. The AVM system at SCRTD records data on schedule adherence, running times, and passenger boardings/alightings automatically, so only fare information would still have to be collected manually. Thus, all point checks and most ride checks made by checkers become unnecessary on routes where AVM collects data. Checkers would be needed only to cover routes not covered by AVM and to conduct fare checks. As AVM data is collected automatically and stored directly on computer tape, no coding and keypunching is necessary; hence SCRTD should be able to make substantial reductions in its data-preparation staff (data technicians and keypunchers) as well as in its schedule-checking staff.

On the other hand, the quantity and degree of detail of AVM data may cause increases in the cost of data processing and analysis. For the four AVM test routes, one tape of raw data was generated daily -- the AVM "log tape." Depending on the respective length and frequency of service of different routes, costs will accrue for tape acquisition and maintenance, computer time, and data processing staff. The head of SCRTD's Service Analysis and Scheduling Department[6] anticipated that the present staff of schedule analysts at SCRTD would be sufficiently large to make full use of AVM data.

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[6] Mr. Joel Woodhull.

Overall, it appears that the budget of the Service Analysis and Scheduling Department could be reduced considerably if data for all routes were to be collected with the AVM system. As discussed earlier, SCRTD is planning to expand and redesign the system to provide data collection capability on any line. SCRTD schedulers estimate that 100 buses with satisfactory passenger counters and the "any line" capability will be able to collect about five times as much data as is presently collected manually.

5.4.2 Bus Operating Costs

The issue of potential productivity improvements through reduced vehicle use was examined in the section dealing with the impacts of AVM on productivity and procedures (see Section 6.3). These improvements were expected to be achievable with an AVM system due to:

- real-time control effects, and
- data availability for planning and scheduling.

The next step to be taken is to estimate the magnitude of the cost reductions that these productivity improvements have to produce to pay for an AVM system.

For this purpose, the following average cost figures (1980/81 estimates) were used:

capital cost per bus	$160,000
annual operating cost per bus	$120,000
capital cost of AVM per bus	$ 10,000
annual operating cost of AVM per bus	$ 500

The estimate for the pro rata capital costs of an AVM system per bus is the current round-number estimate usually cited by experts in the field for a full AVM system, while the annual operating cost per bus is based on the 200-bus implementation in Los Angeles.

For purposes of illustration, a "round number" analysis has been performed. Assuming a 10-year life for both AVM-equipment and buses, the capital costs can be annualized. Using an interest rate of 10%, they amount to $26,000 per bus and $1,600 for the AVM system on a per-bus basis. Thus, a non-AVM bus can be considered in terms of $146,000 in annual capital and operating costs over a period of 10 years. The respective costs for an AVM bus would add up to $148,100. The $2,100-difference per year can be transformed into a single figure by calculating its present value, which is about $13,000 per bus, or $2.6 million for all 200 buses. Comparing this amount to the present value of the 10-year cost stream of a non-AVM bus (i.e., $146,000 per annum), which equals about $900,000, one can come to a rough conclusion about the relative magnitude of the costs associated with AVM. It seems that for about the same price either three regular buses or an AVM system for 200 buses can be purchased and operated over a period of 10 years. In other words, a transit operator would have to do without the use of 3 buses in order to install an AVM system for 200 vehicles, which is equivalent to a reduction in the available vehicle fleet of about 1.5%. In case, however, these 200 AVM-equipped buses had "any line" capability, SCRTD would only have to save 3 buses out of its entire fleet of 2,800 buses in order to experience AVM benefits systemwide. Thus the annualized capital and operating cost of the AVM system would be reduced from $2,100 per AVM-equipped bus to $150 per bus in SCRTD's fleet.

The required improvement in vehicle productivity that AVM would have to produce to pay for itself, however, appears to be somewhat higher than 1.5% for one principal reason: the benefits of AVM, like cost savings from more efficient vehicle utilization, will only be realized several months after the AVM system has been bought, installed, and put into service. In addition, service cutbacks made to increase the efficiency of vehicle utilization may result in foregone revenues.

To summarize, it appears that an AVM system would need to induce a reduction in costs of more than 1.5%, probably about 2-3%, in order to pay for itself, if it did not lead to an increase in ridership. This alternative of rendering AVM economically self-sufficient will be investigated in the next subsection. The experience of other transit districts that have also tested AVM systems indicated that increases in productivity on the order of 3-5% or more might be possible depending upon the initial level of efficiency in the transit operations to be covered by AVM.

5.4.3 Passenger Revenue

Unfortunately, from the rider's or potential rider's point of view, in most situations the changes in service reliability, security, and ride comfort that follow the implementation of an AVM system may be almost imperceptibly small as opposed to startlingly obvious. Therefore, it will generally be difficult if not impossible to connect any change in ridership to use of AVM.

Nonetheless, a quick and straightforward calculation indicates that a relatively small increase in ridership on AVM lines would be sufficient to make AVM pay for itself. Continuing the calculations of the preceding subsection, one can again assume annualized capital and operating costs for AVM of about $2,100 per bus. This value is approximately equivalent to costs of $6.00 per day per bus. Before the fare increase in July 1981, the average fare paid per SCRTD passenger was 35 cents; with the new regular fare set at 85 cents (up from 65 cents), an average fare of 50 cents per passenger seems to be a realistic estimate to work with. On this basis, 12 additional passengers a day per AVM bus would cover AVM's $6.00/day cost per bus. This number of new riders is 2% of SCRTD's present weekday average of approximately 600 boardings per bus. Thus, if an AVM system had to rely solely on new revenues to pay for itself, it would need to induce a ridership increase of at least two percent.[7] Assuming again the possibility of "any line" capability for AVM buses, the AVM system would cost less than 50 cents per day per bus in the entire fleet. In this case, only one additional passenger per day could cover the cost.

An AVM-induced ridership increase does not have to be considered independently. Any combination of cost reductions through productivity improvement and revenue increase through induced ridership that adds up to $2,100 per AVM bus per year will serve the purpose of making AVM pay for itself.[8]

5.5 OVERALL OUTLOOK FOR AVM'S ECONOMIC VIABILITY

An AVM system does not automatically generate revenues or reduce costs. Its benefits must be extracted through proper and sufficient use. The cost-effectiveness or cost-ineffectiveness of an AVM system will depend on the level of performance of maintenance personnel, division dispatchers, control-room dispatchers, drivers, AVM computer operators, and planning and scheduling staff. In turn, the level of performance achieved and sustained by these employees will depend on the degree of commitment demonstrated by their managers to overcoming obstacles and to assimilating AVM into the transit property's way of doing things.

Although the economic viability of AVM can be plausibly argued, it has not yet been convincingly demonstrated in any U.S. application. The analysis presented above suggests that cost reductions or ridership increases of 2-3% on the lines covered by AVM would be sufficient to cover the costs of an AVM system. It depends on the transit property, however, as to whether real-time control and MIS data are used in a way to realize sufficient productivity and ridership benefits from the employment of an AVM system.

If changes of 2-3% appear too large to be feasible in a particular case, AVM might still be justifiable. Among the three areas of potential AVM benefit -- real-time control, management information, and security -- only the first two can be expected to result in monetary

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[7] Probably the only way to detect and attribute a ridership change as small as two percent to AVM would be to conduct an on-board survey that asked respondents about their impressions of the service on the line and their ridership frequency related to it.

[8] Of course, if one chose to argue that AVM-induced revenue increases need cover only 40% of the costs of the AVM system because that is approximately the current farebox return rate at SCRTD, then a ridership increase due to AVM of only 0.8% could be considered sufficient.

benefits to a transit property. Improved transit security might actually save a transit district from various law suits and the related costs, but this is too speculative to be assessed. If one assumes arbitrarily, for example, that the management of a transit property attributes 10% of AVM's usefulness to its real-time control impacts, 60% to the value of the data made available to planners and schedulers, and 30% to the improvements in transit security, then only 70% of the total cost of AVM might have to be recovered through cost and revenue changes. The last 30% might be considered a necessary investment that does not yield monetary returns, but protects the lives and property of bus drivers and passengers.

6. AVM EXPERIENCE IN OTHER BUS SYSTEMS

Although AVM experience in the United States has been relatively limited and mostly since 1977, more than thirty implementations of AVM or AVM-related systems have been made since 1958 when the first Automatic Vehicle Location system was tested (and allowed to expire) in London. After a gap of ten years, in 1968, AVM activities began again with tests in Chicago and Hamburg, West Germany; both of these cities have a form of AVM operational today (Chicago's Emergency Vehicle Location system is currently used only for security purposes and not real-time control or management information). During the early seventies interest in AVM expanded more rapidly abroad, especially in Europe, than in the U. S. Zurich, Switzerland, which began experimenting with AVM in 1971, has been employing AVM as standard operating procedure for several years now. Another of the more well-known early entrants (1974) into AVM technology is Dublin, Ireland, which now has 900 vehicles operating within the AVM context. A brief history and chronology of AVM developments is presented in a recent UMTA booklet (April 1981) entitled, "Automatic Vehicle Monitoring: Program Digest".[1]

AVM activity in the United States has picked up in the past five years. Three of the most recent test applications of AVM systems have the most bearing on the evaluation and interpretation of the Los Angeles AVM Demonstration because they focused on real-time control of line performance. These tests took place in the period 1979-1980 in New York City, Toronto (Canada), and Stockholm (Sweden).

All of these three systems used the sharp signpost technology. In Toronto and Stockholm, odometers were employed to calculate vehicle locations between signposts. The tests involved from 60 to 250 buses deployed on 4 to 12 routes. In addition to the voice radio adapted to receive signpost signals and to transmit digital data, the on-vehicle equipment typically consisted of infrared-beam passenger counters (except New York), a device for the driver to enter route and run number, an in-vehicle display unit or a unit to give "start"/"wait" messages, and a silent alarm system. The time required to poll all buses varied from 3 seconds (Toronto) to 60 seconds (New York). In the respective control centers, one dispatcher (two during peak periods in Toronto) worked at a dispatching console equipped with different variations of CRT (cathode ray tube) screens: Toronto used a console with three color CRT displays, Stockholm had a single computer-terminal CRT, and in New York, dispatchers could choose either a graphic or tabular display of bus information. Special features among these

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[1] The 40-page booklet is available from the U.S. Government Printing Office, item no. 1981 701-052/414.

consoles were the display of a complete listing of out-of-tolerance buses (regarding schedule adherence) in New York, and an aggregate schedule-adherence quality rating provided in Stockholm. The major real-time control strategies were usually aimed at headway bunching and early buses.

The results of three tests revealed (modest) improvements in schedule adherence (especially a reduction of early buses). The accuracy of the data collected for planning and scheduling was deemed sufficient, although improvements were considered necessary in the area of passenger-count information. Overall, the evaluations were generally favorable, and the three systems are still in use. In Toronto, an expansion to all buses (250 to 270) of the division involved in the test is planned to be operational by May 1982.

The operation of AVM systems in two West German cities -- Hamburg and Darmstadt -- was observed briefly during the summer of 1981 by one of the co-authors of this report.[2] Both systems operate with sharp signposts and odometers, which are regularly reset and calibrated against known distances. In Hamburg, 100 out of 900 buses are part of the system; in Darmstadt the entire system of 7 streetcar lines and 14 bus lines (i.e., 76 vehicles) is under AVM control. Each of these two AVM systems is an established operational system, far beyond the test stage. The on-vehicle equipment is similar to that used in the systems described above. A major difference is the passenger-counting technology: AVM buses are equipped with sensors to report the pressure in the air-spring suspension, which, because it varies with the weight of the body of the vehicle, is used to give an indication (as a % of full load) of the passenger load on the bus.

Darmstadt shows the special advantages of a system-wide AVM implementation. The major value of AVM is seen in limiting the propagation of disturbances and breaks in service, possible because dispatchers can work out alternative routings and temporary reassignments of vehicles to other routes. In addition, the AVM dispatcher can monitor and control interroute connections, especially the timed transfer of seven lines at a downtown plaza in Darmstadt.

Transit operators both in Hamburg and Darmstadt noted a clear improvement in system performance after the implementation of AVM. In Hamburg, an expansion to most of the 900 buses is planned.

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[2] Douglas Daetz

7. KEY FINDINGS AND CONCLUSIONS

7.1 INTRODUCTION

The major results of the impact assessment of the AVM demonstration have to be viewed from a perspective that takes the following factors into account:

1. The AVM system was implemented on only a part of SCRTD's bus system, being limited to four routes that required about 7% of SCRTD's base-period and peak-period bus assignments. Many potential benefits of AVM in the areas of real-time control, security, and management information cannot be fully realized in a partial implementation.[1] In addition, some problems would not have arisen in a systemwide demonstration, e.g., the assignment of non-AVM buses to AVM routes (which resulted in gaps in the data), or non-AVM dispatchers sometimes dealing with problem situations on AVM buses.

2. The time frame within which the demonstration was finally scheduled was too limited to investigate a number of issues. In some cases, the expected chain of impacts had not yet occurred (e.g., improvements in the level of service --> more positive passenger attitudes --> higher transit demand), and in other cases, the planned actions based on AVM data had not been taken (e.g., the compilation of management reports and subsequent changes to the schedules of AVM routes).

3. The demonstration was not an "experiment," for one was dealing with an open and not a closed system. Conclusions about AVM have been sought amidst a blend of conscious and unconscious, coordinated and uncoordinated actions upon an operating transit system. Furthermore, a lack of empirical data in connection with several hypothesized areas of AVM impact and AVM costs has meant that much of the argument concerning AVM benefits and costs in those areas remains theoretical, suggestive, or anecdotal instead of being based on analysis of hard data.

4. Some areas that might have revealed interesting results were not examined. For example, weekend data was not processed, but weekend situations (such as a surge in beachbound patrons on a hot afternoon) may have presented some of the best opportunities

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[1] Security benefits require the complete geographical coverage of the system in case a bus is taken off-route, whereas real-time control and management information benefits can only be optimized for a set of AVM routes that function as a complete (sub)system.

for the effectiveness of real-time control to have been seen. Similarly, significant AVM real-time control impacts might be waiting for discovery in the raw data for the "night" time block (6:00PM to 6:00AM).

Given these caveats, then, the following sections summarize the major results of the socioeconomic impact assessment.

7.2 KEY FINDINGS CONCERNING THE AVM DEMONSTRATION IN LOS ANGELES

Implementation of the AVM System

Managers, planners, dispatchers, and drivers affected by AVM were generally in favor of the new system. However, managers and planners indicated some dissatisfaction about the fact that complete and reliable passenger counting had not been achieved by the end of the demonstration. This data was considered a crucial element of management information for planning and scheduling, an area of AVM impact that together with security aspects was foremost in the interests of SCRTD management.

Among the AVM dispatchers, some were enthusiastic about the new avenues AVM opened for them, others felt basically positive toward it, and some were not comfortable with their change of roles (from simply responding to trouble calls to taking active control of bus operations). Dispatchers were trained in the use of the AVM console and various real-time control options, but their overall frequency of tactical control actions was considerably lower than had been expected.

Drivers had mixed attitudes as well. Several precautions had been taken to assure their cooperation with the system: the unions had been informed in advance, only moderate use of real-time control was planned in order to avoid feelings of being controlled or manipulated, and AVM data was not used for disciplinary actions (e.g., against early drivers). Many drivers appreciated the security aspects of the AVM system, or the help in maintaining their schedules. Some indicated at the end of the demonstration that not enough use had been made of the available real-time information to control drivers running early. On the whole, however, drivers seemed to accept AVM.

Real-time Control Impacts

The level of real-time control exercised on AVM routes did not cause any dramatic changes in schedule adherence during the demonstration. The overall gains turned out to be a matter of only six to ten seconds. Some improvements were realized in the distribution of schedule deviations during the demonstration: the percentage of early buses decreased on all four AVM test routes (including the route that had not been subject to dispatcher control).[2] On the other hand, a consequence of the reduction in the percentage of early buses was an increase in the percentage of late buses. The net result, however, was in most cases an increase in the share of on-time buses (i.e., buses within 3 minutes of schedule).

Security Benefits

The limited amount of data available for the analysis of AVM's impacts on the response times to buses calling for assistance did not permit a confirmation or rejection of the hypothesized AVM benefits in this area. However, some bus-interception experiments conducted toward the end of the demonstration suggested that the information provided by the AVM system was markedly superior to estimates based on schedule information in locating and intercepting a bus in an emergency, especially if the bus was running off-route.

No results could be obtained concerning the extent to which the AVM system might be deterring crime on transit vehicles. SCRTD initiated a campaign against transit crime in October 1980, whose effects were so extensive that an analysis of the separate influence of the AVM system was not possible.

Management Information for Planning and Scheduling

The actual usefulness of AVM-generated data for planning and scheduling could not be fully examined to date. By the end of the demonstration, SCRTD's planned Management Information System (MIS) had not yet begun to generate the management reports desired by planners and schedulers, and no substantive schedule changes had been made based on AVM data. The analysis of available AVM output, however, indicated that AVM data might be useful for efficient allocation of scarce transit resources, e.g., through pointing out vehicle-hours or layover times suitable for cutbacks, more appropriate allocations of running times along routes, and by describing demand conditions by season, day-of-week, or time-of-day.

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[2] The fact that the uncontrolled AVM route showed a reduction in early buses similar to that of the dispatcher-controlled routes, together with the fact that there was some improvement in schedule adherence on the AVM routes before dispatcher control began, indicates that the demonstration itself (apart from real-time control) may have been responsible for some of the change in schedule deviation on each route. Such a result is an example of the "Hawthorne effect," i.e., an improvement in the performance of workers simply as a result of knowing that they are being observed.

7.3 CONCLUSIONS AND TRANSFERABILITY OF RESULTS

The analysis of numerous aspects of the AVM demonstration in Los Angeles and a review of reports on the recent AVM experience of other transit systems have led to some conclusions about the Los Angeles AVM demonstration and the use of AVM in general. Transit operators planning to install an AVM system may find these results important in their decision-making process.

Implementation of an AVM System

The smoothness of incorporation of an AVM system into transit operations depends to a large extent on the organization, procedures, and staff of the implementing transit property. If an AVM system is used for real-time control, the selection and training of the AVM dispatchers becomes a crucial issue in this respect, and the following points must be considered:

- Usually younger dispatchers accept the new technology more readily than more senior ones.

- Dispatchers might receive more thorough and motivating training, perhaps including a visit (3 to 5 days) to another transit district where AVM dispatchers are operating successfully. (New AVM dispatchers in Darmstadt, West Germany, were sent to observe Zurich's AVM dispatchers for one week.)

- It appears advantageous during the first year of AVM operation to avoid rotation of AVM dispatcher assignments as much as possible, because a high dispatcher turnover introduces discontinuities and requires repeated training periods. However, once all dispatchers eligible for AVM duty have been trained, it can be beneficial to seek ways to avoid dispatcher isolation from drivers. (In Toronto and Darmstadt, dispatchers regularly rotate out as inspectors and/or drivers.)

- The work load of AVM dispatchers may have to be lightened. It appears that one dispatcher can provide effective real-time control for no more than 80 to 100 buses.

- AVM dispatchers in Los Angeles regularly had to clear coordination failures when division dispatchers failed to enter bus information into the system in time. Other transit systems avoid this problem through data entry by the individual bus drivers at the start of each run.

Apart from the AVM dispatchers in the central control center, a continuous and serious effort is required on the part of all other AVM-affected staff as well. At SCRTD, among this staff were the division maintenance personnel responsible for keeping buses and bus equipment in working order and for the daily assignment of AVM buses to AVM routes, the division dispatchers responsible for the prompt entry into the computer system of assignment and deassignment data for each bus, drivers on AVM routes who have to comply with the commands of AVM dispatchers and cooperate with them in solving problem situations, and planners and schedulers responsible for making effective use of the AVM management-information data. In the Los Angeles demonstration, the presence of a technically-trained on-site TSC manager was considered by SCRTD to be a crucial factor leading to the success of the project.

Real-Time Control Impacts

In Los Angeles a number of factors limited the effectiveness of real-time control actions by AVM dispatchers, which in turn resulted in rather modest changes in overall schedule adherence. As some of these factors were also present in other AVM experiments, transit operators may expect them to play a role in future implementations. Among the major aspects are the following:

- Goodness-of-fit of the original bus schedules. Two of the controlled AVM test routes already operated with relatively good schedule adherence (67% and 77% of buses within 3 minutes of schedule) before AVM control began. In such cases, no substantial changes can be expected.

- Low frequency of tactical control actions. From the outset of the demonstration, SCRTD had made the decision not to press the real-time control issue too hard and not to employ disciplinary measures against drivers with large deviations from schedule in order to win the acceptance of bus drivers and their union. Also, dispatchers had to deal with many non-tactical situations (e.g., the data-entry problems mentioned above) which limited the time they could devote to tactical control actions. In addition, there was no clear consensus with regard to the most appropriate strategy dispatchers should use in each individual tactical situation, so they tended to intervene in selected cases only (e.g., extreme schedule deviation).

- Inherent limits to real-time control. Many observers familiar with traffic volumes in Los Angeles and Route 83 along Wilshire Boulevard indicated that Route 83 may actually have been beyond control by AVM under the given circumstances of traffic congestion, passenger demand, multiple branches, and operation out of three divisions.

To improve the effectiveness of real-time control, it might be helpful to make tactical control actions a function of headways, applying "debunching" strategies to routes with short headways and schedule adherence strategies to routes with long headways (as implemented in Stockholm). In addition, dispatchers might be encouraged by some real-time feedback concerning a route's operating quality, maybe in the form of an overall index for schedule deviation or bus bunching (a "line quality index" for schedule deviation is employed in Stockholm; a special "cluster" symbol for bus bunching is available on dispatcher displays in New York City).

Management Information for Planning and Scheduling

An AVM system may appear desirable to many transit properties because of its capability to collect complete, accurate, and up-to-date information regarding running times, schedule deviations, passenger boardings/alightings, and passenger loads. SCRTD used a passenger-counting system with treadle mats on the steps of the front and back bus doors. This technology had shown superior counting accuracy over infrared-beam systems in tests conducted by Gould in 1977-78. During the demonstration, however, the system tended to report passenger loads that were lower than the actual figures because passenger boardings were undercounted more often than alightings. While such count errors can be addressed by changes in equipment installation, software algorithms, or technology, the real significance of modest errors in passenger loading must be examined in the context of how the data is to be used in decision-making, and how accurate the manual counts are that transit systems normally rely upon for similar decisions.

The AVM system already supplies all other information reliably. In order to realize all potential benefits with the data, a transit system needs the commitment of adequate data processing and analysis staff in the planning and scheduling departments. Initially, there may be a need for outside programming support to develop the computer programs that generate the management reports.

Transit managers can use these reports to plan improvements in the level of service (e.g., fine-tuned schedules) and to either reduce operating costs on existing routes, or to expand service at no increase in cost. The extent of these changes will partly depend on policy decisions made by the individual transit system. Among these decisions are limits for minimum layover times, headway lengths on low-demand routes, and the coverage to be provided during low-demand times of the day (e.g., nights or weekends). Some transit districts that have recently tested AVM or similar data-gathering systems (e.g., Toronto, Cincinnati, or Los Angeles) estimate that schedule revisions based on AVM data will possibly save 3-5% or more in operating costs. It is estimated that savings of 2-3% would be sufficient to offset the additional costs of an AVM system such as the one used in Los Angeles.

Technology

Apart from passenger counting systems, for which experience with the technology and installation is sparse, AVM technology is considered to be well developed and mature for use in transit systems with various modes. So far, AVM has been employed in systems with buses, rail vehicles, or combinations of the two (as in Darmstadt). The implementation of AVM technology at SCRTD was constrained by the crowded frequency spectrum in Los Angeles; extending the system to include more buses without additional radio channels for transmitting data would require an increase in the time to complete a polling cycle. Smaller transit districts, or districts in less urbanized areas, might not face these limitations.

Scope of AVM Systems

Transit managers can build up an AVM system that matches the area(s) of benefit they wish to emphasize. In Chicago, AVM was introduced for security reasons; New York City, however, had a major interest in real-time control. In any case, the effectiveness of each AVM system depends to a large degree on the commitment of managers, planners, dispatchers, drivers, and other staff at the transit organization.

At a very low level of use, many potential benefits may not be realized. In such cases, other alternatives may be more cost-effective, e.g., schedule adherence may be improved through better selection and training of bus drivers. Also, if as many buses as possible per route (at least per run sequence in a route) are operated from the same division, irresponsible drivers will receive more peer pressure from their colleagues. For security purposes, more police on buses -- both in uniforms and undercover -- may deter crime from transit locations, as SCRTD's campaign against crime starting October 1980 demonstrated. Management information can be obtained with more checkers and different sampling schemes for data collecting. Thus, if no sufficient level of use of the AVM system can be guaranteed, other options might prove to be more advantageous.

In the Los Angeles demonstration, enough staff was available to operate the AVM system and use its output. However, in the short time of actual testing, some issues of interest had to remain open for future investigation. Among these aspects are a better developed set of tactical actions and a way to provide simple control feedback for the use of AVM dispatchers; or an examination of the effectiveness of real-time control in achieving interline connections (even timed transfer), in limiting service disruptions, and in tracking individual buses after issuing a control command. The analysis of multi-user benefits (e.g., transit and police), random-route vehicle productivity, and special bus stop information units was originally planned in Los Angeles, but could not be carried out due to reductions in the scope and duration of the demonstration. All of the open issues listed above may still be explored with the technology as implemented in Los Angeles.

Ultimately, the expansion of the capabilities of an AVM system by adding new technology may enable the user to realize additional benefits that were beyond the scope of the Los Angeles demonstration. Some possible improvements are the adding of remote sensing of vehicle parameters and automatic alarm signaling of critical conditions; a combination with traffic-signal priority for transit vehicles; and the preparation of up-to-date schedule adherence information that is available to passengers through a telephone call. Other ideas and technologies may be gained through the international cooperation of transit operators with active AVM systems.

Appendix A

SUPPLEMENTARY PRESENTATIONS OF DEMONSTRATION RESULTS

Exhibit A.1

SURVEYS OF AVM DISPATCHERS
(JANUARY/FEBRUARY 1981 AND JUNE/JULY 1981)

	(Jan/Feb)	(June/July)
Surveys distributed	8	8
Surveys returned	7	6

Survey Questions[3]	Dispatcher Responses (%) Jan. (all) (n = 7)	June (same)[1] (n = 3)	June (new)[2] (n = 3)	June (all) (n = 6)
1. Did you complete the first AVM dispatcher survey in Jan./Feb?				
Yes	—	100	0	50
No	—	0	100	50
2. How do you think the new AVM system affects your job? (Multiple responses permitted)				
Makes it easier	100	67	100	83
Makes it more difficult	57	33	0	17
Doesn't affect it	0	0	0	0
Other	29	0	0	0
3. How do you think the AVM system affects bus operations? (Multiple responses permitted)				
Maintenance of on-time service	57	67	100	83
Better driver/dispatcher communication	71	67	100	83
Fewer buses required on AVM lines	14	33	0	17
Improves driver security	86	67	100	83
Improves passenger security	86	67	100	83
No effects	0	33	0	17
Other	0	0	0	0
4. How do you think the AVM system affects ridership? (Multiple responses permitted)				
Increase on AVM lines	43	0	0	0
Decrease on AVM lines	0	0	0	0
No effect	43	67	100	83
Don't know	14	33	0	17
Other	14	0	0	0
5. Do you think the AVM system is accepted by drivers?				
Yes	86	67	100	83
No	0	0	0	0
Maybe	14	0	0	0
Don't know	0	33	0	17
Other	0	0	0	0

Exhibit A.1 (Continued)

SURVEYS OF AVM DISPATCHERS (CONTINUED)
(JANUARY/FEBRUARY 1981 AND JUNE/JULY 1981)

Survey Questions[3]	Dispatcher Responses (%) Jan. (all) (n = 7)	June (same)[1] (n = 3)	June (new)[2] (n = 3)	June (all) (n = 6)
6. In comparison with your first impression of the AVM system, is your attitude now:				
More favorable	—	33	67	50
Less favorable	—	33	0	17
About the same	—	33	33	33
7. Do you think the AVM system is accepted by dispatchers in general?				
Yes	57	67	33	50
No	14	33	0	17
Maybe	14	0	0	0
Don't know	0	0	67	33
Other	29	0	0	0
8. Do you think the AVM system can pay for itself?				
Yes	43	0	67	33
No	57	67	33	50
Maybe	0	0	0	0
Don't know	0	33	0	17
Other	0	0	0	0

[1] Dispatchers who also completed the survey in January/February.

[2] Dispatchers who did not complete the survey in January/February.

[3] Questions 1 and 6 were asked in the second survey only.

Exhibit A.2

SURVEYS OF AVM DRIVERS
(DECEMBER 1980 AND JUNE 1981)

	(1980)	(1981)
Surveys distributed	30	60
Surveys returned	26	34
Usable surveys	25[1]	34

Survey Questions[4]	Driver Responses (%)			
	1980 (all) (n = 25)	1981 (same)[2] (n = 17)	1981 (new)[3] (n = 17)	1981 (all) (n = 34)
1. Did you complete the first AVM driver survey in December 1980?				
Yes	—	100	0	50
No	—	0	100	50
2. How do you think the new AVM system affects your job? (Multiple responses permitted)				
Makes it easier	84	53	65	59
Makes it more difficult	0	24	12	18
Doesn't affect it	16	41	29	35
Other	4	0	12	6
3. How do you think the AVM system affects bus operations? (Multiple responses permitted)				
Maintenance of on-time service	76	41	65	53
Better driver/dispatcher communication	64	47	35	41
Fewer buses required on AVM lines	0	0	18	9
Improves driver security	64	47	59	53
Improves passenger security	56	47	35	41
No effects	40	29	29	29
Other	0	6	18	12
4. How do you think the AVM system affects ridership?				
Increase on AVM lines	36	6	18	12
Decrease on AVM lines	4	0	0	0
No effect	44	59	65	62
Don't know	8	6	12	9
Other	8	18	6	12
No response	0	12	0	6
5. Do you like the AVM system?				
Yes	—	53	76	65
No	—	18	18	18
Undecided	—	29	6	18
6. Do you think the AVM system is accepted by drivers in general?				
Yes	60	41	53	47
No	24	24	29	26
Maybe	8	35	18	26
Don't know	8	0	0	0

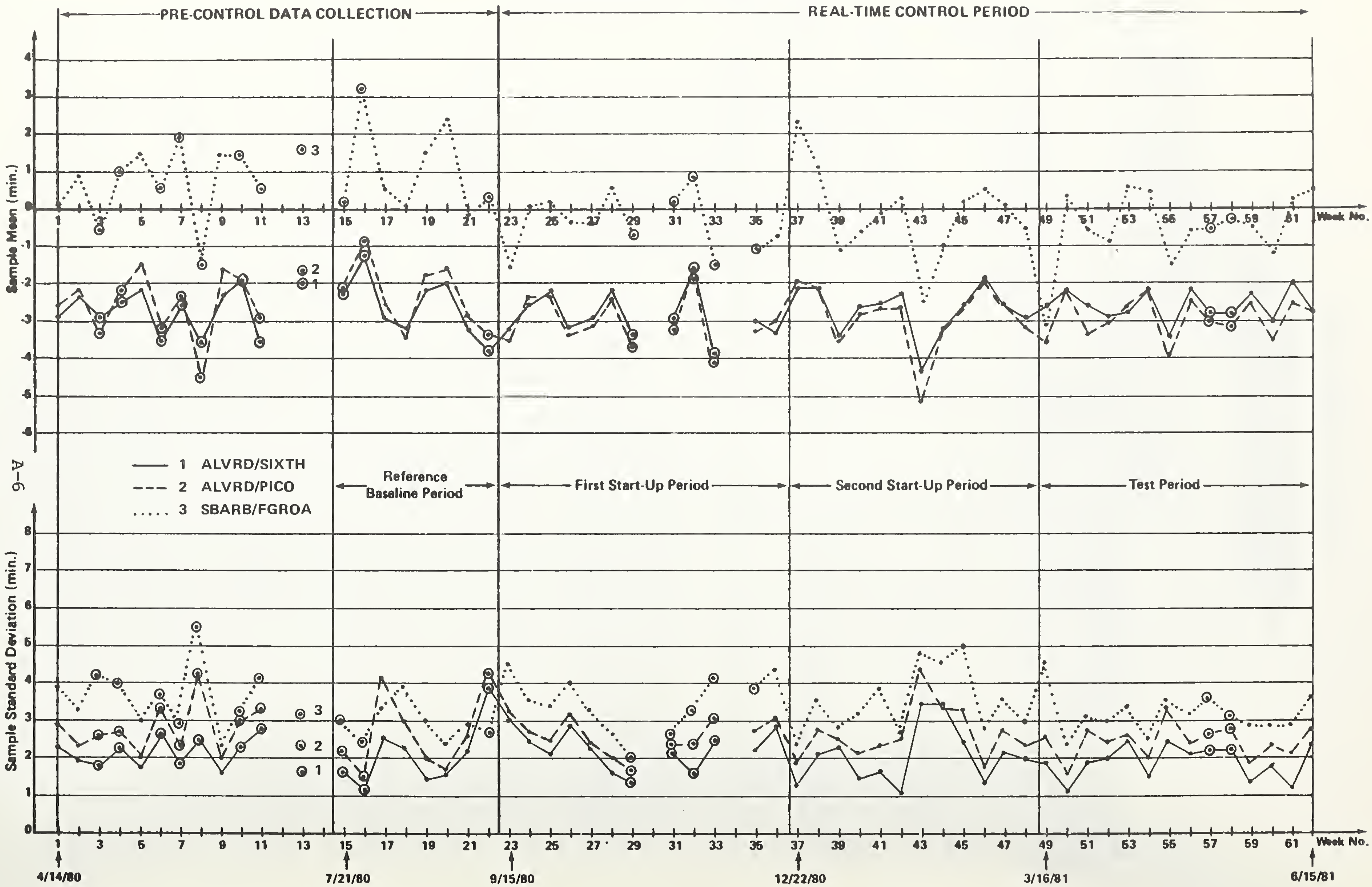
SURVEYS OF AVM DRIVERS (CONTINUED) (DECEMBER 1980 AND JUNE 1981)

Survey Questions[4]	Driver Responses (%)			
	1980 (all) (n = 25)	1981 (same)[2] (n = 17)	1981 (new)[3] (n = 17)	1981 (all) (n = 34)
7. Do you think the AVM system can pay for itself?				
Yes	24	6	29	18
No	40	47	53	50
Maybe	16	18	6	12
Don't know	20	29	12	21
Other	0	0	0	0
8. Have you operated a bus with an in-vehicle display?				
Yes	—	47	47	47
No	—	53	53	53
9. If yes, did you find it useful in helping you to stay on schedule?		(n = 8)	(n = 8)	(n = 16)
Yes	—	50	50	50
No	—	50	50	50

[1] One survey form was returned with one comment only.
[2] Drivers who also completed the survey in 1980 } see question 1.
[3] Drivers who did not complete the survey in 1980 } see question 1.
[4] Questions 1, 5, 8 and 9 were asked in the second survey only.

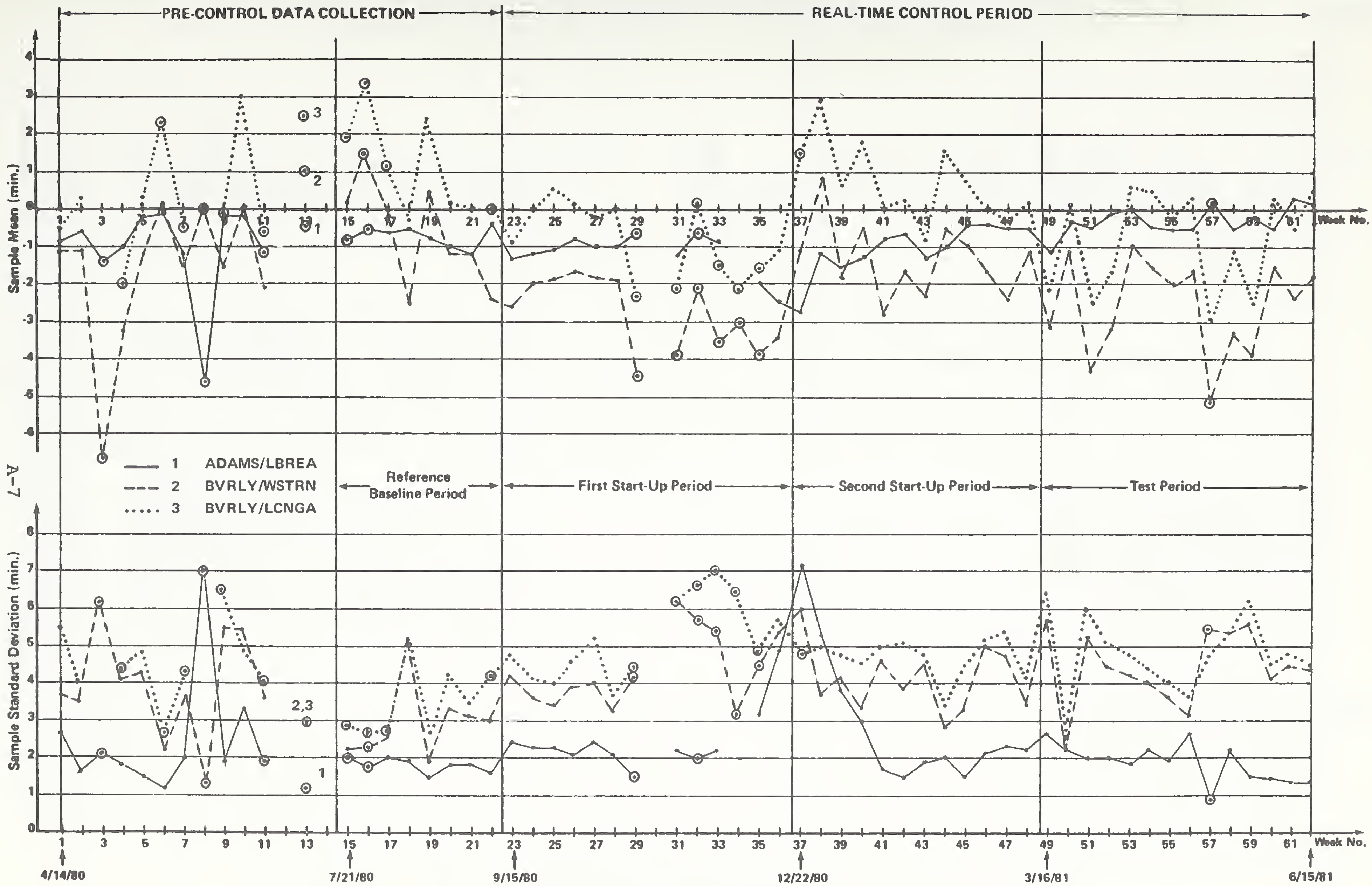
Exhibit A.3

WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 41
(SOUTHBOUND – P.M. BLOCK)



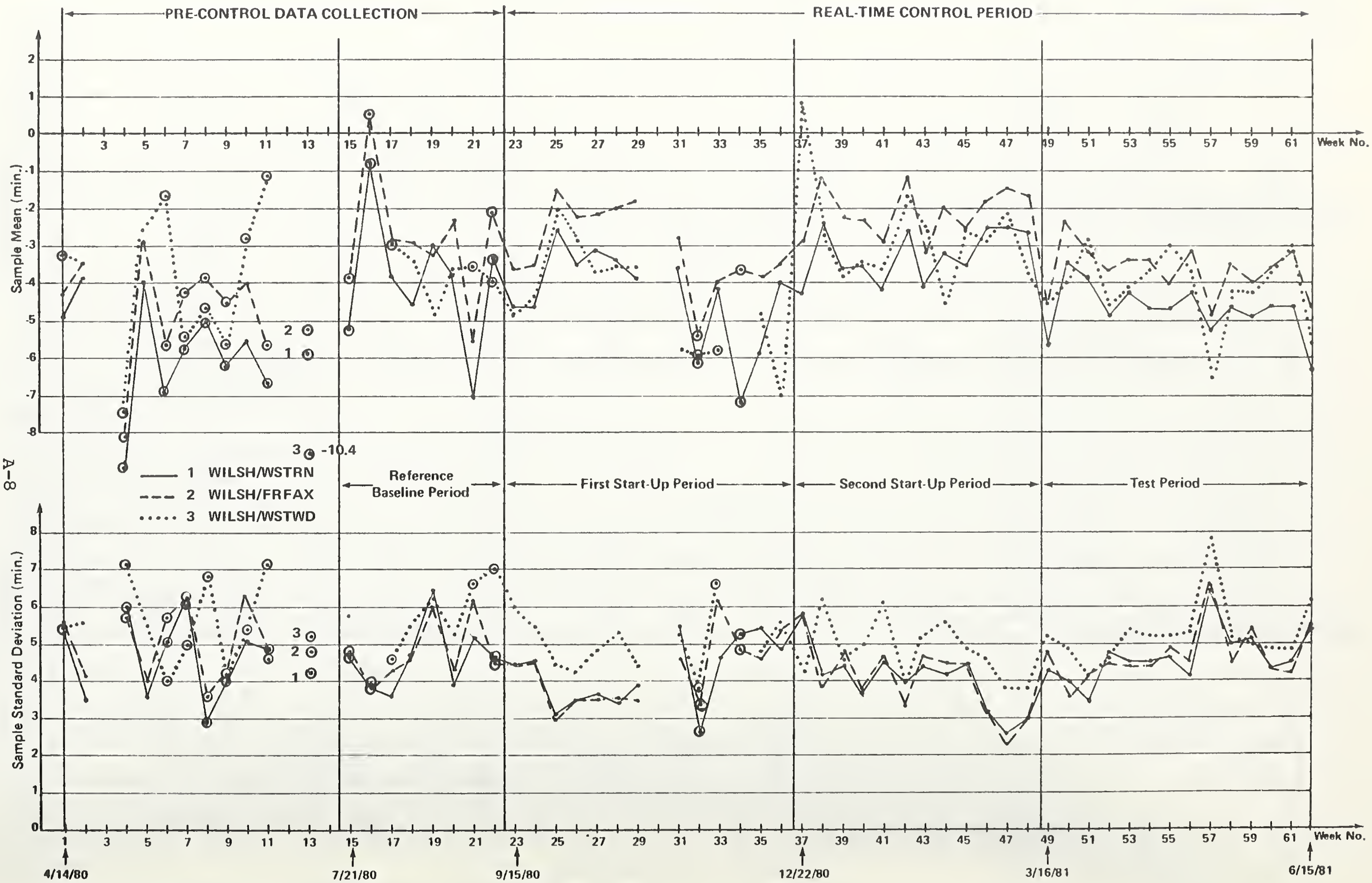
Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.4 **WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 44 (NORTHBOUND – P.M. BLOCK)**



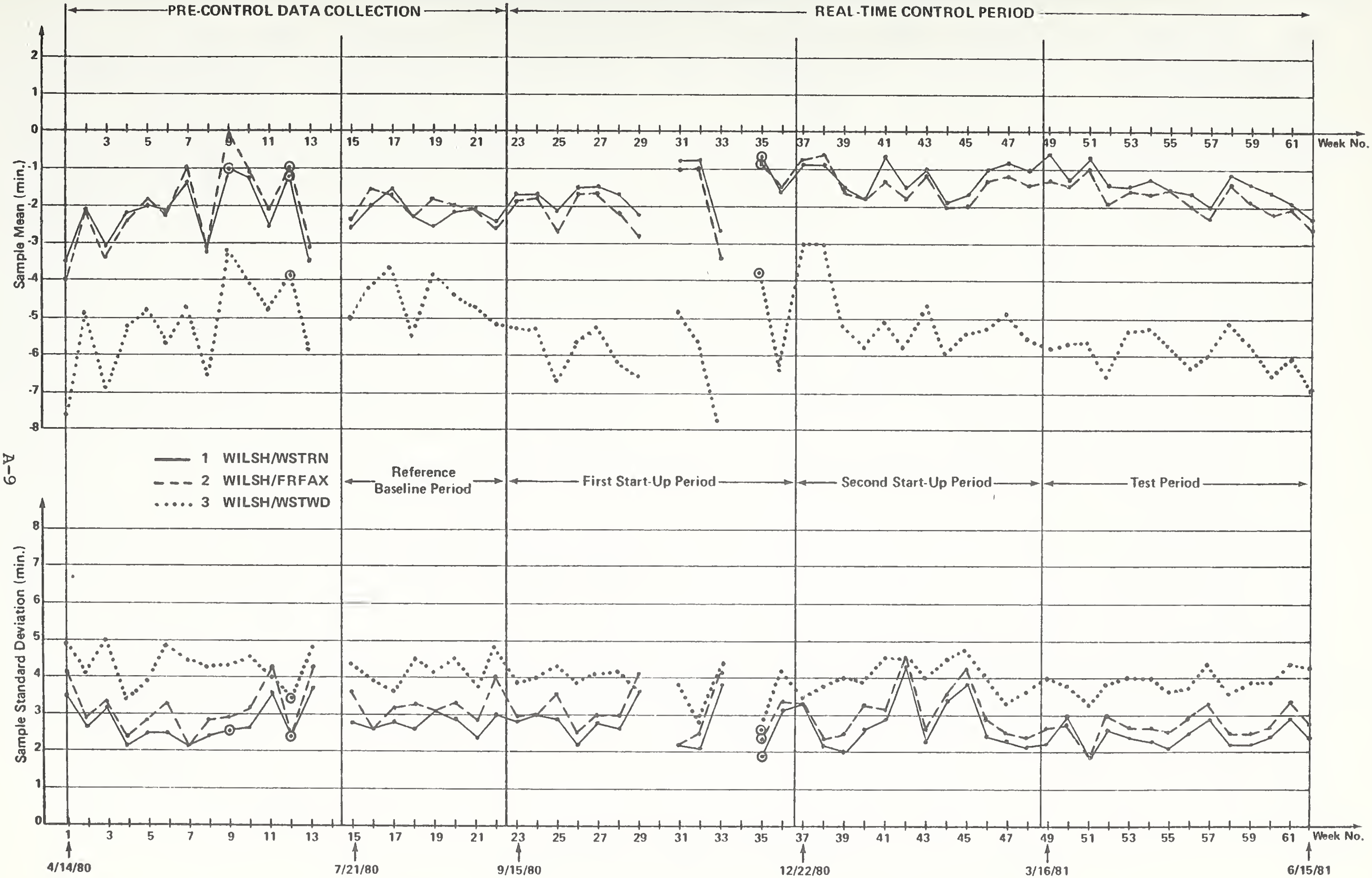
Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.5 **WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 83 LOCAL (WESTBOUND — P.M. BLOCK)**



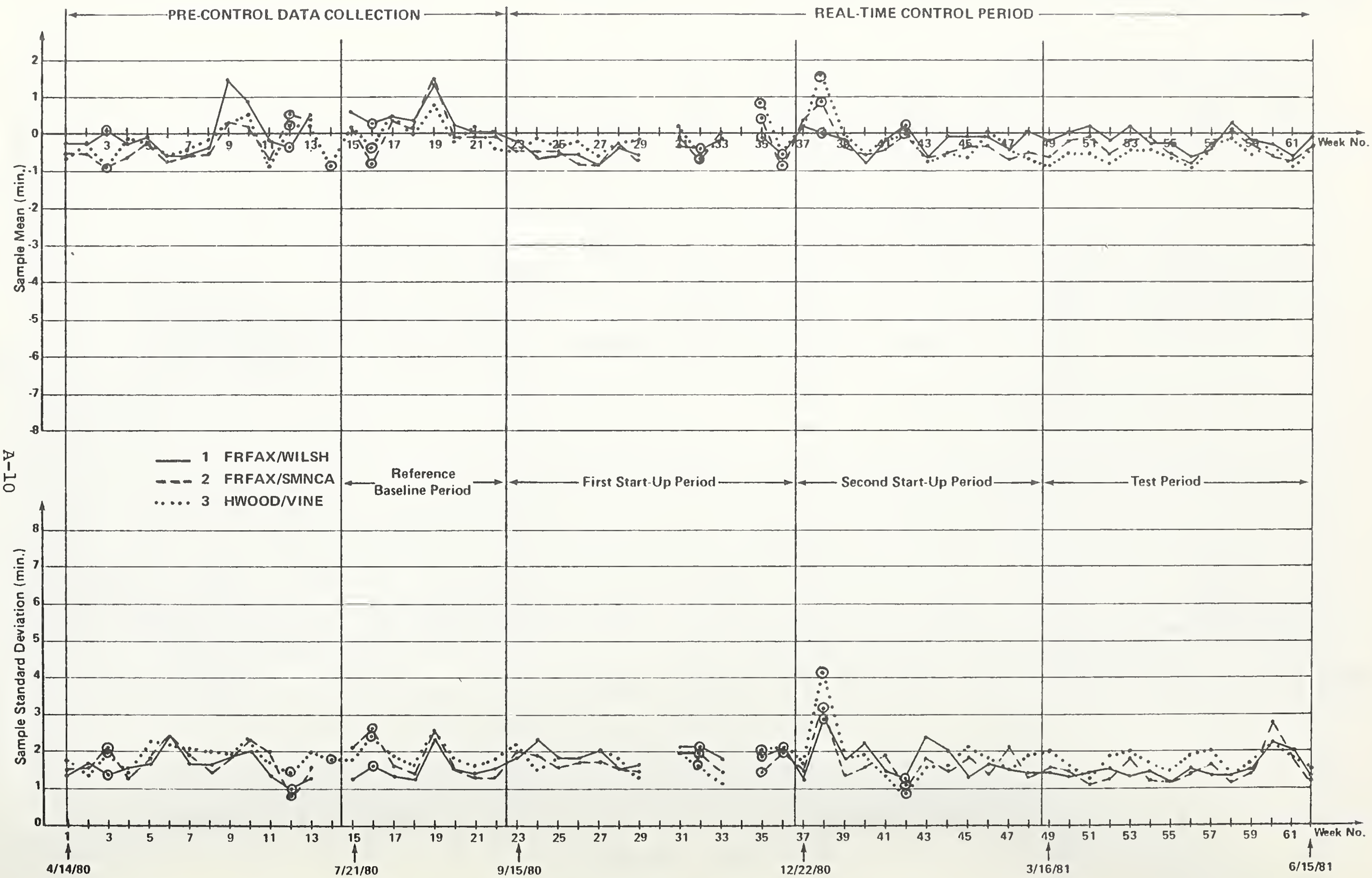
Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.6 **WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 83 LIMITED (WESTBOUND – A.M. BLOCK)**



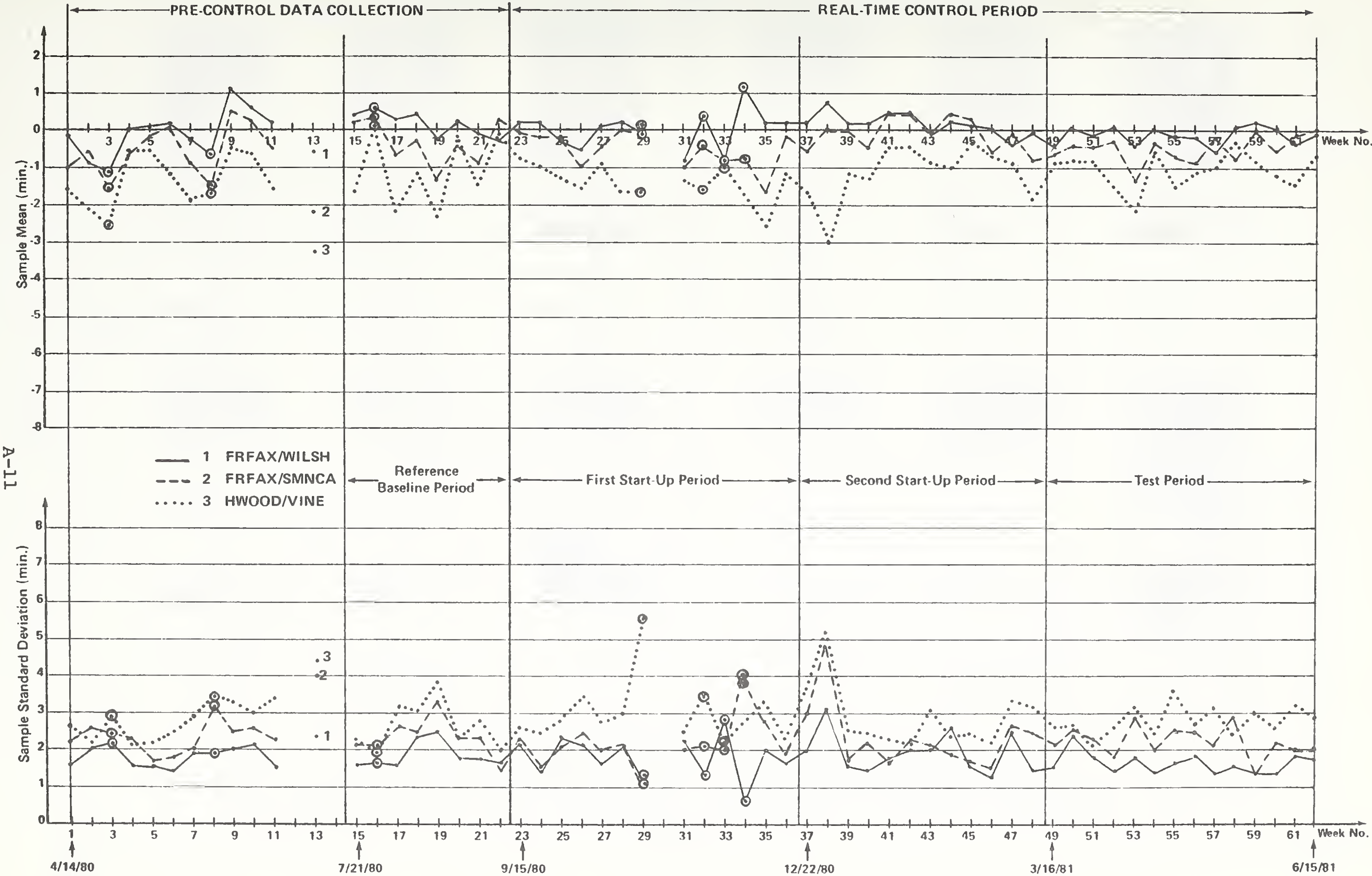
Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.7 WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 89 (NORTHBOUND – A.M. BLOCK)



Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.8 WEEKLY VARIATION IN SCHEDULE ADHERENCE: ROUTE 89
(NORTHBOUND — P.M. BLOCK)



Circled data points indicate fewer than 20 cases in sample.
No data points are plotted for fewer than 5 cases in sample.

Exhibit A.9

COMPARISON BETWEEN BASELINE AND TEST PERIODS OF THE PERCENT OF BUSES EARLY, ON-TIME, AND LATE: ROUTE 83 LIMITED

ROUTE 83 LIMITED

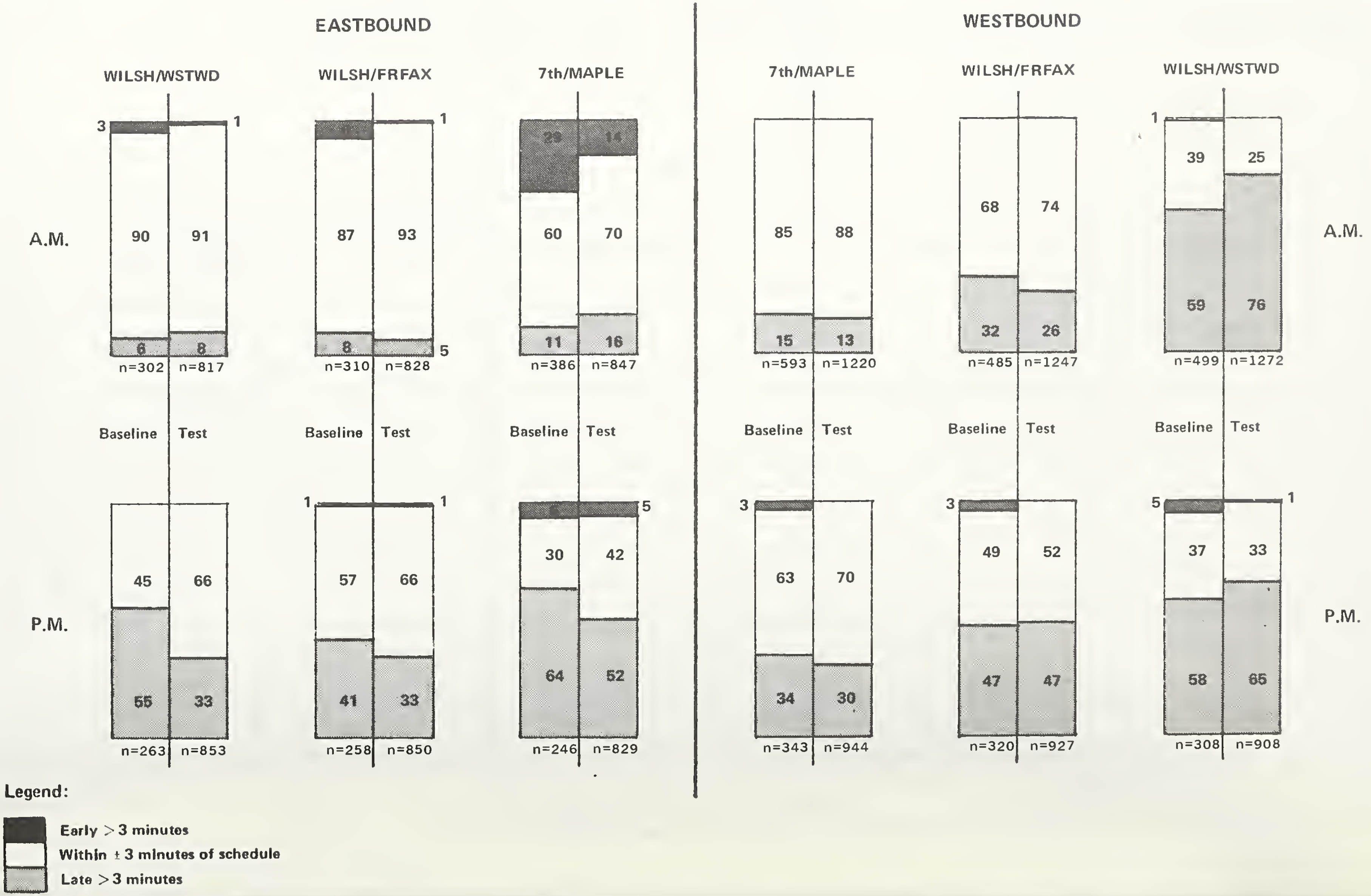


Exhibit A.10

COMPARISON BETWEEN BASELINE AND TEST PERIODS OF THE PERCENT OF BUSES EARLY, ON-TIME, AND LATE: ROUTE 89

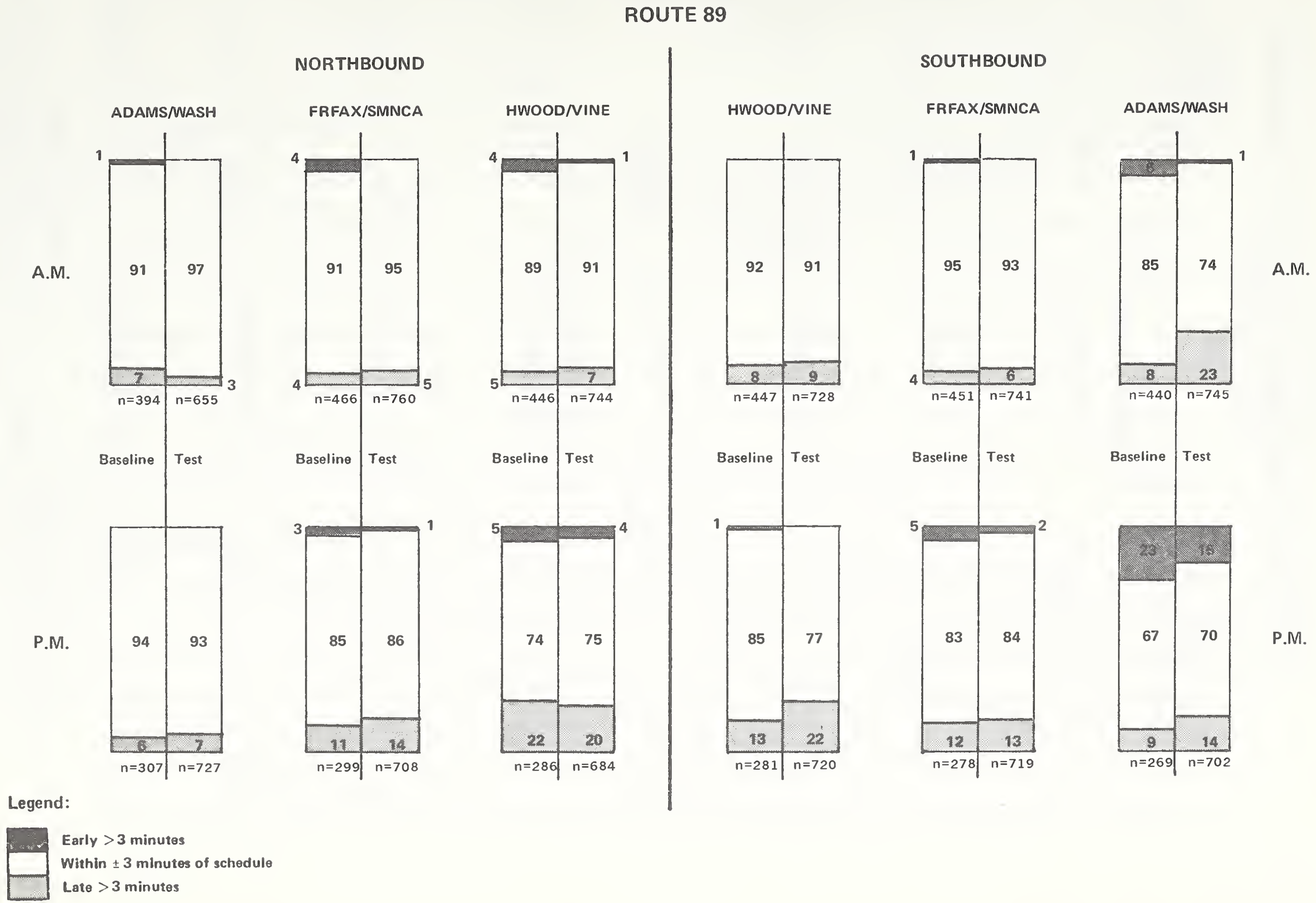
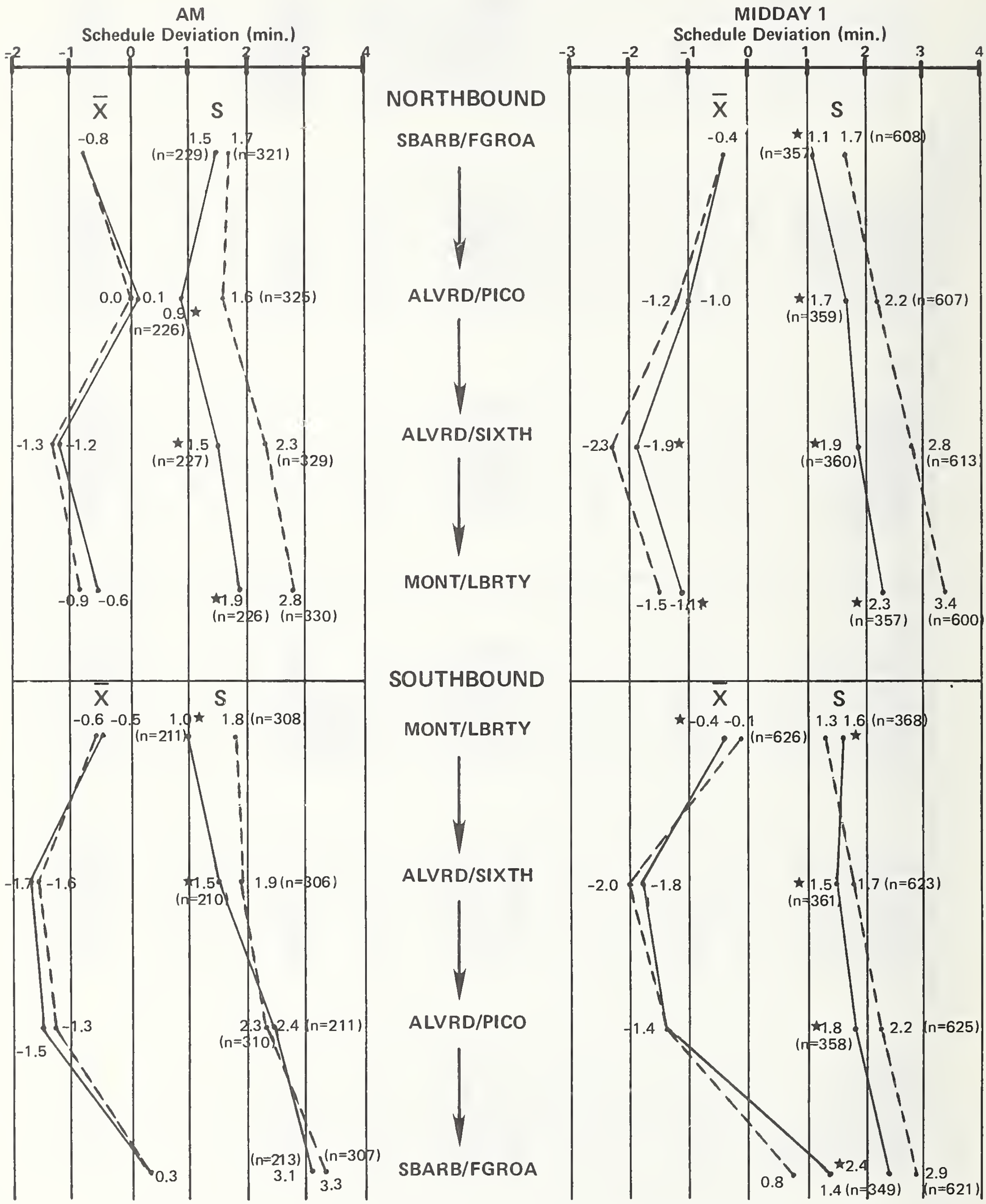


Exhibit A.11

EFFECT OF IN-VEHICLE DISPLAYS ON SCHEDULE ADHERENCE
(Route 41 — Morning)



— — Pre-IVD Period (3/16/81 to 5/8/81)

—— IVD Period (5/18/81 to 6/19/81)

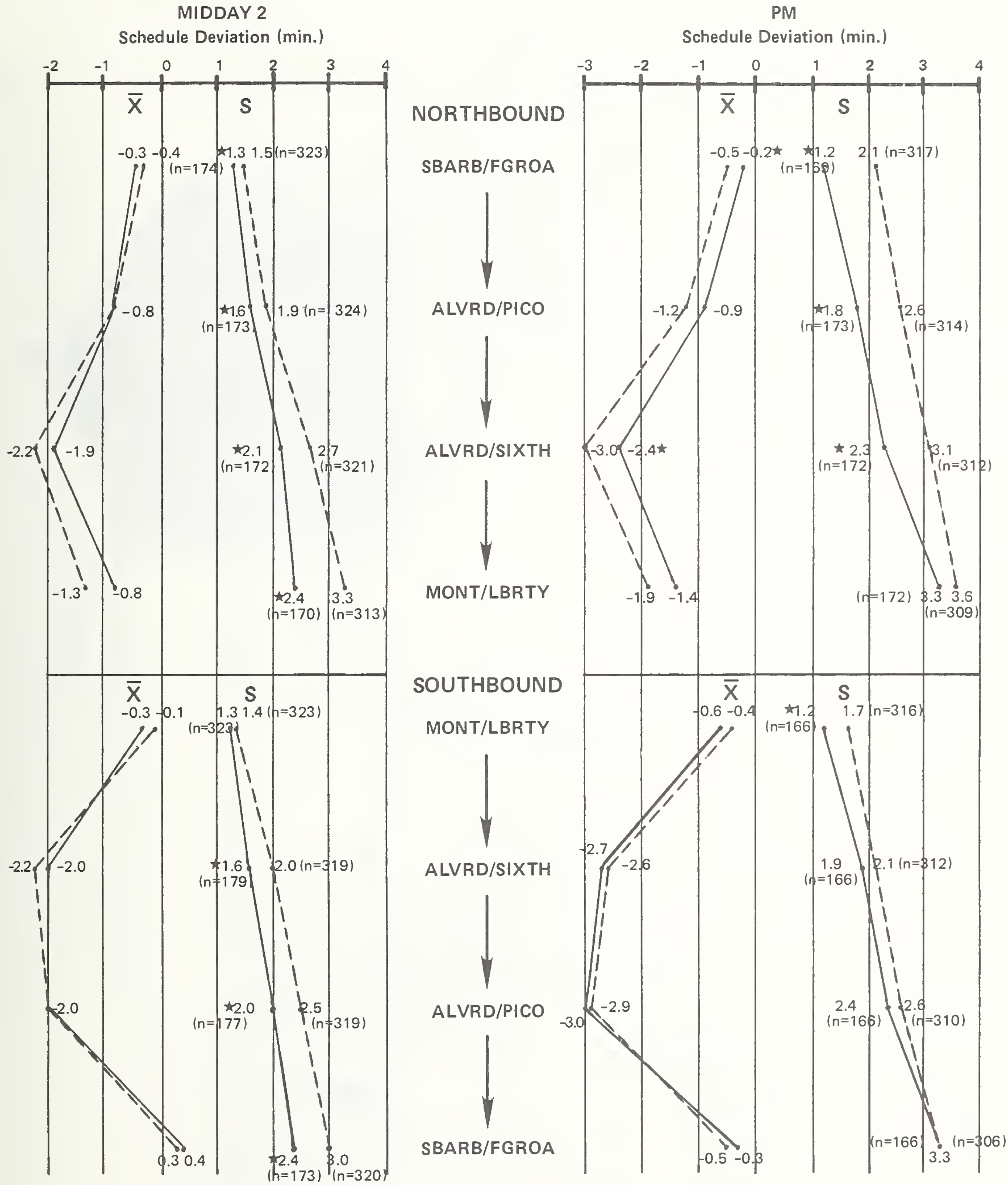
★ Difference between pre-IVD and IVD periods is statistically significant ($\alpha = 0.05$)

$\overline{X}$ = Average schedule deviation

S = Sample standard deviation of schedule deviation

Exhibit A.12

EFFECT OF IN-VEHICLE DISPLAYS ON SCHEDULE ADHERENCE
(Route 41 — Afternoon)



– – Pre-IVD Period (3/16/81 to 5/8/81)

—— IVD Period (5/18/81 to 6/19/81)

★ Difference between pre-IVD and IVD periods is statistically significant (α = 0.05)

X̄ = Average schedule deviation

S = Sample standard deviation of schedule deviation

Exhibit A.13

MAP OF AVM AND CONTROL ROUTES

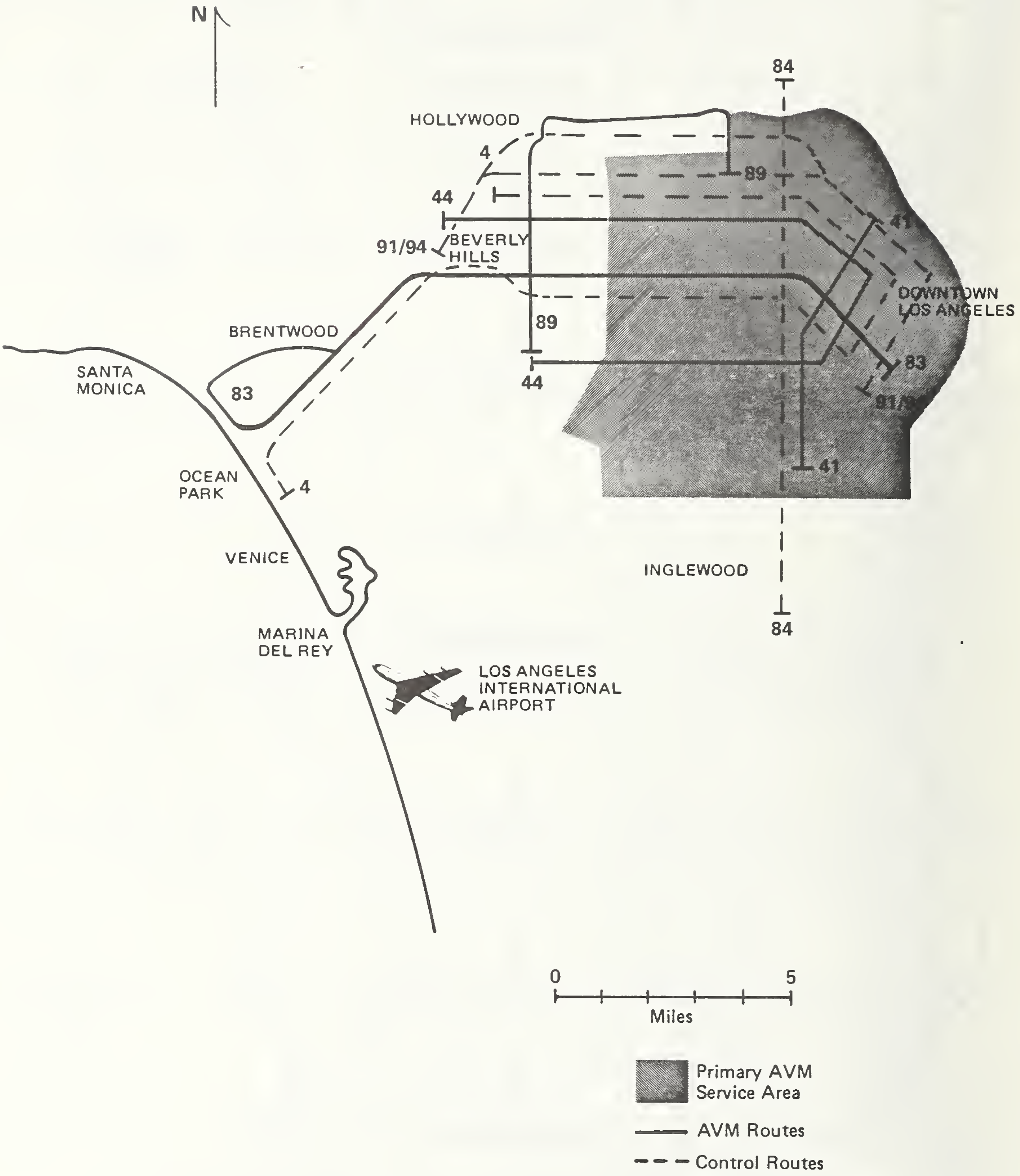
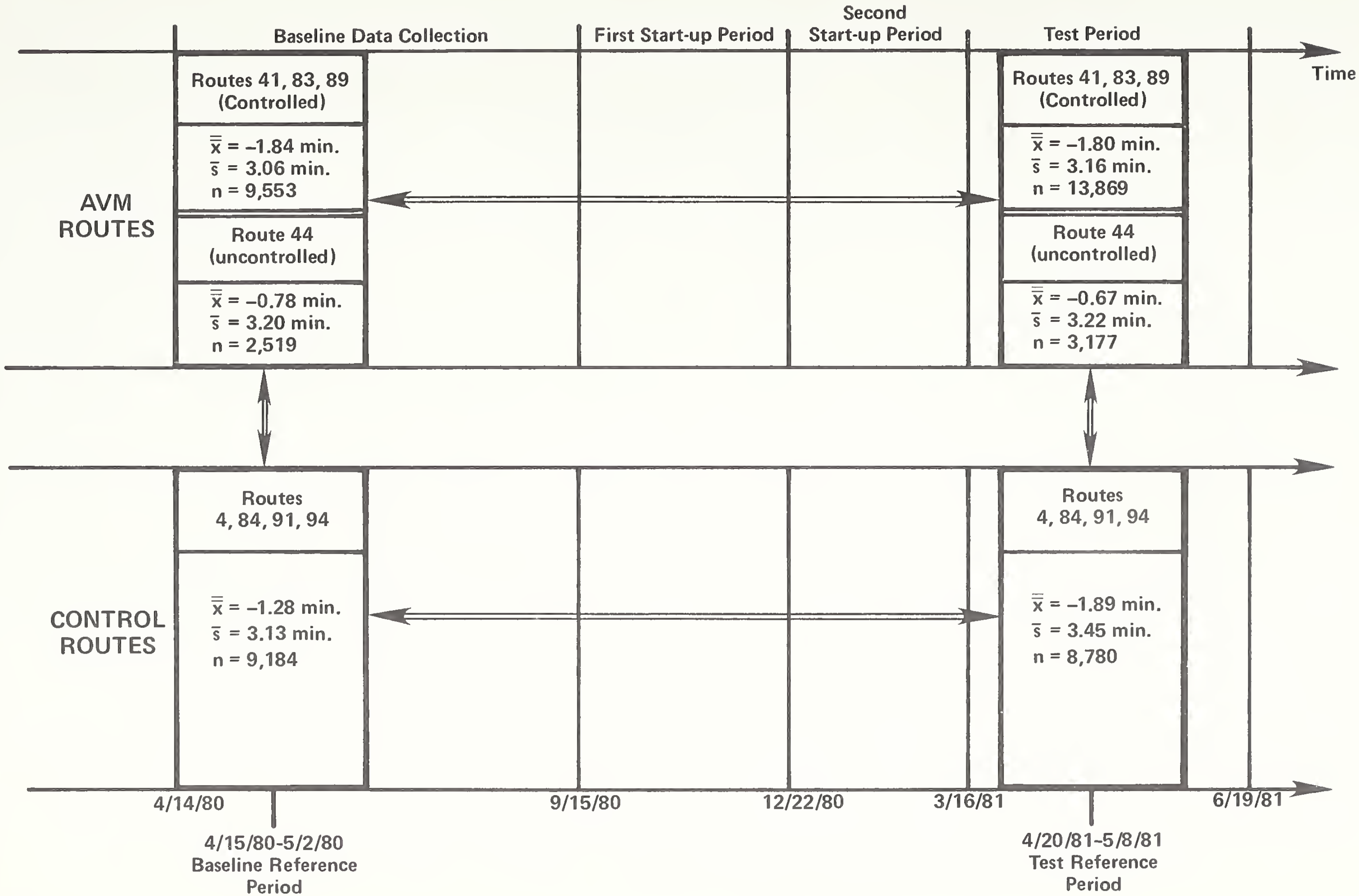


Exhibit A.14

COMPARISON OF SCHEDULE ADHERENCE ON AVM AND CONTROL ROUTES



Appendix B

REPORT OF NEW TECHNOLOGY

The Los Angeles Automatic Vehicle Monitoring (AVM) Demonstration represents the first installation of a "full" AVM system in an operating bus system in the United States. The "full" AVM system, which coupled a passenger-counting subsystem and a silent-alarm capability with the basic AVM vehicle-location system, permitted the first U.S. exploration of all potential areas of AVM benefits -- real-time control, passenger and driver security, and management information. The system offered real-time display for dispatchers of data concerning the position, schedule deviation, and passenger load of AVM-equipped buses operating within range of battery-powered transmitters mounted on streetlight poles. Four of the Southern California Rapid Transit District's 220 routes served as AVM test routes. The data collected on bus performance, passenger boardings and alightings, and passenger loads, along with data on dispatcher use of the display console's functions, was automatically recorded on magnetic tape for later computer processing and analysis aimed at improving schedules, bus performance, and dispatcher control strategies.

This report provides the first independent assessment of the socioeconomic impacts of the AVM technology on the operations of the host transit district. Such an assessment is needed in order to document the events of the federally-funded Los Angeles AVM Demonstration and the new insights gained from it, and to relate the Los Angeles experience to past, concurrent, and possible future applications of AVM or AVM-like systems. The report also presents an analysis of the costs of an AVM system, estimates the annualized cost (equivalent uniform annual cost) per bus of purchasing and operating an AVM system, and relates the cost information to the gain in vehicle productivity that would be required for an AVM system to pay for itself in a bus-transit application.

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