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of Transportation
**Urban Mass
Transportation
Administration**

The Automated Bus Diagnostic System Demonstration in New York City

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Cambridge MA 02142

December 1983
Final Report

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16. Abstract

The Automated Bus Diagnostic System (ABDS) is a microprocessor-based test and diagnostic tool that permits rapid sequential inspection and fault isolation of bus components. The evaluation examined ABDS performance, its operational and economic impacts, and the applicability of this concept for other transit operators. The primary evaluation approach was to compare operational and economic data for the experimental buses and a control group of buses.

The ABDS demonstration proved that diagnostic equipment can be successfully installed and operated at a major transit system maintenance facility. However, reluctance to use the Maintenance Area Unit by some maintenance personnel was a problem throughout the demonstration. In contrast, the Fuel Island Unit seemed to have been readily accepted. The data indicated that the ABDS equipment itself performed very well.

During the evaluation period, ABDS repair hours increased for the experimental group as compared to the control group. However, ABDS-type road calls were reduced to a greater degree for the experimental buses. In addition, total out-of-service time for the experimental group was less than for the control group during the last two months. Therefore, it appears that the added repairs on the experimental group reduced their road calls and down time.

The economic analysis showed that operational costs exceeded quantifiable benefits for the evaluation period. However, there were several maintenance and service benefits which could not be quantified. Furthermore, a six-month period is too short to fully evaluate the economics of this concept. More evaluation of ABDS is needed to determine long-term benefits and cost effectiveness.

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PREFACE

This report was prepared for the UMTA Service and Management Demonstration Program by the Service Assessment Division of the Office of Systems Assessment at the Transportation Systems Center (TSC). This study presents an evaluation of the results of an Automated Bus Diagnostic System (ABDS) demonstration co-sponsored by the Tri-State Regional Planning Commission and the New York City Transit Authority (NYCTA).

The author wishes to acknowledge the assistance of a number of people who contributed to this report. Martin Feuerstein of the New York City Transit Authority spent substantial time and effort in providing the ABDS and non-ABDS maintenance data and descriptive information on NYCTA. John Pavlovich of Tri-State provided the background information on the demonstration. Chuck Redifer and James Sutton of Hamilton Test Systems supplied data on the ABDS equipment operations, modifications, performance and cost. Dr. George Wang of TSC and David Skinner of the System Development Corp. (SDC) performed the statistical analyses. Robert Crosby and Len Somers of SDC provided data processing support. Carla Heaton and Bernd Kliem of TSC furnished helpful comments on the preparation of this report. Maria Ragone and Maribel Pedroza were responsible for typing most of this document.

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

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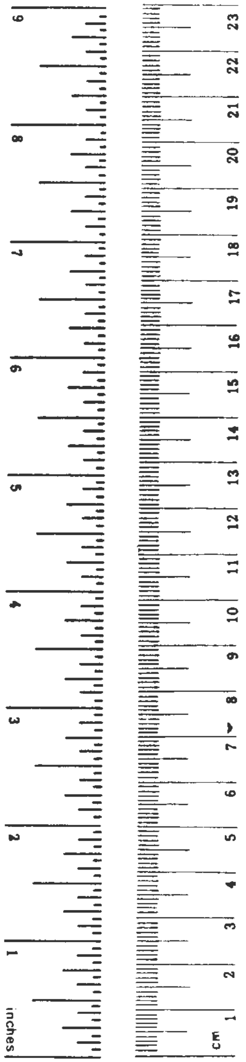
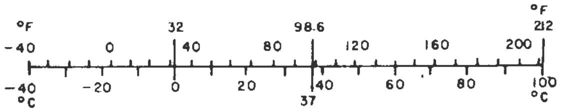
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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

DEMONSTRATION OVERVIEW

In response to a growing problem with the quality and efficiency of bus maintenance practices nationwide, the Urban Mass Transportation Administration awarded a demonstration grant to the Tri-State Regional Planning Commission for the testing of an Automated Bus Diagnostic System (ABDS). The ABDS was designed to improve the effectiveness of bus maintenance through early detection of bus defects, improved diagnosis and fault isolation, and a reduction in improper repairs. It was anticipated that the efficiency of bus operations would be improved by decreasing the number of in-service breakdowns and reducing the number of spare buses required to maintain scheduled service.

The ABDS is a microprocessor-based test and diagnostic tool that permits rapid sequential inspection and fault isolation in buses and their subsystems. The equipment consists of two computerized diagnostic units, one in the fuel island area and one in the maintenance area, and on-bus instrumentation which interfaces with the diagnostic units through cable connections. The Fuel Island Unit (FIU) provides for an automatic test sequence to determine the general health of each bus during the fuel island service period each day. The Maintenance Area Unit (MAU) can automatically perform prescribed test sequences designed to pinpoint the location of faults in the vehicle. The MAU is used for testing of instrumented buses which fail certain tests on the FIU, as well as for testing of all instrumented buses experiencing certain types of road calls and after completion of 6000-mile inspections. When the system compares actual failed tests with the fault matrices stored in the system, a specific fault can be identified to the replaceable component level. Once corrective action has been taken, verification of successful repair can be quickly determined by retesting the vehicle subsystem affected. The bus-mounted sensors and on-board electronics generate the data which are accessed through the FIU and MAU electrical umbilical connectors and the MAU multiport transducer connection. In all a total of 68 measurements are possible.

The New York City Transit Authority (NYCTA) and the Tri-State Regional Planning Commission, with the assistance of a consultant, Sperry Systems

Management, developed the various aspects of the demonstration. Careful attention was given during the preliminary planning stage to the selection of buses for the test and the logistics of retrofitting the buses with ABDS instrumentation. NYCTA conducted the test at the Queens Village Bus Depot; this site was selected because of amenable labor union personnel, low maintenance staff turnover and absenteeism, negligible vandalism, and a suitable bus fleet. Queens Village has an assignment of 210 buses which operate 5.7 million miles over 12 routes. A total of 38 of these buses had operational instrumentation during the evaluation period. Forty similar buses were selected as a control group for comparison purposes.

EVALUATION OVERVIEW

The evaluation was conducted by the Transportation Systems Center, with data and descriptive material supplied by NYCTA, the Tri-State Regional Planning Commission, and Hamilton Test Systems, the contractor for the ABDS equipment. The evaluation of ABDS operation covered the period February 11, 1982 to July 31, 1982, the only period when the ABDS equipment was both operational and intensively used. Only 32 experimental and 35 control group buses were used in the comparative evaluation since six experimental and five control buses were out of service for large portions of the before or after periods due to defects which ABDS was not designed to detect.

The evaluation examined the ABDS performance, the resulting operational and economic impacts, and the applicability of this concept for other transit operators. The primary evaluation approach was to compare operational and economic data for the experimental buses to the same data from the set of control group buses.

There were omissions in the data that were available for the analysis, however, which limit the conclusiveness and transferability of the evaluation findings. No empirical data were provided on manual diagnostic times for a comparison with ABDS diagnostic times although estimates for manual diagnosis of selected faults were provided as a consensus by several experienced maintenance personnel. No information was available on the quality check of completed repairs. There was no accurate method of determining the frequency of proper MAU use or the frequency of failed test reports for which no defect was found. The cost of parts used in ABDS type repairs could not be determined. There also were some inconsistencies in bus and ABDS equipment out-of-service time data obtained from different sources.

ABDS EQUIPMENT UTILIZATION AND RELIABILITY

FIU testing added about 50 seconds of fuel island dwell time for experimental buses, but total dwell time was still within the standard 3 minute allowance per bus. However, if appropriate modifications to the existing test procedures were made, the additional time needed to perform the ABDS testing would be very small.

Test records indicate that not every in-service experimental bus was tested at the fuel island each night. However, there were several legitimate reasons why this might have happened. Therefore, it seems that the fuel island testing procedures were followed quite well after the first couple of months of full operation.

The MAU was used properly about 40 percent of the time following an FIU failed test. Another 21 percent of the time, the MAU was used during the repair but not in the proper sequence. It seems that the MAU was not used as often as it should have been in diagnosing defects indicated in FIU tests. Data are not currently on hand to determine how many road call problems should have been tested on the MAU.

According to Hamilton Test Systems' data, the FIU was out of service on only six days during the six-month evaluation period due to equipment problems. However, FIU test records indicated five additional weekdays for which no FIU test results were obtained and at least eleven more for which many fewer than expected were found. It is likely that these additional FIU out-of-service days were caused by procedural or human errors on the part of NYCTA personnel. For instance, on at least three occasions a supervisor departed work with the locking key for the FIU. Hamilton records showed no out-of-service days for the MAU during the six-month evaluation period.

The true reliability of the on-board instrumentation is uncertain although there were some known instances of malfunctions. The on-board instrumentation sometimes interfered with bus repairs. When this occurred the instrumentation was usually removed or disconnected. In general, the experimental buses were out of service only for short periods of time while the instrumentation was being put back into an operable condition. A large part of the instrumentation's interference with bus repairs was due to the prototype nature of the bus instrumentation package.

An attitudinal survey was administered by NYCTA in order to obtain the opinions of the Queens Village Depot foremen and mechanics towards the ABDS. Only 10 mechanics had ever used the MAU and only six had used it more than five times. Overall, the MAU received a lower rating from users on fault diagnosis than might have been expected, yet most of them believed that it should be used. About 46 percent of the mechanics who had never used the MAU expressed a desire to use it, another result that might not have been expected. Virtually none of them felt that they had enough training to use it, however. It should be noted that even though anonymity was promised for those responding to the survey, the survey forms contained a serial number which could have biased the answers furnished.

MAINTENANCE IMPACTS

It was anticipated that the diagnostic testing would reduce ABDS detectable repairs on the experimental buses. Maintenance activity on the buses was transformed to an equivalent basis for comparison purposes. Since out-of-service data were not available in the before period, the buses were compared on the basis of the number of days the buses could have been in service (potential bus days). Monthly comparisons of experimental and control group ABDS detectable repairs and repair hours are shown in Figures 1 and 2. The overall before-after comparison showed the experimental group receiving over 72 percent more repairs per potential bus day during the after period while the control group was experiencing over 31 percent more repairs. More importantly, repair hours per potential bus day decreased by over 18 percent for the control group from the before to the after period, while they increased by over 32 percent for the experimental group. The apparent

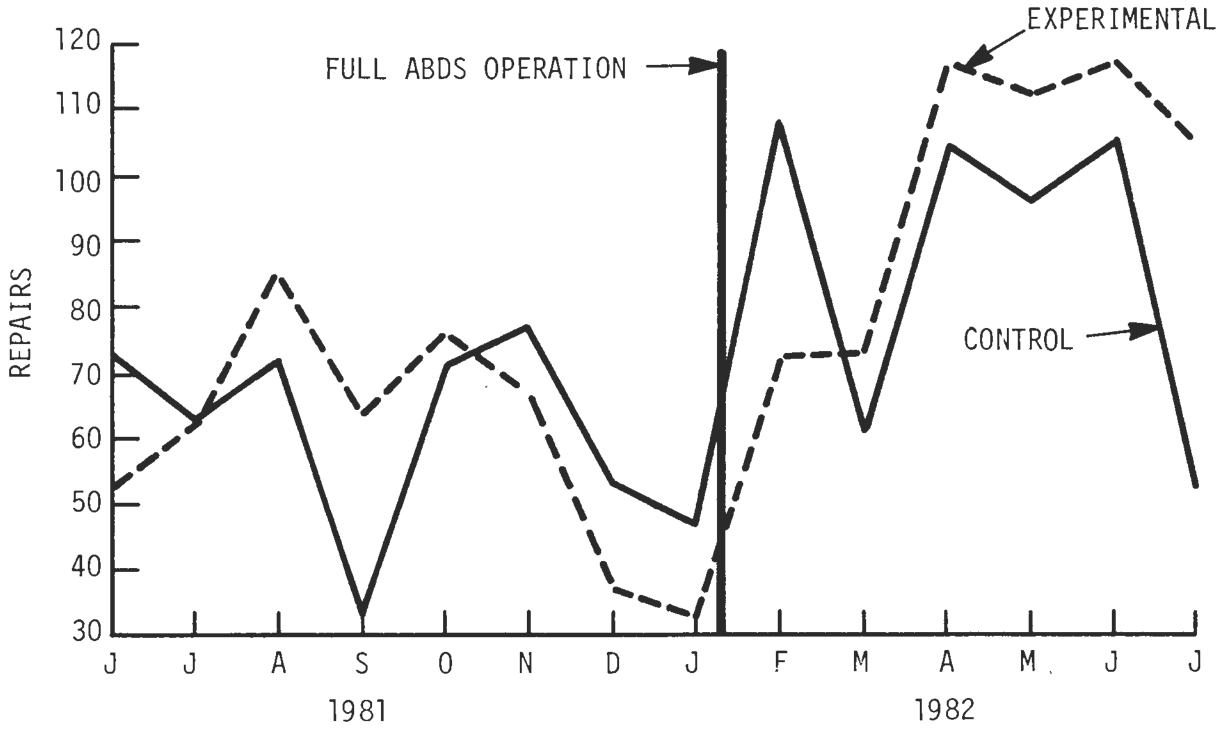


FIGURE 1. ABDS DETECTABLE REPAIRS

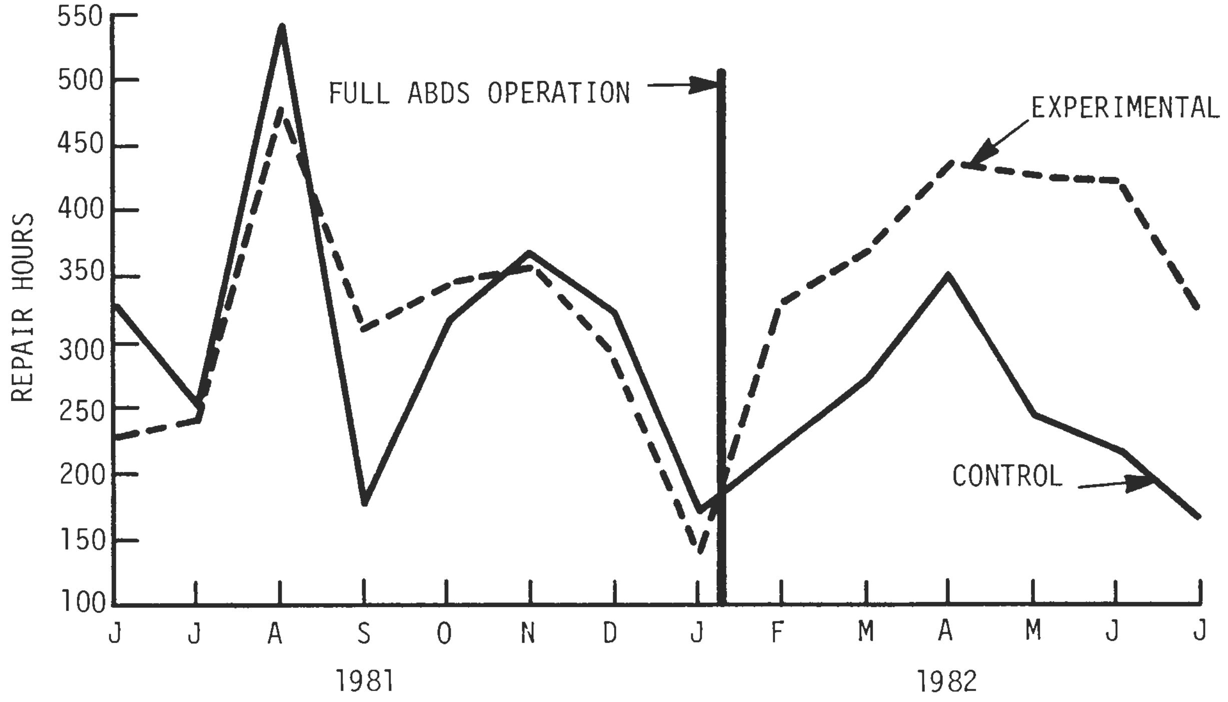


FIGURE 2. ABDS DETECTABLE REPAIR HOURS

explanation of the increased experimental group repairs and repair hours is that the ABDS equipment found defects which were repaired but which would not have been found without ABDS. It would be anticipated that, over some extended period of time, these repairs would reduce the number of major bus component failures. Such an impact was not observed within the evaluation period, probably because it was of insufficient length.

About 80 to 85 percent of all bus repairs and repair hours were in the non-ABDS detectable category. Non-ABDS repairs and repair hours per potential bus day increased by 18 and 22 percent, respectively, for the experimental group from the before to the after period, and by 6 and 9 percent for the control group. A possible explanation for the greater increase in experimental bus non-ABDS repairs and repair hours is that during the course of the extra ABDS repairs performed on these buses, additional non-ABDS faults were discovered which might otherwise have gone undetected.

One of the principal expected advantages of ABDS was the ability to diagnose faults more precisely and quickly. However, the manner in which maintenance information was recorded precluded the acquisition of diagnostic time data directly. Therefore, NYCTA selected eight maintenance supervisors and management personnel to produce an estimate of the time involved to manually check the items which the ABDS does automatically. In all instances, the ABDS tests were shown to take much less time than the manual tests. The differences amounted to several hours for some tests.

OPERATIONAL IMPACTS

Since the experimental buses received more repairs than the control group, they accumulated more out-of-service time. However, the trend by month shows out-of-service days decreasing for the experimental buses but increasing for the control group (Figure 3). Total out-of-service time for the experimental group was less than that for the control group during the last two months of the demonstration. It would seem that the added repairs on the experimental group were reducing their out-of-service time.

ABDS detectable road calls were reduced in the after period for both bus groups (Figure 4), but were reduced more for the experimental buses (30

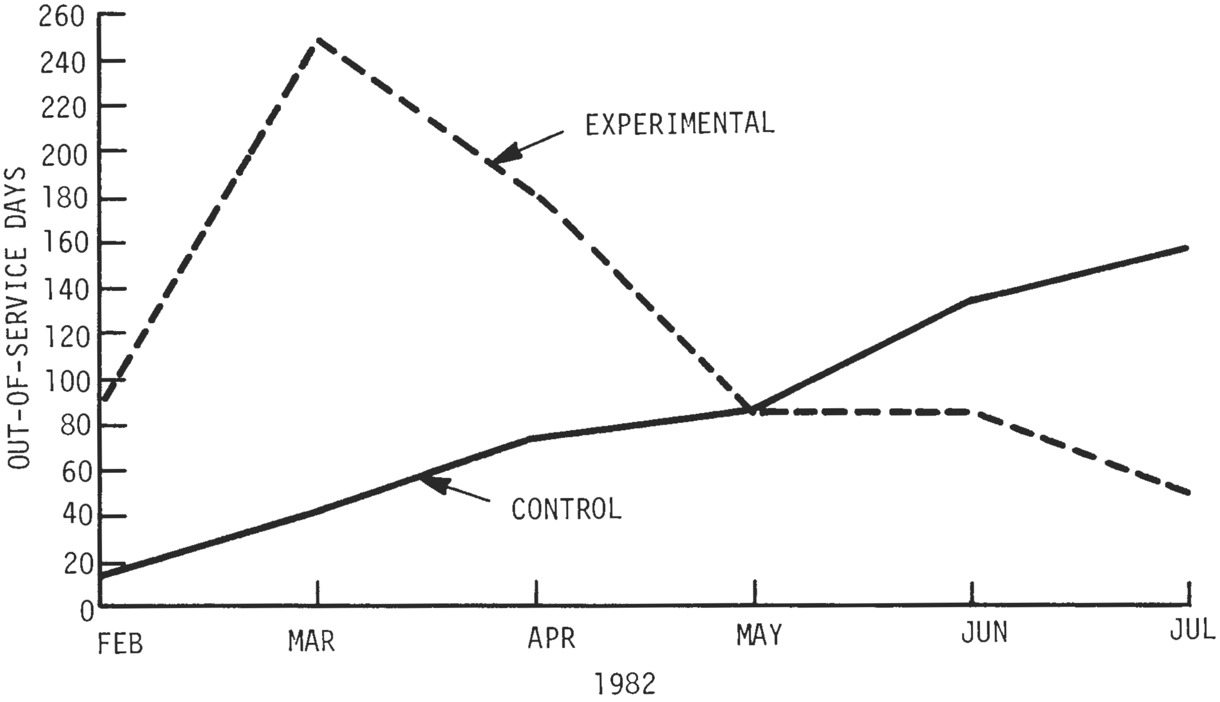


FIGURE 3. OUT-OF-SERVICE DAYS

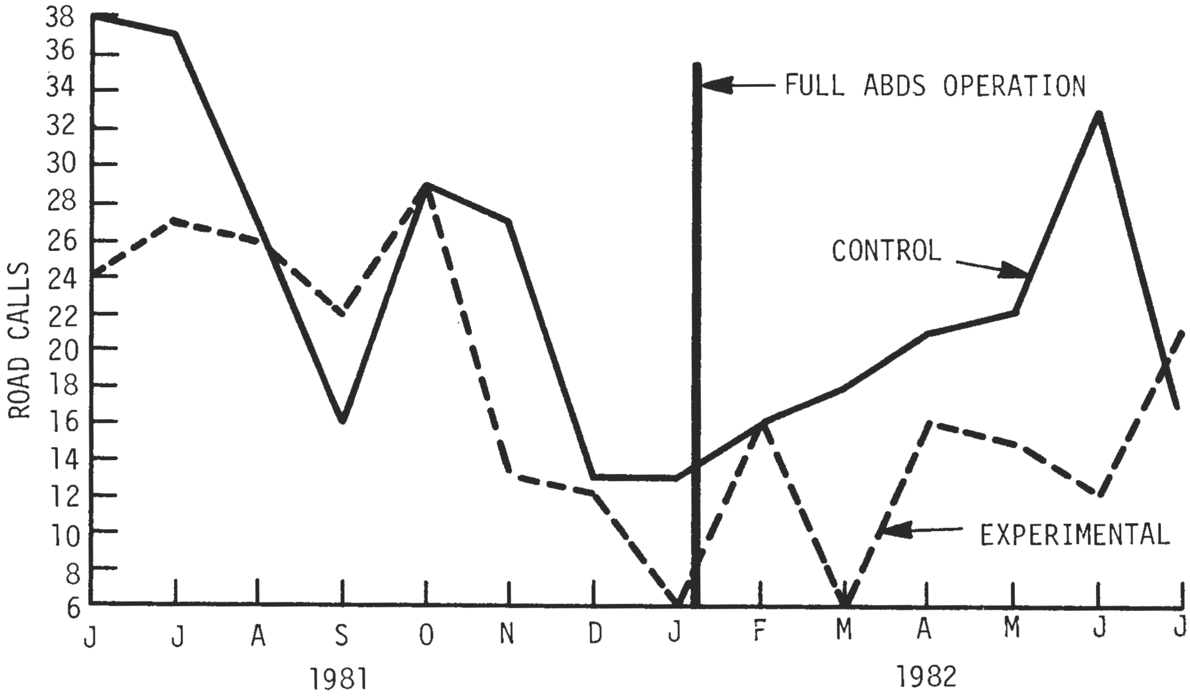


FIGURE 4. ABDS DETECTABLE ROAD CALLS

percent) than for the control group (12 percent). This reduction in ABDS road calls is the principal benefit measured in the evaluation from use of the ABDS equipment.

ECONOMIC IMPACTS

It is not possible to perform a rigorous economic analysis given the experimental nature of the project with large start-up costs that would not occur in the investment for normal operational use of the equipment. For the six-month test period, costs attributable to ABDS operations were $22,382 -- which included the ABDS equipment maintenance and repair, the materials and power consumed in normal use of the ABDS, and maintenance labor. The cost savings from reduced road calls were estimated at $1800 by NYCTA.

There are several qualifications which limit the implications of the economic analysis. Two expected major advantages of ABDS -- improved diagnosis and fault isolation, and the upgrading of the quality of maintenance through automated checkout of completed repairs -- could not be addressed by the evaluation due to lack of data. There also was an inability to quantify the impacts of reduced road calls, reduced out-of-service time and better service, or to assess long-term demonstration impacts. Additionally, maintenance labor savings resulting from faster ABDS fault diagnosis were not achievable in this demonstration due to NYCTA's practice of allowing mechanics to take a standard amount of time for specific repairs.

CONCLUSIONS

The ABDS demonstration proved that diagnostic equipment can be installed at a maintenance facility of a major transit system. The transit union agreed to cooperate in the test and the testing equipment was successfully installed and operated. However, reluctance to use the MAU by some maintenance personnel remained a problem throughout the demonstration. In contrast, the FIU seemed to have been readily accepted. The data indicated that the ABDS equipment itself performed very well. It is significant that the ABDS equipment continues in regular use at the Queens Village Depot.

The short-term results of increased repairs and repair hours indicated in this ABDS evaluation probably would be experienced by other transit operators using the same approach. In return for this added repair effort, NYCTA experienced fewer ABDS related road breakdowns, and a steady reduction in out-of-service time. Similar short-term results likely can be expected for others who might install diagnostic equipment. Unfortunately, this demonstration was not operational for a sufficient length of time to provide any indication of longer term maintenance and operational results.

The financial analysis showed that calculated or estimated operational costs exceeded quantifiable benefits for the six-month evaluation period. However, it must be realized that this was a prototype system and that there were several real or probable maintenance and service benefits from ABDS utilization which could not be quantified in this evaluation. Furthermore, a six-month operational period is too short a period of time in which to evaluate the economics of this concept which could have substantially different long-term effects.

With careful planning and improved equipment, lower costs should be possible at other locations. Nevertheless, it is questionable whether quantifiable benefits would exceed quantifiable costs in the short term. Over a long period, there is a better chance for the benefits of early detection and repair to produce more favorable results. Furthermore, reduced road calls almost certainly would produce operational benefits beyond the cost savings attributed to them. The importance of such operational benefits as better service reliability and schedule adherence, and greater passenger convenience should not be disregarded merely because a monetary value cannot be put upon them.

The ABDS demonstration results could have been influenced by a number of factors including the small number of buses instrumented for ABDS, the age of the buses, the deficiency in the utilization of the MAU, and the allowance of standard repair times for some component repairs. Furthermore, data were completely lacking on two key expected advantages of ABDS, specifically, faster and more accurate diagnostics and the quality check on repairs. Nevertheless, the results of the NYCTA experiment can provide useful information for others contemplating ABDS type implementation.

A number of questions remain to be answered after this ABDS experiment, particularly with respect to long-term impacts. More evaluation of the use of ABDS is needed to determine long-term benefits and cost effectiveness.

1. PROJECT OVERVIEW

1.1 DEMONSTRATION

1.1.1 Demonstration Background

During the past few years, a diminishing level of experience in the bus maintenance force nationwide has led to maintenance error and has significantly contributed to a growing unreliability in service performance. Increased emphasis on training, although essential as a part of the long term solution to such a problem, was not considered sufficient as a near term solution.

Recent successful experience with automatic and semi-automatic diagnostic techniques in other industries had great appeal as an immediate remedy that could later complement the benefits of a prolonged emphasis on maintenance training. Encouragement from the transit industry led to the development of an Automatic Bus Diagnostic System Demonstration project. An Urban Mass Transportation Administration (UMTA) Section 8 Planning grant was awarded to Tri-State Regional Planning Commission, the local grant recipient, who in turn contracted for a feasibility study of the Automated Bus Diagnostic System concept. Based upon the results of the feasibility study, an UMTA Section 6 Demonstration Grant was awarded to Tri-State Regional Planning Commission, who contracted for purchase of the equipment and on-board bus modifications and made an argeement with the New York City Transit Authority to test the equipment in an operating environment.

1.1.2 Demonstration Description

The Automated Bus Diagnostic System (ABDS) demonstration was conducted at the Queens Village Depot of the New York City Transit Authority. The ABDS equipment is intended to be a tool to help detect bus defects before they cause a serious problem, to pinpoint the specific component which is not performing up to standard, and to indicate the repair which would correct the problem. Defects are identified through a series of limited tests at the fueling island each night or through more extensive testing in the maintenance area. On-board instrumentation interfaces with off-board computers which read the test measurements and compare them to the satisfactory performance ranges for the individual bus. Any bus which fails any of the fuel island unit (FIU) tests are examined by the foreman with subsequent disposition to the maintenance area for further testing or repair, back into service with the stipulation that it be sent to the maintenance area at a later time, or back into service with no further action required. This last situation occurs if the foreman judges the test result not to be a valid problem. The maintenance area unit (MAU) is used to test buses following a FIU failed test, certain types of road calls, or certain reported bus faults. Buses failing the MAU tests are usually repaired soon thereafter.

A total of 40 buses, including 30 General Motors 1970 coaches and 10 Flxible 1973 coaches, were initially equipped with instrumentation although only 38 had such instrumentation during the evaluation period. A similar set of 40 buses were established as a control group for comparison purposes and as a means of accounting for external influences.

The evaluation of this system was conducted by the Transportation Systems Center, with substantial assistance from the New York City Transit Authority (NYCTA) in providing data and writing background and descriptive portions of this report. Hamilton Test Systems, who designed and monitored the performance of the ABDS equipment, provided data on the equipment for this report. Tri-State also submitted background material for the report. The evaluation covered the period February 11, 1982 to July 31, 1982, which was the only time during the original demonstration period (June 1981 to July 1982) when the ABDS system was both operational and being intensively used.

1.1.3 Demonstration Objectives

The objective of the ABDS was to improve the efficiency of daily bus operations, the 3,000 and 6,000 mile scheduled maintenance and the overall effectiveness of bus maintenance for the NYCTA. It was anticipated that operating efficiency would be improved by:

1. Increasing the operational reliability of buses in service, thereby decreasing the number of in-service breakdowns.
2. Identifying buses which consume excessive amounts of fuel, oil and coolant for possible corrective maintenance.
3. Enabling a depot to satisfy its requirement for buses in service with a smaller total complement of buses.

The effectiveness of bus maintenance should be improved by:

4. Early detection of defective components or conditions, thereby reducing the deleterious effect on associated components.
5. Improved diagnosis and fault isolation resulting in a reduction of improper maintenance actions and component replacements.
6. Upgrading the quality and thoroughness of maintenance as a result of automated checkout of completed repairs.

If these goals and objectives were realized, better service to the bus-riding public would result while enhancing the effectiveness of operating and maintenance personnel.

1.2 EVALUATION

1.2.1 Key Issues and Evaluation Strategy

The objective of the evaluation was to determine whether or not ABDS utilization achieved the expected results, how well it performed, and the operational and economic effects of its use, as well as to assess the applicability of this concept for other transit operators. The primary evaluation approach was to compare the experimental buses with the control buses for such items as ABDS detectable repairs, repair hours, and road calls and the resulting availability and performance of the buses. Pre- and post-implementation data were also compared in order to determine ABDS effects. The financial impact of ABDS was estimated through a cost-benefit assessment. The evaluation sought to determine any trade-offs which might exist between the positive and negative effects of ABDS usage. The effect on demonstration results of the operating environment in which ABDS was tested also was examined.

Evaluation results were examined for statistical significance using one-way and two-way analysis of variance models. Since the two types of buses used in the demonstration were found to be statistically equivalent, only the one-way analysis of variance results are discussed in this report.

Some buses of both the experimental and control groups were judgmentally excluded from the numerical comparison of results contained in later Sections due to lengthy out-of-service time in either the pre- or post-implementation periods. The statistical analysis showed that this exclusion had little effect on the results.

1.2.2 Overview of Project Data Collection

Data for the technical analysis of the demonstration came from several sources, but the majority of it came from NYCTA's vehicle information system (VISTA) and records stored in the FIU and MAU computer files. All bus maintenance information and out-of-service data was available through VISTA, an automated information system. The FIU and MAU test results were provided by NYCTA through programs developed by Hamilton Test Systems. Hamilton supplied data on the ABDS and bus instrumentation, including all down time, causes of down time, maintenance and repair cost, hardware cost, equipment modifications and acceptable test range modifications. A survey of the mechanics working at the Queens Village Depot was administered by NYCTA in an effort to understand the mechanics' opinions of the ABDS. TSC conducted its own small measurement of the fuel island dwell time of instrumented buses versus the dwell time of the control group buses in order to calculate the added FIU testing time.

It must be noted that there were serious omissions in the data that were available for TSC's evaluation. For example, there was no record kept of manual diagnostic times for comparison with known ABDS diagnostic times. Reduced diagnostic time was one of the supposed benefits of ABDS. The only information provided on this subject was a subjective estimate of manual diagnostic times for specific bus problems made by eight selected individuals from NYCTA.

Another missing item was information on the quality control check on completed repairs. From the data that was available, it was impossible to identify whether the MAU quality control checks were made or whether any improper repairs were identified by them. The quality check was supposed to be another advantage of ABDS.

It would have been most useful to have had an accurate method of tracking maintenance activity following a FIU fail, a road call, or a trouble report in order to determine whether the MAU was used properly. However, MAU tests and maintenance actions were recorded only by date and not by time clock. As a result TSC had to make some assumptions concerning the timing of certain actions when estimating whether the MAU was used properly in each repair sequence. Additionally, the number of times in which no fault could be found following a FIU failed test report was not directly available. Therefore, TSC also had to make some assumptions in generating an estimate of the frequency of "false" test results.

Another area in which data were lacking was in the recording of labor time associated with NYCTA and Hamilton staff personnel in planning, monitoring, processing data and administering various demonstration elements. Consequently, in several instances the contract or grant amounts are all that are available but they do not represent the actual cost of the manpower employed.

Another missing item was the cost of the parts used in ABDS repairs. This was not estimated by TSC due to a lack of confidence expressed by NYCTA with respect to the accuracy of this information.

There also were some inconsistencies in the bus out-of-service data provided by NYCTA when compared to maintenance activity, and in the ABDS on-board and off-board equipment out-of-service time provided by Hamilton when compared to FIU and MAU test activity.

The large quantity of important data that were not available for use in this evaluation underscores the necessity of more adequate preparation for conducting an evaluation of demonstration results and impacts. Much more could have been said about the quantifiable and non-quantifiable value of ABDS if arrangements had been made to collect the missing information.

2. DEMONSTRATION SETTING

2.1 NEW YORK CITY TRANSIT AUTHORITY

The New York City Transit Authority (NYCTA) was created by the New York State Legislature in June, 1953 to operate all New York City-owned bus and subway lines. Since March, 1968, NYCTA has been governed by the Board of the Metropolitan Transit Authority.

The Surface Transit Division of NYCTA is charged with the responsibility of providing reliable bus service to a population of 6.3 million people over 233 routes. Its physical plant consists of 4,160 buses, 20 bus depots and 2 base maintenance facilities.

Surface Transit employs 15,532 people of which 3,916 form the Maintenance Department. The function of the Maintenance Department is to provide the number of buses required for scheduled service and to insure the reliability, performance and cleanliness of these buses.

2.2 QUEENS VILLAGE DEPOT

The Queens Village Bus Depot became operational in September, 1974. It currently has an assisgnment of 210 buses which operate 5.7 million miles on 12 routes.

3. PLANNING AND IMPLEMENTATION

3.1 PLANNING

3.1.1 Development of Concept

Transit management has been concerned for some time about the shortage of good mechanics to maintain their bus fleets. While recruiting efforts produced candidates, most lacked the essential technical skills and experience to work on diesel engines. Extensive training programs failed to solve the problem because many candidates left the transit properties a short time after completing the training program. These circumstances warranted testing a new approach in bus maintenance.

The concept would emphasize the use of technology in diagnosing bus faults and minimize the dependence on the need for experienced technical personnel. Diagnostic capabilities could be continually enhanced without losing the expertise. As a first-generation effort, the automatic bus diagnostic system should consist of components available 'off-the-shelf'.

The Tri-State Regional Planning Commission, in cooperation with the New York City Transit Authority, submitted a grant application to the Urban Mass Transportation Administration to fund the demonstration effort.

3.1.2 Rationale for Demonstration Design

The co-sponsors of the program, with the assistance of a consultant, developed the various aspects of the demonstration. The consultant canvassed the major transit operators to identify those areas of bus maintenance which posed the most serious problems. These findings were combined with the NYCTA maintenance requirements to develop functional specifications; attention was then focused on the logistics of the demonstration.

The demonstration design called for an experimental group and a control group with each group consisting of fifty buses that were identical in composition and homogenous in their operating characteristics and maintenance history.

The selected site for the demonstration was the Queens Village Bus Depot. This site was chosen for the following reasons:

1. Labor union personnel were already amenable to another experimental effort underway at this facility.
2. Absenteeism and turnover of maintenance staff were lower than at other facilities. These factors were considered critical to maintaining the effectiveness of the training effort.
3. Vandalism and theft were negligible.
4. The bus fleet assigned to this garage provided the best opportunity to obtain pre-demonstration homogeneity between the experimental and control groups.

A major incident occurred that forced the test groups to be reduced from 100 to 80 buses. The experimental design included twenty 1981 Flxible 870 buses which had to be removed from service because of structural faults. The consultant indicated that this change would have a negligible effect on the demonstration results.

3.1.3 ABDS Equipment Specification

The ABDS design called for the diagnostic units to operate at two work areas: (1) the fuel island service station for daily checkouts and (2) the maintenance area for conducting a complete performance test for detecting and isolating existing or potential faults. The ABDS units should be interchangeable. Performance specifications were developed for use by the New York City Transit Authority.

3.1.4 Organizational Responsibilities

Six primary participants were involved in the ABDS Program: (1) UMTA as grantor; (2) the Tri-State Regional Planning Commission as grantee/co-sponsor; (3) the New York City Transit Authority as co-sponsor and project manager; (4) Sperry Systems as consultant on feasibility analyses and preliminary design; (5) Hamilton Test Systems, Inc., a division of United Technologies, as manufacturer of the ABDS equipment; and (6) the Transportation Systems Center as technical evaluator of the overall demonstration.

Tri-State was the contracting agent with all parties except the Transportation Systems Center. In this capacity, Tri-State monitored contractor performance and reimbursed contractors for their work upon assurance that the work was completed. The Transit Authority served as project manager responsible for certifying that the ABDS was manufactured in accordance with the performance specifications. The Authority was also responsible for providing data to the Transportation Systems Center and others in their evaluation efforts.

3.1.5 Key Concerns

During the course of the preliminary planning stage, several potential problems were identified that required careful consideration.

1. Union acceptance of the technology
2. Selection of buses
3. Successful retrofitting of the buses
4. Scheduling of buses for retrofitting
5. Troubleshooting and emergency repair of ABDS units.

From the onset, union participation was sought once Hamilton Test Systems had been selected as the equipment manufacturer. Union representatives were invited to attend all meetings and encouraged to participate in discussions. Their participation was especially welcomed in the human factors aspects of the equipment design and during the factory acceptance tests of the ABDS unit. The acceptance of the rank and file at Queens Village was reinforced by having the contractor transport to Queens Village a similarly designed unit for automobile diagnostics in order to demonstrate the use of this equipment on the automobile of each bus

mechanic. The effectiveness of this demonstration was probably the most convincing factor in getting union support for using ABDS.
The selection of buses had to insure two groups equal in every way possible. By reviewing the NYCTA bus history files, homogeneity between groups was obtained.

ABDS required the installation of the instrumentation kit aboard the buses. This activity involved retrofitting, for the first time, 40 experimental buses with cables, sensors, and other accessory equipment. The installation had to be done without hampering accessibility to the engine for engine repairs while providing easy replacement of faulty ABDS hardware. In retrospect, this aspect of the program was the most difficult to undertake and the most time consuming to complete.

Scheduling of the buses for retrofitting presented a series of logistical problems for NYCTA because of the suspension of the use of the newly procured Flxible 870 buses. The shortage of buses for revenue service made scheduling of buses critical and placed absolute urgency on the buses being returned to revenue service as soon as possible. A cooperative effort between Hamilton Test Systems, its subcontractor and the NYCTA helped achieve the goals of the concerned parties.

The level of sophistication of the ABDS equipment called for having expeditious response time to failures in the equipment. Hamilton Test Systems was cooperative in the endeavor by assigning staff to the garage a minimum of four days per week during the actual demonstration. This experience would prove to be extremely helpful in recommending design changes for subsequent versions of the ABDS system.

3.2 IMPLEMENTATION

3.2.1 ABDS Equipment Installation

The ABDS Fuel Island Unit was semi-permanently installed on one of the depot's two fuel islands. Special meters were affixed to the existing consumable meters to monitor diesel fuel, engine oil and coolant usage.

Three electrucal conduits were installed to the FIU cabinet via an overhead run. The conduits contained A/C power lines, signal wires for the consumables from the three meters, and low pressure gas hoses for the unit's emission analyzer gases. When the data collection and transmission capability was added to ABDS, a telephone and modem was installed inside the FIU cabinet.

The Maintenance Area Unit (MAU) was equipped with casters to permit it to be moved anywhere within the maintenance area. Seven electrical drop lines allowed use of the MAU at the 14 hoist and pit areas.

The instrumentation of the 40 buses in the ABDS experimental group was provided by Hamilton Test Systems (HTS). The buses were instrumented by a sub-contractor under contract to HTS.

3.2.2 ABDS Equipment Testing

Prior to delivery of the ABDS units by HTS, design acceptance tests were conducted at their factory in Windsor Locks, Connecticut. Following delivery and installation at Queens Village Depot, a post-installation test and acceptance was performed.

A wiring test device was employed to insure correct wiring hookup and sensor operation on all instrumental buses. As a final step, the buses were tested using the MAU to make certain that both bus and unit were functioning harmoniously.

3.2.3 Training ABDS Users

HTS developed and administered the ABDS training program for the maintenance personnel at Queens Village Depot. Training was provided to three groups: supervisory, fuel island personnel and bus maintainers.

Supervisors and foremen were given 8 hours training in FIU start-up and shut-down procedures, and FIU and MAU operation. Major emphasis was placed on printout interpretation.

All regularly assigned and reserve fuel island personnel were trained in FIU operation. This hands-on training was provided to two groups totaling 11 men for 4 hours per group.

Bus maintainers were trained in FIU and MAU operation in groups of 6-8 men for 20 hours. A maximum amount of time was spent on actual hands-on operation of the MAU. The secondary emphasis was on FIU and MAU printout interpretation.

3.2.4 ABDS Equipment Phase-In

Once training and shakedown of the ABDS equipment and buses was completed, ABDS became part of the depot's maintenance operation. An operating procedure was prepared to specify when ABDS was to be used. This procedure outlined usage during instances of road calls, FIU test fails and 6,000 mile scheduled operations.

To assure that ABDS buses pulling into the depot went through the ABDS equipped fuel island, large red signs were erected in the driveway approach areas. Decals imaging these signs were placed at five positions on the experimental buses.

4. EQUIPMENT OPERATIONS, RELIABILITY AND UTILIZATION

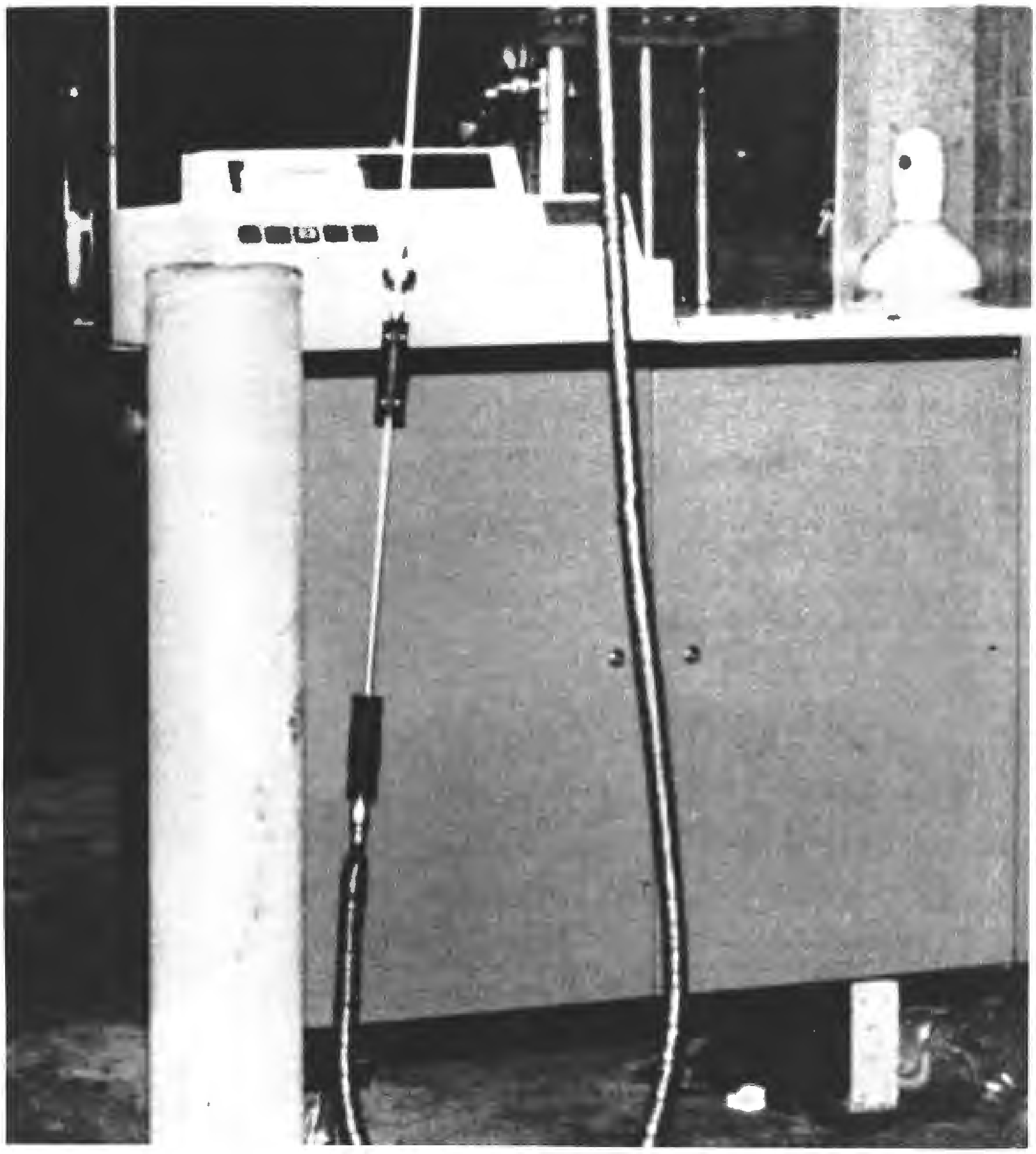
4.1 OPERATIONS

4.1.1 ABDS System Description

The Automatic Bus Diagnostic System is a microprocessor-based test and diagnostic tool that permits rapid sequential inspection and fault isolation in diesel-powered buses and their subsystems. The system consists of bus mounted sensors and two separate test units, a "Fuel Island unit," and a "Maintenance Area Unit." The Fuel Island Unit provides for an automatic test sequence to determine the general health of each bus during the fuel island service period each day (Figure 4-1). The Maintenance Area Unit is designed to provide 3,000 and 6,000 mile inspection testing; an after repair verification of vehicle condition; and diagnosis of the failures detected by the Fuel Island Unit (Figures 4-2 and 4-3), certain types of road call failures and certain types of failures reported by operators.

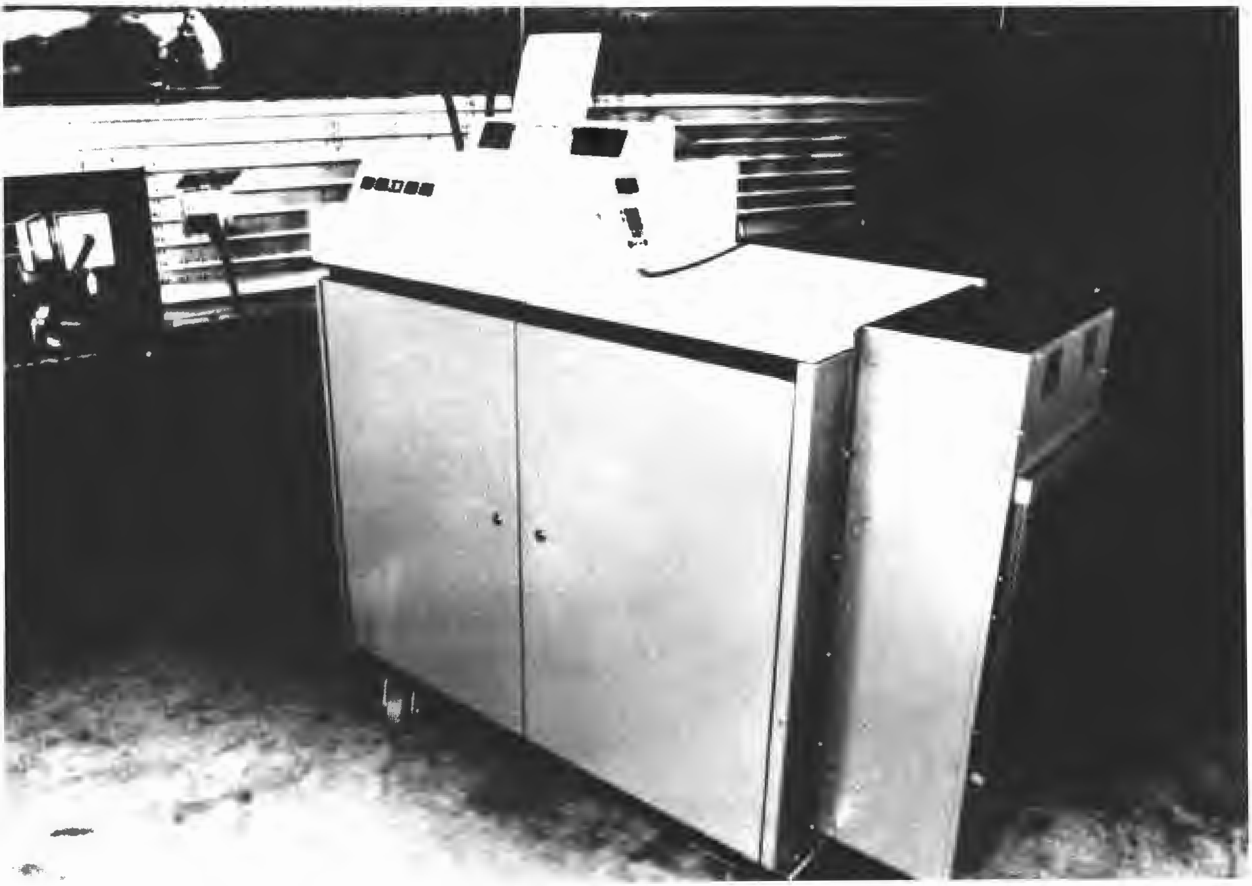
The bus mounted sensors (Figures 4-4 and 4-5) and on-board electronics generate the data which are accessed through the FIU and MAU electrical umbilical connectors and the MAU multiport transducer connection. The on-board electronics contains the components and circuitry to enable the computer to read the bus identification number, operating condition latches, and the test voltages, currents, temperatures and engine oil viscosity. The electronics also control engine functions during the testing process. Various air and fluid pressure measurements are taken only at the Maintenance Area via the multiport transducer interface. In all a total of 68 measurements are possible (Figure 4-6).

The Fuel Island Unit consists of a computer console, control panel and the cabling used to interface with the bus. The Fuel Island Unit performs a check with minimal disruption to current procedures and timing with all required testing completed in less than 3 minutes per bus. At the Fuel Island the bus is connected to the computer and runs through a sequence of



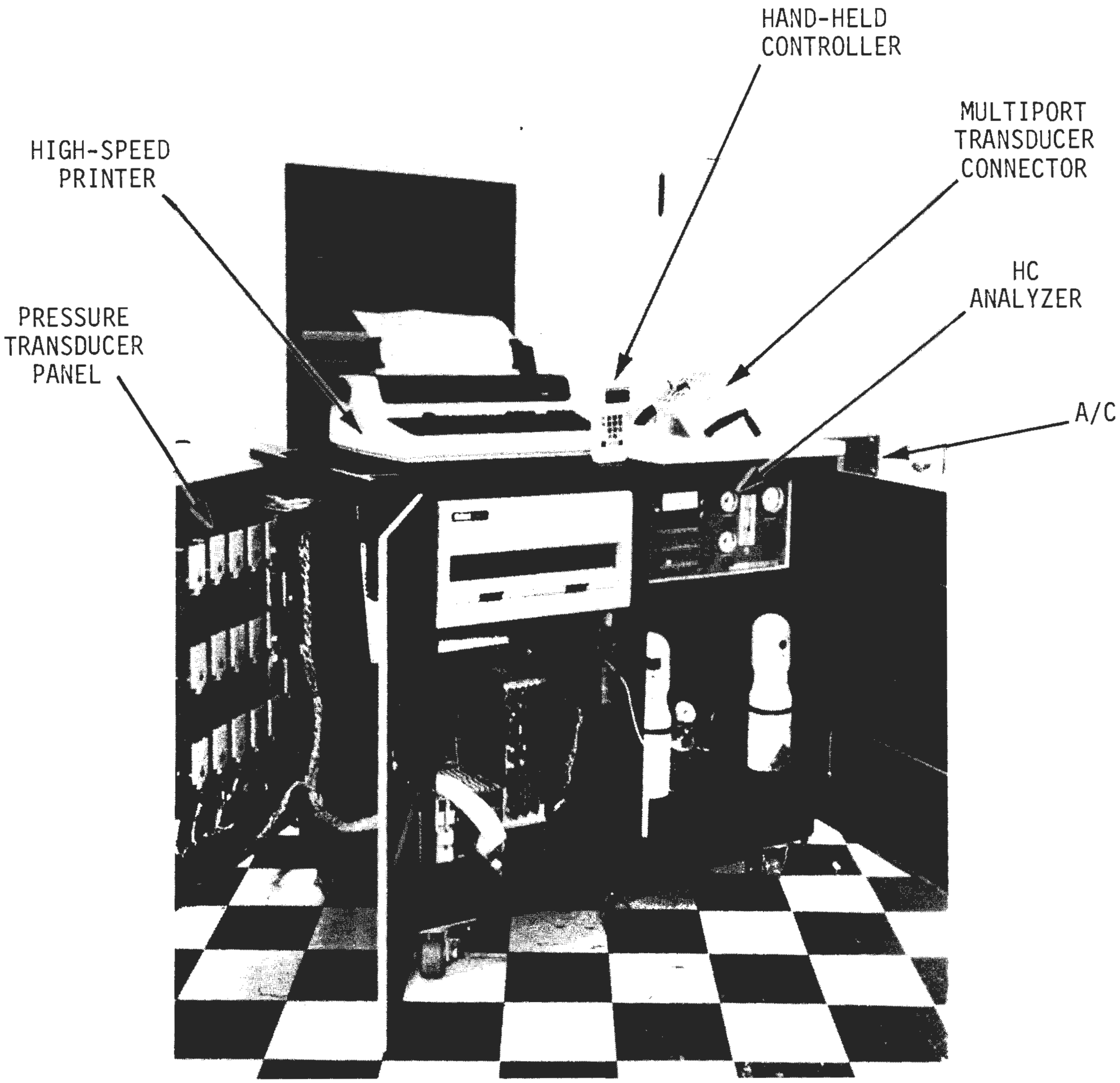
Courtesy of Hamilton Test Systems

FIGURE 4-1. FUEL ISLAND UNIT IN PLACE



Courtesy of Hamilton Test Systems

FIGURE 4-2. MAINTENANCE AREA UNIT CONNECTED TO BUS



Courtesy of Hamilton Test Systems

FIGURE 4-3. OPEN VIEW OF MAINTENANCE AREA UNIT

ENGINE RPM MAGNETIC PICKUP
ENGINE FAN RPM MAGNETIC PICKUP
ENGINE COOLANT TEMPERATURE & LATCH
CONVERTER OIL TEMPERATURE & LATCH
AIR CONDITIONING MONITOR TEMPERATURE & LATCH
AIR CONDITIONING SELECTED LATCH
GENERATOR CHARGE CURRENT SHUNT
BLOWER MOTOR NO. 1 CURRENT SHUNT
BLOWER MOTOR NO. 2 CURRENT SHUNT
CONDENSER MOTOR CURRENT SHUNT
BATTERY CURRENT SHUNT
VISCOSITY METER
ENGINE COMPARTMENT CRANK WARNING BUZZER
BUS NUMBER

BATTERY POSITIVE VOLTAGE
BATTERY JUNCTION BLOCK VOLTAGE
BATTERY NEGATIVE (REFERENCE) VOLTAGE
ENGINE GROUND (STARTER MOTOR NEGATIVE) VOLTAGE
STARTER MOTOR POSITIVE VOLTAGE
CONDENSER MOTOR VOLTAGE
BLOWER MOTOR NO. 1 VOLTAGE
BLOWER MOTOR NO. 2 VOLTAGE
GENERATOR DC VOLTAGE
GENERATOR FIELD VOLTAGE
GENERATOR RELAY VOLTAGE
STARTER SWITCH VOLTAGE
STARTER SOLENOID VOLTAGE

Courtesy of Hamilton Test Systems

FIGURE 4-4. BUS MOUNTED SENSORS AND VOLTAGE MEASUREMENT LOCATIONS

CRANKCASE PRESSURE TRANSDUCER

ENGINE OIL PRESSURE TRANSDUCER

WATER PUMP PRESSURE TRANSDUCER

FUEL PUMP OUTPUT PRESSURE TRANSDUCER

PRIMARY FUEL FILTER DIFFERENTIAL PRESSURE TRANSDUCER

SECONDARY FUEL FILTER DIFFERENTIAL PRESSURE TRANSDUCER

BLOWER INPUT PRESSURE TRANSDUCER

AIR BOX PRESSURE TRANSDUCER

DRY AIR TANK PRESSURE TRANSDUCER

FRONT BRAKE CHAMBER PRESSURE TRANSDUCER

REAR BRAKE CHAMBER PRESSURE TRANSDUCER

CONVERTER OUTPUT PRESSURE TRANSDUCER

CONVERTER DIRECT DRIVE PRESSURE TRANSDUCER

CONVERTER MAIN PRESSURE TRANSDUCER

CONVERTER HYDRAULIC PRESSURE TRANSDUCER

CONVERTER INLET PRESSURE TRANSDUCER

CONVERTER OIL FILTER DIFFERENTIAL PRESSURE TRANSDUCER

NUMBER ONE CYLINDER IDENTIFICATION PROBE

Courtesy of Hamilton Test Systems

FIGURE 4-5. SENSORS CONNECTED TEMPORARILY TO BUS

TYPICAL ABDS BUS

● PRESSURES	17
● TEMPERATURES	4
● VOLTAGES	13
● DISCRETES (IN AND OUT)	32
● SPEEDS	2
TOTAL	68

Courtesy of Hamilton Test Systems

FIGURE 4-6. TOTAL MEASUREMENTS

tests to determine the general condition of each critical bus component. This diagnostic is designed specifically to provide an early warning detection of failures which could cause an in-service breakdown. The bus consumables (fuel, oil, coolant) are automatically recorded in order to provide an indication of excessive consumption. A summary record of each vehicle's consumption is maintained. At the completion of each individual bus test a "Fuel Island Test Report" is printed. This printed test report provides the operator with a PASS/FAIL record of each test that will allow him to send the bus on its assigned route or to the maintenance area for further diagnostic tests. Under normal situations, the entire procedure should be accomplished in approximately 180 seconds, including 25 seconds for shifting and 80 seconds for fueling. The time required to interrogate each vehicle and process the data completely with a hard copy printout is approximately 40 seconds.

The Maintenance Area Unit consists of a computer console, control panel and the cabling and hoses used to interface with the bus. The Maintenance Area Unit is able to automatically perform prescribed test sequences designed to detect the presence of faults in the vehicle. This is accomplished by automatically comparing the test results with known and stored vehicle operational limits. Additionally, any test can be individually run if required to further pin-point or verify a specific fault. When the system compares the recorded data patterns with actual failed test or tests with the fault matrices stored in the system, a specific fault can be identified to the replaceable component level, (starter, fuel pump, etc.).

In addition to fault identification, the comparison of recorded data patterns with the stored fault matrices will produce specific repair codes. For each repair code, the user's manual will contain a corresponding repair instruction. This repair instruction will provide specific information on what component to replace or check. Once corrective action has been taken, verification of successful repair can be quickly determined by retesting the vehicle subsytem affected.

A vehicle diagnostic test report is generated only as result of performing a test sequence. Each diagnostic is generated for a specific vehicle subsystem, and in most cases, will point to a particular component in that subsystem. A given sequence may test one or more vehicle subsystems. A test sequence is run until the "Diagnostic Test Report" produced no longer has any diagnostic repair codes.

A number of the ABDS tests are dynamic in nature as opposed to conventional steady state measurement techniques. These dynamic tests directly relate to one of the ABDS principal capabilities: specifically, the ability to evaluate the condition of an engine or powerpack without the use of a dynamometer.

4.1.2 Fuel Island Unit Tests

At the fuel island, the bus is connected to the computer and run through a series of tests. The fuel island test cycle automatically sequences through 12 individual tests. These tests are as follows:

1. Engine Oil Viscosity
2. Air Conditioner (call for cooling, cold air furnished)
3. Engine Coolant Temperature Monitor
4. Converter Oil Temperature Monitor
5. Cranking Speed
6. Starter Cranking Voltage (+)
7. Starter Cranking Voltage (-)
8. Battery Cranking Voltage (+)
9. Battery No Load Voltage (+)
10. Fuel Added
11. Oil Added
12. Coolant Added

A thirteenth test, an emissions analysis, was originally part of the sequence. This was eliminated in October 1981 due to a failure of the analyzer device.

The sequence in which the tests are run is fixed. There are two kinds of tests - those which acquire analog data (and determine whether the test passed or failed on the basis of the test data being in or out of limits), and those which just check a discrete event (and determine whether the test passed or failed on the basis of the discrete setting). If a test's data can't be acquired, or a test's pass/fail determination can't be made, that test will be considered "failed."

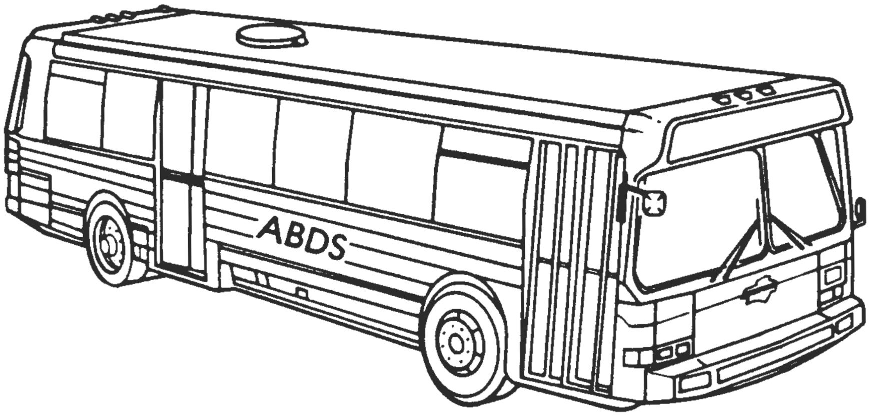
The operator will be prompted whenever his intervention is required. An audible alarm will be sounded for three seconds prior to the bus engine being cranked. When the sequence of tests has finished, the engine test results will be printed and stored on floppy disks automatically. There are no diagnostics associated with the fuel island tests.

When the automatic sequence of tests for a bus has been completed, the "header" information will be printed, followed by the test results (Figure 4-7). Each test results line will consists of: test number, low limit, test value, out-of-limits indicator (*) if applicable, and high limit (in that order). The discrete checking test will not have limits; they will have the word PASS or Fail printed in the test value columns of their print lines. At the bottom left corner of the vehicle test report, the word PASS or FAIL will be printed to indicate the final condition of the bus.

If all tests passed, the bus status will be PASS. If one or more tests failed, the bus status will be FAIL.

4.1.3 Maintenance Area Unit Tests

In the maintenance area, the bus is first connected to the ABDS via the electrical and pneumatic umbilical cables. The mechanic is then prompted by the system through the Hand Held Controller (Figure 4-8) for information such as date, starter voltage, and test number. Once this preliminary information has been obtained, the operator is free to run any engineering tests, individual tests, sequences, or mini-sequences in any order he desires. He can interact with these tests at specified times by means of the Hand Held Controller. Once the vehicle test or test sequence has been started the system will perform the prescribed test(s) automatically.



DATE	TIME	BUS NUMBER	MILEAGE

TEST NUMBER	LOW LIMIT	TEST VALUE	HIGH LIMIT

TEST NUMBER	TEST DESCRIPTION	UNITS
1	ENGINE OIL VISCOSITY	----
2	AIR CONDITIONER	----
--	CALL FOR COOLING	----
--	COLD AIR FURNISHED	----
3	CONVERTER OIL TEMPERATURE MONITOR	----
4	ENGINE COOLANT TEMPERATURE MONITOR	----
5	CRANKING SPEED	RPM
6	STARTER CRANKING VOLTAGE (+)	VOLTS
7	GROUND STRAP VOLTAGE DROP	VOLTS
8	BATTERY CRANKING VOLTAGE (+)	VOLTS
9	BATTERY NO LOAD VOLTAGE (+)	VOLTS
10	TIRES	----
--	LEFT REAR OUTER	----
--	LEFT REAR INNER	----
--	RIGHT REAR OUTER	----
--	RIGHT REAR INNER	----
11	FUEL ADDED	GALLONS
12	OIL ADDED	QUARTS
13	COOLANT ADDED	QUARTS
14	EMISSIONS (HC)	PPM
15	BYPASS SW. DEPRESSED	

Courtesy Hamilton Test Systems

FIGURE 4-7. VEHICLE TEST REPORT

Courtesy of Hamilton Test Systems

FIGURE 4-8. HAND HELD CONTROLLER

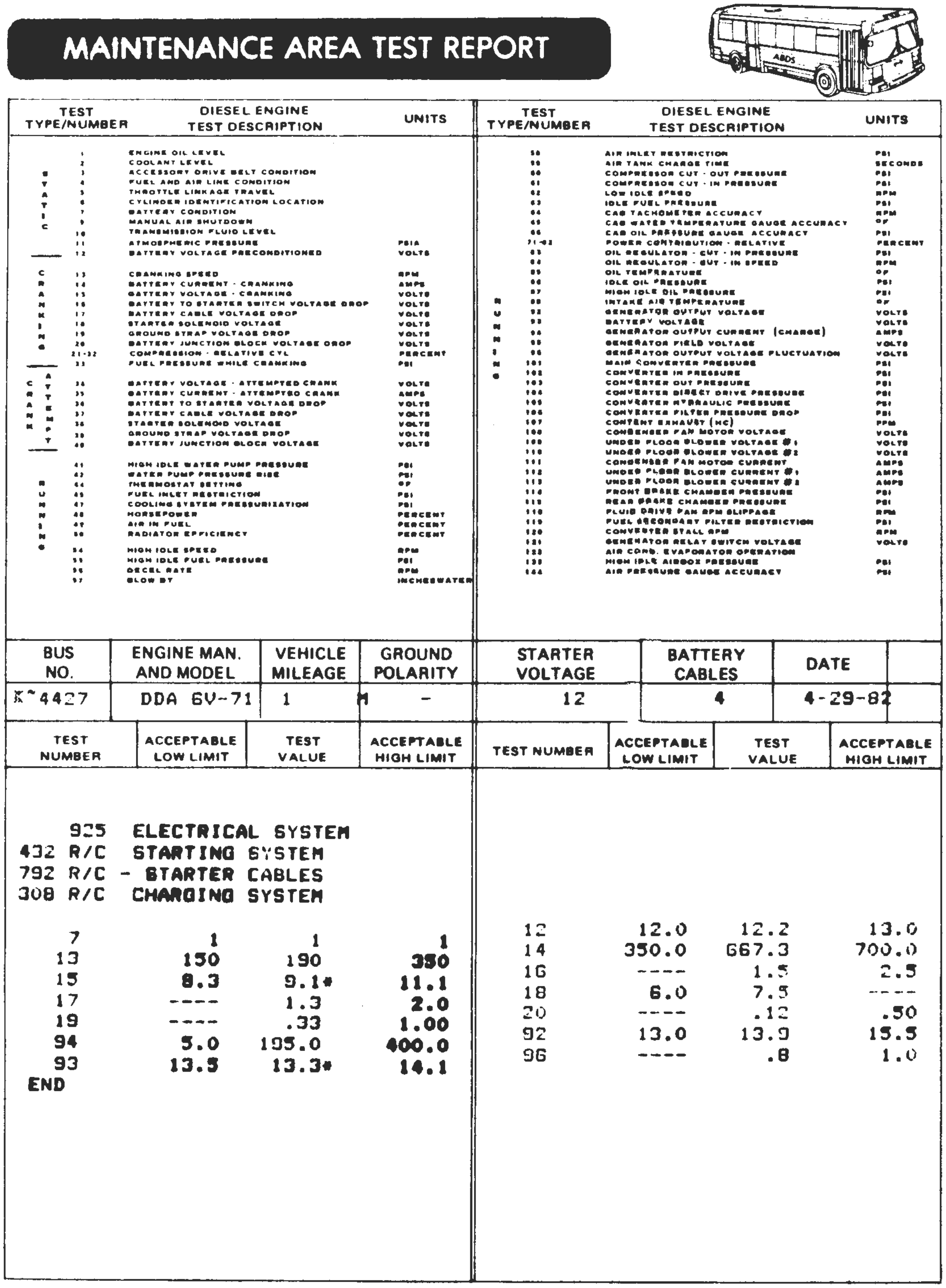
There are four types of tests which can be run in the normal operation of the system.

1. Individual tests (presently numbers 1 to 150) can be run one at a time by the operator. No diagnostics are generated when tests are run individually.
2. Engineering tests (200 series) allow the operator to continuosly observe various values of currents, voltages, temperatures, and pressures of the vehicle as well as the engine speed. These tests are not used by the computer for diagnostics, but allow the operator to observe vehicle conditions and possibly make his own determination.
3. Many of the individual diagnostic tests are part of mini-sequences where one test collects data for itself as well as other tests. The tests in a sequence are automatically performed in a pre-determined order.
4. Sequence testing (900 series) is used when diagnostics are desired. A sequence leads the operator through a prescribed series of tests from which diagnostics are generated. Sequences are complaint and component oriented.

The operator will signal that he is finished testing a vehicle by means of the Hand Held Controller. The operator will be able to view the vehicle "header" information, test results, and diagnoses by means of a printed test results report. This report is printed on a form on which the top portion describes each test and the bottom portion contains the printed test results and diagnoses (Figure 4-9). The diagnostic information consists of an identification of the subsystem being diagnosed as well as a repair code number. The operator then consults a repair code manual which tells him what actions to take to correct the problems indicated by the specific repair code number printed. The information which is printed on the test report also is stored on the engine test results floppy disk.

4.1.4 Standard Operating Procedures

4.1.4.1 Fuel Island System - At the start of fuel island operation, the foreman prepares the Fuel Island Unit Computer for operation. The foreman then supervises other personnel in the performance of their duties with respect to ABDS as well as all other fuel island tasks. The fuel island operation for ABDS buses is to be as follows.



MAINTENANCE AREA TEST REPORT

TEST TYPE/NUMBER		DIESEL ENGINE TEST DESCRIPTION	UNITS
STATIC	1	ENGINE OIL LEVEL	
	2	COOLANT LEVEL	
	3	ACCESSORY DRIVE BELT CONDITION	
	4	FUEL AND AIR LINE CONDITION	
	5	THROTTLE LINKAGE TRAVEL	
	6	CYLINDER IDENTIFICATION LOCATION	
	7	BATTERY CONDITION	
	9	MANUAL AIR SHUTDOWN	
	10	TRANSMISSION FLUID LEVEL	
	11	ATMOSPHERIC PRESSURE	PSIA
	12	BATTERY VOLTAGE PRECONDITIONED	VOLTS
CRANKING	13	CRANKING SPEED	RPM
	14	BATTERY CURRENT - CRANKING	AMPS
	15	BATTERY VOLTAGE - CRANKING	VOLTS
	16	BATTERY TO STARTER SWITCH VOLTAGE DROP	VOLTS
	17	BATTERY CABLE VOLTAGE DROP	VOLTS
	18	STARTER SOLENOID VOLTAGE	VOLTS
	19	GROUND STRAP VOLTAGE DROP	VOLTS
	20	BATTERY JUNCTION BLOCK VOLTAGE DROP	VOLTS
	21-32	COMPRESSION - RELATIVE CYL	PERCENT
	33	FUEL PRESSURE WHILE CRANKING	PSI
CRANK ATTEMPT	34	BATTERY VOLTAGE - ATTEMPTED CRANK	VOLTS
	35	BATTERY CURRENT - ATTEMPTED CRANK	AMPS
	36	BATTERY TO STARTER VOLTAGE DROP	VOLTS
	37	BATTERY CABLE VOLTAGE DROP	VOLTS
	38	STARTER SOLENOID VOLTAGE	VOLTS
	39	GROUND STRAP VOLTAGE DROP	VOLTS
	40	BATTERY JUNCTION BLOCK VOLTAGE	VOLTS
RUNNING	41	HIGH IDLE WATER PUMP PRESSURE	PSI
	43	WATER PUMP PRESSURE RISE	PSI
	44	THERMOSTAT SETTING	°F
	45	FUEL INLET RESTRICTION	PSI
	47	COOLING SYSTEM PRESSURIZATION	PSI
	48	HORSEPOWER	PERCENT
	49	AIR IN FUEL	PERCENT
	50	RADIATOR EFFICIENCY	PERCENT
	54	HIGH IDLE SPEED	RPM
	55	HIGH IDLE FUEL PRESSURE	PSI
	56	DECEL RATE	RPM
	57	BLOW BY	INCHESWATER

TEST TYPE/NUMBER		DIESEL ENGINE TEST DESCRIPTION	UNITS
RUNNING	58	AIR INLET RESTRICTION	PSI
	59	AIR TANK CHARGE TIME	SECONDS
	60	COMPRESSOR CUT - OUT PRESSURE	PSI
	61	COMPRESSOR CUT - IN PRESSURE	PSI
	62	LOW IDLE SPEED	RPM
	63	IDLE FUEL PRESSURE	PSI
	64	CAB TACHOMETER ACCURACY	RPM
	65	CAB WATER TEMPERATURE GAUGE ACCURACY	°F
	66	CAB OIL PRESSURE GAUGE ACCURACY	PSI
	71-82	POWER CONTRIBUTION - RELATIVE	PERCENT
	83	OIL REGULATOR - CUT - IN PRESSURE	PSI
	84	OIL REGULATOR - CUT - IN SPEED	RPM
	85	OIL TEMPERATURE	°F
	86	IDLE OIL PRESSURE	PSI
	87	HIGH IDLE OIL PRESSURE	PSI
	88	INTAKE AIR TEMPERATURE	°F
	92	GENERATOR OUTPUT VOLTAGE	VOLTS
	93	BATTERY VOLTAGE	VOLTS
	94	GENERATOR OUTPUT CURRENT (CHARGE)	AMPS
	95	GENERATOR FIELD VOLTAGE	VOLTS
	96	GENERATOR OUTPUT VOLTAGE FLUCTUATION	VOLTS
	101	MAIN CONVERTER PRESSURE	PSI
	102	CONVERTER IN PRESSURE	PSI
	103	CONVERTER OUT PRESSURE	PSI
	104	CONVERTER DIRECT DRIVE PRESSURE	PSI
	105	CONVERTER HYDRAULIC PRESSURE	PSI
	106	CONVERTER FILTER PRESSURE DROP	PSI
	107	CONTENT EXHAUST (HC)	PPM
	108	CONDENSER FAN MOTOR VOLTAGE	VOLTS
	109	UNDER FLOOR BLOWER VOLTAGE #1	VOLTS
	110	UNDER FLOOR BLOWER VOLTAGE #2	VOLTS
	111	CONDENSER FAN MOTOR CURRENT	AMPS
	112	UNDER FLOOR BLOWER CURRENT #1	AMPS
	113	UNDER FLOOR BLOWER CURRENT #2	AMPS
	114	FRONT BRAKE CHAMBER PRESSURE	PSI
	115	REAR BRAKE CHAMBER PRESSURE	PSI
	118	FLUID DRIVE FAN RPM SLIPPAGE	RPM
	119	FUEL SECONDARY FILTER RESTRICTION	PSI
	120	CONVERTER STALL RPM	RPM
	121	GENERATOR RELAY SWITCH VOLTAGE	VOLTS
	122	AIR COND. EVAPORATOR OPERATION	
	133	HIGH IDLE AIRBOX PRESSURE	PSI
	144	AIR PRESSURE GAUGE ACCURACY	PSI

BUS NO.	ENGINE MAN. AND MODEL	VEHICLE MILEAGE	GROUND POLARITY	STARTER VOLTAGE	BATTERY CABLES	DATE
K~4427	DDA 6V-71	1	N -	12	4	4-29-82

```
   925  ELECTRICAL SYSTEM
432 R/C  STARTING SYSTEM
792 R/C - STARTER CABLES
308 R/C  CHARGING SYSTEM
```

TEST NUMBER	ACCEPTABLE LOW LIMIT	TEST VALUE	ACCEPTABLE HIGH LIMIT
7	1	1	1
13	150	190	350
15	8.3	9.1*	11.1
17	----	1.3	2.0
19	----	.33	1.00
94	5.0	195.0	400.0
93	13.5	13.3*	14.1
END			

TEST NUMBER	ACCEPTABLE LOW LIMIT	TEST VALUE	ACCEPTABLE HIGH LIMIT
12	12.0	12.2	13.0
14	350.0	667.3	700.0
16	----	1.5	2.5
18	6.0	7.5	----
20	----	.12	.50
92	13.0	13.9	15.5
96	----	.8	1.0

Courtesy of Hamilton Test Systems

FIGURE 4-9. MAINTENANCE AREA TEST REPORT

All ABDS buses (visibly marked in several bus locations) are to be tested at fuel island # 1 after each day of use, in accordance with the Operator's Check List. After testing is completed, the bus shifter is directed to park the bus on the "ready" line if the bus passed the fuel island testing. If the bus failed the testing, the bus is to be parked on the "bad order" line. At any time during or after fuel island operation, the foreman will analyze the FAIL printouts to determine what action is indicated for the failed bus.

The Test 15 value is examined first. The bus is not held out-of-service for a Test 15 FAIL but repairs may need to be made to the on-board ABDS equipment. For the remaining tests the following actions are indicated.

Test 1 FAIL -	Hold the bus out-of-service for a Gerin oil analysis.
Tests 2-5 FAIL -	Hold the bus out-of-service for MAU testing the following morning.
Tests 6-9, 14 FAIL -	Foreman will decide whether the bus is to be held out-of-service for MAU testing the following morning or to have the bus pulled in for testing later in the day.
Test 11 FAIL -	If only Test 11 failed, put bus back into service.
Test 12 FAIL -	Have the bus checked for coolant leaks.

At the end of the day's fuel island operation, the foreman or a mechanic shuts down the FIU computer.

4.1.4.2 Maintenance Area - The Maintenance Area Unit is to be used for testing of ABDS instrumented buses as follows:

1. Any instrumented bus which fails the following tests on Fuel Island Unit:

   a) Tests 2 thru 9
   b) Test 14

2. All instrumented buses, immediately upon completion of a 6000 mile inspection. Sequence 999-General Health Test is used.

3. Any instrumented bus which is cited for any of the following road calls.

   a) Bus dead
   b) Electrical
   c) Fumes in bus
   d) Chronic no heat
   e) Oil low/leak
   f) Overheat/cooling
   g) Transmission
   h) Engine

The following procedure is to be adhered to when a bus is cited for any of the above road calls:

1. Check bus visually for a visable and/or obvious defect.
2. If the visual check is not conclusive then the bus is to be tested on the Maintenance Area Unit.

All use of the MAU, except for the 6,000 mile inspection, will observe the following rules:

1. Before any repairs are made the correct sequence for the problem will be used to test the bus.
2. After the sequence is run the resulting repair code numbers, printed at the top of the printout, will be looked up to determine the repairs needed.
3. The repairs called for will be made, using the Meter functions of the MAU wherever possible.
4. Following the repairs the same sequence will be run again to quality check the repairs.

4.1.5 Staffing

Four persons are usually involved in ABDS fuel island operations. One person (a shifter) drives the bus into the proper fuel island position, turns the engine off while the test is being conducted, and drives the bus to its subsequent destination. A second person removes the money from the farebox. A third person fuels the bus and checks the tires. The fourth person connects the electrical umbilical cable to the bus, monitors the ABDS testing, checks and adds necessary oil and coolant, reviews the overall PASS/FAIL report and directs the bus to the "ready" or "bad order" line.

The Queens Village Depot operates two fuel islands. The ABDS fuel island opens at 6:00 PM and runs until 2:00 AM. Personnel from the second fuel island move to the ABDS fuel island during breaks and when the first crew has finished their shift.

A small number of observations of experimental and control group bus dwell times at the fuel island indicated a differential of about 50 seconds (2 minutes 17 seconds versus 1 minute 27 seconds). Both are well within the standard 3 minute allowance. Approximately 30 seconds are wasted while the computer provides time for the emissions analyzer test which is no longer being performed. Another 25 seconds are consumed while the FIU test results are being printed out. The FIU personnel must wait until the end of the printout in order to see the overall PASS/FAIL indication which dictates the disposition of the bus. If the overall PASS/FAIL indication were printed at the top of the page the bus could be sent away before the full page was printed out and much of the 25 seconds could be saved. Similarly, if the FIU test sequence program were rewritten, the time wasted on the emissions test could be eliminated. As a result, if appropriate modifications to the existing test procedures were made, the additional time needed to perform the ABDS testing would be small.

At Queens Village even the current additional dwell time for ABDS testing is of little consequence. There are, at present, slack periods at the fuel islands in which no buses are being serviced. Therefore, increases or decreases of individual bus dwell times of 1 minute or less, particularly in view of the situation in which the buses are serviced in less than the 3 minute allocation, should have no adverse cost impact on NYCTA.

4.2 ABDS EQUIPMENT RELIABILITY

4.2.1 Fuel Island Unit

Hamilton Test Systems representatives submitted data on out-of-service time for the FIU unit. According to this data, during the period February 11, 1982 to July 31, 1982, the FIU was out-of-service on only six days from July 3 to July 8 inclusive. As this period encompassed a three day holiday weekend, only three days of heavy FIU usage was missed. Based on the average number of FIU tests made during the prior and subsequent weeks, about 69 FIU tests would have been conducted on the three weekdays and 16 FIU tests on the holiday weekend. These 85 FIU tests missed would represent 2.8 percent of the 2431 valid FIU tests actually conducted during the evaluation period. This would indicate a very high level of reliability for the FIU system. The only failure reported was a failure of the DEC computer floppy drive following a service call by a DEC service representative.

Upon examination of FIU test records, there were five additional weekdays for which no FIU test results were indicated and at least eleven more for which many fewer than expected were indicated. Normally, about 235 more tests would have been expected on these days than were actually performed. The reasons for the low testing rate on these days are not known. It is likely, however, that procedural or human errors on the part of NYCTA personnel often were responsible. For example, on at least three occasions a supervisor departed work with the locking key for the FIU.

Before and after the evaluation period, the FIU system was down a total of four other times according to Hamilton records. Three of these instances were caused by failures in the cable connector and one was due to vandalism to the printer. A total of 36 additional days were lost due to these other problems. However, in all except the thirteen days in August 1982, the FIU was receiving very low utilization and very little data was lost.

4.2.2 Maintenance Area Unit

Hamilton records show no out-of-service days for the MAU during the evaluation period. However, after the demonstration period ended it was out of service at four different times covering nine days during the month of August. Two of these instances were due to failures of the computer board and the other two were due to defects in the floppy drive. Overall, the MAU appeared to perform very well.

4.2.3 Bus Instrumentation

There are no available data to indicate the true reliability of the on-board instrumentation or the frequency of replacement of pieces of it. There were certainly instances where an erroneous bus number was recorded on a FIU test report. This indicates some on-board instrumentation malfunction. Eighty-two of these occurrences were recorded. However, the corresponding reasons for the malfunctions were unknown. The occurrences represent 3.3 percent of the number of valid FIU tests recorded.

The on-board instrumentation interfered with some bus repairs. When this occurred, the instrumentation was removed. During the evaluation period, the on-board equipment was not operational for varying periods of time on 13 of the 32 experimental buses used in the analysis. These periods ranged from 6 to 93 days. The lengthy periods of inoperable instrumentation were not caused by problems with the instrumentation. Rather, the instrumentation was removed due to major Base Facility maintenance work which, in some cases, was not completed for several months. In general, the experimental buses were out of service only for short periods of time while the instrumentation was being put back into an operable condition.

A large part of the instrumentation's interference with bus repairs was due to the fact that the demonstration funding allowed only a prototype bus instrumentation package to be developed. This was a most reasonable approach in view of the uncertainty of the value of ABDS in maintenance. A Hamilton representative estimates that the development cost of a "transparent" bus instrumentation package that would be factory installed rather than field retrofitted would be several hundred thousand dollars.

4.2.4 False Test Results

There were at least three ways in which apparently "false" test results were generated. In 64 instances during the evaluation period, the FIU generated a FAIL test report but no maintenance activity was performed on that bus as a consequence of the FIU fail and the bus passed a subsequent FIU test. There also were a number of instances in which a maintenance action was performed following a FIU FAIL report but no defect was discovered. On some occasions, a bus which was suspected of having some defect was given multiple FIU tests until a failure appeared. All of these might be classified as "false" test results. However, it does not mean that all these tests gave invalid results.

Some of these occurrences could be explained by test limits which were not properly set. The test limits were judgmental in nature when they were set for the first time. As operational experience with ABDS grew, some limits were found to be too high or too low and were adjusted. Limits for six FIU tests and 24 MAU tests, in fact, were changed after initial establishment. Limits that were set too close to the normal operational range might be exceeded for some buses due to some unusual operating condition but would not be a true indication of a bus fault. In this case it likely would pass the next test or reveal no fault through MAU testing. In addition, there certainly were instances in which a bus would have to be either hot or cold for a problem to be caught by the FIU but was tested under the opposite condition. This could explain some of the instances in which a bus would pass one test but fail a subsequent one or pass a test after having failed a previous one. There was never a situation in which a bus consistently failed a FIU or MAU test where the problem was not found and corrected.

Even though false test results could generally be explained, it does not mean that false test results were not a problem. If a maintenance action was performed on a bus in which no defect could be found, the bus was needlessly held out of service and maintenance labor hours were wasted. It would seem likely that few of these instances would have occurred under completely manual maintenance activities. Consequently, it appears that checking out false test results contributed to the increased number of ABDS detectable repair hours for experimental buses as compared to the control group.

4.3 ABDS EQUIPMENT UTILIZATION

4.3.1 Fuel Island Unit

Each bus which is in passenger service during the day is supposed to pass through the fuel island each night to have the cash removed from the farebox as well as to be fueled, to have oil or coolant added if necessary, and to have the tires checked. If the bus is one of the experimental group, it is supposed to pass through fuel island #1 for ABDS testing. However, records taken from the FIU computer and matched with NYCTA out-of-service reports indicate that not every bus was tested as it should have been. Table 4-1 compares by month the number of bus weekdays when the experimental buses were ready for morning pull-out with their on-board instrumentation operational with the number of valid tests at the FIU on those days. Only weekdays were used in this comparison since very few FIU tests were recorded on weekends and it was not known how many of the experimental buses were actually used in service.

The data would appear to indicate that it took two months for the FIU procedures to become reasonably well established. However, in no month did the percentage of buses tested at the fuel island exceed 80 percent. There could be at least five reasons why this happended: the experimental bus could have been put through the wrong fuel island; the bus could have gone through the proper fuel island but not have been tested; the on-board instrumentation might have been malfunctioning; the bus might not have been ready for morning pull-out but not indicated as such in NYCTA

TABLE 4-1. FIU UTILIZATION

MONTH	WEEKDAYS BUS IN SERVICE WITH ABDS WORKING	VALID FIU TESTS	PERCENTAGE
Feb	280	173	61.8
Mar	537	350	65.2
Apr	443	351	79.2
May	397	307	77.3
Jun	570	416	72.9
Jul	412	322	78.2
	2639	1919	72.7

records; or the bus might have been out of service at the end of the day. Given the likelihood particularly of the latter three reasons occurring, it seems justifiable to conclude that the fuel island testing procedures were followed quite well after March.

4.3.2 Maintenance Area Unit

For certain categories of road calls and FIU fails, the malfunctioning bus was supposed to be tested on the MAU. There were 323 valid FIU fail reports during the evaulation period which resulted in 222 repair sequences. In 64 instances a subsequent FIU test was passed by the bus with no intervening maintenance action recorded. In most other instances multiple FIU fail tests were recorded before the repair was accomplished. Of the 222 repair sequences, 167 were of a nature that should have been tested on the MAU. However, only 67 times (40.1 percent) was the MAU used properly, i.e., the MAU tests were performed prior to a maintenance action or the bus passed the MAU testing and no maintenance action was required. In another 35 repair sequences (20.9 percent), the MAU was used during the repair or after it was accomplished. The only valid reason for the MAU not being used was when a visual inspection of the bus revealed the defect. It is not known how often this occurred. Nevertheless, it seems appropriate to conclude that the MAU was not used as often as it should have been in diagnosing defects indicated in FIU tests.

As was mentioned previously, the MAU was to be used in diagnosing defects for certain categories of road calls. It was also used during the 3000 and 6000 mile inspections and for some problems reported by the bus operators. A total of 78 ABDS detectable road calls were recorded for the experimental buses during the evaluation period. Data are not currently in hand to determine how many of these were in categories that should have been tested first on the MAU. However, in only 5 instances was the MAU used before a repair was made and in 6 instances was the MAU used during the repair sequence. Overall, it would seem that the MAU test procedures were not performed as often as they should have been.

5. MAINTENANCE IMPACTS

This Section discusses the effect of ABDS equipment utilization on depot maintenance by means of a comparison of maintenance activity performed on the experimental and control groups for ABDS and non-ABDS detectable repairs. The comparison of manual versus ABDS fault diagnostic times, the interference of the on-board instrumentation with bus repair, and the attitude of maintenance personnel towards the ABDS are also discussed.

5.1 REPAIR ACTIONS/HOURS

All maintenance actions performed on buses are recorded on standard forms and subsequently entered into the Vehicle Information System (VISTA) computer file. Each maintenance activity is reported by the mechanic doing the work or the responsible foreman. The maintenance record contains the following elements (examples of some of these elements are contained in Appendix A):

Purpose Code - used to identify the system or component of a bus on which work is being done.

Responsibility Code - used to identify the location at which the maintenance action is performed.

Bus Number - each bus is assigned a five digit identification number.

Maintenance Type Code - used to classify maintenance activity by scheduled operation, corrective maintenance or road call repair.

Location Code - used to identify the location on a bus where specific components reside in more than one position, i.e., brakes, pistons, etc.

Defect Code - used to identify why a particular maintenance activity is being performed.

Repair Action Code - used to describe the type of repair action taken to return a component to service.

Exceptional Occurrence Code - used to indicate and isolate activities that result from special occurrences or situations, i.e. vandalism, fire, overtime, etc.

Road Call Code - a non technical description of problem causing the road call.

Out-of-Service Code - used to explain why a bus is not able to make a morning pull-out for revenue service.

Date - the month, day and year the activity is being reported.

Employee Maintenance/Foremen Number - a six digit identification number for the individual performing the work.

Maintenance Time - the number of hours and minutes spent on each specific maintenance activity whether or not the work was completed.

Mileage - the number of miles travelled by the bus at the time of the maintenance action.

The ABDS was designed to detect bus faults associated with a specific set of purpose codes. These include certain types of air conditioning, brake, cooling system, fuel line, engine, electrical and transmission faults. The full list of ABDS purpose code descriptions are listed in Appendix B. For the remainder of this report these purpose codes will be described as ABDS detectable faults. All other purpose codes will be classified as non-ABDS detectable faults. The repair actions and the repair times associated with both categories of faults are discussed in this Section.

5.1.1 ABDS Detectable Repairs

All maintenance records were examined in order to determine the total number of separate repair actions performed on the experimental and control buses. All repairs with the same purpose code, performed on the same day or on succeeding days as long as the bus had not been returned to revenue service in the meantime, were called a single repair action for this analysis. All repair times connected with this repair action were accumulated. The ABDS detectable repairs and the corresponding repair hours are shown in Tables 5-1 and 5-2 for the experimental and control group buses for the period June 1, 1981 to February 10, 1982 when the ABDS equipment was utilized very little, and the period February 11, 1982 to July 31, 1982 when the equipment was utilized intensively. The former period will be termed the "before" period for this analysis and the latter will be called the "after" period.

In the before time frame, the number of total repairs on the experimental buses was somewhat higher on a per bus basis than for the control buses.

TABLE 5-1. ABDS DETECTABLE REPAIRS

	EXPERIMENTAL BUSES			CONTROL BUSES		
	24	8	32	26	9	35
MONTH	GM	FLX	TOT	GM	FLX	TOT
6/81	40	12	52	53	20	73
7/81	46	16	62	50	13	63
8/81	58	27	85	58	14	72
9/81	50	14	64	26	7	33
10/81	47	29	76	54	17	71
11/81	52	15	67	58	19	77
12/81	25	12	37	43	10	53
1/82	25	8	33	38	9	47
2/82p	18	3	21	8	10	18
	361	136	497	388	119	507
2/82p	41	10	51	16	14	30
3/82	53	20	73	41	20	61
4/82	89	28	117	83	21	104
5/82	101	11	112	73	23	96
6/82	88	29	117	89	16	105
7/82	86	18	104	33	18	51
	458	116	574	335	112	447

REPAIRS PER 1000 BUS DAYS

Potential	Before	$\frac{497}{8.160} = 60.9$	$\frac{507}{8.925} = 56.8$
Potential	After	$\frac{574}{5.472} = 104.9$	$\frac{447}{5.985} = 74.7$
Available	After	$\frac{574}{4.617} = 124.3$	$\frac{447}{5.488} = 81.5$

TABLE 5-2. ABDS DETECTABLE REPAIR HOURS

	EXPERIMENTAL BUSES			CONTROL BUSES		
MONTH	24 GM	8 FLX	32 TOT	26 GM	9 FLX	35 TOT
6/81	184	43	227	231	99	330
7/81	189	52	241	222	32	254
8/81	309	171	480	273	268	541
9/81	244	65	309	154	23	177
10/81	243	101	344	231	85	316
11/81	252	107	359	223	144	367
12/81	242	47	289	279	41	320
1/82	109	28	137	133	38	171
2/82p	87	9	96	41	28	69
	1859	623	2482	1787	758	2545
2/82p	186	47	233	105	47	152
3/82	277	91	368	155	116	271
4/82	326	110	436	271	79	350
5/82	357	68	425	205	38	243
6/82	336	85	421	186	31	217
7/82	226	98	324	105	59	164
	1708	499	2207	1027	370	1397

REPAIR HOURS PER 1000 BUS DAYS

Potential	Before	$\frac{2482}{8.160} = 304.2$	$\frac{2545}{8.925} = 285.2$
Potential	After	$\frac{2207}{5.472} = 403.3$	$\frac{1397}{5.985} = 233.4$
Available	After	$\frac{2207}{4.617} = 478.0$	$\frac{1397}{5.488} = 254.6$

Almost all of the differences occurred on the eight experimental Flxibles. Both groups exhibited substantial month to month variation. In the after period, the total number of repairs, when adjusted for the number of days in the period, increased for all categories of buses. However, the number of repairs increased substantially more for the experimental group than for the control group. The total number of experimental bus repairs was fairly uniform after the first two months. Within the experimental group, the 1970 GM buses required much more attention per bus than the 1973 Flxible buses. The reason for the difference between the GM and Flxible buses in the after period is uncertain. It does not appear to be related to age since the GM buses received proportionately less repair activity in the before period and the GM control buses received only slightly more repairs per bus than the Flxibles in the after period.

At the bottom of Table 5-1, the buses are compared on an equivalent basis -- per 1000 bus days. Since out-of-service data were not available in the before period, the buses first were compared on the basis of the number of days the buses could have been in service (potential bus days). This comparison shows the experimental group receiving over 72 percent more repairs during the after period while the control was experiencing over 31 percent more repairs. When the number of out-of-service days are taken into account (available bus days), the difference between the experimental and control group becomes larger. Figure 5-1 shows graphically the greater number of repair actions per bus for the experimental than for the control group.

A more important comparison of maintenance activity on the different bus groups is the number of repair hours expended on each. Table 5-2 reveals reasonably close overall totals for the experimental and control buses in the before period. The GM and Flxible buses are also reasonably close in total repair hours per bus for both groups. However, when comparing repair hours during the before and after periods by potential bus days, the difference between the experimental and control buses is substantial. Whereas the number of repair hours per 1000 potential bus days went down over 18 percent for the control group, the same ratio for the experimental group increased by over 32 percent. When comparing repair hours per 1000

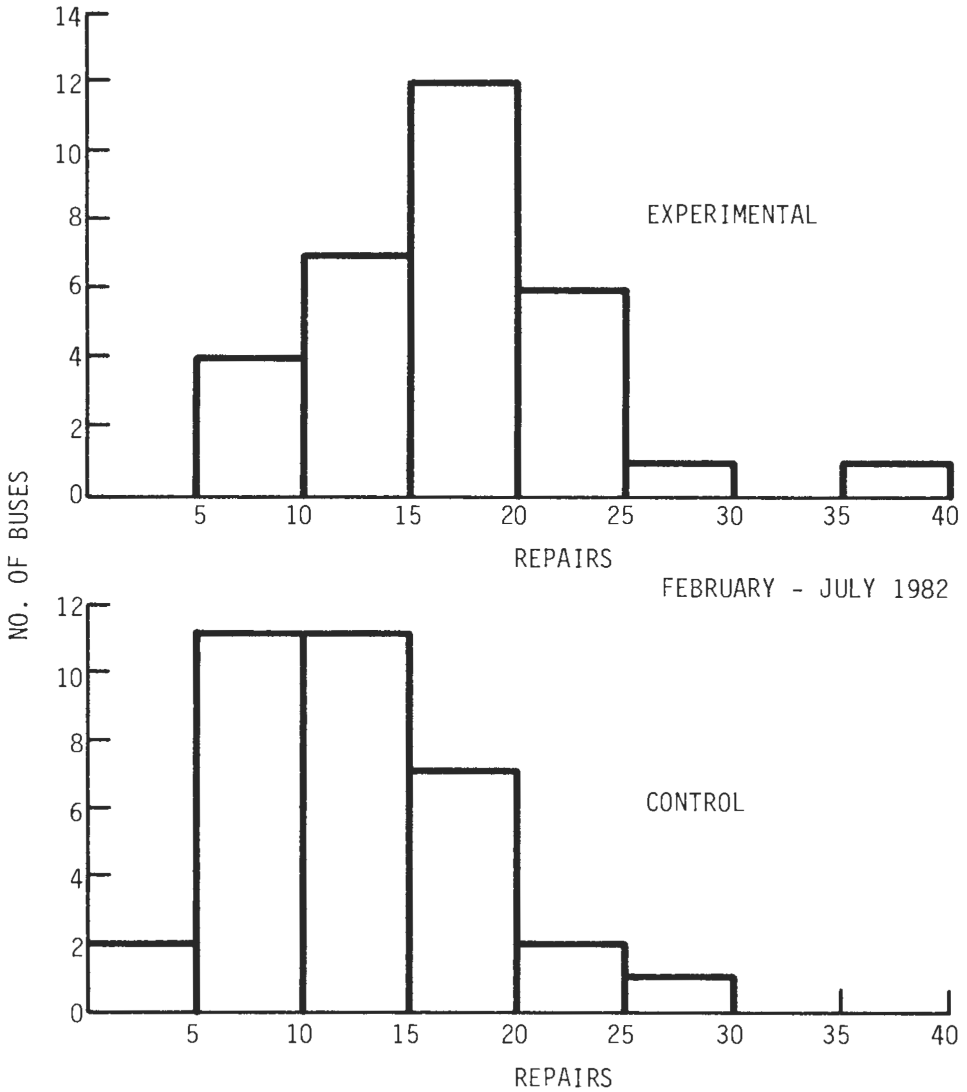


FIGURE 5-1. ABDS DETECTABLE REPAIRS

available bus days in the after case, the difference between the experimental and control buses increased somewhat from almost 73 percent (potential) to 83 percent (available). Figure 5-2 illustrates the differences betweens the two groups by individual bus repair hours. Statistical tests of the differences between experimental and control group ABDS detectable repair hours, using a one-way analysis of variance model, indicated that the differences were statistically significant at the 99 percent confidence level.

The apparent explanation of the increased experimental group repairs and repair hours is that the ABDS equipment found defects which were repaired but which would not have been found without ABDS. It would be anticipated that, over some period of time, these repairs would reduce the number of major bus component failures. It is also possible that eventually the number of ABDS type repair hours might be reduced per bus in comparison to non-instrumented buses. This did not happen within the evaluation period, possibly because the evaluation period was of insufficient length, due to circumstances beyond the control of UMTA or TSC as discussed in Section 1.1.2.

5.1.2 ABDS Detected Repairs

The preceding Section discussed the number of repair actions and the hours to repair the defects which the ABDS equipment was designed to detect. However, not all of these defects were discovered or repaired by use of the ABDS equipment.

All repairs performed following either a failed test on the FIU or the MAU were examined. Following an FIU failed test, an ABDS type repair was counted as being detected by the ABDS whether or not the MAU was used in the fault diagnosis. In some situations an MAU failed test can be the first indication of a defect when the MAU is used following a road call, a driver trouble report or 3000 and 6000 mile inspections. In these cases, an ABDS type repair was counted as detected by ABDS so long as the bus was not put back into service (determined by bus mileage) between the time of the failed test and the repair.

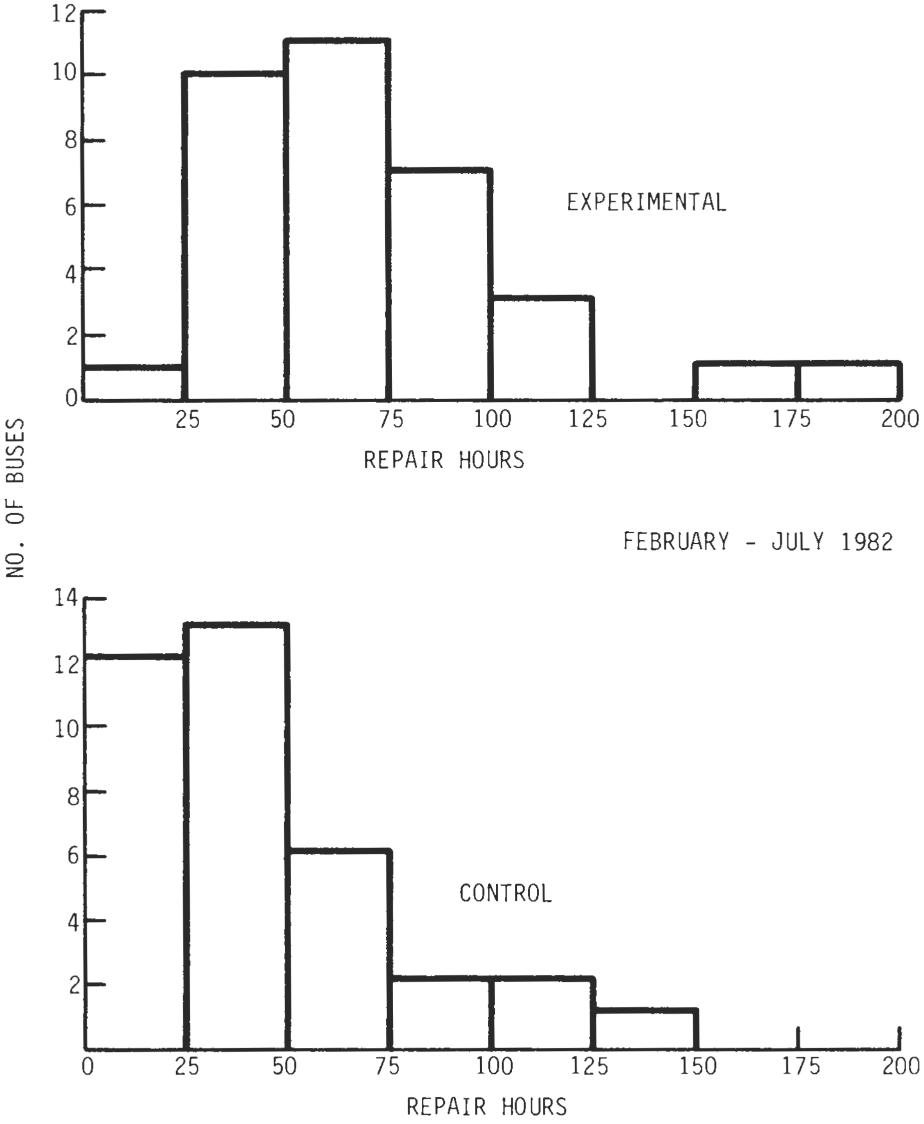


FIGURE 5-2. ABDS DETECTABLE REPAIR HOURS

Of the 574 ABDS type repairs performed during the evaluation period, 330 were judged as being actually detected by the ABDS. Thirty-eight of the 574 ABDS type repairs were accomplished during periods when Hamilton records indicated that the bus instrumentation was inoperable and could not have been used for fault detection. In addition, ABDS type faults discovered during scheduled maintenance operations or ABDS repairs made during major campaigns to check and correct specific items on all buses would not be detected by ABDS. The number of repairs made under these circumstances is unknown.

5.1.3 Non-ABDS Detectable Repairs

All bus defects which the ABDS equipment was not designed to detect were termed non-ABDS detectable faults. Non-ABDS repairs were examined for three reasons: to determine the percentage of all bus repairs which the ABDS equipment could detect; to serve as an indicator of possible external influences that could have affected demonstration results; and to determine whether the experimental buses might have been given special attention for all types of repairs.

A large majority of bus repairs fell into the non-ABDS category. Table 5-3 reveals that 2806 non-ABDS type repairs were performed on the experimental buses in the before period and 2224 in the after period, representing 85 percent and 79 percent respectively of combined ABDS and non-ABDS repairs performed on these buses during the two periods. For the control group 3215 and 2293 non-ABDS type repairs were performed during the two periods, or 86 percent and 84 percent respectively of all ABDS and non-ABDS repairs performed during the two periods. When compared per 1000 potential bus days, non-ABDS repairs increased by 18 percent for the experimental group and 6 percent for the control group from the before to the after period. When adjusted for out-of-service time, experimental group repairs are somewhat higher still. Examination of the GM versus Flxible buses did not reveal any large differences in either the experimental or the control groups.

TABLE 5-3. NON-ABDS DETECTABLE REPAIRS

	EXPERIMENTAL BUSES			CONTROL BUSES		
	24 GM	8 FLX	32 TOT	26 GM	9 FLX	35 TOT
6/81	274	91	365	280	104	384
7/81	313	96	409	288	84	372
8/81	288	108	396	339	86	372
9/81	270	62	332	283	79	362
10/81	288	119	407	351	146	497
11/81	197	81	278	265	93	358
12/81	164	76	240	248	67	315
1/82	194	101	295	276	98	374
2/82p	65	19	84	73	55	128
	2053	753	2806	2403	812	3215
2/82p	129	46	175	146	46	192
3/82	206	82	288	260	83	343
4/82	329	115	444	359	129	488
5/82	388	107	495	352	102	454
6/82	291	131	422	388	91	479
7/82	299	101	400	233	104	337
	1642	582	2224	1738	555	2293

REPAIRS PER 1000 BUS DAYS

Potential	Before	$\frac{2806}{8.160} = 343.9$	$\frac{3215}{8.925} = 360.2$
Potential	After	$\frac{2224}{5.472} = 406.4$	$\frac{2293}{5.985} = 383.1$
Available	After	$\frac{2224}{4.617} = 481.7$	$\frac{2293}{5.488} = 417.8$

When non-ABDS detectable repairs were looked at on an individual bus basis (Figure 5-3), it can be seen that the repairs for the control group are much more tightly clustered than the repairs for the experimental group. This would indicate much more variability in non-ABDS type repairs for the experimental group, a result which has no apparent explanation.

Non-ABDS repair hours (Table 5-4) exhibit a similar pattern to the non-ABDS repairs. The experimental group received 10,028 hours of non-ABDS maintenance type activity in the before period and 8226 hours in the after period, or 80 percent and 79 percent, respectively, of combined ABDS and non-ABDS repair hours during these periods. For the control group, comparable values are 11,265 non-ABDS maintenance hours (82 percent of total maintenance hours) in the before period and 8250 non-ABDS maintenance hours (86 percent of total maintenance hours) in the after period. The only major difference between the GM and Flxible buses was in the after period in which the Flxible control group buses required less maintenace than any of the other categories. There is no apparent explanation for this result.

The non-ABDS detectable repair hours increased 22 percent per 1000 potential bus days from the before to the after period for the experimental group but only 9 percent for the control group. When adjusted for out-of-service time the difference between the control and experimental groups becomes somewhat larger. Figure 5-4 graphically shows the differences between the two groups on an individual bus basis.

It is evident that the experimental group received more maintenance attention for both ABDS and non-ABDS faults. However, the difference between the experimental and control groups in the before and after periods was greater for the ABDS detectable elements. The ABDS detectable repair hours per 1000 potential bus days increased by 32 percent for the experimental group but decreased by 18 percent for the control group, whereas the non-ABDS detectable repair hours per 1000 potential bus days increased by 22 percent for the experimental group and 9 percent for the control group. The reason for the large increase in ABDS detectable repairs for the experimental group has been previously stated. A possible

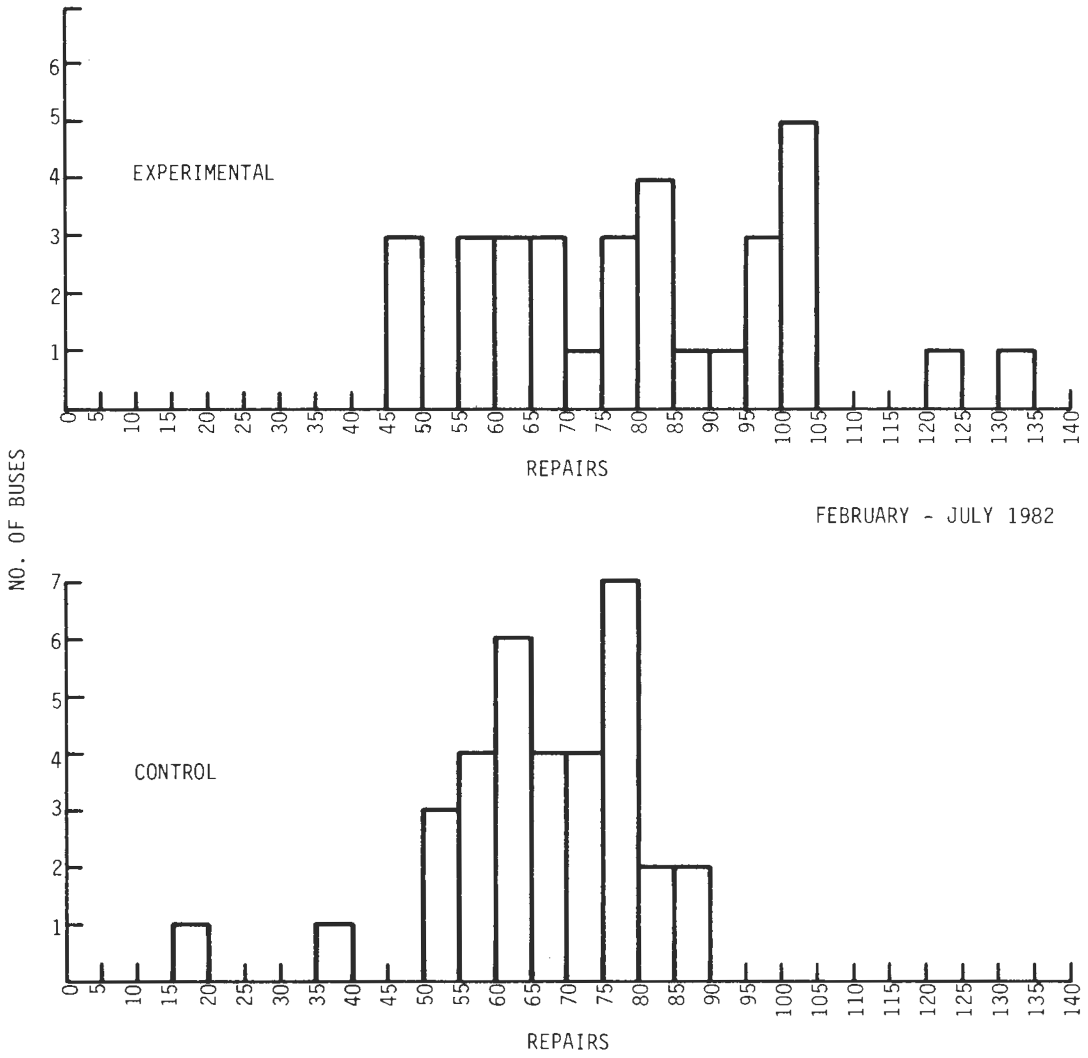


FIGURE 5-3. NON-ABDS DETECTABLE REPAIRS

TABLE 5-4. NON-ABDS DETECTABLE REPAIR HOURS

	EXPERIMENTAL BUSES			CONTROL BUSES		
	24	8	32	26	9	35
MONTH	GM	FLX	TOT	GM	FLX	TOT
6/81	773	351	1124	1079	225	1304
7/81	933	415	1348	726	350	1076
8/81	807	313	1120	785	432	1217
9/81	953	157	1110	1022	233	1255
10/81	1064	458	1522	935	432	1367
11/81	816	258	1074	921	526	1447
12/82	621	262	883	1157	233	1390
1/82	1145	167	1312	908	403	1311
2/82p	270	265	535	406	492	898
	7382	2646	10028	7939	3326	11265
2/82p	383	187	570	428	125	553
3/82	1105	306	1411	1178	323	1501
4/82	1269	624	1893	1302	399	1701
5/82	1410	359	1769	1278	393	1671
6/82	951	601	1552	980	366	1346
7/82	780	251	1031	1236	242	1478
	5898	2328	8226	6402	1848	8250

REPAIR HOURS PER 1000 BUS DAYS

Potential Before $\frac{10028}{8.160} = 1228.9$ $\frac{11265}{8.925} = 1262.2$

Potential After $\frac{8226}{5.472} = 1503.3$ $\frac{8250}{5.985} = 1378.4$

Available After $\frac{8226}{4.617} = 1781.7$ $\frac{8250}{5.488} = 1503.3$

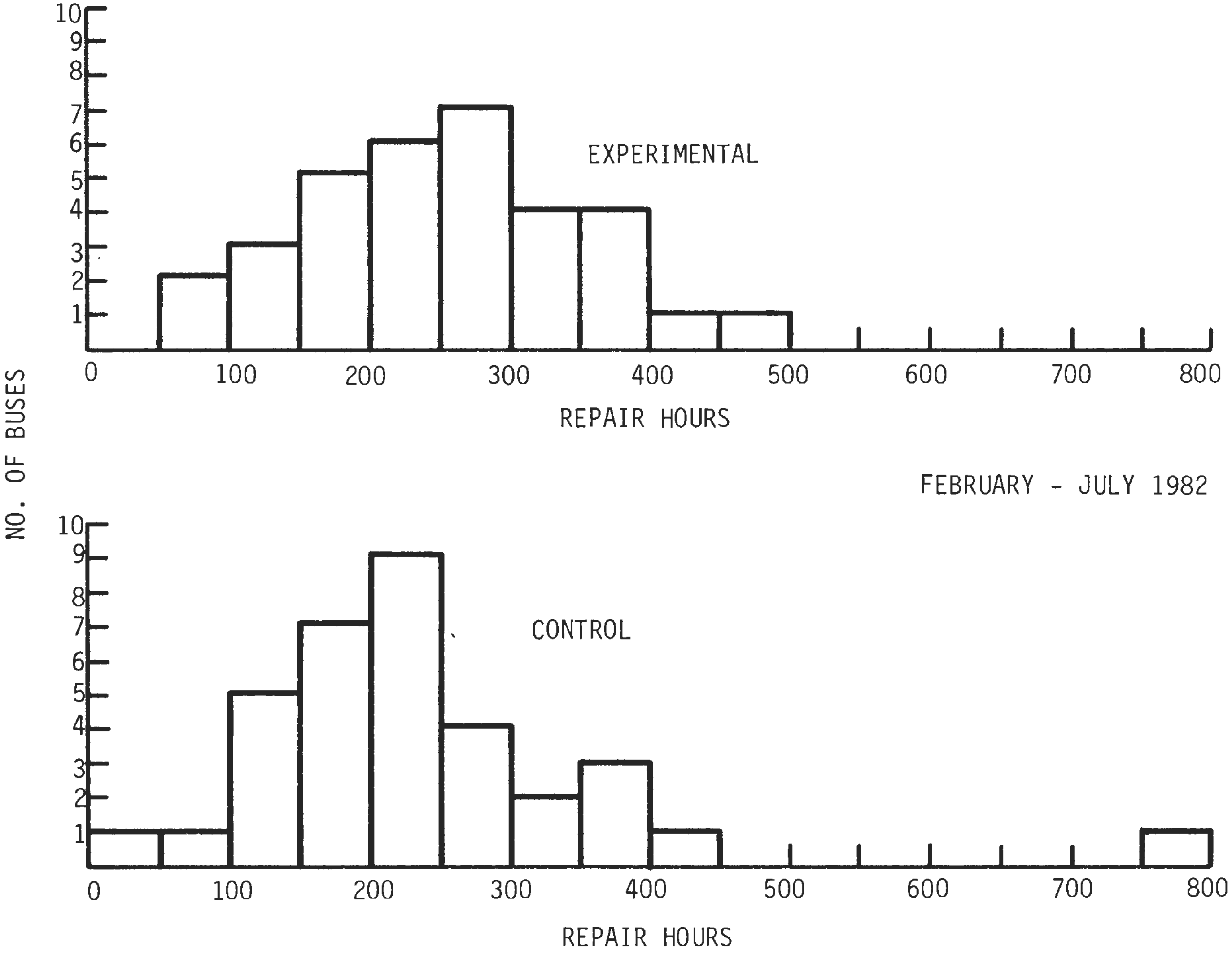


FIGURE 5-4. NON-ABDS DETECTABLE REPAIR HOURS

explanation for the greater increase in experimental bus non-ABDS repair hours is that during the course of the extra ABDS repairs performed on these buses, additional non-ABDS faults were discovered which might otherwise have gone undetected.

5.1.4 Hours Per Repair

The repair hours discussed above include both the time to diagnose the problem and the time to correct it. Diagnostic time alone was not recorded. Therefore, the hours per repair were examined to determine whether ABDS might have reduced the total time involved in diagnosing and repairing ABDS type defects.

The total number of repair hours divided by the total number of repairs produces the hours per repair shown in Table 5-5. For ABDS detectable faults, the hours per repair decreased for both the experimental and control groups in the after period. However, the hours per repair for the control group decreased to a greater extent, 38 percent versus 23 percent. For non-ABDS detectable faults, the hours per repair increased slightly for both groups, about 3 percent for the control group and 4 percent for

TABLE 5-5. HOURS PER REPAIR

		ABDS DETECTABLE FAULTS		NON-ABDS DETECTABLE FAULTS	
BASIS OF COMPARISON	PERIOD	EXP	CON	EXP	CON
Per 1000 potential bus days	Before	5.00	5.02	3.57	3.50
Per 1000 potential bus days	After	3.84	3.12	3.70	3.59
Per 1000 available bus days	After	3.84	3.12	3.70	3.59

the experimental group. It is difficult to find a logical explanation for these results. In the case of hours per repair, the adjustment for out-of-service time is negated.

5.2 DIAGNOSTIC TIME COMPARISON

One of the principal advantages of ABDS was expected to be the ability to diagnose faults more precisely and quickly. However, the manner in which maintenance information was recorded precluded the acquisition of diagnostic time data from the VISTA files. Only total repair times were available. An effort to record diagnostic times through observation by supervisors resulted in too few observations to make meaningful comparisons. The approach finally adopted by NYCTA was to have individuals familiar with maintenance procedures estimate the time involved to manually check the items which the ABDS does automatically. Eight maintenance supervisors and management personnel were selected to produce this estimate.

Table 5-6 contains the ABDS versus manual estimates for FIU tests, the frequency with which these tests are normally conducted and the time to perform the MAU test sequences for a given fault indication. Table 5-7 contains the time comparison for road call diagnostic MAU sequences and two other frequent maintenance area uses. The ranges in the estimates represent a combination of the estimates of eight different people and the varying time that might be required to diagnose the simplest to the most complex cause of a specific malfuction. In all instances, the ABDS tests are shown to take much less time than the manual tests. The differences can amount to several hours for some tests.

It should be noted that the times indicated are for tests that are not strictly equivalent. For example, the manual tests sometimes include items which the ABDS does not test for and vice versa. The method of developing the manual test times also causes some uncertainty. Nevertheless, as TSC was not involved at a sufficiently early stage of the evaluation to correct this deficiency these are the only diagnostic time comparisons that are available.

TABLE 5-6. FIU TESTS DIAGNOSTIC TIME COMPARISON

FUEL ISLAND TESTS		ABDS	TA MANUAL
#1	Engine Oil Viscosity/Gerin Test		
	Time interval	daily	3,000 miles
	Time required	2 seconds	15 minutes
#2	Air Conditioner Failure		
	Time interval	daily	when & if reported
	Time required	2 seconds	2 minutes
#3	Converter Oil Temperature Overheat		
	Time interval	daily	Road Call
	Time required	2 seconds	2 hours
	Diagnostic Time MAU/Manual	6-8 min.	30 min.-1 hour
#4	Engine Coolant Temperature Overheat		
	Time interval	daily	Road Call
	Time required	2 seconds	2 hours
	Diagnostic Time MAU/Manual	12-17 min.	1 hr.-1 1/2 hrs.
#5	Engine Cranking Speed		
	Time interval	daily	Road Call
	Time required	3 seconds	2 hours
	Diagnostic Time MAU/Manual	8-16 min.	20 min.-2 hrs.
#6-#9	Battery/Starter/Cables		
	Time interval	daily	Road Call
	Time required	3 seconds	2 hours
	Diagnostic Time MAU/Manual	8 min.	15 min.-1 hour

TABLE 5-7. MAU TESTS DIAGNOSTIC TIME COMPARISON

MAINTENANCE AREA SEQUENCES	ABDS	TA MANUAL
Road Call for Bus Dead	7-16 min.	1-2 hrs.
Road Call for Electrical	8 min.	2-4 hrs.
Road Call for Fumes	8 min.	15-30 min.
Road Call for Chronic No Heat	2-17 min.	15 min.-1 hr. 10 min.
Road Call for Oil Low/Leak	10 min.	20-30 min.
Road Call for Overheat/Cooling	12-17 min.	20-45 min.
Road Call for Transmission	6-8 min.	15 min.-2 hrs.
Road Call for Engine	8 min.	20 min.-8 hrs.
OTHER MAINTENANCE AREA USES		
General Health (after 6,000 mile inspection)	60 min.	8-16 hrs.
Quality Control of Base Shop PRS	10-15 min.	4 hrs.

It should also be noted that faster diagnosis of faults would not necessarily translate into faster repair time due to NYCTA's practice of allowing mechanics to take a standard amount of time to accomplish certain diagnoses and repairs.

5.3 BUS INSTRUMENTATION INTERFERENCE

The on-board ABDS instrumentation consisted of a series of wires and pressure lines connected at many points in the bus, but primarily in the vicinity of the engine and transmission, and drawn to interface points at the right rear of the bus for access by the FIU and MAU connecter cables. In some instances, a portion of the instrumentation had to be removed when a particular component was replaced. A few buses which were returned from the Base Maintenance Facility at East New York to Queens Village Depot had the bus instrumentation completely or substantially removed. If Queens Village mechanics replaced the instrumentation ABDS labor hours were incurred. However, the small number of ABDS labor hours involved in instrumentation replacement did not materially affect the ABDS results.

5.4 MECHANICS' ATTITUDES TOWARDS ABDS

In order to elicit the opinions of the Queens Village Depot foremen and mechanics towards the ABDS, an attitudinal survey was administered by NYCTA. A total of 52 survey forms were returned at least partially completed. Only 10 of the persons returning the questionnaire had ever used the ABDS equipment. The responses from those who had used the equipment and those who had not used the equipment are summarized separately in Appendix C.

All of the six mechanics who had used the MAU more than five times thought it was easy to learn to use. Three of the mechanics who had used the MAU five times or less thought that it was hard to learn to use, but easy once you got used to it. Four of the ten users did not like to use it. Five users thought that the MAU pinpointed electrical problems most of the time while four thought it successful about half of the time. Respondents thought the MAU did not do as well on hydraulic pressure problems. Four users believed that the MAU helped to diagnose problems faster most of the time while four thought that it helped about half of the time.

Twenty-one of the persons who had never used the equipment did not want to use it while eighteen of them would like to use it. None had requested not to use the MAU. Only two of the non-users and six of the users thought that they had sufficient training for MAU use. Fifteen of the non-users believed that the MAU should be used as a quality check while eighteen believed that all of the buses should be instrumented. Only one of the users expressed the opinion that the MAU should not be used for quality checking, while two thought that buses should not be instrumented.

Overall, the MAU received a lower rating from users on fault diagnosis than might have been expected, yet most of them believed that it should be used. About 46 percent of the mechanics who had never used the MAU expressed a desire to use it, another result that might not have been expected. Virtually none of them felt that they had enough training to use it, however.

6. OPERATIONAL IMPACTS

This Section contains a comparison of experimental and control group bus availability as measured in out-of-service days and on-street performance as measured in road calls. Out-of-service time and road calls were the only operational characteristics that could be measured in this evaluation.

6.1 BUS AVAILABILITY

One of the stated objectives of the ABDS demonstration was to reduce the number of buses required to be on-hand to provide the scheduled service. However, Table 6-1 and Figure 6-1 show that the experimental buses experienced a greater number of out-of-service days than the control buses. The statistical analysis indicated a 90 percent confidence level for this result. Since the experimental buses received more ABDS and non-ABDS repairs than the control group, it is not surprising that they would accumulate more out-of-service time. However, the trend by month shows out-of-service days decreasing for the experimental buses but increasing for the control group. It would seem that the added repairs on the experimental group were reducing their out-of-service time.

TABLE 6-1. OUT-OF-SERVICE DAYS

MONTH	EXPERIMENTAL BUSES	CONTROL BUSES
Feb	86	14
Mar	250	42
Apr	181	74
May	84	86
Jun	86	134
Jul	51	157
	738	507

It should be noted that a bus held out-of-service for repairs would be counted as out of service for the whole day if it was not available for the morning pull out. (This bus could receive anywhere from a few minutes to a whole day of repair activity, or perhaps none at all depending on the

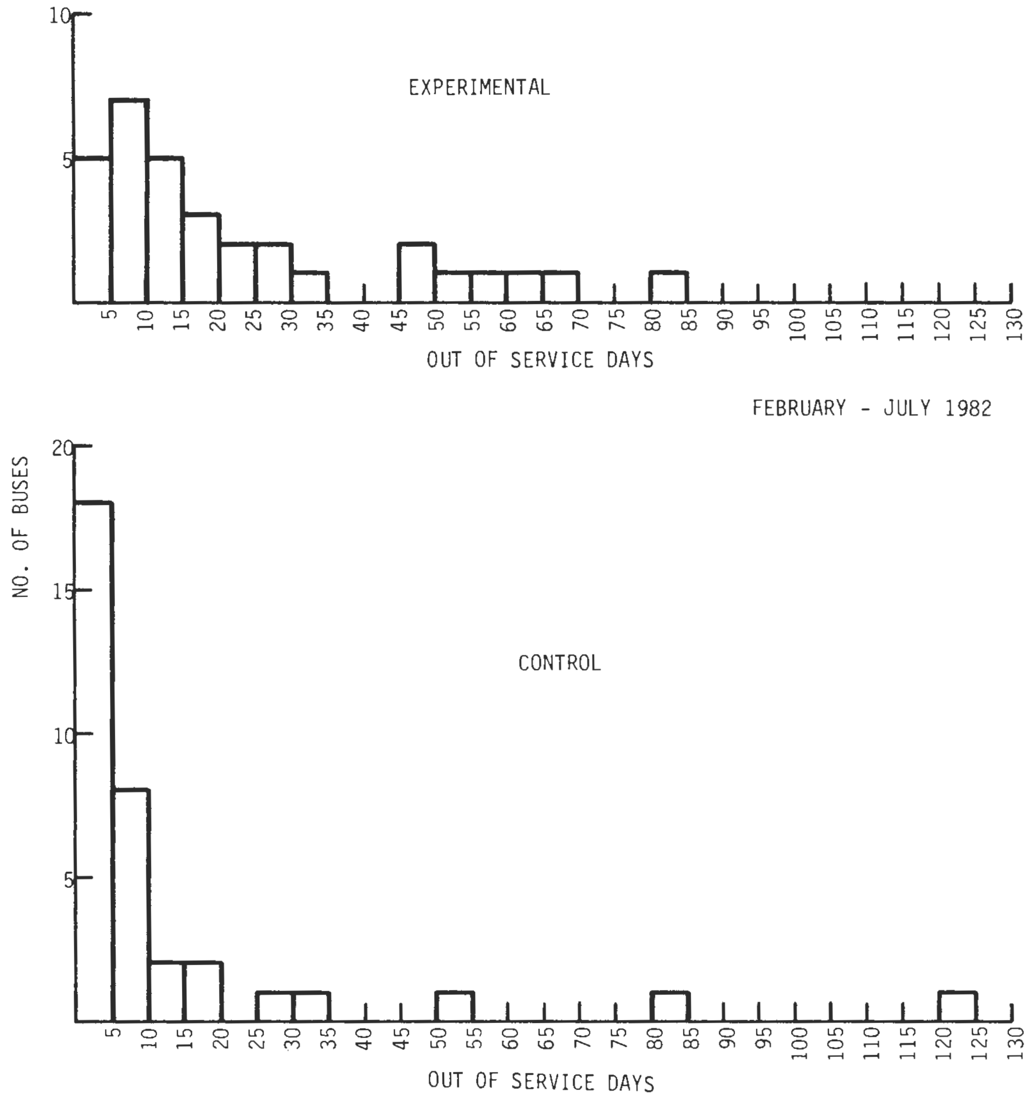


FIGURE 6-1. TOTAL OUT-OF-SERVICE DAYS

workload of the maintenance personnel at the time). Conversely, a bus pulled in to the depot during the day as a result of a road call or for some other scheduled or unscheduled maintenance action would not be classified as out-of-service for that day.

Due to the manner in which out-of-service time was recorded it was not possible to differentiate between ABDS and non-ABDS related causes. It also was not possible to compare out-of-service data on a before-after basis as the before data were not available.

6.2 ROAD CALLS

One of the anticipated benefits of ABDS was a reduction in the number of in-service breakdowns, or road calls. Table 6-2 contains ABDS detectable road calls for the experimental and control buses during the before and after periods. The Table reveals that road calls were reduced in the after period for both groups, but were reduced more per 1000 potential bus days for the experimental buses (30 percent) than for the control group (12 percent). When adjusted for out-of-service time the difference between the two groups is reduced slightly. The statistical analysis of ABDS road calls indicated that the difference between the experimental group and the control group was significant at the 99 percent confidence level, signifying that the ABDS equipment was responsible for the result.

ABDS, therefore, appears to have substantially reduced ABDS detectable road calls for the experimental buses in comparison to the control group. This trend is also apparent in Figure 6-2, which illustrates ABDS road calls for the individual buses in the two groups. Data from Table 6-2 also indicate that ABDS detectable road calls were reduced much more for the experimental Flxible buses than for the General Motors buses although no explanation for this is apparent. This reduction in ABDS road calls is the principal benefit measured in the evaluation from use of the ABDS equipment.

Non-ABDS detectable road calls were also examined. Table 6-3 shows a reduction of about 45 percent for both groups from the before to the after

TABLE 6-2. ABDS DETECTABLE ROAD CALLS

	EXPERIMENTAL BUSES			CONTROL BUSES		
MONTH	24 GM	8 FLX	32 TOT	26 GM	9 FLX	35 TOT
6/81	20	4	24	27	11	38
7/81	20	7	27	30	7	37
8/81	14	12	26	23	4	27
9/81	17	5	22	13	3	16
10/81	19	10	29	20	9	29
11/81	11	2	13	16	11	27
12/81	8	4	12	10	3	13
1/82	5	1	6	11	2	13
2/82p	7	1	8	2	3	5
	121	46	167	152	53	205

	EXPERIMENTAL BUSES			CONTROL BUSES		
MONTH	24 GM	8 FLX	32 TOT	26 GM	9 FLX	35 TOT
2/82p	6	2	8	7	4	11
3/82	3	3	6	14	4	18
4/82	14	2	16	17	4	21
5/82	14	1	15	17	5	22
6/82	11	1	12	28	5	33
7/82	19	2	21	10	6	16
	67	11	78	93	28	121

ROAD CALLS PER 1000 BUS DAYS

Potential	Before	$\frac{176}{8.160} = 20.4$	$\frac{205}{8.925} = 23.0$
Potential	After	$\frac{78}{5.472} = 14.3$	$\frac{121}{5.985} = 20.2$
Available	After	$\frac{78}{4.617} = 16.9$	$\frac{121}{5.488} = 22.0$

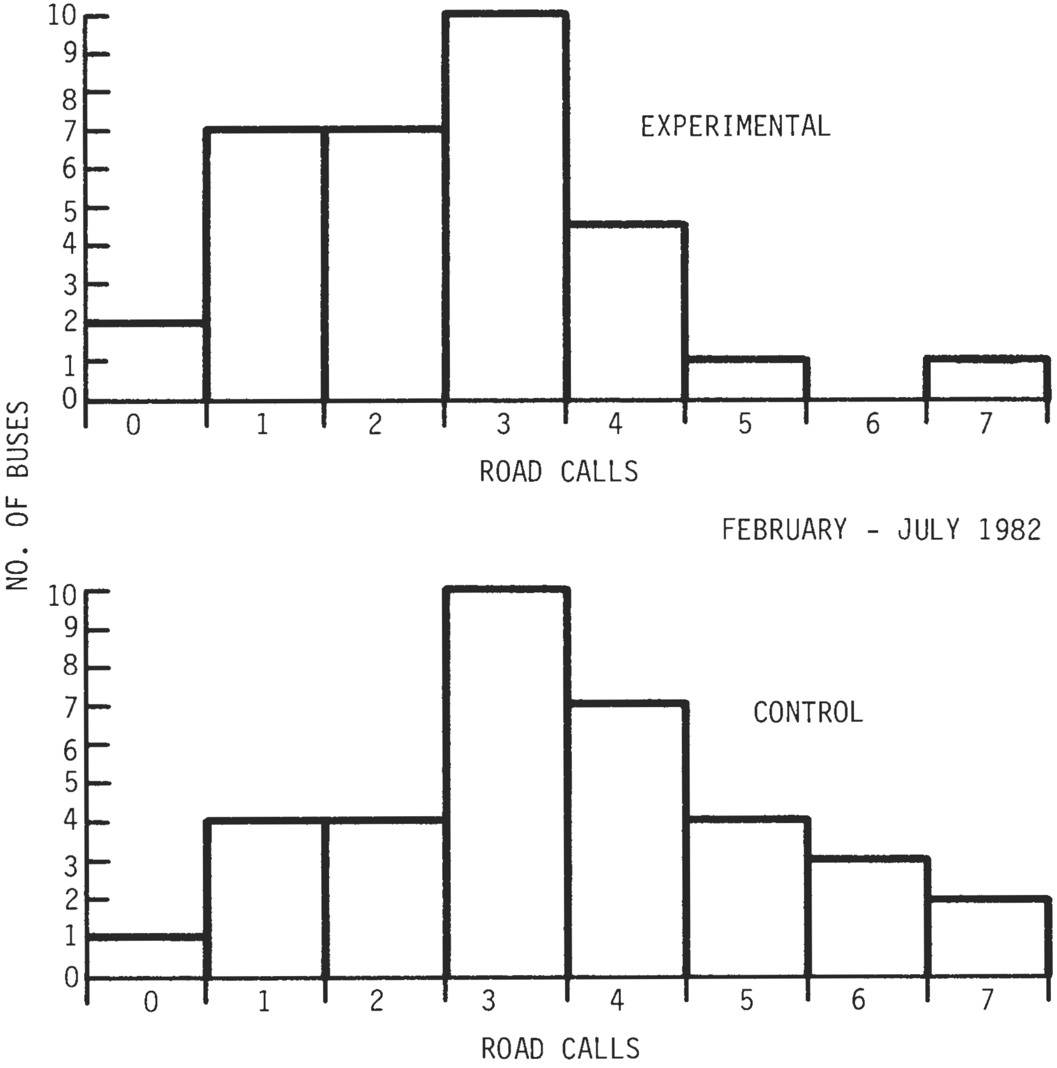


FIGURE 6-2. ABDS DETECTABLE ROAD CALLS

TABLE 6-3. NON-ABDS DETECTABLE ROAD CALLS

	EXPERIMENTAL BUSES			CONTROL BUSES		
	24	8	32	26	9	35
MONTH	GM	FLX	TOT	GM	FLX	TOT
6/81	71	28	99	71	31	102
7/81	62	16	78	78	24	102
8/81	45	18	63	63	12	75
9/81	42	15	57	56	24	80
10/81	54	24	78	86	33	119
11/81	40	14	54	57	30	87
12/81	34	17	51	46	17	63
1/82	42	16	58	51	18	69
2/82p	14	1	15	13	8	21
	404	149	553	521	197	718
2/82p	19	11	30	22	8	30
3/82	24	11	35	50	11	61
4/82	25	8	33	33	9	42
5/82	31	8	39	35	13	48
6/82	26	5	31	40	11	51
7/82	31	6	37	16	14	30
	156	49	205	196	66	262

ROAD CALLS PER 1000 BUS DAYS

Potential	Before	$\frac{553}{8.160} = 67.8$	$\frac{718}{8.925} = 80.5$
Potential	After	$\frac{205}{5.472} = 37.5$	$\frac{262}{5.985} = 43.8$
Available	After	$\frac{205}{4.617} = 44.4$	$\frac{262}{5.488} = 47.8$

period, with the experimental group being lower in both periods. There are no major differences between the GM and Flxible buses, although the Flxibles exhibited slightly better performance during the after period.

The 45 percent reduction in non-ABDS type road calls would ordinarily be a surprising result. However, NYCTA states that the implementation of intensive ABDS utilization coincided with the return to service of the repaired Flxible Advanced Design Buses. This eliminated the critical bus shortage and allowed maintenance to be performed on buses that required it, rather than to defer maintenance in the interest of meeting as much of the scheduled service as possible (which was the situation prior to February 1982). The deferral of maintenance would be expected to result in a high rate of road calls such as was experienced during the before period. The ability to keep the bus out-of-service to perform desired repairs permitted the increased repairs to be performed in the after period as discussed in Section 5.1.

7. ECONOMIC IMPACTS

This Section examines the cost of the demonstration including start-up and operational expenditures, the cost savings of quantifiable operational improvements, and the net economic effect of ABDS usage on NYCTA. Benefits that could not be quantified and limitations of the economic analysis are also discussed.

7.1 DEMONSTRATION FUNDING

Prior to the UMTA Section 6 demonstration grant, Tri-State Regional Planning Commission had received an UMTA Section 8 planning grant in the amount of $172,581. This grant funded Sperry Systems Management's efforts including a project feasibility study, assistance in developing a Request for Proposal for the ABDS equipment, the development of an evaluation plan and an evaluation report.

Section 6 demonstration funding was provided by UMTA in several increments. An initial amount of $210,000 was awarded to Tri-State in 1975. Subsequent grant modifications added $290,000 in 1978, $100,000 in 1980 and $100,000 in 1981. Altogether, the grants totalled $700,000. Individual line items in the final budget were as follows:

TABLE 7-1. FINAL DEMONSTRATION BUDGET

$ 33,000	Salaries
10,000	Training
8,000	Travel Expenses
599,910	Hamilton Test Systems Contract
7,000	Data Transmission Hardware
2,000	ABDS Supplies and Materials (in addition to that included in the Hamilton contract)
5,000	Miscellaneous Expenses
35,090	Tri-State Administration
$700,000	

According to statements made by representatives of NYCTA, Tri-State and Hamilton, expenses incurred under the Section 6 grant exceeded reimbursements by substantial amounts. Hamilton's effort, especially, greatly exceeded their compensation. Nevertheless, all contributed the extra effort in order to carry out the demonstration in the best possible manner.

7.2 START-UP COSTS

The total actual cost of initiating the demonstration is not known since records generally were not kept after expenditures for staff time exceeded final demonstration budget allowances. In several instances only the budget amounts or the contract levels are known. The Sperry Systems Management contract for $172,581 was mentioned above. The final amount of the Hamilton Test Systems contract was $619,410 which consisted of $233,310 for the on-bus hardware design and the development and delivery of two ABDS units, $266,600 for the development and installation of on-bus instrumentation, $59,500 for the hardware and software for data transmission, $58,300 for technical support, and $1700 for maintenance and repair of the ABDS equipment. Actual bus instrumentation was accomplished by a subcontractor to Hamilton.

Although the total amount is not known, Hamilton spent considerably more on the program than their reimbursement. Unanticipated expenses were encountered in redoing much of the bus instrumentation which was not done properly. They also provided one full time person and one part time person on site at Queens Village Depot during all of the evaluation period and for a substantial period of time prior to the evaluation period. This was not originally planned but which Hamilton subsequently felt was necessary to insure that the ABDS equipment was used properly. The report generation capability also turned out to be more complex to develop than originally estimated.

There is no precise estimate for the number of man hours consumed or the expense incurred in training NYCTA personnel in the use of the ABDS equipment. The grant allowed $10,000 for this purpose. The best available estimate is that the NYCTA labor cost of training exceeded $13,000. However, more people were trained than necessary since many who were trained never used the ABDS equipment. Hamilton suggests 16 hours of training for each mechanic and foreman involved in ABDS MAU testing, 4 hours for each person working the FIU and 2 hours for each foreman or other personnel designated to setup or shutdown the FIU.

Table 7-2 contains an estimate of the total project start-up cost. Both contracts and all hardware and software items plus training were considered to be start-up expenses. In addition, an assumption was made that one-half of other non-operational expenses (NYCTA salaries, travel, Tri-State administration) would be considered start-up costs and the other half would be operational expenses. Total start-up costs were estimated to be $903,561.

The cost to plan and implement this demonstration was very high due to the experimental nature of the project and the need to design and develop the equipment to be used. Hamilton Test Systems states that the cost of a production model system will be much less than the design and development cost of the prototype system for this demonstration. The cost to instrument a large number of buses still would be substantial, however -- about $2000 per bus exclusive of installation.

7.3 OPERATIONAL COSTS FOR THE ABDS EQUIPMENT

Since the time to operate the FIU was accomplished within the 3 minutes allotted per bus for fuel island functions, no extra cost is attributed to FIU testing. Recommended changes would eliminate most of the additional FIU test time. Therefore, the principal operational costs for the FIU and MAU, exclusive of labor, were equipment maintenance, supplies and power.

7.3.1 ABDS Equipment Maintenance/Modification

The ABDS demonstration was a prototype program. Therefore, the cost of adjustments to hardware and software was included in Hamilton overhead and no specific records were kept regarding these adjustments. Hamilton personnel estimate that about 2 hours per week were spent on preventive maintenance and repair of the FIU and MAU units.

TABLE 7-2. START-UP COST ESTIMATE

Under Section 8 Grant		
	$172,581	Sperry contract
	53,525	NYCTA in-kind services
	$226,106	
Under Section 6 Grant		
	$16,500	NYCTA salaries
	4,000	Travel
	13,000	Training
	7,000	Data transmission hardware
	619,410	Hamilton contract
	17,545	Tri-State administration
	$ 677,455	
TOTAL	$903,561	

The cost of repairs and maintenance to the Digital Equipment Corporation (DEC) computer equipment in the FIU was covered by a maintenance agreement with DEC repair service. The monthly cost was $160.00. The cost of repairs and maintenance to the DEC equipment in the MAU was paid on a per call basis. Invoices received from June 1981 through June 1982 totalled $401.00.

7.3.2 Supplies

As part of the contract, Hamilton furnished the supplies (paper, ribbons, spare parts, etc.) for the test equipment. Hamilton estimated this cost to be about $6000 over a fourteen month period.

7.3.3 Power

The cost of supplying the power to run the FIU and MUA is the only other principal cost of operating the equipment. The prototype FIU required 14.5 amps @ 110 volts A.C. while the MAU required 14.6 amps @ 110 volts A.C. However, Hamilton figures that a production model FIU should require no more than 4.0 amps @ 110 volts A.C. and a MAU no more than 8.9 amps @ 110 volts A.C. The reduced power requirements would be due to the elimination of the emissions analyzer on both units and the air conditioner on the FIU.

The power consumption of the FIU and MAU would be in the range of 2450 Kilowatt hours of electricity during the after period based upon eight hours per day for the FIU and one hour per day for the MAU. NYCTA's cost for electricity was 3.25¢ per Kilowatt hour, which would have cost about $80 over the evaluation period.

7.4 REPAIRS

Although it was hoped that the ABDS equipment would reduce repair hours for ABDS detectable faults, it did not have this effect during the evaluation period. As discussed in Section 5.1, repair hours were higher on the experimental buses for ABDS detectable faults. For purposes of comparison on an equivalent basis, the repair hours per available bus day were chosen. The difference between the experimental and control groups' ABDS repair hours per available bus day multiplied by the number of experimental bus days operated during the after period resulted in a calculation of 1031 additional ABDS detectable repair hours for the experimental buses. The average mechanic straight time cost (provided by NYCTA) is $17.79 which includes fringe benefits but excludes overhead charges. The cost of these extra repair hours therefore would be $18,341 for the evaluation period if all repairs were conducted without use of overtime. On a yearly basis this would amount to $39,149 or $1223 per bus.

The added repairs would unquestionably result in the consumption of additional parts. NYCTA claims that it is virtually an impossible task to identify the parts used in ABDS repair actions. Consequently, the added cost of parts cannot be estimated.

Although non-ABDS type repairs were also higher for the experimental group, the cost of these repairs has not been attributed to the ABDS equipment since there is no direct evidence to indicate that ABDS and non-ABDS type repairs were related. It is likely, however, that some of the non-ABDS detectable faults were discovered during the added ABDS type repair activity.

7.5 ROAD CALLS

The ABDS system did result in a reduction in road calls. Table 6-2 indicated 5.1 fewer road calls for ABDS type faults for the experimental buses per 1000 available bus days than for the control group or 24 fewer ABDS type road calls for the total number of experimental bus days operated. NYCTA estimates that a road call costs $75 for a mechanic to go to the bus and either fix it on the road or bring it back to the garage. These costs do not include the cost of repairs performed back at the Depot. Therefore, the cost savings of the reduction in road calls resulted in an estimated savings of $1800 over the demonstration period. When translated to a yearly figure, this would amount to $3842.

7.6 OVERALL FINANCIAL IMPACT

In this Section, cost savings or added costs are ascribed to those items for which costs could be determined or estimated and the advantages and disadvantages of ABDS are discussed.

Some costs associated with the planning and implementation of ABDS were identified while others were not. The total estimated start-up costs under both the Section 8 and Section 6 grants were identified in Section 7.2. The start-up costs included the Sperry and Hamilton contracts, a portion of NYCTA and Tri-State staff salaries and travel expenses, ABDS equipment training and data transmission hardware. The start-up cost estimate totalled $903,561.

The operational costs for the ABDS equipment include the maintenance and repair costs for the FIU and MAU equipment, the power consumed in operating the units, and the paper, ribbons, and parts consumed in normal use of the system. These costs were estimated to be $1361 for maintenance and repair (no cost estimate is available for Hamilton personnel's maintenance and equipment adjustment); $80 for power; and $2600 for supplies and spare parts for the FIU and MAU. Therefore, quantifiable operational costs for the ABDS equipment over the evaluation period were estimated to be $4041.

Operational costs also include the labor and parts consumed in making repairs. The ABDS type repairs performed on the experimental buses were estimated to cost $18,341 more than ABDS type repairs performed on the control buses during the evaluation period. However, parts cost could not be determined from the available data.

The only benefit discovered during the evaluation which could be quantified was an estimated cost savings of $1800 for reduced road calls.

On a pure financial basis, ABDS cost more than it saved during the six month evaluation period. Considering operating aspects alone, the ABDS costs exceeded cost savings by $20,582. On an annual basis this would equate to $1372 per bus per year. If start-up costs were added and amortized over a ten-year period at a 10 percent discount rate, the cost per bus would have been another $4600 per year. However, the demonstration start-up costs were very high due to the experimental nature of the project and the prototype equipment that had to be developed. It should be noted that the start-up costs were borne principally by UMTA and the operational costs principally by NYCTA.

There are several qualifications which limit the practical implications of the financial investigation. The first is that a six month evaluation period is inadequate to measure long term effects of early fault detection and repair. An expectation of the demonstration was that ABDS would lead to fewer repair hours since early fault detection and correction ought to reduce future time consuming repairs of major component failures. The evaluation data provides no clues as to whether ABDS would ultimately produce this result. However, this possibility cannot be ruled out.

A second factor to consider is whether the use of eight and eleven year old buses had an effect on the demonstration results. Although both the experimental and control groups were of the same model and vintage, it is possible that ABDS would prove more advantageous for newer buses with fewer problems than for older buses in a more degenerative state.

A third issue is that the financial analysis could not take into account possible non-quantifiable benefits of reduced road calls and the apparent trend of a reduction in out-of-service time. Fewer bus breakdowns obviously translate into greater schedule adherence, fewer service interruptions, and better overall service, which should result in a more favorable public attitude towards NYCTA and increased patronage. Other research conducted by TSC* identifed the importance of service reliability in reducing operating costs and inducing additional transit ridership.

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* Mark Abkowitz, et al, TRANSIT SERVICE RELIABILITY, U.S. Department of Transportation, Transportation Systems Center, Cambridge, MA, December 1978, UMTA-MA-06-0049-78-1, 192 pp.

Two of the expected major advantages of ABDS could not be addressed by the evaluation since data were unavailable with which to measure them. These were improved diagnosis and fault isolation, which would reduce improper maintenance actions and component replacements, and the upgrading of the quality of maintenance through automated checkout of completed repairs. Indeed, ABDS should have accomplished these goals. ABDS does test for faults much quicker than a mechanic can. Normally, this would result in faster repairs. However, NYCTA's practice of allowing mechanics to take a standard amount of time for certain repairs prevented the achievement of reduced repair time for these repairs. During the before period, when the MAU equipment was used only occasionally, a few cases were documented in which problems persisted on buses, in spite of repeated repair efforts, until they were checked out on the MAU and quickly solved.

The MAU was to be used to check-out ABDS type completed repairs. However, there was no time clock on the MAU and no information was availble to indicate whether an MAU test was intended to diagnose a problem or check out a repair. Consequently, it is not known whether an improper repair was ever discovered by the MAU.

In summary, ABDS did not have a positive financial impact on NYCTA during the six-month evaluation period. Nevertheless, the possibility exists that ABDS would show more favorable results if examined over a longer period of time and data were available to measure and assess its potential advantages. Some expected ABDS benefits could not be assessed in this evaluation, in some instances because the necessary data were not collected and in others because the impact could not be measured.

8. CONCLUSIONS

8.1 IMPLEMENTATION

The ABDS demonstration proved that diagnostic equipment can be installed at a maintenance facility of a major transit system. The transit union agreed to cooperate in the test and the testing equipment was successfully installed and operated. However, problems with a subcontractor's installation of the on-board instrumentation, the reluctance of some foremen and mechanics to use the MAU, and the lack of an official ABDS standard operating procedure until well after the demonstration should have been operational caused an eight-month delay until February 1982 in intensive use of the ABDS equipment. It is significant, nonetheless, that the ABDS equipment is still being used at the Queens Village Depot.

Reluctance to use the MAU by some maintenance personnel remained a problem throughout the demonstration. A survey revealed that only six of the ten persons who had used the MAU said that they liked it and only 18 of the 42 non-users said they would like to use it. This attitude indicates a lack of wholehearted support for the demonstration at the working level. The situation might have been different if all the buses at the Queens Village Depot had been instrumented and use of the MAU became a matter of routine. In contrast the FIU seemed to be readily accepted.

8.2 ABDS EQUIPMENT PERFORMANCE

Data provided for the evaluation indicated that the off-board ABDS equipment was out of service very little from February through July 1982. The FIU was out of service for only six days. In addition, there were four other times before or after the evaluation period when the FIU was out of service. Three of these were due to the connector cable and the fourth was due to vandalism. The MAU was not out of service at all until August 1982, when it was down four times due to computer board or floppy drive failures.

There is no conclusive evidence that the ABDS ever gave false test results that could not be explained. This does not imply that the FIU never generated a failed test result for which no fault could be found. This did happen on a number of occasions. There were instances in which the individual test limits for the buses were not set properly and would cause buses to fail tests when there was no defect. Many test limits were changed during the course of the demonstration. There also were some instances in which multiple FIU tests were conducted, one after another, with different FAIL/PASS results indicated. Neither this nor the previous situation necessarily means that the FIU test results were false, although it could. Since there is no proof of false test results, we must conclude that the ABDS equipment appeared to perform very well.

8.3 COSTS

From the demonstration goals and objectives, it would seem that NYCTA hoped that the ABDS would result in a maintenance cost savings through faster fault detection, more accurate repairs, fewer major component failures, fewer road breakdowns and a need for fewer spare buses. The first three impacts could not be measured easily or at all in the evaluation. A subjective comparison of ABDS and manual diagnostic times for specific bus problems indicated much faster diagnostic time using ABDS. However, this did not translate into cost savings due to work practices at NYCTA. The lesser number of road calls observed for ABDS type repairs would result in cost savings. Nevertheless, the estimated cost savings due to fewer road calls were exceeded by the added costs of repairing the extra faults detected by ABDS.

The evaluation data give no clue as to the long term maintenance cost impact of early fault detection and repair. A reduction in the spare bus requirement did seem to be achieved during the evaluation period. However, it was not possible to quantify this benefit.

The cost-benefit analysis showed that calculated or estimated operational costs exceeded quantifiable benefits by $20,582 for the six-month after period. The start-up costs that could be estimated, if amortized on a ten-year, 10 percent discount rate basis, would raise this figure to $87,340 for the evaluation period. However, there were several real or probable maintenance and service benefits from ABDS utilization that could not be quantified in this evaluation. Furthermore, a six-month operational period is too short a period of time in which to evaluate the economics of this concept. ABDS could have substantially different long-term effects. Nevertheless, if a judgement were to be made based on six-month evaluation results, it would be that the experiment did not have a positive economic impact during this period and that it gave little or no indication of long-term economic impacts.

8.4 OPERATIONAL IMPACTS

In addition to the financial impact discussed above, ABDS had an operational impact on Queens Village maintenance. The added faults detected by ABDS resulted in added repair hours. Fortunately, the Queens Village Depot had an infusion of extra buses at about the start time of the after period and, therefore, buses could be held out of service until they could be fixed. Prior to this time, buses were needed for revenue service and were only held out of service for repairs if absolutely necessary. The added faults discovered by ABDS would have exacerbated this situation and many of the indicated problems might not have been fixed. However, the faster fault diagnostic ability of the MAU should be a benefit, especially in an overloaded maintenance shop.

Although a goal of the demonstration was to reduce the spare buses required, the opposite effect was found during the early months of the evaluation period. However, during the last two months of the evaluation, the out-of-service time for the experimental group dropped below that for the control group. It appeared, therefore, that towards the end of the evaluation period the goal of reducing the spare bus requirement was being achieved. This result is somewhat surprising as repair hours had not decreased prior to July.

Reduced road calls would produce benefits beyond the cost savings attributed to them. Better service reliability and schedule adherence, fewer mechanic trips out of the garage, and greater passenger convenience are some of the non-quantifiable benefits. The importance of these benefits should not be disregarded simply because a monetary value cannot be put upon them. Better service reliability should be a goal of all transit operators.

Although it could not be proven in the evaluation due to lack of information, it would be expected that the quality of maintenance for ABDS detectable items was better than for non-ABDS detectable items. The ability to pinpoint faults, to have specific repairs indicated and to check to assure that the repair was done correctly must have improved the quality of ABDS type repairs, even though the MAU was not used as often as it should have been.

8.5 TRANSFERABILITY

The ABDS demonstration in New York City proved that diagnostic equipment can be installed and operated. It would be erroneous, however, to expect the same magnitude of results to be manifest at other locations. Nevertheless, the short-term results -- a higher number of repairs and repair hours for experimental bus component failures which the ABDS was designed to detect than to repair the identical faults on control group buses -- probably would be experienced by other transit operators using the same approach.

The added repair effort had other consequences, namely, greater initial out-of-service time for repairs, the initial need for a greater reserve of buses in order to maintain scheduled service, and higher costs. In return for this added repair effort, NYCTA experienced fewer ABDS related road breakdowns, and a steady reduction of out-of-service time. A similar relationship -- better service in return for greater repair effort -- likely could be expected, at least in the short term, by other transit operators trying this diagnostic approach. Unfortunately, this demonstration was not operational for a sufficient length of time to provide any indication of longer term results. It would seem likely that repairs would not increase but it is uncertain whether or how much repairs would decrease.

The ABDS demonstration results were influenced by a number of factors which deserve mention. An important consideration is the manner in which the test was conducted. ABDS instrumentation was put on only 40 of the 200 buses operated from the Queens Village Depot. Therefore, only 20 percent of the buses were to be specially treated. The ABDS equipment was not used as often as it should have been possibly because it was easy to forget, intentionally or not, that ABDS testing was to be done on these buses. Moreover, it was not until early 1982 that an official Standard Operating Procedure, in which the manner of using the ABDS equipment was spelled out, was developed and enforced. Furthermore, the ABDS equipment was installed on buses that were eight and eleven years old at the beginning of the testing period and, presumably, in a state approaching replacement based on an assumed bus life of 12 years. It is entirely possible that the results might have been different if newer buses were used. It is also possible that an ABDS experiment might have produced more favorable results at a transit authority without standardized repair times. This latter factor unquestionably inhibited the achievement of some of the hoped for benefits of ABDS.

Data for the evaluation were also an important consideration. Data were completely lacking on two key expected advantages of ABDS, specifically, faster and more accurate diagnostics and the quality check on repairs. Consequently, it could not be proven that these important potential advantages were, in fact, real. Also, there were inconsistencies discovered in data derived from different records. The extent of data inaccuracies were not known. Presumably, they were not sufficiently large so as to change the results. Further, the small number of buses involved in the comparison reduces the definitiveness of the evaluation results.

Inadequate or inaccurate data notwithstanding, the results of the NYCTA experiment can provide useful information for others contemplating ABDS type implementations. With careful planning and improved equipment, lower costs should be possible. The fact that this was both a demonstration and the first test of a <u>prototype system</u> increased the level of cost incurred in the project and need not be experienced elsewhere. At locations where repair time standards are not utilized greater ABDS benefits should result. Nevertheless, it is questionable whether quantifiable benefits would exceed quantifiable costs at least in the short term. There is a better chance in the long term for the benefits of early detection and repair to produce more favorable results. There also exists the possibility that non-quantifiable benefits might make ABDS desirable even if the quantifiable costs exceed benefits. More evaluation of ABDS operation needs to be done before the quantifiable value of the use of ABDS, other than reduced road calls and a trend of reduced out-of-service time, can be determined.

Finally, there remain a number of unanswered questions after this first ABDS experiment. In order to provide the answers, it seems desirable to test this concept elsewhere with a carefully developed implementation plan and a carefully structured evaluation which would measure long-term impacts. It also would be desirable to explore the possibility of examining other diagnostic tools such as built-in diagnostics which are now being developed for transmissions and engines.

APPENDIX A. MAINTENANCE CODES

PURPOSE CODE	SYSTEM
A	Air Conditioning
B	Air Brake System
C	Cooling System
D	Fuel System
E	Engine
F	Fare Collection
G	Body and Frame
J	Electrical System
L	Locator System
M	Front Axle
N	Rear Axle
P	Propeller Shaft
R	Radio
S	Suspension
T	Transmission
W	Wheels
X	Misc. Bus and Depot Material
Y	Steering
Z	Scheduled Operations

The major systems were further segregated into components and sub-components as necessary. The following example illustrates the manner in which purpose codes were assigned to elements of the Cooling System, Purpose Code C.

PURPOSE CODE	DESCRIPTION
C	Cooling System
C01	Radiator
C0101	Core, Radiator
C0102	Filler Neck & Cap, Radiator
C0103	Mounting, Radiator
C0104	Shrouds & Baffles, Radiator
C0105	Surge Tank, Radiator
C0106	Surge Tank Regulator, Radiator
C0107	Thermostat, Radiator
C0108	Stutter Stat, Radiator
C02	Water Pump
C03	Water Tubes, Hoses & Fittings
C0301	Air Compressor Water Lines
C0302	Transmission Water Pipes
C0303	Water Vent Line
C04	Fan, Cooling System
C0401	Fan Blade
C040101	Oil Seal, Fluid Fan
C0402	Fan Drive
C040201	Housing, Fan Drive
C040202	Mounting, Fan Drive
C040203	Oil Valve, Fan Drive
C040204	Oil Hose, Fan Drive
C040205	Oil Seal, Fan Drive
C040206	Housing, Fan Drive
C040207	Accessory, Fan Drive
C99	Misc Cooling System

Maintenance Type Code

The maintenance type codes are used to classify maintenance activity by various classes including:

S - Scheduled Operation (S.O. or S.O. Pick-Up)
C - Corrective Maintenence
R - Road Call Repair at Location
T - Road Call Repair on Road

TABLE OF COMMONLY USED LOCATION CODES

Purpose Code	Short Component Description	Location Codes
B22	Camshaft, Brakes	LF, RF, LR, RR
B24	Chamber, Brakes	LF, RF, LR, RR
B25	Diaphragm, Brakes	LF, RF, LR, RR
B30	Shoe and Lining, Brakes	LF, RF, LR, RR
B3010	Mounting, Brake Shoes	LF, RF, LR, RR
B3011	Spider, Brake	LF, RF, LR, RR
B301110	Anchor Pin, Brake Spider	LF, RF, LR, RR
B301111	Bushing, Brake Spider	LF, RF, LR, RR
B3012	Springs and Pins, Brake Shoes	LF, RF, LR, RR
B32	Slack Adjuster, Brakes	LF, RF, LR, RR
D0501	Injector, Fuel	ALL, L1, L2, L3 L4, R1, R2, R3, R4
D0502	Rack Control Lever, Fuel Injector	L, R
E0902	Connecting Rod, Crankshaft	ALL, L1, L2, L3 L4, R1, R2, R3, R4
E0903	Bearing, Connecting Rod	ALL, L1, L2, L3 L4, R1, R1, R3, R4
E0904	Seal, Crankshaft	F, R
E0905	Sleeve, Crankshaft	F, R
E17	Mount, Engine	F, R
E20	Piston, Rings and Sleeves, Engine	ALL, L1, L2, L3 L4, R1, R2, R3, R4

TABLE OF DEFECT CODES
(as of August, 1980)

Code	Description	Code	Description
202	Assy/Wire Wrong	209	No Charge
248	Bent/Dent/Twist	206	No Tn Off/Close
251	Broken/Sheared	205	No Turn On/Open
210	Burnt Out	219	Noise Unusual
235	Carbonized	262	Not Working
253	Chipped/Pitted	260	Odor/Fumes
215	Connection, Bad	214	Open Circuit
234	Contaminated	201	Out of Adjstmnt
250	Cracked/Split	217	Overcool/Cold
249	Crushed, Destroy	216	Overheated/Hot
257	Curb Wear	245	Pressure High
247	Cut/Torn	244	Pressure Low
261	Defective	243	Pressure No
232	Dirty	265	Pulls
239	Empty/Dry/Lub	263	Required
255	Flat	227	Rubbing/Binding
230	Flow Restricted	246	Rupture/Pncture
231	Foreign Object	236	Rusted/Corroded
229	Frozen/Lock/Jam	252	Sharp, Rough
266	Gasket Defective	213	Shorted
212	Grounded	226	Slow/Sluggist
267	Hdwre Defective	218	Smoke/Burn Mark
223	Hardware Missing	259	Stalling
264	Inaccessible	233	Sticky/Gummy
207	Indicator Lamp	200	Test/Insp. Fail
211	Insulation Bad	228	Tight/Stiff
203	Intermittent	208	Tripped/Blown
238	Leaking	221	Unseated/Slip

REPAIR ACTION CODES

For Work Completed: (500 Series)		For Work Not Completed: (700 Series)	
Code	**Description**	**Code**	**Description**
503	Add Fluid	714	**In SVC - For BS
507	Adjust/Align	707	**Insuff Info
504	Bleed	704	**Insuff Labor
524	Bodywork/Patch	705	**Insuff Parts
508	Calibrate	703	**Insuff Time
511	Change Out (R/R)	706	**Insuff Tools
521	Charged	713	**OS For Repair
525	Clear	702	**Temp Repair
518	Fabricate	709	**Serviceable
537	Fumigate	701	**To Other Shop
526	Hardware Rplace	711	*Bus Not at Loc
500	Inspect/Test	708	*Bus Return SVC
510	Install Only	710	*Pulled Off Job
502	Lubricate/Oil	700	*Sent to Vendor
517	Machine	715	*No Part - Bypadd
513	Modify/Update	716	**Tripper
531	New Fuse/Brker		
516	Paint		

Exceptional Occurrence Code

Code	Description	Report Description
1	Vandalism	VAND
2	Collision	COLL
3	Fire	FIRE
4	Flood	FLOD
5	Special Test	TEST
6	Warranty	WARR
7	Campaign Change or Modification	CMOD
8	Work for Other Locations	OTHR
9	Overtime	OVTM

ROAD CALL CODES

Code	Description	Code	Description
800	ACCELERATN PROB	858	GLASS BROKEN
850	ACCIDENT	824	HORN PROBLEM
801	AIR LOW	860	MIRROR PROBLEM
889	BODY PART LOOSE	823	NO HEAT
803	BRAKES, LONG	825	OIL LOW/LEAK
804	BRAKES, PROBLEM	829	OVERHEAT
805	BUS NOT MOVE	862	PASSENGER PROBLEM
875	BUZZER DEFECT	872	RADIO/LOCATOR
871	DEAD ENGINE	864	SEAT BROKEN
808	DEFROST NOWORK	827	STEERING PROB
809	DESTINATION SIG	866	STUCK MUD/SNOW
811	DIFFERENTIAL	828	SUSPENSION PROB
813	DOOR FAILURE	868	TIRE FLAT
852	DRIV NOT AT LOC	888	TOW-IN
814	ELECTRICAL PROB	831	TRANS PROBLEM
815	ELEC - NO SIGNALS	834	W/S WIPER PROB
820	EXHAUST PROB	832	WATER LEAK
826	FARE BOX PROB	833	WHEEL LUG LOOSE
854	FIRE DAMAGE	870	WINDOW PROBLEM
822	FUEL LEAK		
856	FUEL, OUT OF		
821	FUMES IN BUS		

BUS OUT-OF-SERVICE CODES — FOR DEPOT USE
(USE WITH VISTA FORM 54)

Code	Description
01	Accelerator
02	Accessory Drive Shaft
03	Air Compressor
04	Air Conditioning
05	Air Leak
06	Alternator
07	At Base Shop
08	Banjo
20	Battery and Tray
21	Bellows
22	Block, Cracked
23	Blower
24	Body Damage
25	Brakes
26	Bulkhead Cracked
27	Cleaning
30	Clutch and Turbine
31	Coach Modification
32	Cooling System
33	Differential
34	Doors
35	Electrical
36	Engine
37	Exhaust System
40	Farebox
41	Fire Damage
42	For Base Shop — Body
43	For Base Shop — Chassis
44	For Base Shop — Engine
45	For Base Shop — PRS/Drive Train
46	For Base Shop — Painting
47	Front End
48	Fuel Leak
49	Fuel Tank
50	Head, Cylinder
51	Heat, None
52	Heavy SO
53	King Pins
54	Kneeling
55	Oil Leak
56	Overheat
57	Part — No Stock
60	Pick Up
61	Power, None
62	Power Pack
63	Pre-Service Check
64	Radius Rods
65	Scheduled Operation (SO)
66	Scrap
67	Seats
68	Shock Absorbers
69	Smoking
70	Special Attention Defects
71	Special Service
72	Stabilizer Bar
73	Starter
74	Steering
75	Storage
76	Suspension, Air
77	Transmission (Converter)
79	Tune-Up
80	Unit — No Stock
81	Vandalism
82	Warranty Work
83	Water Leak
84	Water Pump
85	Windows
86	Windshields
87	Wipers
88	Won't Start
90	Tripper — For Base Shop
92	Tripper

APPENDIX B. ABDS PURPOSE CODES

PURPOSE CODE	DESCRIPTION
A	AIR CONDITIONING
A01	COMPRESSOR, A/C
A0101	CLUTCH,COIL&FLYWHEEL,A/C COMP
A0102	MOUNTING(CRADLE), A/C COMP
A0103	CLUTCH,AIR CYL , A/C COMP
A010301	LINES&FITTINGS,AIR CYL CLUTCH
A0104	DRIVE SHAFT , A/C COMP
A010401	U JOINT, A/C COMP DR SHAFT
A010402	YOKE,FLANGE, A/C COMP DR SHAFT
A0105	CYLINDER HEAD ASSY,A/C
A010501	PISTON, A/C COMP HEAD
A010502	LINER, A/C COMP HEAD
A010503	HEAD, A/C COMP HEAD
A0106	CRANKSHAFT , A/C COMP
A0107	SUCTION&DISCHARGE VALV ASSY
A0108	LINES&FITTINGS,A/C COMP
A02	CONDENSER & MOUNTING,A/C
A0201	FAN & MOTOR, A/C CONDENSER
A0202	CONDENSER COMPARTMENT,A/C
A020201	DRAIN,COND COMPARTMENT,A/C
A020202	HOOD,COND COMPARTMENT,A/C
A020203	FAN MOTOR MOUNT,A/C CONDENSR
A03	ALTERNATOR , A/C
A0301	MOUNT & DRIVE, A/C ALTERNATOR
A04	VOLTAGE REGULATOR,A/C
A15	EVAPORATE SYS , A/C
A18	FAN MOTOR , A/C
B	AIR BRAKE SYSTEM
B10	AIR GOVERNOR
B12	AIR TANK
B14	AIR COMPRESSOR
B1410	CRANKCASE,AIR COMPRSR
B1411	CYLINDER BLOCK,AIR COMPRESSOR
B1412	CYL HEAD,AIR COMPRESSOR
B1413	CRANKSHFT,AIR COMPRESSOR
B1414	CONNECT ROD,AIR COMPRESSOR
B1415	PISTON&PIN,AIR COMPRESSOR
B1416	PISTON RING,AIR COMPRESSOR
B1417	MOUNTING,AIR COMPRESSOR
B1418	DISCHGE FITTING,AIR COMPRESSOR
B1419	DISCHGE MUFFLR,AIR COMPRESSOR
B1420	DRIVE/BELT,AIR COMPRESSOR
B1421	LINES&HOSES,AIR COMPRESSOR
B1422	FITTINGS,AIR COMPRESSOR

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B24          CHAMBER,BRAKES
B34          VALVES,AIR BRAKE SYSTEM
B3410          AIR SAFETY VALVE,BRAKES
B3411          AIR SUPPLY VALVE,BRAKES
B3412          APPLICATION VALVE,BRAKES
B3413          BRAKE RELAY VALVE,BRAKES
B3414          CHECK VALVE,BRAKES
B3415          DOOR REG VALVE,BRAKES
B3416          EXPELLO VALVE,BRAKES
B3417          GRADUSTAT REG VALVE,BRAKES
B3418          INTERLOCK REG VALVE,BRAKES
B3419          INTERLOCK SHTTLE VALVE,BRAKES
B3420          INVERSION VALVE,BRAKES
B3421          SHUTOFF VALVE,BRAKES
B3422          WIPER&SUSP REG VALVE,BRAKES


C          COOLING SYSTEM
C01          RADIATOR,COOLING SYSTEM
C0101          CORE,RADIATOR
C0102          FILLER NECK&CAP,RADIATOR
C0103          MOUNTING,RADIATOR
C0104          SHROUDS & BAFFLES,RADIATOR
C0105          SURGE TANK,RADIATOR
C0106          SURGE TANK REGULATOR,RADIATOR
C0107          THERMOSTAT,RADIATOR
C0108          STUTTER STAT,RADIATOR
C02          WATER PUMP,COOLING SYSTEM
C03          HOSES&FITTINGS,COOLING SYSTEM
C0301          AIR COMPRESSOR WATER LINES
C0302          TRANSMISSION WATER PIPES
C0303          WATER VENT LINE
C04          FAN,COOLING SYSTEM
C0401          FAN BLADE,COOLING SYSTEM
C040101          OIL SEAL, FLUID FAN
C0402          FAN DRIVE,COOLING SYSTEM
C040201          HOUSING,FAN DRIVE
C040202          MOUNTING,FAN DRIVE
C040203          OIL VALVE, FAN DRIVE
C040204          OIL HOSE, FAN  DRIVE
C040205          OIL SEAL, FAN  DRIVE
C040206          RESERVOIR,FAN DRIVE
C040207          ACCESORY,FAN DRIVE


D02          FUEL LINES
D0201          FILTER, PRIMARY FUEL
D0202          FILTER, SECONDARY FUEL
D0203          MOUNTING,FUEL FILTER
D0204          PUMP,FUEL
D0205          FILTER GASKET,FUEL
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E         ENGINE
E01         ACCELERATOR,ENGINE
E0101         CONTROL RODS,ACCELERATOR
E0102         CONTROL CONDUITS,CABLES,ACCELERA
E0103         CONTROL SLIDING ENDS,ACCELERATOR
E0104         CROSS SHAFT.LEVERS ACCELERATOR
E0105         INTERLOCK,ACCELERATOR
E0106         PEDAL,ACCELERATOR
E0107         REGULATOR,ACCELERATOR CYLINDER
E02         ACCESSORY DRIVE,ENGINE
E03         AIR INTAKE,ENGINE
E0301         AIR FILTER,ENGINE
E0302         MANIFOLD,AIR INTAKE
E0303         HOUSING,AIR FILTER,ENGINE
E0304         AIR SILENCER,ENGINE
E05         BLOWER.ENGINE
E0501         DRIVE,BLOWER
E0502         SHAFT,BLOWER
E0503         SHIM PACK, BLOWER
E0504         INLET,BLOWER
E0505         OIL LINES,BLOWER
E0506         SCREEN,ENGINE BLOWER
E19         OIL,LUBE,ENGINE
E1901         AIR COMPRESSOR OIL LINES
E1902         PAN,OIL
E1903         LEVEL INDICATOR,OIL
E1904         PUMP,OIL
E1905         FILTER,OIL
E1906         COOLER,OIL
E1907         OIL GAUGE OIL LINES
E1908         OIL PUMP & FILTER OIL LINES
E1909         PRESSURE REG & RELIEF VALVE
E1910         FILTER BASE,OIL
E20         PISTON.RINGS&SLEEVES,ENGINE
E2001         PISTON RINGS,ENGINE
E2002         PISTON RING SET,ENGINE
E2003         PISTON SLEEVE,ENGINE
E2004         PISTON & PIN,ENGINE
E26         VALVES,ENGINE
E2601         EXHAUST VALVE
E2602         OPERATING MECHANISM,VALVES
E2603         VALVE COVER
E2604         COVER GASKET.VALVE
E27         POLLUTION SYSTEM,ENGINE
E2701         INJECTORS,POLLUTION SYS
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J	ELECTRICAL SYTEM
J10	BATTERY,ELEC SYS
J1010	CABLE,BATTERY,ELEC SYS
J101010	TERMINAL END,BATT CABLE
J1011	GROUND STRAPS,BATT CABLE
J1012	TERMINAL CLAMPS,BATTERY
J22	INSTRUMENT PANEL&CLUSTER
J2210	AIR GAUGE
J2212	COOLANT INDICATOR
J2214	OIL GAUGE
J26	REGULATOR,VOLT&CURRENT
J28	RELAYS,ELECTRICAL
J2810	SIGNAL RELAY
J2811	SENSING RELAY,ELECTRICAL
J34	SOLENOIDS,ELECTRICAL
J3410	A/C PUMP DOWN SOLENOID
J3412	REAR DOOR SOLENOID
J3414	STARTING MOTOR SOLENOID
J3416	TRANSMISSION SOLENOID
J3418	TRANS REVERSE SOLENOID
J39	STARTER MOTOR
J3910	CABLE,STARTER
J3912	DRIVE,STARTER MOTOR

T	TRANSMISSION,HYDRAULIC (H/T)
T28	CYLINDER,SHIFT-HYD TRANS
T30	EXCHANGER,FLUID HEAT-H/T
T54	SEAL,INPUT/OUTPUT-HYD TRANS
T62	TORQUE CONVRTER HYD TRANS
T6210	IMPELLER,HYD TRANS
T621010	BRG ASSY,IMPELR-HYD TRANS
T6212	TURBINE,HYD TRANS
T621210	BRG ASSY,TURBIN-HYD TRANS
T6214	HOUSING,TORQ CONV-HYD TRANS

APPENDIX C. MECHANIC SURVEY RESPONSES

USER RESPONSES

ABDS MECHANIC SURVEY

The New York City Transit Authority is in the process of evaluating the Automated Bus Diagnostic System (ABDS) being tested at the Queen's Village Maintenance facility. The Authority wishes to get your views concerning the ABDS system, whether you have actually used it in the course of your regular maintenance work or not. Please give your honest opinions as the responses will be anonymous.

1. How many times since February 1, 1982 have you used the ABDS equipment to diagnose a bus problem?

(4) o 1-5 times
(1) o 6-10 times
(1) o 11-20 times
(20) o Over 20 times
o Never used (SKIP TO QUESTION 9)

2. Do you think that the ABDS equipment was hard to learn to use?

(3) o Yes
(7) o No

3. Do you think that the ABDS equipment was easy to use once you were used to it?

(9) o Yes
(0) o No
(1) o Never used it enough to get used to it

4. Do you like to use the ABDS equipment?

(6) o Yes
(4) o No
(PLEASE EXPLAIN WHY)______________________________

5. How often does the ABDS equipment pinpoint the location of electrical problems?

(1)o Always
(5)o Most of the time
(4)o About half of the time
(0)o Usually does not
(0)o Never

6. How often did the ABDS equipment pinpoint the location of hydraulic pressure problems?

(1) o Always
(3) o Most of the time
(3) o About half of the time
(1) o Usually did not
(1) o Never

7. Do you think that the ABDS equipment helps you to diagnose problems faster?

(1) o Always
(4) o Most of the time
(4) o About half of the time
(1) o Usually does not
(0) o Never

8. In what way do you feel that the ABDS equipment could be improved to make it more helpful? (PLEASE DESCRIBE) ____________________
____
____
____________________ (SKIP TO QUESTION 10)

9. Would you like to use the ABDS equipment?

o Yes
o No

10. Have you requested <u>not</u> to use the ABDS equipment?

(9) o No
(2) o Yes (PLEASE EXPLAIN WHY) ____________________
____
____

11. Have you taken any other action to <u>avoid</u> using the ABDS equipment?

(9) o No
(0) o Yes (PLEASE DESCRIBE) ____________________
____
____

12. Do you feel that you have had sufficient training on how to use the ABDS equipment?

(6) o Yes
(4) o No

13. What sort of comments have you heard from other persons who have used the ABDS equipment?

(2) o Generally favorable
(6) o Mixed
(2) o Generally unfavorable
(0) o Haven't heard any

14. What sort of comments have you heard from other persons who have <u>not</u> used the ABDS equipment?

o Generally favorable
(3) o Mixed
(5) o Generally unfavorable
(2) o Haven't heard any

15. Do you think that repeating the ABDS test to insure that a repair has corrected the problem is a good idea?

(0) o Don't know
(9) o Yes
(1) o No (PLEASE EXPLAIN WHY)______________________________
____
____

16. Do you think that all the buses in the garage should be equipped to be able to be tested on the ABDS equipment?

(8) o Yes
(2) o No (PLEASE EXPLAIN WHY)______________________________
____
____

17. Please check your age group.

(0) o Under 20
(2) o 20 - 30
(5) o 31 - 40
(0) o 41 - 50
(3) o 51 - 60
(0) o Over 60

18. How many years have you been working for the New York City Transit Authority as a mechanic, maintenance supervisor or maintenance foreman?

(1) o Less than 2 years
(1) o 2 - 5 years
(2) o 6 - 10 years
(5) o Over 10 years

NON-USER RESPONSES

ABDS MECHANIC SURVEY

The New York City Transit Authority is in the process of evaluating the Automated Bus Diagnostic System (ABDS) being tested at the Queen's Village Maintenance facility. The Authority wishes to get your views concerning the ABDS system, whether you have actually used it in the course of your regular maintenance work or not. Please give your honest opinions as the responses will be anonymous.

1. How many times since February 1, 1982 have you used the ABDS equipment to diagnose a bus problem?

o 1-5 times
o 6-10 times
o 11-20 times
o Over 20 times
(42) o Never used (SKIP TO QUESTION 9)

2. Do you think that the ABDS equipment was hard to learn to use?

o Yes
o No

3. Do you think that the ABDS equipment was easy to use once you were used to it?

o Yes
o No
o Never used it enough to get used to it

4. Do you like to use the ABDS equipment?

o Yes
o No
(PLEASE EXPLAIN WHY)____
____
____

5. How often does the ABDS equipment pinpoint the location of electrical problems?

o Always
o Most of the time
o About half of the time
o Usually does not
o Never

6. How often did the ABDS equipment pinpoint the location of hydraulic pressure problems?

o Always
o Most of the time
o About half of the time
o Usually did not
o Never

7. Do you think that the ABDS equipment helps you to diagnose problems faster?

o Always
o Most of the time
o About half of the time
o Usually does not
o Never

8. In what way do you feel that the ABDS equipment could be improved to make it more helpful? (PLEASE DESCRIBE)____________________
____
____
______________________________(SKIP TO QUESTION 10)

9. Would you like to use the ABDS equipment?

(18) o Yes
(21) o No

10. Have you requested <u>not</u> to use the ABDS equipment?

(36) o No
(0) o Yes (PLEASE EXPLAIN WHY)____________________
____
____

11. Have you taken any other action to <u>avoid</u> using the ABDS equipment?

(36) o No
(1) o Yes (PLEASE DESCRIBE)____________________
____
____

12. Do you feel that you have had sufficient training on how to use the ABDS equipment?

(2) ○ Yes
(35) ○ No

13. What sort of comments have you heard from other persons who have used the ABDS equipment?

(5) ○ Generally favorable
(13) ○ Mixed
(5) ○ Generally unfavorable
(15) ○ Haven't heard any

14. What sort of comments have you heard from other persons who have <u>not</u> used the ABDS equipment?

(1) ○ Generally favorable
(10) ○ Mixed
(6) ○ Generally unfavorable
(20) ○ Haven't heard any

15. Do you think that repeating the ABDS test to insure that a repair has corrected the problem is a good idea?

(21) ○ Don't know
(15) ○ Yes
(1) ○ No (PLEASE EXPLAIN WHY)

16. Do you think that all the buses in the garage should be equipped to be able to be tested on the ABDS equipment?

(18) ○ Yes
(14) ○ No (PLEASE EXPLAIN WHY)

17. Please check your age group.

(0) ○ Under 20
(3) ○ 20 - 30
(11) ○ 31 - 40
(13) ○ 41 - 50
(8) ○ 51 - 60
(5) ○ Over 60

18. How many years have you been working for the New York City Transit Authority as a mechanic, maintenance supervisor or maintenance foreman?

(3) o Less than 2 years
(5) o 2 - 5 years
(6) o 6 - 10 years
(23) o Over 10 years

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