TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-RD-76-160	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
Urban Traffic Control and Bus Priority System Operations and Maintenance - Final Report

5. Report Date
June 1976

6. Performing Organization Code

7. Author(s)

8. Performing Organization Report No.
FCP 32B1-022

9. Performing Organization Name and Address
Sperry Systems Management Division
Sperry Rand Corporation
Great Neck, N. Y. 11020

10. Work Unit No.

11. Contract or Grant No.
FH-11-7605

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20591

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Contract Manager - Gail D. Smith (HRS-31)

16. Abstract

This report presents a comprehensive review of the UTCS/BPS operation and maintenance. The results and conclusions presented herein highlight system and equipment operating and maintenance experience and the costs, management and staffing for these related tasks.

17. Key Words
Preventive Maintenance
System Reliability
Maintenance Costs
Traffic Operations

18. Distribution Statement
No restriction. Copies of report are available from:
National Technical Information Services
Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	185	

Form DOT F 1700.7 (8-69)

FOREWORD

An Urban Traffic Control and Bus Priority System has been implemented in the District of Columbia by Sperry Systems Management under Federal Highway Administration Contract No. FH-11-7605, Advanced Control Technology in Urban Traffic Control Systems - Installation. The system includes on-street surveillance and control elements and a central office data processing facility. This report relates the overall experience gained in the daily operation and maintenance of the system.

CONTENTS

CONTENTS (Cont.)

CONTENTS (Cont.)

ILLUSTRATIONS

ILLUSTRATIONS (Cont.)

TABLES

SECTION 1

INTRODUCTION, CONCLUSIONS, AND SUMMARY

1.1 INTRODUCTION

This volume comprises the final report on the operation and maintenance phase of the Urban Traffic Control System (UTCS).

Prior phases of the UTCS program were also conducted for the Federal Highway Administration (FHWA) by Sperry Systems Management, and included design and installation, Bus Priority System (BPS) development and implementation, and UTCS network expansion. Documentation for these programs is listed in Appendix C, Reference 1-1.

Completion of the final installation phase provided an integrated UTCS/BPS computer-controlled traffic control system. The major purpose of UTCS was to serve as a real-world research facility to test new and advanced traffic control strategies and programs.

Three generations of advanced signal control strategies have been developed and evaluated. Each generation represents a more responsive and necessarily a more complex data processing and control system. Documentation relating to the evaluation results will be released by FHWA in another volume.

A secondary, but most necessary and valuable output of the UTCS program is the knowledge gained in terms of system operation; equipment design, installation, and maintenance; and cost and staffing requirements. This report addresses itself to the aforementioned operational and maintenance experience.

1.2 CONCLUSIONS

The objective of using an integrated computer-controlled traffic control system for the development and evaluation of advanced control strategies has been met. The overall system design, hardware, and operating capability has been demonstrated for more than three years to be reliable, flexible, and suited for use in any other urban environment.

Application of the physical plant design is independent of specific manufacturers' hardware. Use of the control concepts is a matter of adapting the standard FORTRAN software system to the particular computer system selected.

The system has been designed around the operator. It makes use of a control panel which eliminates the need for highly-skilled personnel. The Traffic Engineer may therefore devote his time and effort to traffic functions rather than system operation. In normal operation the required computer-related skills are not so intricate that they cannot be readily learned.

The displays and control panel permit rapid field and central equipment malfunction detection, thereby reducing the possible effect that a hardware failure will have on traffic flow. The displays and operator control panel also provide the means for rapid reaction and adjustment to the system, if required.

The system has also proven its ability to collect, display, and process real-time data, thereby allowing the Traffic Engineer to constantly monitor system operation and traffic movement. This surveillance capability greatly reduces the need for field studies and provides the engineer with data, as needed, for both system evaluation and pattern modifications.

During the time the system has been operated and maintained, it has successfully proven its flexibility, operability, maintainability, and reliability.

1.3 SUMMARY

This report consists of seven major sections: Section 1, Introduction, Conclusions, and Summary; Section 2, System Operating Experience; Section 3, Equipment Experience; Section 4, Maintenance Experience; Section 5, Maintenance Management; Section 6, Applicability of Experience to other cities; and Appendices. The Appendices include the Vehicle Detector Status Table and the Field Equipment Complement Summary. Reference 1-1 is also included which lists all available published reports relating to the UTCS/BPS program.

Sections 2, 3, and 4 relate to the operating, equipment, and maintenance experience for both Central and field.

Section 2 is concerned primarily with the physical operation of the system, data collection, environmental requirements, and software support.

Section 3 discusses equipment operability and reliability, whereas Section 4 presents an overview of system maintenance experience and new repair and installation techniques.

Section 5 addresses itself to the management of all maintenance tasks, including subcontractor monitoring, staffing, training, operating costs, documentation, and required resources.

Section 6 relates the experience of the UTCS/GPS project to other cities planning or having in operation a system of similar type.

SECTION 2

SYSTEM OPERATING EXPERIENCE

UTCS/BPS was placed on line in late 1972 and was operational through mid 1976. During this period, three generations of traffic control software and bus priority algorithms were developed, exercised, and evaluated. The system was operated for the purpose of evaluating advanced control strategies and to provide the District of Colombia with an operable control system.

The system manager was responsible for the first generation software, installation, operation, and maintenance of the system. The system manager provided personnel to operate the system from the computer center (Central), as well as personnel to assist with the operation and perform system maintenance at Central and in the field. The operational experience of the central and field personnel is described in sections 2.1 and 2.2.

2.1 CENTRAL OPERATING EXPERIENCE

The UTCS Computer Center was the focus of most system operations. It was normally staffed by one central operator provided by the system manager. Certain tasks were operator-performed on schedule, and other tasks were performed only when needed; including activation and deactivation of the system, inspecting the system for proper operation, collecting data to evaluate the system, and experimenting with system variables to fine-tune overall system performance. The central operator also performed basic maintenance on the system hardware, simple updates to the software, troubleshooting of failures, maintained log books and documentation, and ran system-related off-line jobs on the computer. When the work load became excessive, one or more assistant operators were provided by the system manager to maintain a smooth operation at Central.

2.1.1 GENERAL TASKS

Since the system is used for research and development of traffic control strategies as well as an operating system for the District of Columbia, the system operator was called upon to perform a wide variety of tasks that would not otherwise have been necessary. The central operator also provided software and analytical support as required. He was specifically involved with five types of work at the control center: hardware installation, software research and development, acceptance tests, system evaluations, and normal operation.

Hardware installation was performed in part by the central operator and other systems management personnel. Equipment installed included the control panel, map and map electronics unit, and communications cabinets.

Research and development work was performed primarily by systems analysts and programmers. The central operator was usually present to assist in system analysis, type update cards on the keypunch, run updates and other jobs on the computer, and operate the system. A typical sequence of events would involve the operator bringing up a system under development, studying it for faults, and bringing it back down. Software personnel would debug the program. The central operator would then type the resulting update cards, run an update on the system, and reactivate it to check that the problems were eliminated.

Once a system program was completed, it would undergo an acceptance test by FHWA. The central operator would activate the system for observation by FHWA and District of Columbia personnel located both in the field and at Central. The central operator would be requested to have the computer take operational control of each intersection and perform signal and section parameter adjustments. Detectors were tested by comparing vehicle counts in the streets with those received by the computer. The acceptance was considered complete when performance by all components was seen to conform to specifications.

System evaluations were performed to gather data for comparing one system's performance with another's. Evaluations were usually run for two weeks at a time. Several evaluations were run in sequence, making evaluation periods last two to three months. At 6:45 am on an evaluation day, the central operator activated the system to be evaluated. The line printer and a magnetic tape unit were prepared to record data every 5 or 15 minutes, depending upon the particular system. The computer controlled traffic until 7 pm, when the system was brought down by the operator. During the 12 hours of evaluation, the operator spent most of his time inspecting system performance and working in conjunction with a field crew to find and repair failed field and communication equipment. A priority effort was exerted by the systems manager to make certain the equipment remained operational during evaluations.

Operational days were similar to evaluation days for the central operator. However, on these days, the system was operated for the purpose of observing its performance and to improve traffic flow in the network.

In the 68 months since the construction of the system first began, the following estimates have been made of the amount of time that the central equipment has been used for the functions described above.

Hardware Installation	25%
Software Research and Development	54%
System Acceptances	1%
System Evaluations	10%
System Operation	10%
	100%

In addition, considerable developmental software work took place during night shift and weekend hours. This work, however, is not represented in the above figures.

2.1.2 SPECIFIC TASKS

In the performance of his duties, the central operator dealt with a sizeable number of system elements. Figure 1 shows the elements which had a functional usefulness to the operator. The many tasks which the operator performed can be specifically described in an organized manner by catagorizing them to the system element to which the job most relates. Circled numbers in the following text refer to Figure 1.

The computer's central processing units 1 operated without attention from the central operator, with the following exceptions. The primary unit (CPU #1) was turned on (brought up) by the operator prior to activating the traffic control system or running an off-line job, and was shut down after the work was completed. There are two switches on CPU #1 which were used to activate or inhibit two functions of the traffic control program. One function was to output system data summaries to a magnetic tape. The other allowed the use of historical system status information upon activation of the traffic control system. The operator brought up CPU #2 if he wished to activate the Bus Priority System. A detailed description of CPU start-up procedures can be found in paragraph 4.1.2 of the UTCS Operator's Manual. The operator also used CPU #2 to inspect the contents of memory cells and occasionally to alter the value of algorithm constants for the sake of experimentation. Other than these simple operations, the CPUs did not need tending by the central operator.

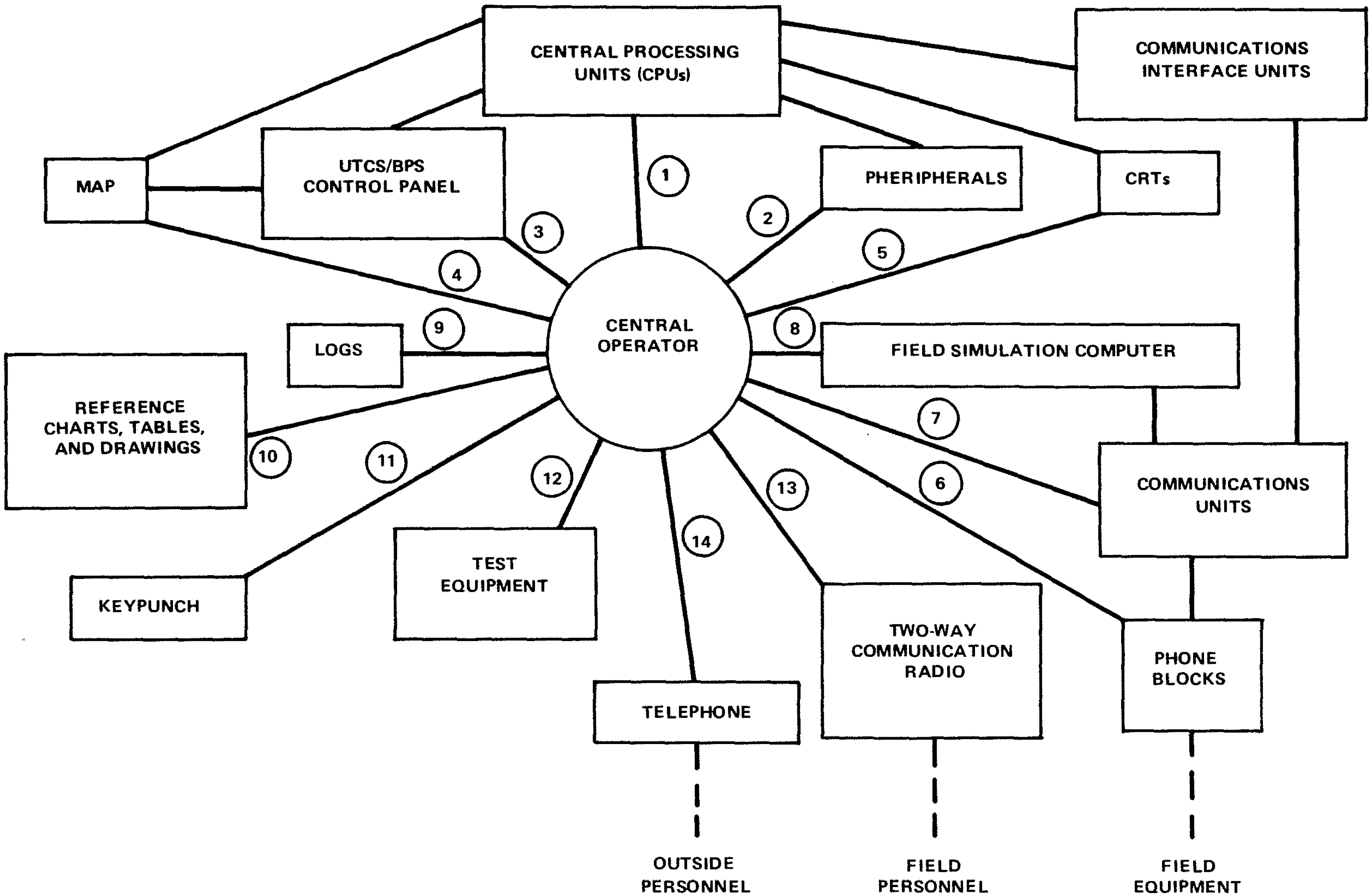

Figure 1. Block Diagram of Operational Relationships Between System Operator and Central Elements

The central operator's daily procedure required him to deal with the computer peripherals 2 more than with the central processing units. Most peripherals were turned on and off as they were needed. These included two teletypewriters, three magnetic tape units, a card reader, card punch, and a line printer. The two rapid access discs (RADs) and computer interface units (CIUs) were left on 24 hours a day.

The operator used the teletypewriter to control CPU #1. Through this device, he updated the computer's internal clock and calendar each time the computer was brought up. He also commanded the computer to perform foreground and background jobs and the computer communicated status messages to the operator via the teletypewriter. A sample of typical operator-computer "dialogue" is shown in Figure 2. A second teletypewriter was available for communication with CPU #2, but was infrequently used by the operator.

The central operator also used the magnetic tape units and the line printer on a daily basis. He would mount and unmount tapes from the tape units as needed, and keep the line printer paper in supply. The printer ribbon would also be periodically replaced. The tape units were used regularly to "boot-in" the RBM system (a master computer control system including language compilers) and the traffic control program. A tape unit and the line printer were used for data compilation during the numerous periods of system testing and evaluation.

The operator was called upon to run a variety of computer side jobs; that is, jobs that were run when the traffic control system was not on-line. These jobs were necessary to the development, evaluation, and updating of the traffic control software, and to the handling of data used for evaluation. Typical side jobs included the following.

- Dumping RAD files onto the line printer for problem debugging
- Making a permanent tape of a system which is on the RAD
- Copying a tape
- Copying cards
- Compiling several days' evaluation data onto one tape
- Running PATGEN (PATGEN is a compilation of thousands of signal and pattern variables)
- Updating traffic control software with cards supplied by the system programmers

```
!!BEGIN IDLERAD RESTORED OK

SIGMA 5/7 RBM, VERSION C02
 PLEASE KEYIN DATE AND TIME
!!KEY-IN
DT 5,10,76,06,46

!!KEY-IN
RUN KING

!!LOADED PROG
KING    RAD RESTORED OK

SIGMA 5/7 RBM, VERSION C02
 PLEASE KEYIN DATE AND TIME
!!KEY-IN
DT 5,11,76,06,39

!!KEY-IN
RUN KING
TYC

!!JCP

!JOB

!SFIL BI,1

!FIN

!!BEGIN IDLE
!!KEY-IN
RUN KING

!!LOADED PROG
KING
!!KEY-IN
RLS KING

!!PROG KING     RELEASEDRAD RESTORED OK

SIGMA 5/7 RBM, VERSION C02
 PLEASE KEYIN DATE AND TIME
!!KEY-IN
DT 5,11,76,06,46

!!KEY-IN
TYC

!!JCP

!JOB

!SFIL BI,1

!FIN

!!BEGIN IDLE
!!KEY-IN
RUN KING

!!LOADED PROG
KING
```

Figure 2. Sample Operator-Computer Dialogue
Recorded on Teletypewriter (reduced)

Some off-line jobs were run to provide support to software personnel working on research and development of advanced traffic control strategies. Other jobs were run as a regular part of system operation and maintenance. All off-line jobs required operator interaction with some of the computer's peripheral equipment either directly, or via the TTY.

The UTCS/BPS Control Panel (3) is the primary piece of traffic control equipment available to the operator. It was not used for side jobs, but was always actively used when the traffic control system was on-line. The operator spent most of each operating day at the panel. Figure 3 shows the console upon which the control panel is centered. The CRTs and map display can be seen to be readily useable from the position at the control console.

The control panel is composed of four sections: system control, map display control, CRT displays control, and malfunction indicators. These can be seen in Figure 4. The system control section was used by the operator to activate and deactivate the traffic control system, to establish the mode of operation for each of the system's sections, to make individual signal parameter changes, and to reactivate field equipment which had been perceived as failed. During system evaluations, parameter and operation mode changes were not performed so that the system could be evaluated in its totally automatic state. At other times, however, the operator was able to exercise the system and attempt to improve flow.

The map (4) and CRT disply (5) controls were used by the operator to obtain a variety of information regarding system status. With such information, he could monitor the performance of the system. Monitoring performance involved watching for occasional field equipment failures, congestion build-ups, and proper functioning of bus priority and critical intersection control systems when active. When field equipment failures were recognized, the operator typically repaired them from the control panel on their first and second occurrence. If a failure continued to recur, it was considered a "hard failure", and troubleshooting procedures were begun. Nonrecurrent failures of vehicle detectors frequently occurred and were attributed to such temporary problems as obstructed traffic lanes.

Troubleshooting procedures for the central operator began with determining whether the failure occurred at Central or in the field. Analysis of signals at the phone block (6) and in the communications racks (7) would usually determine the location of the trouble. Further troubleshooting procedures are described in section 4.1.1

Figure 3. Systems Operator's Console Showing Map Display, CRTs, and Control Panel

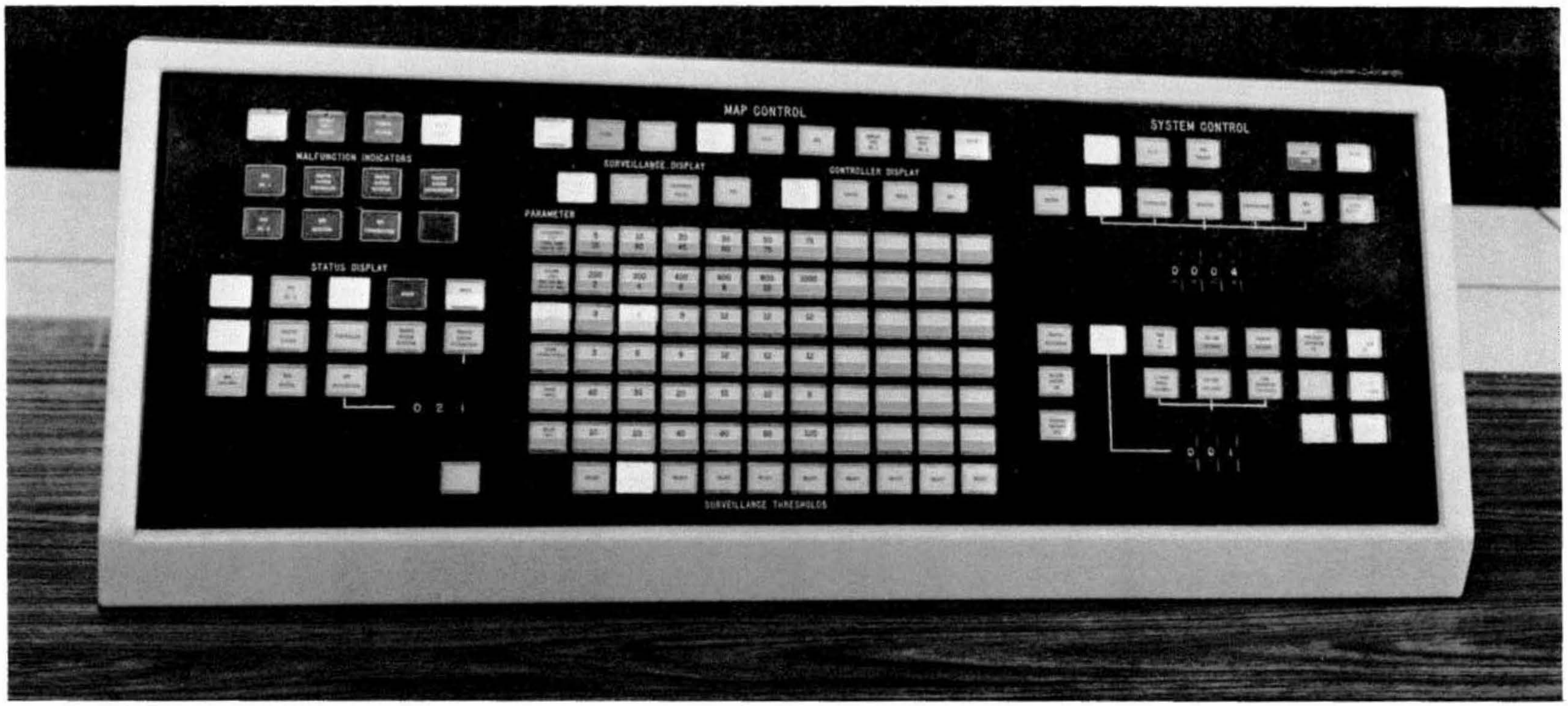

Figure 4. UTCS Control Panel

The system manager furnished the control center with a field simulation computer (8). During research and development, it was used by the operator and programmers to test traffic control programs without affecting actual field traffic control equipment. A switch on the control console activated relays in the communication cabinets which directed computer-generated traffic control signals to the simulator instead of to the street.

Due to the complexity of the UTCS/BPS system, a considerable amount of documentation was maintained. This material was needed for daily operation by Central and field personnel. One copy of all tables, maps, charts, printouts (10) and logs (9) was kept at Central. The job of keeping the documentation updated was the responsibility of the central operator.

The following logs were maintained.

- Systems Operation Log. The Systems Operation Log has daily entries which serve as a diary of the traffic control system. For a given date and time, each entry tells the reader which operator was on duty at the control center, what tasks were being performed, the system status and performance, and the weather. This information was recorded regularly by the operator. Normally, each day when he began his shift, he checked the Systems Operation Log to see if another operator or programmer had reported any unusual conditions or equipment failures. This log served as the only sure means for one system user to communicate necessary information regarding changes in system status to other users. A sample page of the log is shown in Figure 5.

- Computer Maintenance Log. The Computer Maintenance Log was maintained by Xerox computer maintenance personnel, not by the operator. However, the operator did assure that it was filled out correctly and he referred to it whenever questions arose regarding maintenance services provided by Xerox.

- Field Equipment Status Log. The operator kept records of damaged loop detectors in the Field Equipment Status Log. Typically, a loop would be reported by the field crew as being damaged; the operator then entered the loop number, date and time of report, degree of destruction, and probable agency responsible. Arrangements could then be made to repair the loop and the entry would be closed out upon such repair.

- Software Log. The operator was required to keep track of timing changes, initiated by the District of Columbia, at system-controlled intersections and update the software accordingly. Upon completion of the update, he recorded his actions in the Software Log. Information included the date, the signals updated, and the system tapes upon which the update was performed.

SPERRY RAND

URBAN TRAFFIC CONTROL SYSTEM
WASHINGTON, D.C.

SYSTEM UTCS-1GC-Exp. SERIAL NO. —

DATE	TIME	OPERATOR	OPERATION
5/10/76	0645	Sperry	Sunny - Streets dry - 63°
		G.W.	Loaded UTCS Expanded system for
			Data Collection - Sections 1-4
			Manual Patterns - Line printer and
			Mag Tape Unit #1 data logging
5/10/76	0915	Sperry	09:15 Line printer report illegible -
		G.W.	fixed line printer ribbon
5/10/76	0945	Sperry	Changed all sections to Manual Pattern #1
		G.W.	
5/10/76	10:25	Sperry	Comm failure - Equipment associated with
		G.W.	Tel. Line 10DD-105 Telephone Co. notified
			Placed CB-202 and 203 in standby
5/10/76	12:00	Sperry	Telephone Co repaired lines - CB 202
		G.W.	and 203 placed in operation
5/10/76	15:30	Sperry	Changed all sections To Manual Pattern # 3
		G.W.	
5/10/76	17:30	Sperry	Changed all sections To Manual Pattern # 4
		G.W.	
5/10/76	19:00	Sperry	System Shut down - End of day report
		G.W.	and data tape collected

Retain Original In Log - Return Copy to Traffic Systems Group, SSMD.

Figure 5. System Operation Log Sample Page (reduced)

When timing changes at system intersections were made, the District of Columbia Department of Transportation (DC-DOT) notified the central operator by providing him with a signal timing sheet (casually called the "TS sheet"). The operator retained a copy of all current TS sheets for system intersections. These were referred to whenever questions arose concerning computerized signal timing. A sample Signal Timing sheet is shown in Figure 6.

The operator determined the new computerized signal timing from the TS sheets. The keypunch (11) was used to type the signal timing onto computer cards which were entered in a data deck. He then ran an update program, PATGEN (PATtern GENeration), which used the data deck to enter the new signal timing into the system. The PATGEN output to the line printer was used, in addition to the TS Sheets, as reference whenever questions arose as to the signal timing patterns used by the computer.

System documentation existed for the purpose of keeping track of field equipment, The system had 201 signal controllers, 597 loop detectors, 144 bus detectors, and numerous items of communication equipment in the field and at central. Major pieces of equipment were identified, described, and located in a rotating card file. The operator referred to the file often during system evaluation, and when lending support to field repair crews. Sample cards from the file are shown in Figure 7. Also used for the same purposes, were drawings of field equipment locations superimposed on maps covering several city blocks. Part of one drawing is shown in Figure 8.

The operator maintained a magnetic tape card file for keeping track of the sizeable tape library that built up during the 5 years of system operation. The library consisted of traffic control system tapes, each with different control algorithms or different updates, data tapes recorded every 15 minutes during system operation, and a variety of special tapes used in running side jobs. Other computer outputs also kept at Central for reference included program listings, end of day reports, and PATGEN.

To complete the list of documentation, a full set of UTCS/BPS System Manuals were maintained at Central for use by the operator. These include volumes devoted to installation operation, maintenance, software, and general system description. Operation and maintenance manuals for all pieces of equipment were available, including manuals for the computers, computer peripherals, communications equipment, and on-street controllers. There were wiring lists of the interconnections between pieces of equipment at Central which were used initially to install and debug the system. On occasion, they were used by the operator for troubleshooting communications failures at Central.

DIAL SCHEDULE		
DIAL	PERIOD	DATE
1	Normal	
2	AM M-F	
3	PM M-F	

TS-735-C 13TH St. + Massachusetts Ave., NW

LOCATION SHEET 1

DEPT. OF HIGHWAYS & TRAFFIC, D.C.
BUREAU OF TRAFFIC ENGINEERING AND OPERATIONS

Clock ☐
Wire ☐
Radio ☐
Decoder ☒

B-6
System and/or Radio Group

REMARKS: QTCS

148

Controller Circuits Used

DIAL NUMBER →		1		2		3		1		2															
INTERVAL	NO	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%	SEC.	%
Mass Green + Walk	1	10.4	13	8.8	11	23.2	29	10.4	13	10.4	13														
" Green + W x n.s. DW x s.s.	2	4	18	9.6	23	4.8	35	4	18	11.2	27														
" " + DW x both sides	3	8.8	29	3.2	27	8	45	8.8	29	3.2	31														
" WBG + EBY	4	4	34	4	32	4	50	4	34	4	36														
" "	5	1.6	36	8.8	43	2.4	53	1.6	36	8.8	47														
" WBY	6	4	41	4	45	4	58	4	41	4	52														
All Red	7	1.6	43	1.6	50	1.6	60	1.6	43	1.6	54														
13TH St Green + Walk	8	21.6	70	16	70	8	70	21.6	70	12.8	70														
" " " + DW	9	18.4	93	18.4	93	18.4	93	18.4	93	18.4	93														
" " Yellow	10	4	98	4	98	4	93	4	98	4	98														
All Red	11	1.6	100	1.6	100	1.6	100	1.6	100	1.6	100														
CYCLE LENGTH		80		60		80		80		80															
RESET 1		60	75	60	75	20	25	64	80	56.8	71														
RESET 2																									
RESET 3																									

Engineer	NR	NR	NR	NR	NR
Date to Shop	6-	27-	72	6-10-	75
Work or Shop Order No.	6	-668		6-75-	3
Approved by	[illegible]			[illegible]	
Date Installed	7-	2-	73	6-10-	75
Initials/Time Installed	WL		WL		2 PM

Figure 6. Sample DC-DOT Signal Timing Sheet (TS Sheet) (reduced)

FIELD CABINETS CB 57

- Street G & 18 St.
- Controller Type: 19-1-16 (* Denotes non-assoc. units)
  - Veh. Det. Elect. Units (incl. Xmtr.) 252* 253* 254 255 256
  - Bus Det. Rcvrs. (incl. Xmtr.) 47 48 49 93*
  - Veh. Det. Xmtrs. only
  - Bus Det. Xmtrs. only
  - Assoc. EBs

Sample Field Cabinets (CB) File Card (front side)

Dwg. No. 253 — **VEH. DET. ELECT. UNITS** — Comp. No. 190

- Det. Rcvr. - CB/EB 57, Pos. 1b V_1 a_1 a_2 a_3
  Freq. 92.5 Kc;
- Loop Loc: Street 18 St. (N. of G St.) Lane 2 Dir. N
- Transmitter: CB 57, Pos. A6 Link No. 63
  Freq. 1860, Tel. Pr. 51, Chan. 13, P_{out} -12 dbm
- Assoc. Controller CB 54
- Central Rcvr;
  Cab. No. 504 Pos. G9 See 4200 Dwg. Sht. 15

Sample Vehicle Detector Electronics Units File Card

Field Cabinets (Cont.)

AϕG Xmtrs.	Freq.	Tel. Pr.	Cent. Rcvr.
MSG 1	1620	51	504-A5
MSG 2	—		
MSG 3	—		Cent. Tr. 504-I1

- Hold & Adv. Rcvr.: Freq. 420, Tel. Pr. O-22, Chan. 1
- Remote associated Veh. Detectors 257
- Remote associated Bus Detectors 50

See 4200 Dwg. Sht. 15

Sample Field Cabinets (CB) File Card (back side)

Dwg. No. 1 — **BUS DETECTORS** — Comp. No. 144

- Loop Loc: Street Wisc. (S. of Hall Pl.) Dir. SE
- Det. Rcvr. B_1 B_2 Zone No. 72
  - CB/EB 123, Pos. B2
- Transmitter (Freq.= 1020)
  - CB 123, Pos. B3; Tel. Pr. 6, Chan. 6, P_{out} -13 dbm
- Assoc. Controller CB 123
- Central Rcvr.
  - Cab. No. 509, Pos. (Rcvr. D6, Filter E6)

See 4200 Dwg. Sht. 35

Sample Bus Detectors File Card

Figure 7. Sample File Cards (reduced)

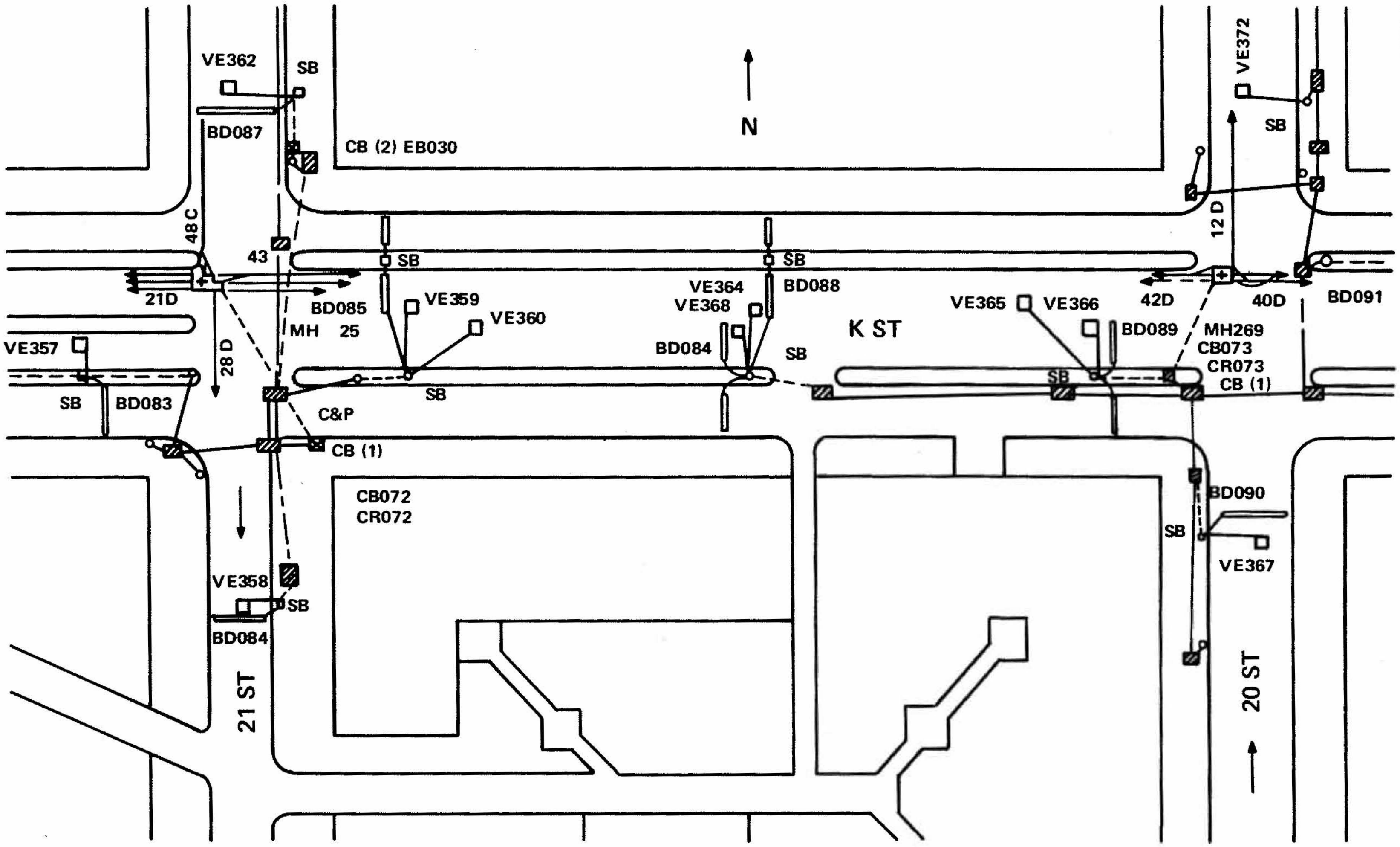

Figure 8. Sample Field Equipment Location Drawing (reduction)

The central operator made almost daily use of such troubleshooting equipment as an oscilloscope, DC voltmeter, and standard hand tools (12). Upon being notified of failed field equipment by the computer, the operator used the meters to monitor communications signals to determine if the failure was in the field. If so, the field crew would be notified. If not, the operator determined the cause of the failure at Central and set about repairing it.

Finally, communication equipment (13) and (14) was available for use by the central operator. A two-way radio system, based at Central, proved to be of invaluable use during many phases of the UTCS program. Mobile units were installed in vehicles belonging to the FHWA and the system manager. Portable units were also used, primarily by system management personnel.

During the system installation periods, the two-way radio system was used by system management personnel to coordinate installations and tests of installed equipment and communication lines. During system acceptance, the radios were used by FHWA and District personnel in the field to make performance requests to the central operator. During evaluation and operational periods, the radios were used by personnel to coordinate repairs and maintenance duties with the central operator.

When problems of an irregular nature occurred, the operator used regular telephone service to obtain help from outside personnel. When a computer system failure was identified, he called the contracted computer maintenance service. During periods when computer performance was critical, as during acceptance and evaluation, the service was kept on call 24 hours per day. When software problems were discovered, the operator notified system management software personnel and the FHWA. The telephone was naturally used by the operator to make a variety of other contacts with outside personnel.

2.2 FIELD OPERATING EXPERIENCE

Operations conducted by the field crew consisted largely of hardware maintenance and repair. Procedures relating to these functions will be described in Section 4.1.1. Field crew personnel also participated in data accumulation and system acceptance testing. These operations are described in Sections 2.2.1 and 2.2.2.

2.2.1 DATA ACCUMULATION

Accumulating traffic count data through the use of field surveys was a necessary task toward developing patterns during system design and installation. Similar work was performed occasionally during the four years of system operation for the purpose of reviewing and updating the developed patterns. Since the traffic patterns of a city are in a constant state of change, the signal patterns that the computer put on the street occasionally needed revision.

Much needed data, and resultant changes, originated with FHWA and DC machine counts. These counts were supplemented by manual counts performed by District personnel, a data collection subcontract to the University of Maryland, and by the field crew. The most useful types of counts were approach volume, turning volume, and pedestrian volume counts. These counts were warranted when changes in traffic patterns were suspected, although not recognized by the system detectors. As long as traffic flow changes were transmitted by the detectors, the computer responded accordingly. However, if for some reason, the detectorized lanes were not totally representative of the approach, the computer would neither recognize nor respond properly to traffic pattern changes. Reasons for suspecting unnoticed changes included: changes in street or intersection geometrics, changes in on-street parking regulations, and changes in near-by land use patterns. Occurance of these changes warranted a field check and possibly a survey by field personnel. When counts were necessary, they were performed using standard traffic engineering techniques.

2.2.2 ACCEPTANCE TESTS

FHWA, District of Columbia, and system management personnel performed acceptance tests in the field with the assistance of other personnel at Central. Tests were performed on both hardware and software systems as their development was completed.

The hardware installation underwent testing twice: once in early 1973 after the initial installation of the system; and once after the first expansion was completed in mid 1975. During this type of test, field and FHWA personnel visited and observed each controller as the Central operator requested computer control, offset adjustments, and main-phase green time allocation. Detector hardware and communications were checked by field personnel both by calibrating and testing the equipment. In addition, the two-way radio was used to identify vehicles to the operator as they passed over the loop detectors. The vehicle counts would then be verified by central personnel witnessing the accumulation of data at the proper location in the computer's memory.

Each new generation of traffic control strategy, and algorithms such as Critical Intersection Control and Bus Priority which were developed under contract to FHWA, were acceptance tested. During this type of test, field and FHWA personnel made qualitative observations by either observing traffic and signal interaction at a given signal or by driving through a section of signals to study signal progression. Quantitative tests were made by counting volume and queues visually in the field and comparing them to data displayed on the CRTs at Central. A radar unit was used in the field to measure vehicle speeds (which were also compared to CRT data). The Bus Priority System was tested by implementing a field vehicle with a bus transmitter so as to simulate a bus. Field and FHWA personnel could then activate the priority system and observe its performance.

SECTION 3

EQUIPMENT EXPERIENCE

The purpose of this section is to describe in some detail the experience gained in reporting equipment failures and to provide some failure rate and MTBF data, on both a subsystem and a system basis. References 3-1, 3-2, and 3-3 list earlier reports on UTCS and UTCS/BPS reliability.

3.1 EQUIPMENT COMPLEMENT

The UTCS/BPS equipment complement consists of the items listed in Table 1. The number of items in the last two columns corresponds to the equipment complement as of May 1, 1976.

The central equipment layout is shown in Figure 9 as it was at the time of system acceptance in November 1972. Figures 10, 11, 12, and 13 show the equipments which are common to the A-phase Green, Hold and Advance, Vehicle Detection, and Bus Detection signal flow paths.

3.2 EXAMINATION PERIOD

System reliability experience is examined from two points of view:

a) UTCS, considered as a separate entity, distinct from the Bus Priority System (Section 3.4)

b) Combined UTCS/BPS (Section 3.6)

The UTCS system reliability, for reasons discussed in Sections 3.3 and 3.5, was examined during two overlapping periods. The shorter of the two periods was 32 months, and extended from the date of system acceptance (11/1/72) to 7/1/75. During this period all equipment was installed and operating, and all intersections were on line. The longer of the two periods was from the date of the first intersection's sign-off (6/15/71) to 7/1/75, a span of approximately 48 months.

TABLE 1. EQUIPMENT COMPLEMENT

Central Facility Equipment		Symbol	Quantity (7-1-74)* UTCS	Quantity (7-1-74)* BPS	Quantity (7-1-75) UTCS	Quantity (7-1-75) BPS
Central Processing Unit		CPU	1	1	1	1
Rapid Access Disk		RAD	2	-	2	-
Computer Interface Unit		CIU	3	-	3	-
Magnetic Tape Unit		MTU	2	1	2	1
Communications Rack						
Comm Rack Power Supply		CRPS	10	-	13	-
Dual Amplifier		DA	40	-	42	-
2FR Receiver	(AØG, VD)	2RCR	608	-	794	-
3FT Transmitter	(H&A)	3TX	111	-	201	-
3FR Receiver	(BD)	3RCR	-	144	-	144
Keyboard Printer		TTY	1	1	1	1
CRT Display		CRT	2	-	2	-
Card Punch		CP	1	-	1	-
Keypunch		KP	1	-	1	-
Map Display		M	1	-	1	-
Control Panel		P	1	-	1	-
Line Printer		LP	1	-	1	-
Card Reader		CR	1	-	1	-
Field Equipment						
Controller		CTR	111	-	201	-
Adapter		ADP	111	-	201	-
Loops		L	497	144	547	144
Loop Detector		DET	497	144	547	144
2FS Transmitter	(AØG, VD)	2FS TX	608	-	794	-
3FS Receiver	(H&A)	3FS RCR	111	-	201	-
3FS Transmitter	(BD)	3FS TX	-	144	-	144

AØG - A Phase Green Return
VD - Vehicle Detector Return
BD - Bus Detector Return
H&A - Hold and Advance Command

*7-1-74 marks the start of installation of an additional 89 intersection increment.

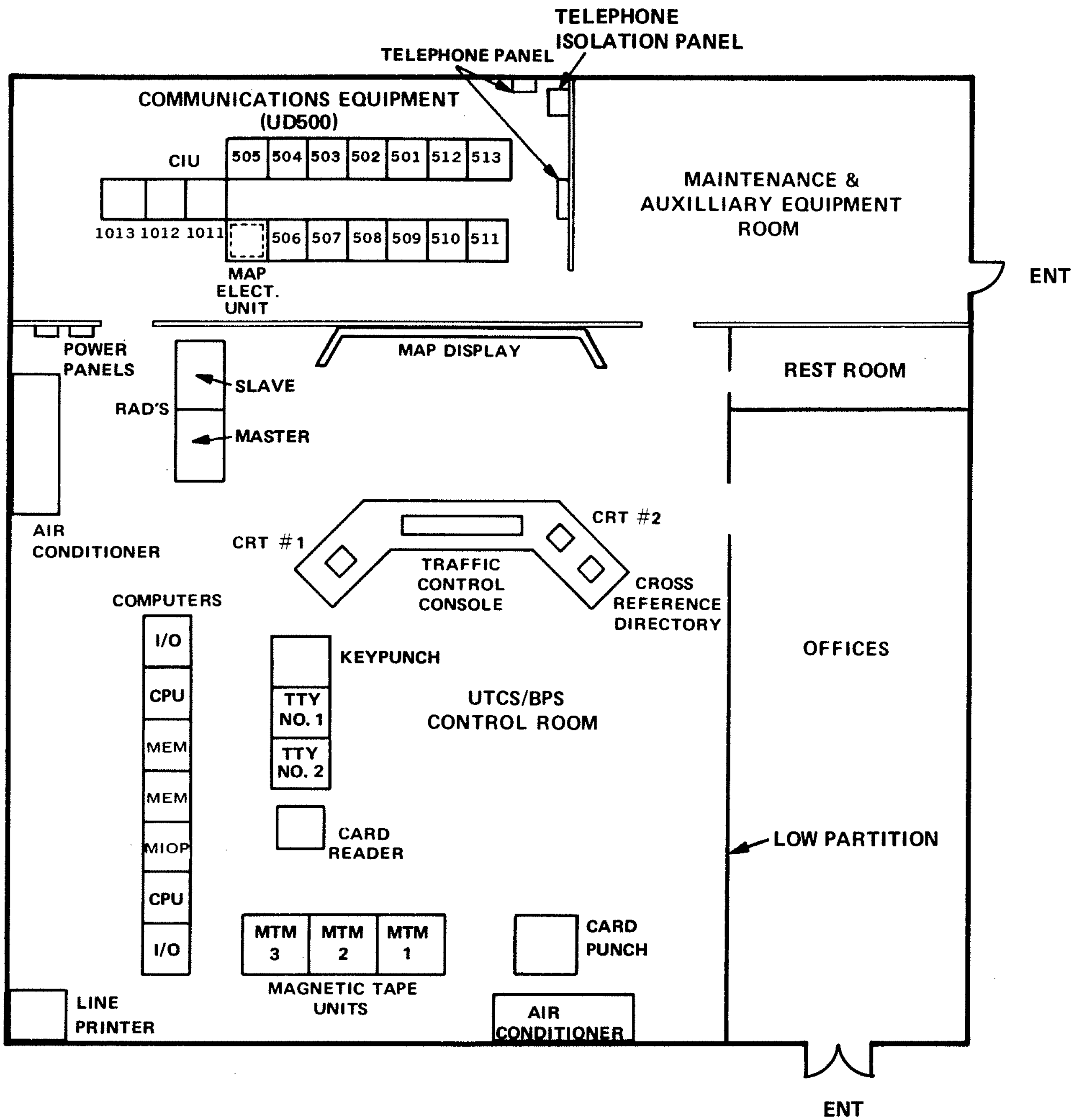

Figure 9. Floor Plan of UTCS/BPS Control Center

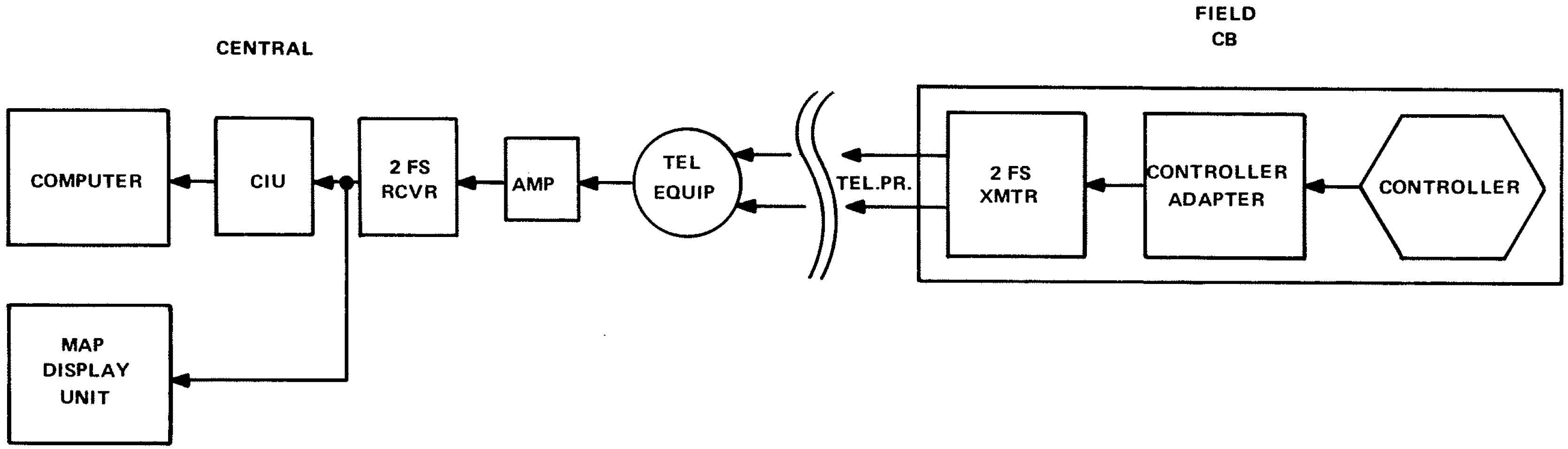

Figure 10. Controller A-Phase Green Signal Flow Diagram

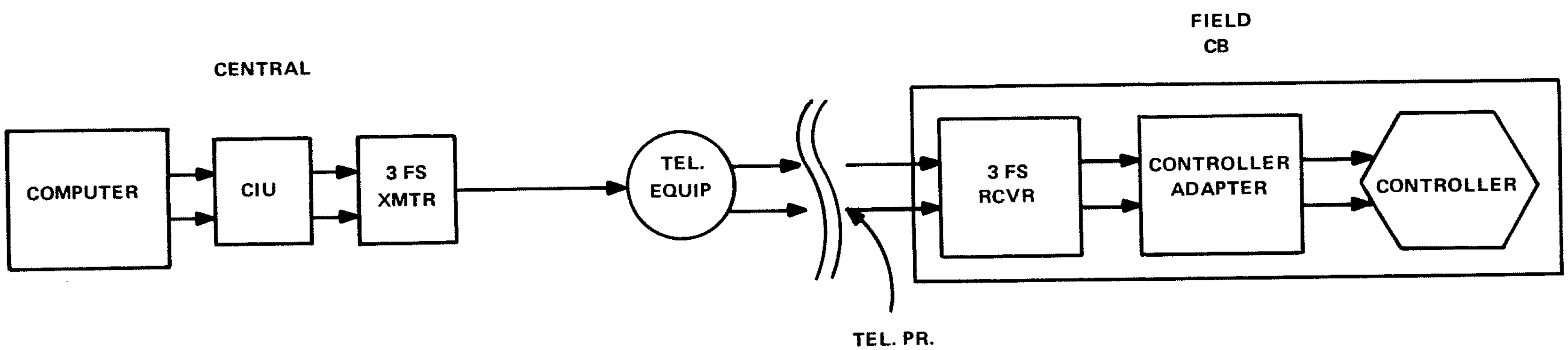

Figure 11. Controller Hold and Advance Signal Flow Diagram

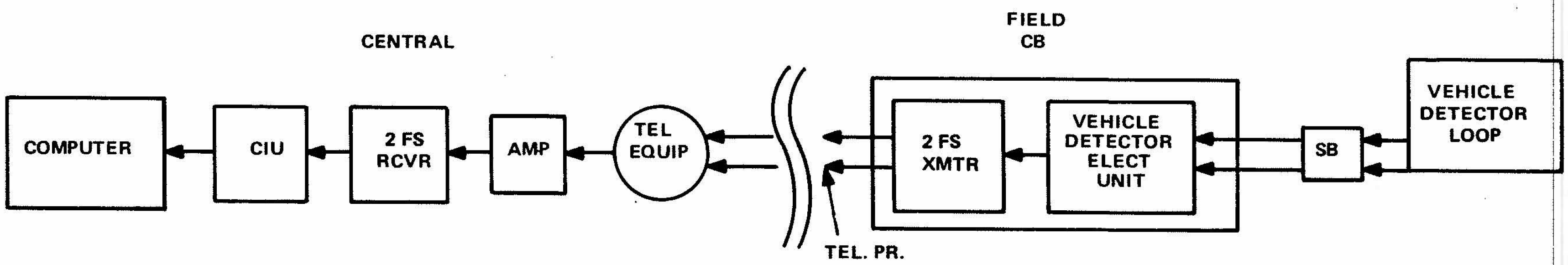

Figure 12. Vehicle Detection Signal Flow Diagram

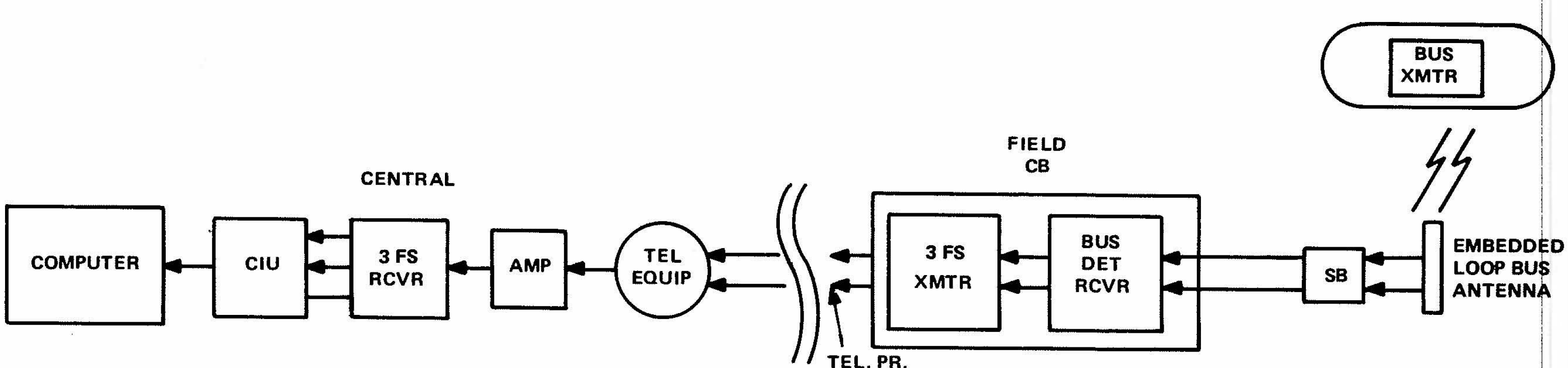

Figure 13. Bus Detection Signal Flow Diagram

The combined UTCS/BPS reliability experience is discussed relative to data obtained from an 81-week operating period extending from November 1, 1972 to June 24, 1972. During this time, as noted previously, the system was operating on a post-acceptance status, with all intersections and equipments nominally on line.

3.3 FACTORS INFLUENCING RELIABILITY EXPERIENCE REPORTING

This section is concerned with some of the factors which influence the accuracy of equipment failure and maintenance reporting.

On the face of it, the raw data of this reliability report (Tables 2 and 3) seems clearly defined and easily obtained. The data consists of the number of failures in each category of equipment, listed by date of failure, together with installation records which provide operation time.

Beneath this simple surface, however, there are legitimate and not easily resolvable questions of interpretation, of which some indication will be given in the following paragraphs.

3.3.1 EQUIPMENT OPERATING LIFETIME

In many cases, it is very difficult to specify the length of time a particular piece of equipment has operated, especially in the case of field equipment.

The first, and natural, assumption is that street equipment operates continuously after installation, which is officially dated by the intersection sign-off date. However, many of the intersections experienced changes in their equipment complement, partly because of the R&D nature of the project. Loops were moved and detectors added or subtracted. Sometimes the loop detectors corresponding to loops which were moved were allowed to remain in their cabinets under an interim arrangement. In some cases, they were eventually removed; in others, the loops were re-installed at a later date and the detectors were then reconnected and once more became operative.

Another factor in determining operating life was that during the system integration period one equipment would often be disconnected from its telephone line channel to Central, and the channel would be used for some time to check out another equipment.

A third factor, also related to UTCS/BPS being an R&D project, was that several contractors were using the UTCS/BPS System to check out advanced software. Therefore, because the UTCS/BPS applications software was frequently replaced with other software packages, there could be no guarantee that a failure would be reported promptly when it occurred.

Still another factor which made it difficult to determine exact operating life is that in the early stages of installation, intersection equipment was often installed prior to the telephone line connection to Central. In those cases, equipment operating life could be longer than the intersection sign off date would indicate, and there is also the possibility of unrecorded equipment failures during this period.

For all these reasons, it is apparent that the connection between sign off date, failure date, and operating life is more tenuous than might appear at first glance.

3.3.2 FAILURE RATES

One of the most important factors affecting loop failure rates was the Metro Subway construction, which went on concurrently with UTCS/BPS installation, integration, and operation. Approximately 27 loops were ripped up during this construction and it is important to separate those loop failures from those which can be charged legitimately as failures. Another 38 loops were damaged by construction other than Metro. Only four were considered as actual random failures.

Another factor which influenced failure rates, again related to the R&D nature of the project, was the fact that controller cabinets and equipment were visited and probed far more frequently than they would have been had the system been purely operational. Statistically, one must expect that a certain number of equipment failures resulted from this added exposure to accidental damage, rather than from natural causes.

Still another factor influencing reported failure rates is that failures which occurred on weekends or holidays were not reported until the following operating day. In some cases, if the system software happened to be one of the experimental packages on that day, the report was further delayed.

Finally, in the case of the telephone lines which were maintained and repaired by the local telephone company, multiple failures were often reported for the same line within a short span of time. In actuality, the problem may not have been cleared up on the first few visits, and this resulted in more failure reports than properly should have been charged to the system.

3.4 UTCS RELIABILITY EXPERIENCE

In Figures 10 through 13, the system equipments are organized according to signal flow. For the purpose of determining reliability, it is more convenient and useful to organize them into subsystems by function. The UTCS System can be broken down as follows:

- Vehicle Detector Subsystem (field)
- Controller Subsystem (field)

- Power Supply Subsystem (field)*
- Central Communications Subsystem (central)
- Computer Subsystem (central)
- Telephone Line Subsystem

The equipments which comprise each of those subsystems are shown in Figures 14 through 17.

Equipment MTBF's are calculated from the relation $(MTBF)_E = \frac{N_E \times L_E}{F_E}$, where N_E = number of equipment units, L_E = operating life in hours, F_E = number of failures during operating life.

Normalized subsystem MTBFs are calculated from the expression $\frac{1}{(MTBF)_{NORM}} = \frac{1}{(MTBF)_{E_1}} + \frac{1}{(MTBF)_{E_2}} + \ldots + \frac{1}{(MTBF)_{E_n}}$ where $(MTBF)_{E_i}$ is the MTBF of the i^{th} equipment component of the subsystem. The normalized subsystem MTBF provides the mean time between failures under the assumption that only one subsystem of a kind exists in the system. The actual subsystem MTBF, which depends on the number of subsystems of a given kind which exist in the system, is calculated from the expression $(MTBF)_S = \frac{(MTBF)_{NORM}}{N_S}$ where N_S = number of subsystems of the given kind in the system and $(MTBF)_{N_S}$ is the normalized subsystem MTBF.

Throughout the following paragraphs, simplifying assumptions have been made where the regorous application of reliability theory would have been impracticable, particularly in the calculation of subsystem MTBFs from equipment MTBFs. In all cases however, these assumptions result in conservative estimates, and the raw data have been included if more rigorous analysis is desired.

4.3.1 FIELD RELIABILITY

Field equipment failures (Table 2) were obtained from:

- Trouble & Failure Reports (TFR)
- Installation Records
- SSM Monthly Activity Reports

\- - - - - - -

*These power supplies furnished power to field communications equipment.

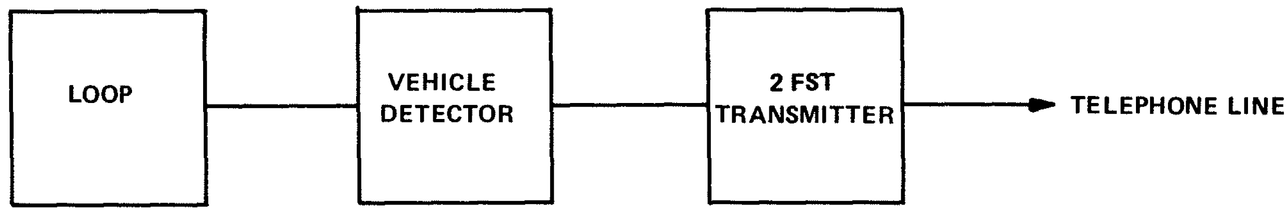

Figure 14. Vehicle Detector Subsystem

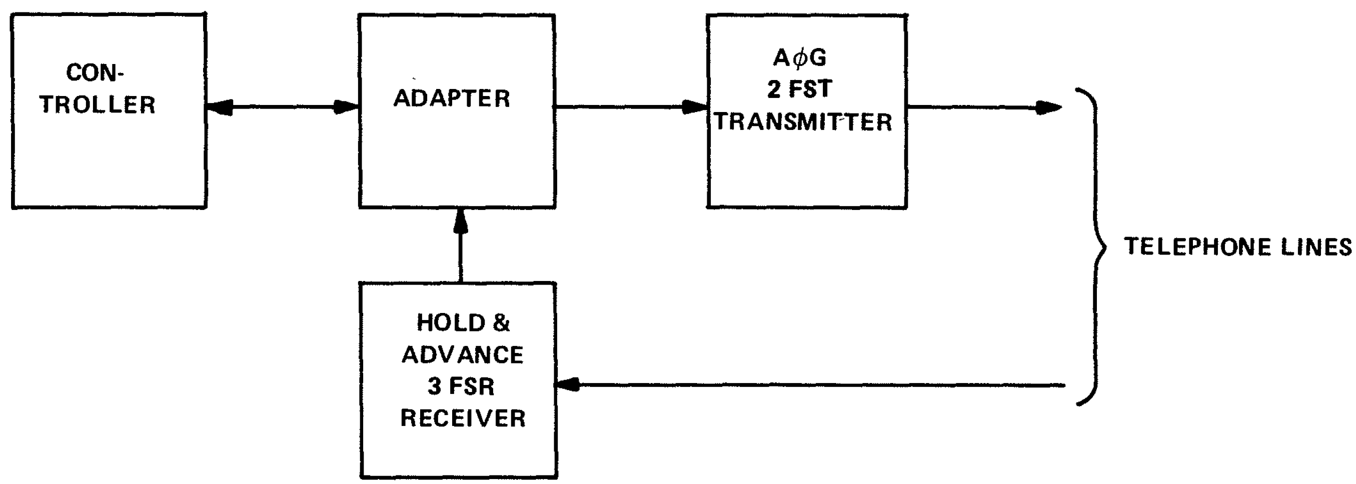

Figure 15. Controller Subsystem

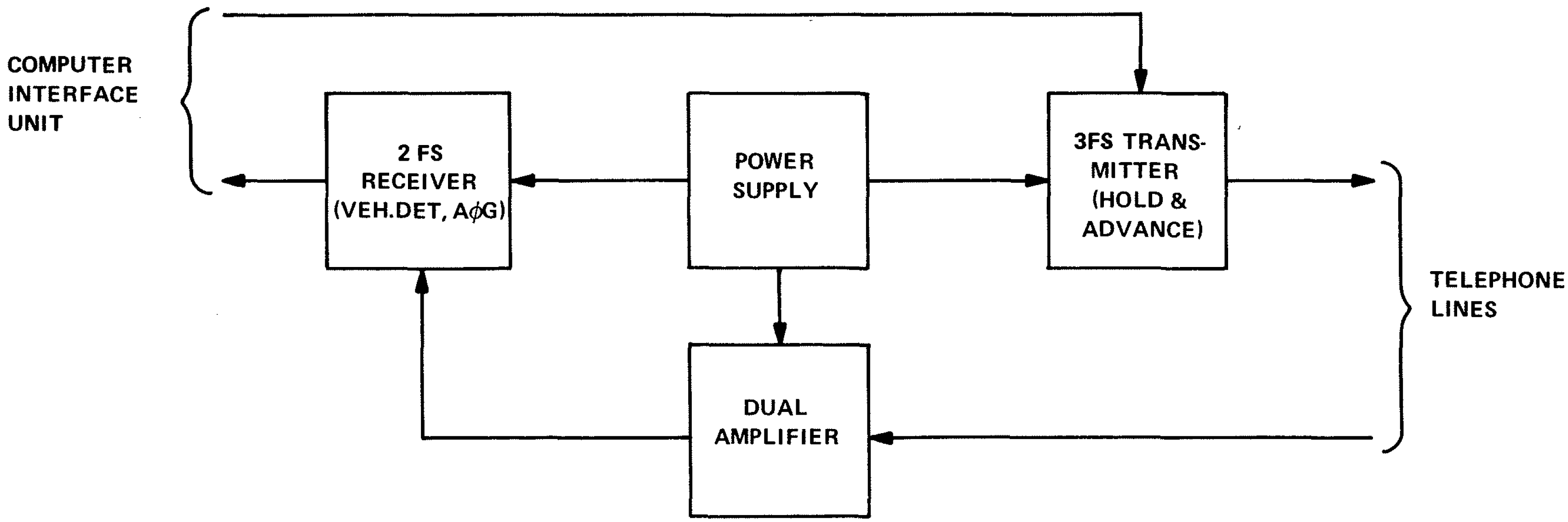

Figure 16. Central Communications Subsystem

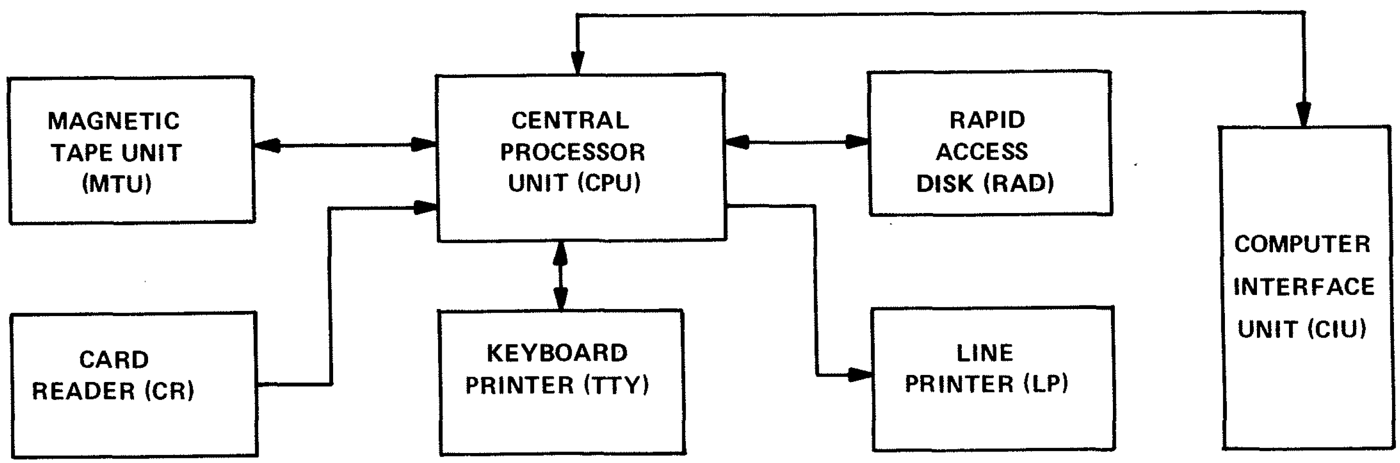

Figure 17. Computer Subsystem

TABLE 2. CHRONOLOGICAL TABLE OF STREET EQUIPMENT FAILURES

2FS Transmitters

3-2-72
3-2-72
5-30-72
7-13-72
7-18-72
8-14-72
8-28-72
9-1-72
9-1-72
9-1-72
9-6-72
10-31-72
10-31-72
12-1-72
12-13-72
12-13-72

1-9-73
1-9-73
1-9-73
1-9-73
1-9-73
3-22-73
5-15-73
5-24-73
5-31-73
6-1-73
7-5-73
7-23-73
7-31-73
7-31-73
7-31-73
7-31-73

2FS Transmitters (cont)

8-21-73
9-6-73
9-9-73
9-13-73
9-13-73
11-12-73
11-19-73

1-8-74
1-29-74
2-11-74
4-2-74
4-3-74
10-20-74
11-5-74
11-5-74
11-22-74
12-10-74

1-21-75
1-21-75
1-21-75
2-11-75
2-28-75
2-28-75
2-28-75
3-4-75
3-4-75
3-4-75
4-24-75
5-7-75
5-7-75
6-11-75

2FS Transmitters (cont)

6-11-75
7-20-75
7-23-75
8-13-75
9-6-75
10-26-75
11-1-75
TOTAL: 70

Loops

9-12-72 to
4-1-76 - 6
TOTAL: 6

3FS Receivers

2-14-72
3-27-72
6-15-72
8-23-72
9-1-72
9-20-72
10-12-72
10-13-72
10-25-72
11-1-72

2-20-73
5-11-73
7-25-73
9-25-73
10-26-73

7-24-74
10-20-74

3FS Receivers (cont)

7-19-75
7-20-75
10-25-75
10-26-75
10-30-75
10-30-75
11-1-75
11-1-75
11-1-75
12-18-75
TOTAL: 27

Power Supplies

3-21-72

1-25-74
10-20-74

8-27-75
10-25-75
10-25-75
10-26-75
12-19-75
TOTAL: 8

Adapters

7-26-71
7-28-71
8-2-71
8-2-71

4-12-72
4-12-72
4-25-72

Table 2. Chronological Table of Street Equipment Failures (cont.)

Adapters (cont)	Vehicle Detectors	Vehicle Detectors (cont)	Vehicle Detectors (cont)
4-28-72	5-8-72	1-11-73	11-6-73
5-5-72	5-20-72	1-11-73	11-7-73
6-8-72	5-30-72	2-7-73	11-12-73
8-14-72	5-31-72	2-20-73	11-16-73
8-23-72	5-31-72	2-22-73	11-27-73
8-31-72	5-31-72	3-7-73	11-27-73
9-13-72	6-14-72	3-21-73	11-28-73
9-18-72	7-7-72	4-16-73	
10-18-72	8-7-72	4-16-73	1-16-74
12-8-72	8-17-72	4-24-73	1-24-74
12-12-72	8-25-72	4-24-73	4-1-74
	9-5-72	5-10-73	4-17-74
1-8-73	9-17-72	5-14-73	5-19-74
4-17-73	10-17-72	5-14-73	10-9-74
6-21-73	10-17-72	5-14-73	10-9-74
10-3-73	10-30-72	5-30-73	
11-29-73	10-30-72	5-30-73	1-21-75
	11-13-72	6-15-73	1-21-75
1-29-74	11-13-72	6-15-73	2-11-75
5-13-74	11-22-72	6-15-73	2-11-75
10-9-74	11-20-72	6-29-73	3-4-75
	12-1-72	7-2-73	3-4-75
1-21-75	12-1-72	7-31-73	4-24-75
3-4-75	12-1-72	8-27-73	4-24-75
3-4-75	12-15-72	9-6-73	4-24-75
7-19-75		9-7-73	5-7-75
8-27-75	1-6-73	10-1-73	5-7-75
11-1-75	1-10-73	10-3-73	6-10-75
12-18-75			
12-18-75			
TOTAL: 34			

Table 2. Chronological Table of Street Equipment Failures (cont.)

Vehicle Detectors (cont)	Vehicle Detectors (cont)
6-11-75	10-26-75
7-19-75	10-26-75
7-19-75	11-1-75
7-19-75	11-1-75
7-20-75	12-18-75
7-20-75	12-18-75
8-27-75	12-18-75
	TOTAL: 95

A. Detector Subsystem

From Figure 14, the detector subsystem components and failure rates within the period 11/1/72 to 7/1/75 are: Why 7/1/75 for date?

- Vehicle Loop 4 failures (total complement 497)
- Vehicle detector 66 failures (total complement 497)
- 2FS transmitter 50 failures (total complement 608)

However, some 2FS transmitters are also used to transmit controller A-phase green to Central. Therefore, the total number of 2FS transmitter failures must be apportioned between the detector subsystem and the controller subsystem.

It is assumed that the number of failures chargeable to the detector subsystem is proportional to the ratio of vehicle detector 2FSTs to total system 2FSTs, i.e.:

$$\text{vehicle detector 2FST failures} = \frac{\text{number of veh det 2FSTs}}{\text{total system 2FSTs}} \times \text{total 2FST failures}$$

$$= \frac{497}{608} \times 50$$

$$= 41$$

During the period 11/1/72 to 7/1/75, the proportions of vehicle detector 2FS transmitters to total system 2FS transmitters (See Table 1) was:

$$\frac{\text{number of vehicle detector 2FSTs}}{\text{total system 2FSTs}} = \frac{497}{608}$$

From Table 2, the number of equipment failures in each of the above listed categories during the period 11/1/72 to 7/1/75 was:

Loop:	4 failures	(total complement = 497)
Detector:	66 failures	(total complement = 497)
Vehicle detector 2FT:	$\frac{497}{608} \times 50 = 41$ failures	(vehicle detector complement = 497; total complement = 608)

(1) Equipment MTBFs

Using the failure rates and sample sizes above, the equipment MTBFs for the 972 day (24 hour/day) operating period are as follows:

$$(\text{MTBF})_{\text{Loop}} = \frac{\text{Number of loops x operating life in hours}}{\text{number of loop failures}}$$

$$(\text{MTBF})_{\text{loop}} = \frac{497 \times 972 \times 24}{4} = \frac{497 \times 23,328}{4} = 2,898,504 \text{ hours}$$

$$(\text{MTBF})_{\text{VEH. DET.}} = \frac{497 \times 23,328}{66} = 175,667 \text{ hours}$$

$$(\text{MTBF})_{\text{2FS TX}} = \frac{497 \times 23,328}{41} = 282,780 \text{ hours}$$

(2) Normalized Vehicle Detector Subsystem MTBF

Using the relation set forth in paragraph 3.4, the normalized vehicle detector subsystem MTBF is given by:

$$\frac{1}{(\text{MTBF})_{\text{NORM, DS}}} = \frac{1}{(\text{MTBF})_{\text{Loop}}} + \frac{1}{(\text{MTBF})_{\text{Det}}} + \frac{1}{(\text{MTBF})_{\text{2FS TX}}}$$

$$\frac{1}{(\text{MTBF})_{\text{NORM, DS}}} = \frac{1}{2,900,000} + \frac{1}{176,000} + \frac{1}{283,000}$$

$$\frac{1}{(\text{MTBF})_{\text{NORM, DS}}} = [.345 + 5.682 + 3.534] \times 10^{-6}$$

$$\frac{1}{(\text{MTBF})_{\text{NORM, DS}}} = 9.561 \times 10^{-6}$$

$$(\text{MTBF})_{\text{NORM, DS}} = 104,600 \text{ Hours}$$ 11.94 yrs

(3) UTCS Vehicle Detector Subsystem MTBF

Using the relation set forth in paragraph 3.4, the actual UTCS vehicle detector subsystem MTBF is:

$$(MTBF)_{DS} = \frac{(MTBF)_{NORM,\ DS}}{N_{DS}}$$

$$(MTBF)_{DS} = \frac{104,600}{497}$$

$$(MTBF)_{DS} = 210 \text{ hours}$$ 8.75 days

B. Controller Subsystem

From Figure 15, the controller subsystem is composed of:

- Controller
- Adapter
- A phase green transmitter (2FS TX)
- Hold/Advance receiver 3 FS RCR

From Table 2 (using the proportions described in paragraph A in the case of the 2FSTs, the number of failures in each category during the period 11/1/72 to 7/1/75 is:

Controller*	:	15 failures	(total complement = 111)
Adapter	:	13 failures	(total complement = 111)
AØG 2FTs	:	$\frac{111}{608} \times 50 = 9$ failures	(AØG complement = 111, total complement = 608)
H/A 3FRs	:	8 failures	(total complement = 111)

(1) Equipment MTBFs

The equipment MTBFs calculated from the above failure rates and sample sizes are:

$$(MTBF)_{CTR} = \frac{111 \times 23,328}{15} = 172,600 \text{ hours}$$

$$(MTBF)_{ADP} = \frac{111 \times 23,328}{13} = 199,200 \text{ hours}$$

- - - - - - -

*This is extrapolated from an observed failure rate of four controllers in a 261-day period (9/12/72 - 6/7/73). Controller maintenance after installation is a District responsibility. Consequently, records are kept separately from UTCS records and in a different format.

$$(MTBF)_{2FST} = \frac{111 \times 23,328}{9} = 287,700 \text{ hours}$$

$$(MTBF)_{3FSR} = \frac{111 \times 23,328}{8} = 323,676 \text{ hours}$$

(2) Normalized Controller Subsystem MTBF

The normalized controller subsystem MTBF is computed from the equations given in paragraph 3.4, as follows:

$$\frac{1}{(MTBF)_{NORM,\ CTR}} = \frac{1}{172,700} + \frac{1}{199,200} + \frac{1}{287,700} + \frac{1}{323,700}$$

$$(MTBF)_{NORM,\ CTR} = 57,500 \text{ hours}$$ 6.56 yrs

(3) UTCS Controller Subsystem MTBF

Since the UTCS system contains 111 controller subsystems, the UTCS controller subsystem MTBF is:

$$(MTBF)_{CTR} = \frac{(MTBF)_{NORM,\ CTR}}{111}$$

$$(MTBF)_{CTR} = 518 \text{ hours}$$ 21.58 days

C. Power Supply Subsystem

From Table 2, there were two field power supply failures in the period from 11/1/72 to 7/1/75. Therefore the equipment MTBF, which in this case is also the normalized subsystem MTBF, is:

$$(MTBF)_{NORM,\ PS} = \frac{111 \times 23,328}{2} = 1,295,000 \text{ hours}$$ 147.83 yrs

The UTCS Power Supply Subsystem MTBF is given by:

$$(MTBF)_{PS} = \frac{(MTBF)_{NORM,\ PS}}{111}$$

$$(MTBF)_{PS} = 11,700 \text{ hours}$$ 1.34 yrs

D. Overall Field System

(1) Normalized Field Subsystem MTBF

Assuming that the overall field subsystem consists of a single detector subsystem, controller subsystem, and power supply subsystem, the normalized field subsystem MTBF is given by:

$$\frac{1}{(MTBF)_{NORM,\ FS}} = \frac{1}{(MTBF)_{NORM,\ DS}} + \frac{1}{(MTBF)_{NORM,\ CTR}} + \frac{1}{(MTBF)_{NORM,\ PS}}$$

$$= \frac{1}{104,600} + \frac{1}{57,500} + \frac{1}{1,295,000}$$

$$(MTBF)_{NORM,\ FS} = 44,000 \text{ hours}$$ 5.02 yrs.

(2) UTCS Field Subsystem MTBF

The UTCS overall field subsystem MTBF, which takes into account the number of each kind of subsystem is given by:

$$\frac{1}{(MTBF)_{FS}} = \frac{1}{(MTBF)_{DS}} + \frac{1}{(MTBF)_{CTR}} + \frac{1}{(MTBF)_{PS}}$$

$$\frac{1}{(MTBF)_{FS}} = \frac{1}{210} + \frac{1}{518} + \frac{1}{11,700}$$

$$(MTBF)_{FS} = 148 \text{ hours}$$ 6.17 days

3.4.2 CENTRAL FACILITY EXPERIENCE

Table 3 lists all central facility failures. The failure data was obtained by correlating entries in the UTCS operating log, the failure reports filled out by Xerox maintenance personnel, and regular maintenance reports also filled out by Xerox personnel.

A. Central Communications Subsystem

The Central Communications Subsystem, as shown in Figure 16, consists of:

- Dual amplifier
- 2FR receiver
- 3FT transmitter
- Power supply

TABLE 3. UTCS CENTRAL FACILITY FAILURES

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
CIU	5/22/72	FT 84 card replaced	1	-	
CIU	5/31/72	FT 84 card replaced	1	-	
CIU	10/29/74	Card replaced	1.5	-	
CIU	6/28/75	Shorted power cable		6	MUX #2
Map	6/1/72	Address card	-	-	
Map	12/19/72	Logic card	-	-	
Map	2/7/73	Driver board	-	-	
Map	2/8/73	Two driver boards	-	-	
Map	6/25/73	Electronics	-	-	
Map	8/10/73	Electronics	-	-	
Map	3/3/75	Electronics	-	-	
Map	4/23/75	12 electronics cards	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	11/20/72	-	-	-	
2FS receivers	1/16/73	-	-	-	
2FS receivers	5/10/74	-	-	-	
2FS receivers	7/18/74	-	-	-	

Table 3. UTCS Central Facility Failures (cont.)

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
2FS receivers	8/27/75	-	-	-	
2FS receivers	10/25/75	-	-	-	
2FS receivers	10/25/75	-	-	-	
2FS receivers	10/26/75	-	-	-	
2FS receivers	12/18/75	-	-	-	
2FS receivers	12/18/75	-	-	-	
3FS transmitters	3/9/72	-	-	-	
3FS transmitters	9/13/72	-	-	-	
3FS transmitters	9/20/72	-	-	-	
3FS transmitters	11/11/72	-	-	-	
3FS transmitters	12/1/72	-	-	-	
3FS transmitters	9/1/73	-	-	-	
RAD	12/21/72	?	2	2	
RAD	1/5/73	Power Supply (PS)	3	3	
RAD	9/14/73	Power Supply (PS)	2.5	2.5	
RAD	11/27/73	Bad Motor Control Unit	4	4	

Table 3. UTCS Central Facility Failures (cont.)

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
RAD	12/4/73 (1)	Vacuum Motor	8	8	See 12/4/73 CPU & MTU entry
RAD	12/17/73	Bad Tachometer	3.5	3.5	RAD #1
RAD	3/21/74	Read Head & Tachometer	9	9	RAD #1
RAD	3/26/74	Shorted Diode	7	7	
RAD	8/18/74	Pressure Hose	5	5	
RAD	12/12/74	Intermittent-Undetermined	2	2	RAD #1
RAD	3/6/75	Intermittent-Undetermined	2.5	2.5	RAD #1
RAD	3/13/75	Intermittent-Undetermined	5	5	RAD #1
CPU	12/28/72	PS for Memory Stack & Memory Card	3	3	
CPU	12/4/73 (1)	Memory Card	8	8	CPU #1
CPU	12/12/73	Memory Card	2	2	
CPU	4/12/74	PS for Memory Stack	4	4	CPU #1
CPU	6/1/74	Memory Stack Circuit Breaker	0.5	0.5	CPU #1
CPU	4/9/74	?	5	5	Night call to Xerox

Table 3. UTCS Central Facility Failures (cont.)

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
MTU	1/16/73	-	undetermined	?	MTU #2
MTU	5/1/73	-	undetermined	?	MTU #2
MTU	6/25/73	-	undetermined	2	MTU #2
MTU	7/6/73	-	undetermined	0	MTU #1
MTU	11/5/73	-	undetermined	?	MTU #1
MTU	11/5/73	-	undetermined	?	MTU #2
MTU	11/27/73	-	undetermined	?	MTU #2
MTU	12/4/73 (2)	"Read" Amplifier	undetermined	8	MTU #2
MTU	12/14/73 (3)	Bad Head	undetermined	3	MTU #2
MTU	12/26/73	-	undetermined	?	MTU #2
MTU	1/15/74	Sense Switch	undetermined	0	MTU #1
MTU	2/5/74	-	undetermined	?	MTU #1
MTU	6/12/74	Capstan Adjustment	undetermined	0	MTU #1
MTU	7/26/74	PS	undetermined	0	MTU #3
MTU	8/9/74	Vacuum Switch	undetermined	0	MTU #3
MTU	8/16/74	Two Vacuum Switches	undetermined	0	MTU #2
MTU	10/11/74	Capstan Motor	undetermined	0	MTU #1
CRT	5/16/73	-	undetermined	0	CRT #1
CRT	2/12/74	-	undetermined	0	CRT #1
CRT	8/19/74	-	72 (4)	0	CRT #1

Table 3. UTCS Central Facility Failures (cont.)

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
CRT	9/5/74	-	24(4)	0	CRT #1
CRT	9/26/74	Blown fuse	5(4)	0	CRT #2
CRT	12/16/74	PS	24(4)	0	CRT #1
CRT	12/28/74	PS	120(4)	0	CRT #2
CRT	5/5/75	PS	Six Weeks (4)	0	CRT #2
Line Printer	4/2/73	-	5	5(6)	
Line Printer	8/31/73	-	undetermined	0	
Line Printer	9/27/73	PS	8.5	0	
Line Printer	12/14/73(5)	-	3	3 hrs	
Line Printer	12/25/73	-	48	0	
Line Printer	12/28/73	Start Up Switch	2	0	
Line Printer	3/14/74	Motor Drive Clutch	5	0	
Line Printer	5/1/75	Bad Vertical format tape		0	
Control Panel	1/28/73	PS Fuse		1	
Card Reader	9/19/74	Drive Bearings	2.5	0	
Card Reader	10/18/74	Stacker Lamp	2	0	
Card Reader	2/10/75	Skew & strobe adjusted	1.5	0	
Card Reader	2/26/75	?	3.5	3.5	
Card Reader	5/2/75	Lamp and PS	3	0	
TTY	1/22/75	Burned out resistors	1.5	1.5	
Dual Amp	1/29/73				

Table 3. UTCS Central Facility Failures (cont.)

COMPONENT	FAILURE DATE	CAUSE OF FAILURE	COMPONENT DOWN TIME (HOURS)	SYSTEM DOWN TIME (HOURS)	COMMENTS
Power Supply	3/14/73				
Power Supply	4/16/75				
Power Supply	3/18/75				

(1) RAD, MTU, CPU failed this date. System down time given is elapsed time to repair all units and return system to full operation.

(2) RAD, MTU, CPU failed this date. System down time given is elapsed time to repair all units and return system to full operation.

(3) MTU & LP both failed this date (see 12/14/73 LP entry). System down time given is elapsed time to repair both units and return system to full operation.

(4) These downtimes are because of poor on-call maintenance service.

(5) See MTU entry 12/14/73.

(6) No system failure; system down because of inability to call service.

The corresponding equipment failures during the 11/1/72 to 7/1/75 examination period are:

Dual amplifier : 1 failure

2FS receiver : 10 failures

3FS transmitter : 3 failures

Power Supply : 3 failures

The central facility operated on a 12-hour daily shift except for weekends and holidays. During the period 11/1/72 to 7/1/75 there were 668 operating days for central facility equipment. Therefore, the Central Communications System MBTF is:

$$(MTBF)_{CC} = \frac{668 \times 12}{1+10+3+3} = \frac{8016}{17} = 472 \text{ hours}$$ 19.67345

B. Central Processor and Peripheral Subsystem

The CPU Subsystem is shown in Figure 17 and consists of:

Central processing unit (CPU)

Rapid access disk (RAD)

Computer interface unit (CIU)

Magnetic tape unit (MTU)

Line printer (LP)

Card reader (CR)

Keyboard printer (TTY)

Failures shown in Table 3, for each category during the examination period, are listed below:

CPU - 6 failures

RAD - 12 failures

CIU - 2 failures

MTU - 17 failures

LP - 8 failures

CR - 5 failures

TTY - 1 failure

Therefore the CPU Subsystem MTBF is:

$$(MTBF)_{CPU} = \frac{8016}{51} = 157 \text{ hours}$$ 6.54 days

C. Critical Computer Subsystem

Failures of the line printer, card reader, or magnetic tape unit will not generally cause a catastrophic system failure. The central processor could continue to operate as long as the failed equipment (e.g. line printer) was not called upon specifically to function.

However, the subsystem composed of central processor, rapid access disk memory, computer interface unit, and keyboard printer is critical. Failure of any of these elements will immediately fail the system*. The MTBF for this subsystem is:

$$(MTBF)_{CS} = \frac{8016}{6+12+2+1} = 382 \text{ hours}$$ 15.92 days

D. Display Subsystem

The display subsystem consists of the control panel, the CRTs and the map display unit. Failures in each of these categories were as follows.

Control panel : 1

CRT : 8

map : 7

Therefore the display subsystem MTBF is:

$$(MTBF)_{DIS} = \frac{8016}{1+8+7} = 501 \text{ hours}$$ 20.88 days

3.4.3 TELEPHONE LINE EXPERIENCE

Table 4 lists 77 telephone line failures for the examination period**. Therefore, the telephone MTBF is:

$$(MTBF)_{TEL} = \frac{23,328}{77} = 303 \text{ hours}$$ 12.63 days

3.4.4 OVERAL SYSTEM MTBF

The entire UTCS system is composed of the following subsystems:

- Vehicle detector (210 hours)
- Controller (518 hours)
- Power Supply (field) (11,700 hours)
- Central communications (472 hours)

*In the case of the TTY, if the system has been brought up, the failure will not occur until another equipment in the system has failed and the system makes an attempt to report it through the TTY.

**Frequently, the same line was visited several times within a short time period raising the possibility that the underlying cause of all the visits was identical. Therefore, the assumption is made here that only failure reports separated by more than a reasonable time will be counted for any one telephone pair.

- Computer (157 hours)
- Display (501 hours)
- Telephone (303 hours)

The MTBF of each subsystem is given in parentheses. The UTCS system MTBF is therefor given by:

$$\frac{1}{(\text{MTBF})_{\text{UTCS}}} = \frac{1}{210} + \frac{1}{518} + \frac{1}{11,700} + \frac{1}{472} + \frac{1}{152} + \frac{1}{303} + \frac{1}{501}$$

$$(\text{MTBF})_{\text{UTCS}} = 49 \text{ hours}$$

Thus, on the average, a failure of some type in the UTCS system can be expected once every two days. This failure rate includes all of the street equipment as well as the central equipment, telephone lines, and computer. It is specific to UTCS in the sense that different equipment complements would result in different MTBFs.

It is important to point out that, although the UTCS MTBF is 49 39 hours, this does not mean that the essential system functions will be interrupted with equal frequency. On the contrary, most of the system failures are not critical, and the critical subsystem MTBF is much higher (Refer to paragraph 3.4.2.c).

Tables 5 and 6 provide a summary of the upper limit reliabilities which have been computed in this section.

3.5 LOWER LIMITS OF SUBSYSTEM RELIABILITY

The MTBFs calculated in the preceding section describe what might be considered an upper limit for subsystem reliability, for the following reasons. All equipment had been installed and operating for some time by 11/1/72. Consequently, the period of infant mortality was over for most equipment, and the MTBFs for the subsystems in some cases are higher than they would be if the infant mortality period was included. In addition, the equipment in the field and in Central was no longer subject to the kind of unintentionally inflicted damage which occasionally occurs during installation and checkout.

TABLE 4. TELEPHONE LINE FAILURES

Date	Pair*	Date	Pair	Date	Pair	Date	Pair
10/7/72	-	5/15/73	-	8/27/73	-	6/5/74	10DD58
12/8/72	-	5/17/73	-	9/7/73	10DD35	6/11/74	10DD65
12/11/72	10DD2	5/20/73	-	9/26/73	10DD29	6/11/74	10DD64
12/21/72	-	5/20/73	-	10/1/73	10DD1	6/25/74	10DD17
		6/1/73	-	10/1/73	10DD3	7/26/74	10DD62
1/9/73	-	6/18/73	-	10/3/73	10DD2	8/1/74	10DD60
1/22/73	-	7/2/73	-	10/11/73	10DD10	8/1/74	10DD55
2/7/73	-	7/2/73	-	11/12/73	10DD17	9/9/74	10DD38
2/28/73	-	7/3/73	-	11/20/73	10DD60	9/26/74	10DD79
3/1/73	-	7/3/73	-	12/3/73	10DD65	10/24/74	10DD65
3/5/73	-	7/5/73	-	12/27/73	10DD2		
3/23/73	-	7/5/73	-			1/22/75	10DD46
4/12/73	-			1/8/74	10DD8	1/22/75	10DD53
4/13/73	-	7/6/73	-	2/6/74	10DD61	1/22/75	10DD64
4/17/73	-	7/12/73	-	3/15/74	10DD10	1/22/75	10DD65
4/17/73	-	7/16/73	-	4/17/74	10DD78	5/20/75	10DD20
4/20/73	-	8/9/73	-	4/22/74	10DD15	5/20/75	10DD56
4/20/73	-	8/17/73	-	5/10/74	10DD25	5/20/75	10DD63
4/20/73	-	8/20/73	-	5/10/74	10DD6	6/4/75	10DD101
4/24/73	-	8/20/73	-	5/21/74	10DD1	6/11/75	10DD13
4/26/73	-	8/23/73					

*During the period 10/7/72 to 8/27/73 the operator was not required to make note of the line pair which failed. This logging procedure was modified after 8/27/73 to include the number of the line pair.

To obtain an accurate system reliability figure, it is necessary to determine the history and operating period of each piece of equipment. This is a most difficult task in the case of UTCS, as discussed in paragraph 3.3. For example, during the entire installation and integration period, sensor locations were in a state of flux. Often, when loops were moved, the electronics were left in a power-on state in the cabinet, to be re-connected at a later date when the loops were re-installed.

Although it is difficult to provide an exact reliability figure, it is possible to provide a lower limit for system reliability which, together with the upper limit already described described, provides bounds within which the actual reliability is confined (see Table 7).

Instead of attempting to determine exact equipment operating life, it is assumed that the equipment complement was installed at a linear rate between the first sign-off date (6/15/71) and the date of system acceptance 11/1/72, as shown in Figure 18. The operating period for the lower-limit MTBF calcuation will be assumed to start at the midpoint of the linear portion of the curve, i.e., at a point 80 days earlier than the acceptance date.

TABLE 5. UTCS EQUIPMENT RELIABILITY (UPPER LIMIT)(1)

Equipment	Number	Number Failed	MTBF (hours)
Roadway Loop	497	4	2,900,000
Vehicle Detector	497	66	176,000
2FS Trans. (veh. det.)	497	41	282,800
Controller	111	15	172,600
Adapter	111	13	199,200
2FS Trans (A phase green)	111	9	287,700
3FSR (Hold & Advance)	111	8	323,700
Field Power Supply	111	2	1,295,000

(1) Based on a 23,328 hour operating period, and rounded to the nearest whole multiple of 100 hours.

TABLE 6. UTCS SUBSYSTEM RELIABILITY (UPPER LIMIT)(1)

Field Subsystems	Normalized MTBF (hours)	UTCS MTBF (hours)
Vehicle Detector	104,600	210
Controller	57,500	518
Field Power Supply	1,295,000	11,700
Overall Field	44,000	148
Central Subsystems		
Central Communications	472	-
Central Processor	157	-
Display	501	-
Telephone	303	
Other		
Critical Computer	382	-
Total System	49	-

(1) Based on a 23,328 hour operating period.

TABLE 7. COMPARISON OF UPPER AND LOWER LIMIT MTBFs FOR VARIOUS UTCS SUBSYSTEMS

Subsystem	Lower Limit Operating Period 2/22/72 - 7/1/75	Upper Limit Operating Period 11/1/72 - 7/1/75
Detector	210	210
Controller	402	518
Power Supply (Field)	9784	11664
Overall Field	136	147
Central Comm.	not valid	501
CPU & Periph.	not valid	157
Critical CPU	not valid	382
Display	not valid	501
Telephone	not valid	303

The actual installation rate is shown in Figure 19, as measured by the percentage of total number of intersections signed off by a given date, and by the percentage of detectors installed.

3.5.1 FIELD SUBSYSTEMS

A. Detector Subsystem

Assuming an operating period extending from February 22, 1972 to July 1, 1975 (972 + 251 = 1223 days), the detector subsystem failures are as follows:

Loop - 5

Vehicle detector - 66 + 17 = 83

Vehicle detector 2FT - $41 + \left(\frac{497}{608} \times 13\right) = 52$

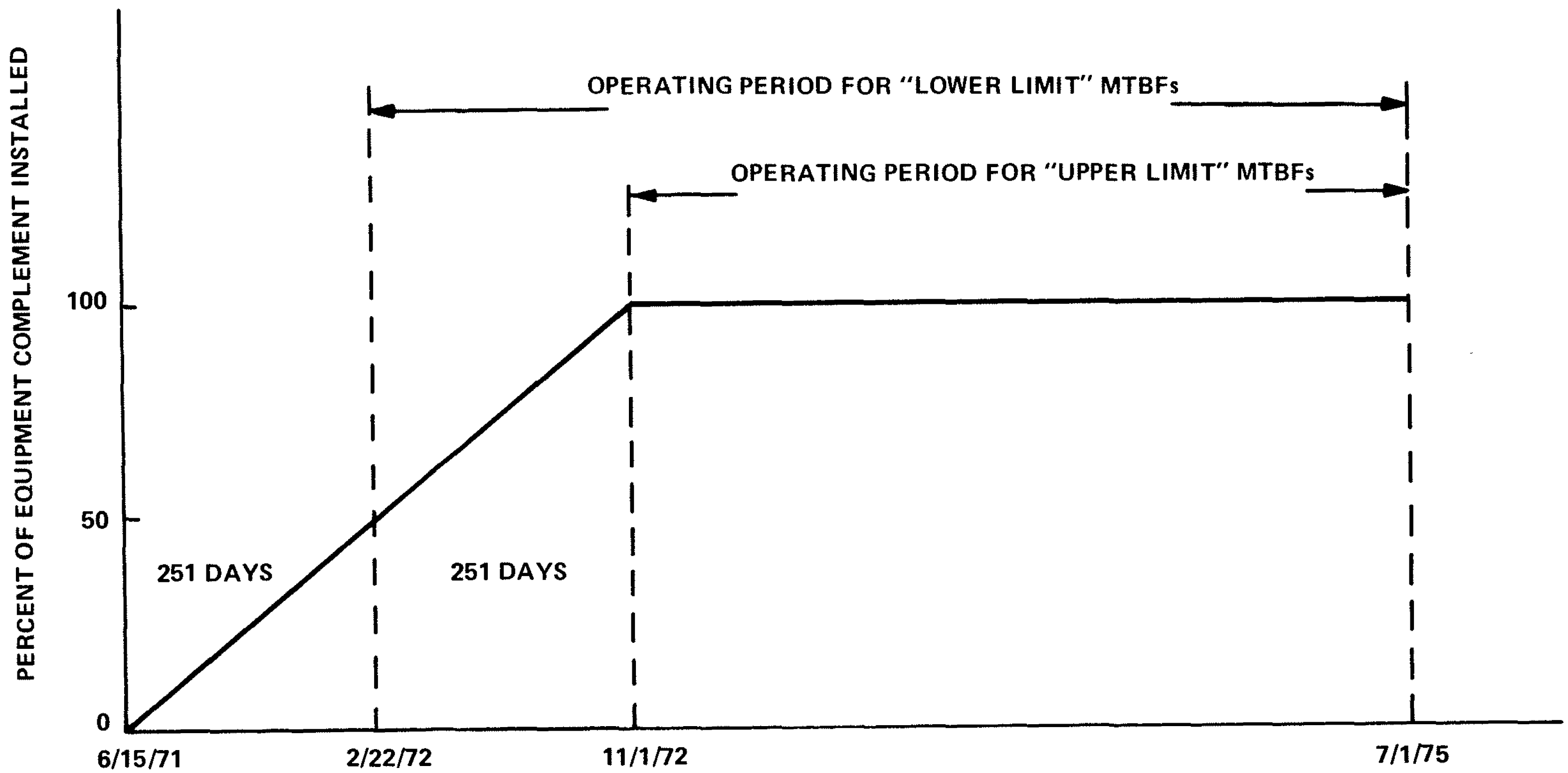

Figure 18. Assumed Installation Rate for Calculation of Lower Limit MTBFs

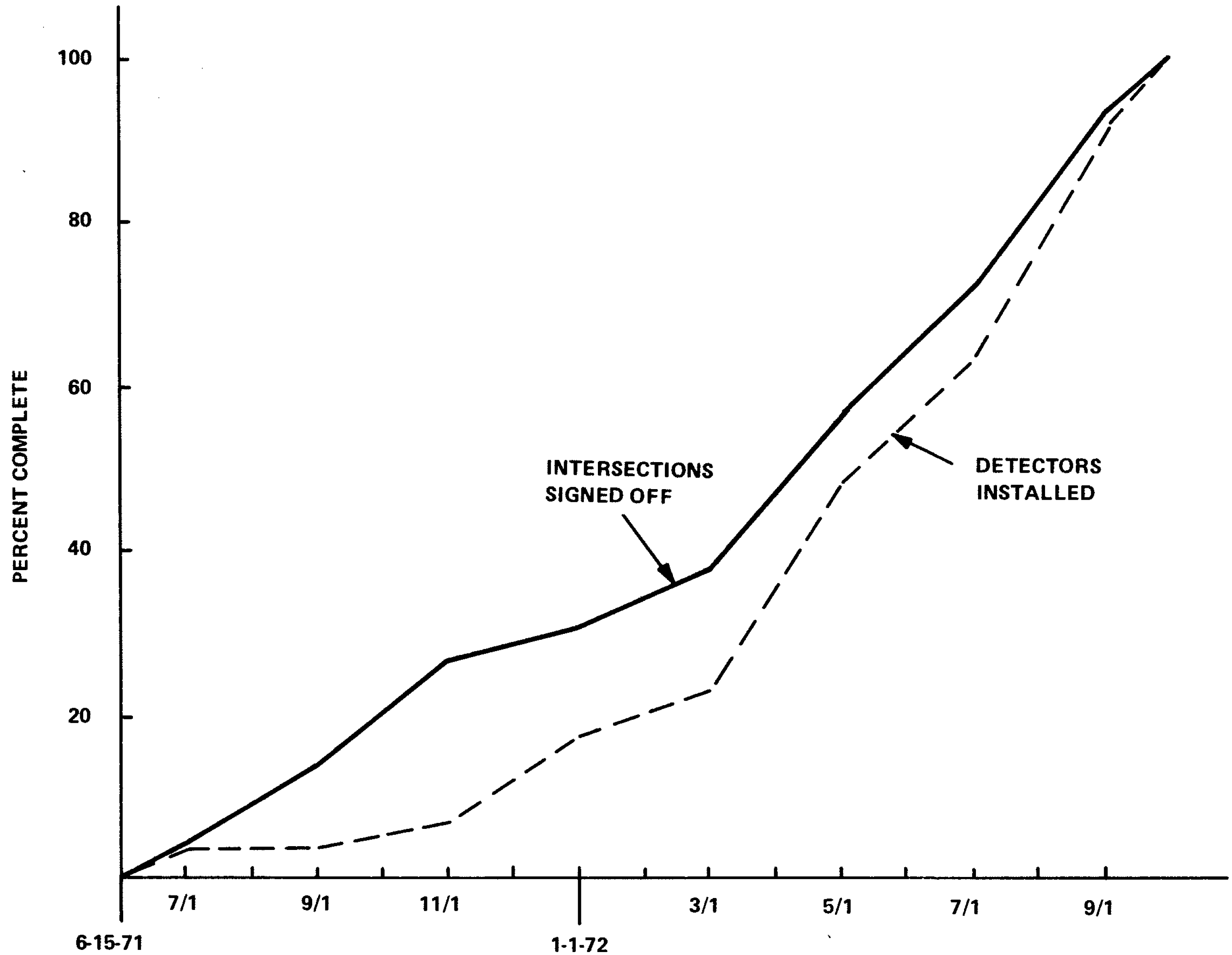

Figure 19. Actual Installation Curve

(1) Equipment MTBF's

Using the relationships given in Section 3.4 and the equipment failure rates above, the following equipment MTBFs can be computed, based on the 1,223-day operating life:

$$(MTBF)_{loop} = 2,918,000 \text{ hours}$$

$$(MTBF)_{veh\ det} = 176,000 \text{ hours}$$

$$(MTBF)_{2FS\ TX} = 280,500 \text{ hours}$$

(2) Normalized Vehicle Detector Subsystem MTBF

The normalized vehicle detector subsystem MTBF is given by:

$$\frac{1}{(MTBF)_{NORM,\ DS}} = \frac{1}{(MTBF)_{loop}} + \frac{1}{(MTBF)_{veh\ det}} + \frac{1}{(MTBF)_{2FS\ TX}}$$

$$(MTBF)_{NORM,\ DS} = 105,300 \text{ hours}$$

(3) UTCS Vehicle Detector Subsystem MTBF

The subsystem MTBF corresponding to the 497 vehicle detector subsystems in UTCS is:

$$(MTBF)_{DS} = \frac{105,300}{497}$$

$$(MTBF)_{DS} \approx 210 \text{ hours}$$

B. Controller Subsystem

The controller subsystem failures during the extended period are:

Controller	:	16*	(total complement = 111)
Adapter	:	16 + 13 = 29	(total complement = 111)
Controller 2FS TX	:	$9 + \frac{111}{608} \times 13 = 11$	(AØG complement = 111; total complement = 608)
Controller 3FS RCR	:	8 + 8 = 16	(total complement = 111)

- - - - - - -

*Extrapolated from an observed rate of 4 failures in 261 days

(1) Equipment MTBFs

From the equipment failure rates above, the following MTBFs can be calculated:

$$(MTBF)_{controller} = \frac{111 \times 29,352}{16} \approx 203,600 \text{ hours}$$

$$(MTBF)_{adapter} = \frac{111 \times 29,352}{29} \approx 112,300 \text{ hours}$$

$$(MTBF)_{2FS\ TX} = \frac{111 \times 29,352}{11} \approx 296,200 \text{ hours}$$

$$(MTBF)_{3FS\ RCR} = \frac{111 \times 29,352}{16} \approx 203,600 \text{ hours}$$

(2) Normalized Controller Subsystem MTBF

The normalized controller subsystem MTBF is given by:

$$\frac{1}{(MTBF)_{NORM,\ CS}} = \frac{1}{(MTBF)_{cont}} + \frac{1}{(MTBF)_{adapt}} + \frac{1}{(MTBF)_{2FS\ TX}} + \frac{1}{(MTBF)_{3FS\ RCR}}$$

$$(MTBF)_{NORM,\ CS} \approx 45,500 \text{ hours}$$

(3) UTCS Controller Subsystem MTBF

The UTCS controller subsystem MTBF, which is based on a complement of 111 subsystems, is:

$$(MTBF)_{CS} = \frac{(MTBF)_{NORM,\ CS}}{111} = 410 \text{ hours}$$

C. Power Supply Subsystem

From Table 2, there were three street power supply failures in the extended period.

(1) Equipment MTBF for the Field Power Supply Subsystem

The equipment (and also the normalized) MTBF for the field power supply subsystem is:

$$(\mathrm{MTBF})_{PS} = (\mathrm{MTBF})_{NORM,\ PS} = \frac{111 \times 29{,}352}{3} \approx 1{,}086{,}000 \text{ hours}$$

(2) UTCS Field Power Supply Subsystem MTBF

Based on the complement of 111 subsystems, the reliability of the UTCS Field Power Supply subsystem is:

$$(\mathrm{MTBF})_{PS} = \frac{(\mathrm{MTBF})_{NORM,\ PS}}{111} \approx 9{,}800 \text{ hours}$$

D. Overall Field Subsystem

The overall field subsystem is composed of Detector, Controller, and Field Power Supply subsystems.

(1) Normalized Overall Field System MTBF

Assuming that the overall field system contains one of each of the subsystems described above, the reliability of this "normalized" field system is:

$$\frac{1}{(\mathrm{MTBF})_{NORM,\ FS}} = \frac{1}{(\mathrm{MTBF})_{NORM,\ DET}} + \frac{1}{(\mathrm{MTBF})_{NORM,\ CONT}} + \frac{1}{(\mathrm{MTBF})_{NORM,\ PS}}$$

$$\frac{1}{(\mathrm{MTBF})_{NORM,\ FS}} = \frac{1}{105{,}300} + \frac{1}{45{,}500} + \frac{1}{1{,}086{,}000}$$

$$(\mathrm{MTBF})_{NORM,\ FS} = 24{,}000 \text{ hours}$$

(2) UTCS Overall Field Subsystem

The MTBF of the UTCS overall field subsystem is:

$$\frac{1}{(\mathrm{MTBF})_{FS}} = \frac{1}{(\mathrm{MTBF})_{DET}} + \frac{1}{(\mathrm{MTBF})_{CONT}} + \frac{1}{(\mathrm{MTBF})_{PS}}$$

$$\frac{1}{(\mathrm{MTBF})_{FS}} = \frac{1}{210} + \frac{1}{410} + \frac{1}{9800}$$

$$(\mathrm{MTBF})_{FS} \approx 135 \text{ hours}$$

Tables 8 and 9 contain summaries of the lower limit equipment reliabilities and lower limit field subsystem reliabilities, respectively.

TABLE 8. UTCS EQUIPMENT RELIABILITY (LOWER LIMIT)[1]

Equipment	Number	Number Failed	MTBF (hours)
Roadway loop	497	5	2,918,000
Vehicle detector	497	83	176,000
2FS trans. (veh. det.)	497	52	280,500
Controller	111	16	203,600
Adapter	111	29	112,300
2FS trans (AØG)	111	11	296,200
3FS RCVR (H&A)	111	16	203,600
Field Power Supply	111	3	1,086,000

TABLE 9. UTCS FIELD[1] SUBSYSTEM RELIABILITY (LOWER LIMIT)[2]

Subsystem	Normalized MTBF (hours)	UTCS MTBF (hours)
Vehicle Detector	105,300	210
Controller	45,500	410
Field Power Supply	1,086,000	9,800
Overall Field	24,000	135

(1) Central facility operation prior to 11/1/72 was mainly in support of integration. Central facility failure data from this period is not suitable for computation of central subsystem reliabilities.

(2) These reliabilities are based on a 29,352 hour operating life.

3.5.2 CENTRAL SUBSYSTEMS AND TELEPHONE LINES

Central facility operation prior to 11/1/72 was mainly in support of the integration effort and consequently should not be used for reliability computations. Similarly, the completeness and accuracy of telephone line failure data prior to 11/1/72 is questionable.

3.6 COMBINED UTCS/BPS RELIABILITY EXPERIENCE

This section is concerned with the effect of BPS equipment on overall system reliability. The problem is approached by first computing BPS subsystem reliability figures and then combining these with the corresponding UTCS subsystem reliabilities in order to obtain a composite figure.

There are three BPS subsystems: the onboard bus transmitting subsystem (Figure 20) (which has no UTCS analog), the BPS detector subsystem (Figure 21), and the central communications equipment (over and above that also required for UTCS) associated with BPS operations. The latter consists only of the 3FR receivers, which are shown as a part of a combined UTCS/BPS central communications system in Figure 22.

3.6.1 BPS ON-BOARD TRANSMITTING SUBSYSTEM

There is no UTCS analog for this BPS subsystem. Table 10 shows the numbers of buses equipped with the transmitters and the number of failures recorded in the period 11/1/72 to 6/24/74. The bus system was inventoried at the later date to determine operational and failure status. Buses are assumed to operate a six day, ten hour per day schedule. Therefore, in the 81-week observation period the total operating hours were 81 x 6 x 10 = 4860 hours. The bus transmitter subsystem MTBF is:

$$(\mathrm{MTBF})_{TS} = \frac{4860}{46} = 106 \text{ hours}$$

3.6.2 BUS DETECTOR SUBSYSTEM

The period of observation for the bus detector subsystem extended from 2/23/73 to 9/16/74, a period of 590 days. The equipment operates 24 hours/day, so the total operating time during the observation period was 590 x 24 - 14,160 hours. As shown in Figure 21, the subsystem equipment consists of:

- Bus loop (total complement : 144)
- Bus detector (total complement : 144)
- 3FS transmitter (total complement : 144)

The number of equipment failures[1] during this period was:

- Bus loops : 3
- Bus detector : 2
- 3FS transmitters : 3

------

(1) Bus system failure data is not included in Table 2. Refer to Reference 2.

A. Equipment MTBFs

Bus detector subsystem equipment MTBFs are given by:

$$(MTBF)_{bus\ loop} = \frac{144 \times 14{,}160}{3} \approx 679{,}700 \text{ hours}$$

$$(MTBF)_{bus\ detector} = \frac{144 \times 14{,}160}{2} = 1{,}020{,}000 \text{ hours}$$

$$(MTBF)_{BD\ 3FST} = \frac{144 \times 14{,}160}{3} = 679{,}700 \text{ hours}$$

B. Normalized Bus Detector Subsystem MTBF

Assuming the bus detector subsystem consists of a single loop, detector, and transmitter, the normalized Bus Detector Subsystem MTBF is given by:

$$\frac{1}{(MTBF)_{NORM,\ BD}} = \frac{1}{(MTBF)_{loop}} + \frac{1}{(MTBF)_{det}} + \frac{1}{(MTBF)_{3FST}}$$

$$\frac{1}{(MTBF)_{NORM,\ BD}} = \frac{1}{679{,}700} + \frac{1}{1{,}020{,}000} + \frac{1}{679{,}700}$$

$$(MTBF)_{NORM,\ BD} \approx 263{,}200 \text{ hours}$$

C. UTCS/BPS Bus Detector Subsystem MTBF

Based on a complement of 144 subsystems, the Bus Detector Subsystem MTBF is:

$$(MTBF)_{BD} = \frac{(MTBF)_{NORM,\ BD}}{144}$$

$$(MTBF)_{BD} = \frac{263{,}200}{144}$$

$$(MTBF)_{BD} \approx 1830 \text{ hours}$$

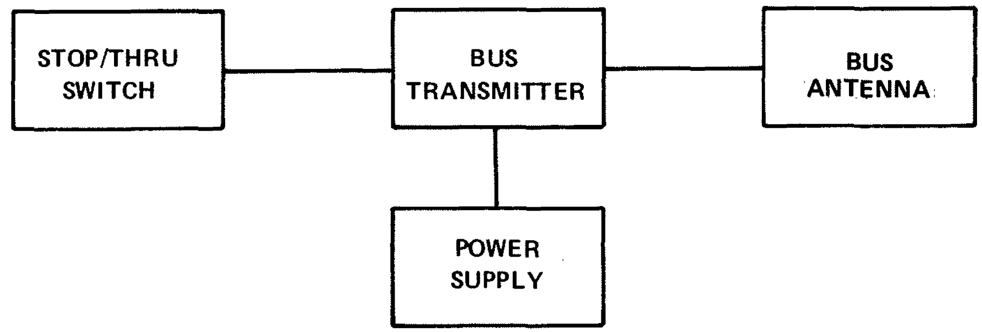

Figure 20. BPS On-Board Transmitting Subsystem

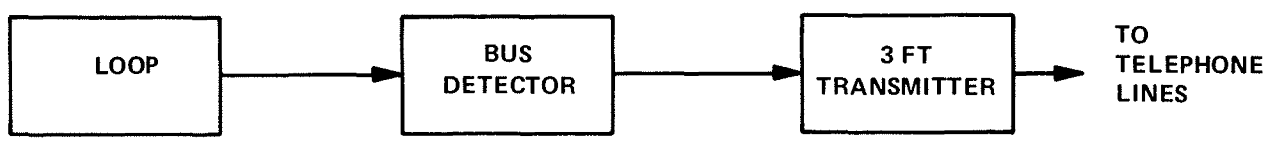

Figure 21. Bus Detector Subsystem

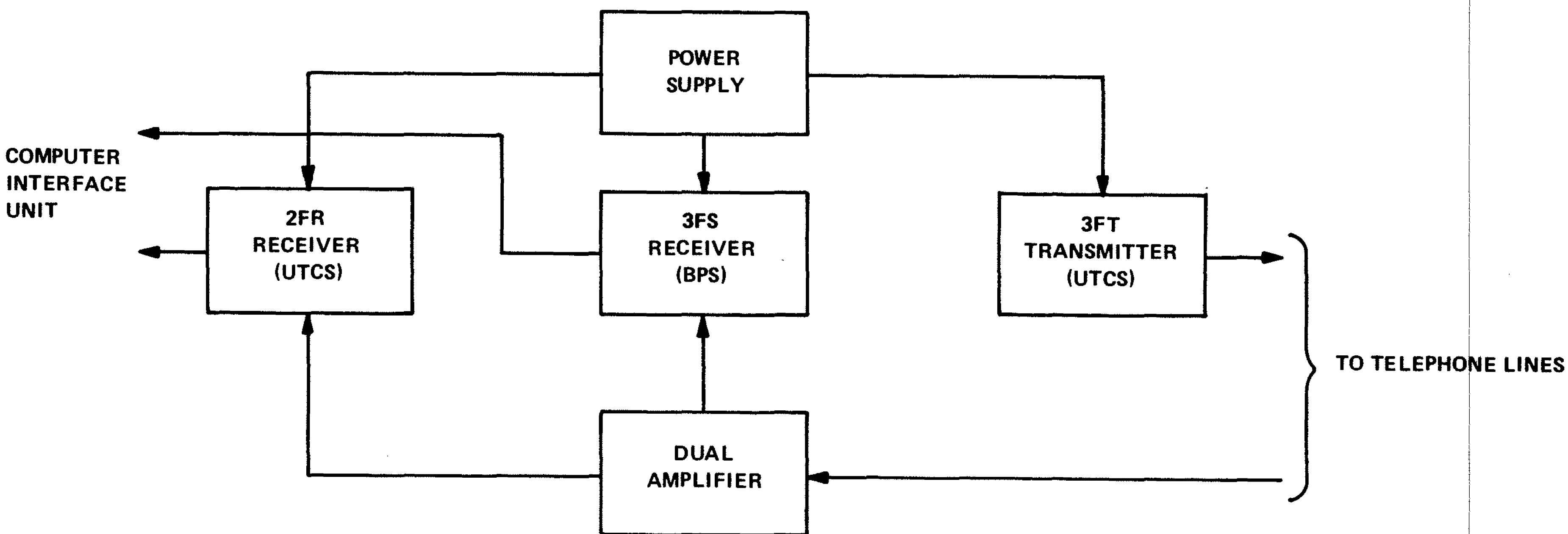

Figure 22. Combined UTCS/BPS Central Communications Subsystem

TABLE 10. TRANSMITTER-EQUIPPED BUSES AND BUS-MOUNTED EQUIPMENT FAILURES IN THE PERIOD 11/1/72 TO 6/24/74

Depot	Number of Buses Initially Equipped	Observed Transmitting Subsystem Failures (1)
Bladensburg	216	21
Northern	112	16
Western	122	9
	450	46

(1) The onboard system consists of an operator-actuated switch as well as a transmitter. However, there were no reported switch failures due to electrical causes. The only switch failures were mechanical, and were caused by operators inadvertently breaking them.

3.6.3 COMBINED UTCS/BPS FIELD SYSTEM

Referring to section 3.4.1 D, the UTCS overall field system, excluding BPS equipment, had an MTBF of 150 hours relative to an observation period of 23,328 hours.

The BPS onboard transmitting system has an MTBF of 106 hours, as shown in paragraph 3.6.1.

Assuming the Bus Detector Subsystem MTBF of 1830 hours is the same for a 23,328 operating period as for the actual operating period of 14,160 hours, the composite UTCS/BPS field system has an MTBF of:

$$\frac{1}{(\mathrm{MTBF})_{\mathrm{FS,\ COMP}}} = \frac{1}{150} + \frac{1}{1830} + \frac{1}{106}$$

$$(\mathrm{MTBF})_{\mathrm{FS,\ COMP}} \approx 60 \text{ hours}$$

3.6.4 COMBINED UTCS/BPS CENTRAL COMMUNICATIONS SUBSYSTEM

Referring to Figure 22, the constituents of the combined central communications subsystem are:

Dual amplifier

2FS receiver

3FS transmitter

Power supply

3FS receiver

During the 8016-hour operating period considered in section 3.4.2 A, the failures were as follows:

Dual amplifier	-1
2FS receiver	-10
3FS transmitter	-3
Power Supply	-3
3FS receivers	-6*

Thus, the combined UTCS/BPS Central Communications Subsystem has an MTBF given by:

$$(\text{MTBF})_{\text{CCS}} = \frac{8016}{1+10+3+3+6} = 349 \text{ hours}$$

3.6.5 COMBINED UTCS/BPS SYSTEM

The combined UTCS/BPS System consists of the following subunits, each of which is accompanied by its MTBF in parenthesis:

- Field subsystem (MTBF = 60 hours, Section 3.6.3)
- Central communications subsystem (MTBF = 349, Section 3.6.4)
- Central processor and peripheral subsystem (MTBF = 157 hours, Section 3.4.2 B)
- Display subsystem (MTBF = 501 hours, Section 3.4.2 D)
- Telephone subsystem (MTBF = 303 hours, Section 3.4.3)

The combined UTCS/BPS system therefore has a reliability given by:

$$\frac{1}{(\text{MTBF})_{\text{UTCS/BPS}}} = \frac{1}{60} + \frac{1}{349} + \frac{1}{157} + \frac{1}{501} + \frac{1}{303}$$

$$(\text{MTBF})_{\text{UTCS/BPS}} = 32 \text{ hours}$$

----

*This figure is projected from an observed rate of 3 failures in the 4,016-hour operating period from 9/13/72 to 9/10/74 (Reference 2).

3.7 CENTRAL SYSTEM AVAILABILITY

3.7.1 CRITICAL SUBSYSTEM

Referring to section 3.4.2 C, the critical central facility equipment consists of:

- CPU
- RAD
- CIU
- TTY

and has an MTBF of 382 hours as was determined in section 3.4.2 C. From Table 3, the average time-to-repair for these elements is 3.5 hours**. Thus, the availability of the critical central processing system is:

$$\text{Critical CPU Availability} = \frac{\text{MTBF}}{\text{MTBF} + \text{MTTR}} + \frac{382}{382 + 3.5} = 99.1\%$$

3.7.2 CPU AND PERIPHERAL (CPUP) SUBSYSTEM

From Section 3.4.2 B, the CPUP Subsystem has an MTBF of 157 hours, and from Table 3, the mean time-to-repair for the constituent elements (CPU, RAD, CIU, MTU, LP, CR, TTY) is 3.8 hours. Thus, the availability of the CPU and peripheral subsystem is:

$$\text{CPUP Availability} = \frac{157}{157 + 3.8} = 97.6\%$$

3.8 FAILURE RATES, MEAN TIME TO REPAIR, AND MAINTENANCE STAFFING REQUIREMENTS

An estimate of maintenance staffing requirements can be made if yearly failure rates and mean-times-to-repair are known. The relationship is:

$$M = F \times \text{MTTR}$$

where:

M = average yearly maintenance time, in hours

F = average yearly failure rate

MTTR = mean time to repair, in hours

- - - - - - -

**This average, which is obtained by averaging the down times reported in Table 3, excludes double reporting of the down-time on 12/4/73, when the RAD AND CPU failed at the same time.

The mean-time-to-repair should include not only the time to identify the cause of the problem and restore the equipment or subsystem to operating condition, but the travel time to and from the repair location.

In practice, mean-time-to-repair is a parameter which requires an extensive and costly time-and motion study to determine. Careful records of travel time between locations must be kept, and primary trouble calls must be separated from secondary(1) calls.

Since a study of this type was not performed, the mean-time-to-repair for UTCS/BPS field equipment is not available, although more controllable conditions at Central made it possible to estimate mean-time-to-repair for the central facility equipment.

However, the UTCS/BPS experience indicates that, for a system of this size and complexity, a minimum staffing requirement is two maintenance personnel (in addition to an operator), one for street equipment and one for the non-computer central equipment such as communications, map, and control panel.

The reason for this requirement is not only the possibility of simultaneous street and central facility failures, but the fact that maintenance personnel functions are broader than maintenance itself. In the case of UTCS/BPS, approximately 30 percent of the maintenance work schedule was devoted to street repairs. The rest was spent on associated duties such as record maintenance, parts purchase, coordination and monitoring of subcontractors and utilities, bench repair, and system evaluation.

------

(1)Primary calls are those which result from failure reports recorded by the system. Secondary calls are those which may appear while maintenance personnel are at the trouble location. For example, maintenance personnel will often make minor repairs to equipment as the need arises, once a controller box is opened, even though no failure report is associated with the repair. This time should not be charged to the failure itself. It is a part of general preventive maintenance, and can account for a considerable fraction of total maintenance requirements.

SECTION 4

MAINTENANCE EXPERIENCE

Maintenance of the Urban Traffic Control System was divided into three categories: control center equipment, field equipment, and software. Control center equipment was maintained by system manager personnel with regular computer maintenance performed by Xerox. Maintenance was performed on field equipment when system manager personnel responded to a trouble call. At that time, all equipment at that particular location was checked for proper operation. Software was maintained by system manager personnel when necessary. The following describes the maintenance experience in these three areas.

4.1 CENTRAL EQUIPMENT

UTCS/BPS provides a continuous on-line check of system operation, it reports malfunction to the central operator, in the form of an audible alarm, and it provides hard copy and CRT displays. Central equipment was comprised of the two computers associated peripherals, computer-communications interface, and the communication equipment. A complete inventory is presented in Table 10.

4.1.1 MALFUNCTION DETECTION AND MAINTENANCE PROCEDURES

A malfunction is indicated and recorded by three detection peripherals. These are the control panel malfunction lamp indicators, the CRT display, and the line printer.

The first indications of a system malfunction are the activation of an audible alarm and illumination of a malfunction indicator. There are seven malfunction indicators located in the upper left section of the Control Panel (Figure 4). These indicators are:

- CPU # 1
- CPU # 2
- Traffic System Controller
- Traffic System Detector
- Traffic System Communication
- BPS Detector
- BPS Communication

The CRT is used by the central operator or technician to obtain detailed information of the location and type of malfunction. A hard copy listing of system malfunctions can be obtained for every 15 minute period; see Appendix C, Reference 4-1.

Experience has shown that the telephone data lines used for communication to and from the Control Center were the most likely source of failure. These lines transmitted the Hold/Advance, A Phase Green returns, and detector information to the system. The telephone lines were leased from the local Bell System Telephone Company and maintained on a trouble call basis. Most of the failures were caused by open pair problems in the main frame of the telephone switching stations. Failures were also caused by open coils used for inductive loading and isolation. The Telephone Company maintained a "best effort" response time, but usually commenced repairs within two hours.

Telephone line problems usually were easy to identify, troubleshoot, and isolate. If an input data line failed, usually five or six controllers would also fail. This would be seen on the control panel as a controller failure indication or as a red indication on the map status display and would be indicative of a telephone line malfunction. Related detectors, associated with the failed controllers, would also appear as communication failures on the control panel malfunction indicators and the failure status page of the CRT.

Output line failures, like input lines, were also detected from the operators control panel. Simultaneous controller malfunctions were usually associated with the same telephone pair problem. A Cross Reference Directory, showing the system equipment associated with both input and output data lines, was used during malfunction repair in order to correlate multiple controller failures after which time the telephone company was notified of the problem and its location. Figure 23 shows the telephone termination panel and test rack.

Maintenance on the computer system was performed each Friday by Xerox Data Services. The services performed were preventive maintenance of the line printer, 3 magnetic tape drives, card reader, card punch, two rapid access disks, and the two computers. Diagnostics were used to check these equipments for failures and to see if all units would function as a system. Failures during the work week were reported to Xerox for assistance and repair.

Any system malfunction traceable to the Sigma 5 computer, or any of its associated peripherals was referred to Xerox customer service for repair. The service contract for maintenance of the computers were based on a 2-hour response time during working hours. The exception to this rule occurred when the Computer Interface Unit (CIU) malfunctioned. At that time, the systems manager personnel isolated the problem to a printed circuit board by using the communications/CIU interface wiring diagrams. Xerox was notified and the board was replaced by Xerox personnel. CIU failures were minimal and did not cause major system problems. See Figure 24 for an internal view of the CIU.

Figure 23. Telephone Termination Panel and Test Rack

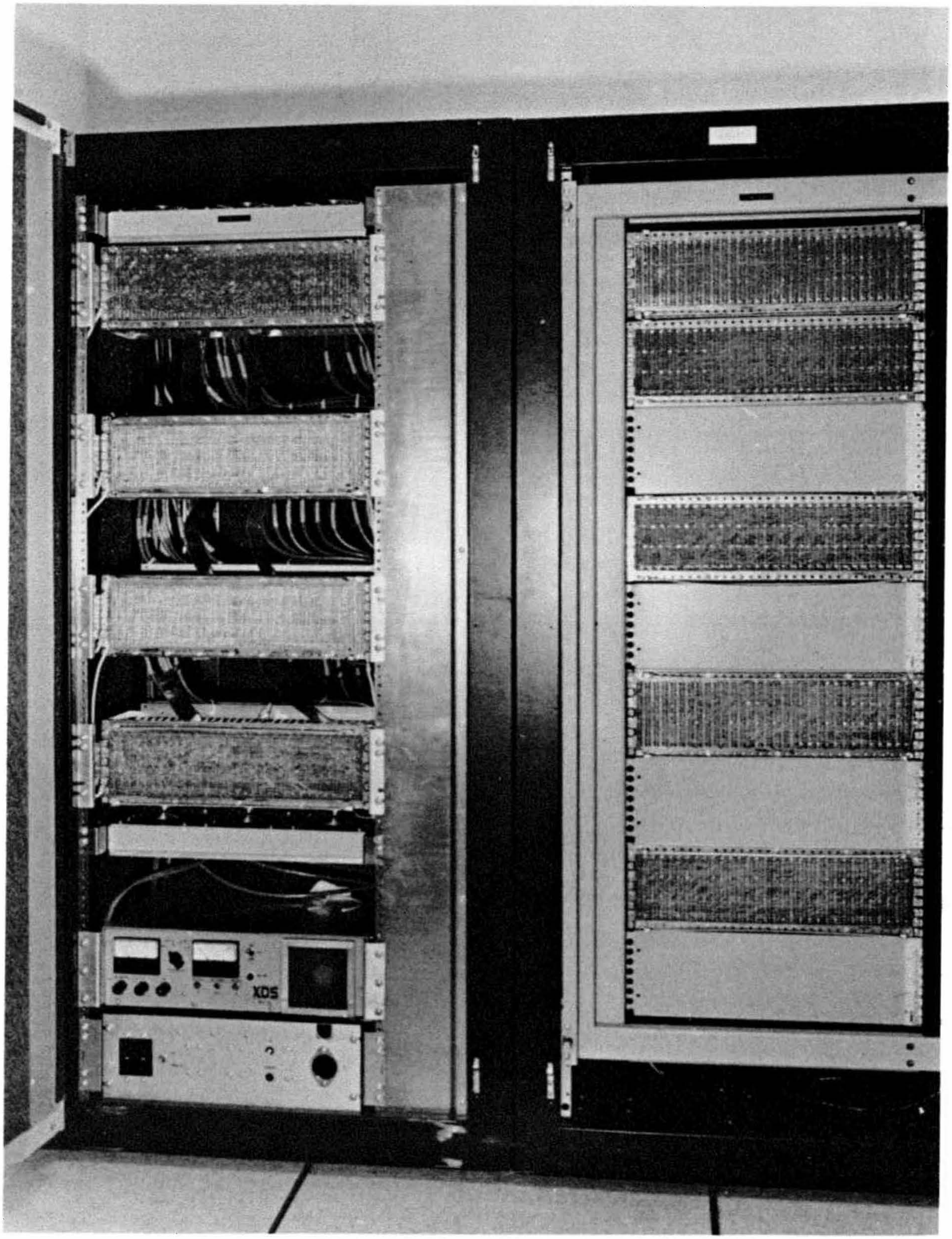

Figure 24. CIU Internal View

The computer system was comprised of two Xerox Sigma 5 CPUs. The memory, shared by both CPUs, consisted of 32k words with an additional 16k words dedicated to each CPU. CPU #1 had access to the full 64k words, whereas CPU #2 accessed only 16k words but had the capability of addressing the memory associated with CPU #1.

The weekly preventive maintenance program was performed each Friday afternoon (4 hours) with the only seemingly repeatable failure being the power supplies which provided the CPU logic voltages.

The Rapid Access Discs (RAD), one with 3 megabytes of storage and the other with 1.5, were used to store the operating system program, UTCS and BPS programs, traffic patterns, and start-up parameters. The RAD operated continuously and became "tempermental" during greater than normal temperature variations.

The system used three Magnetic Tape Drives; two were dedicated to the UTCS CPU, and the third could be switched to either CPU. Adjustments of the tape drives proved to be critical. Weekly checks were performed for read-write compatability.

The card reader was a generally reliable unit. Care was taken to keep the photo-electric system clean for accurate card readout. The only true problem associated with the card reader was the "picker" tolerance. Different thickness cards, within the same deck, created a problem at times.

The card punch and line printer caused no real problem to system operation. Daily cleaning of the line printer was required due to the accumulation of paper dust.

Figures 25 and 26 show all the UTCS/BPS control center equipment.

When a malfunction occured in the map display, inputs and outputs from the Map Electronics Unit were checked first (Figure 27). The fault usually indicated was loss of a telephone line to an A Phase Green input receiving module. This fault would cause the map to improperly display both red and green simultaneously at that particular map location, indicating a failure to a printed circuit board in the Map Electronics Unit. The map output display was under constant demand for both traffic flow and failure status. The map display indicator lamps were continually checked for outages. During replacement of map bulbs, the map power supply was turned off to avoid shorting the lamp driving transistors (Figure 28). If this occurred, a dim glow from both the red and green lamps indicated that the lamp drivers were faulty. Replacement of these transistors was performed by isolating the printed circuit board and using the Map Display Test Set and controller

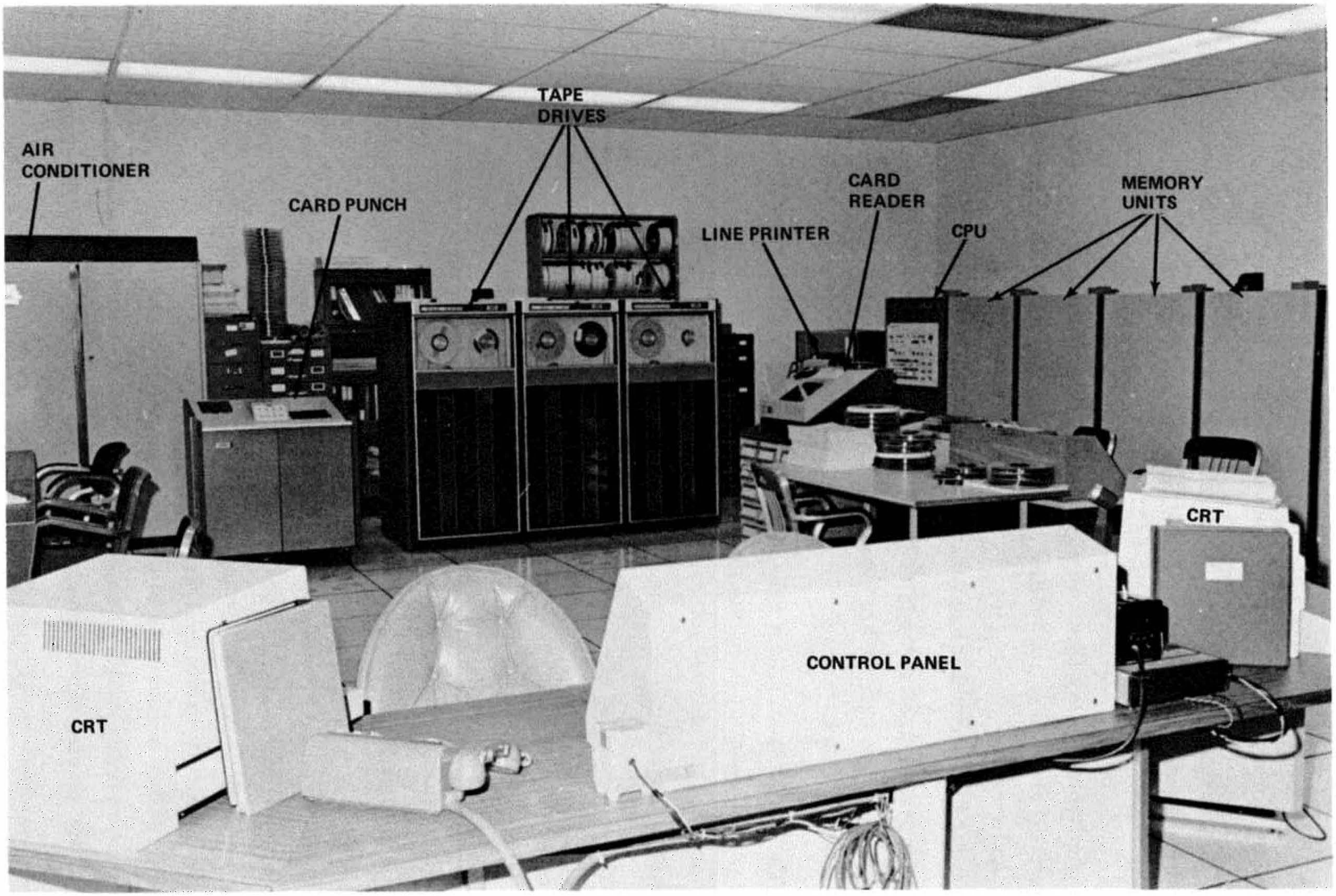

Figure 25. View of Control Center from Rear of Control Console (front of room)

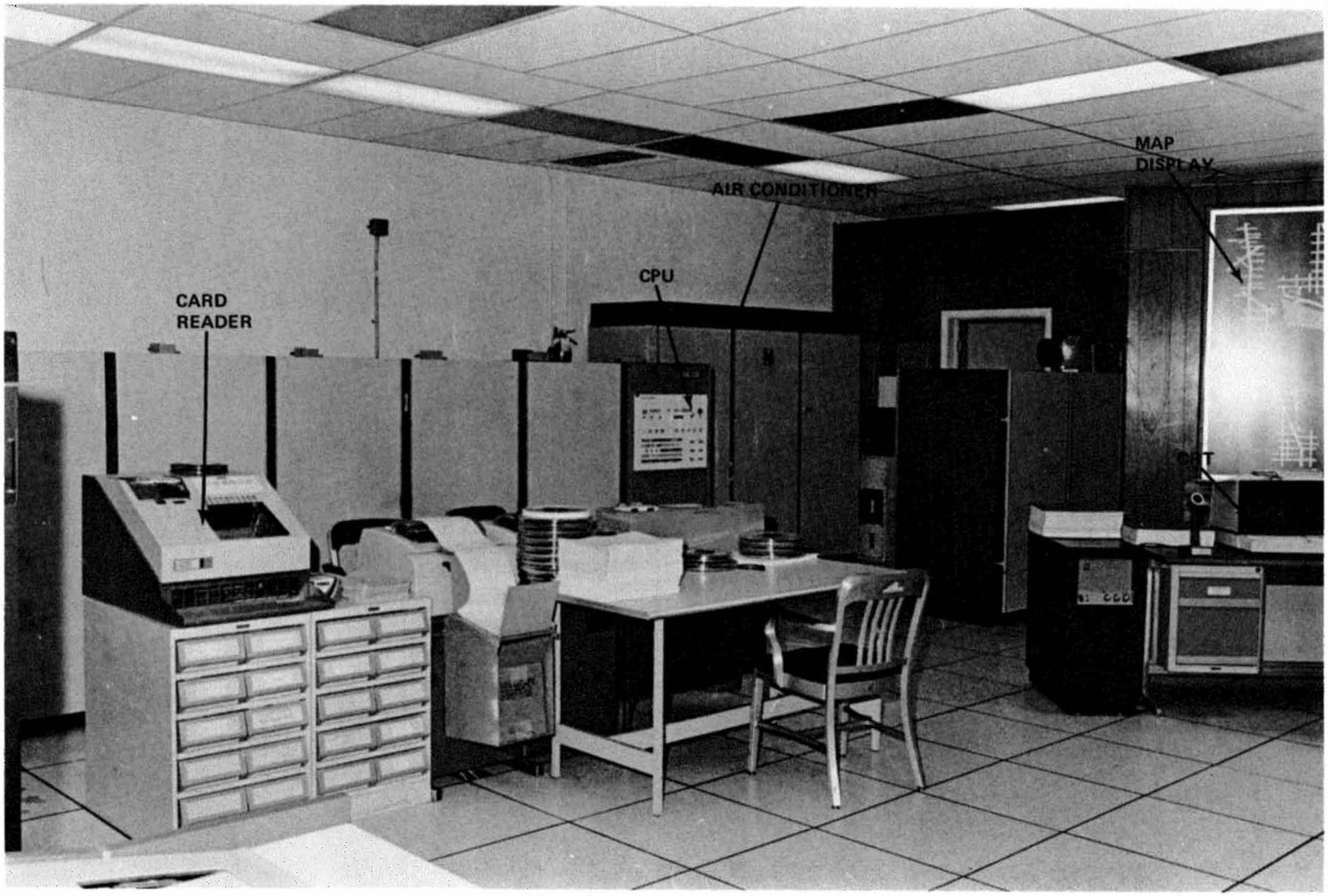

Figure 26. View of Control Center from Rear of Room

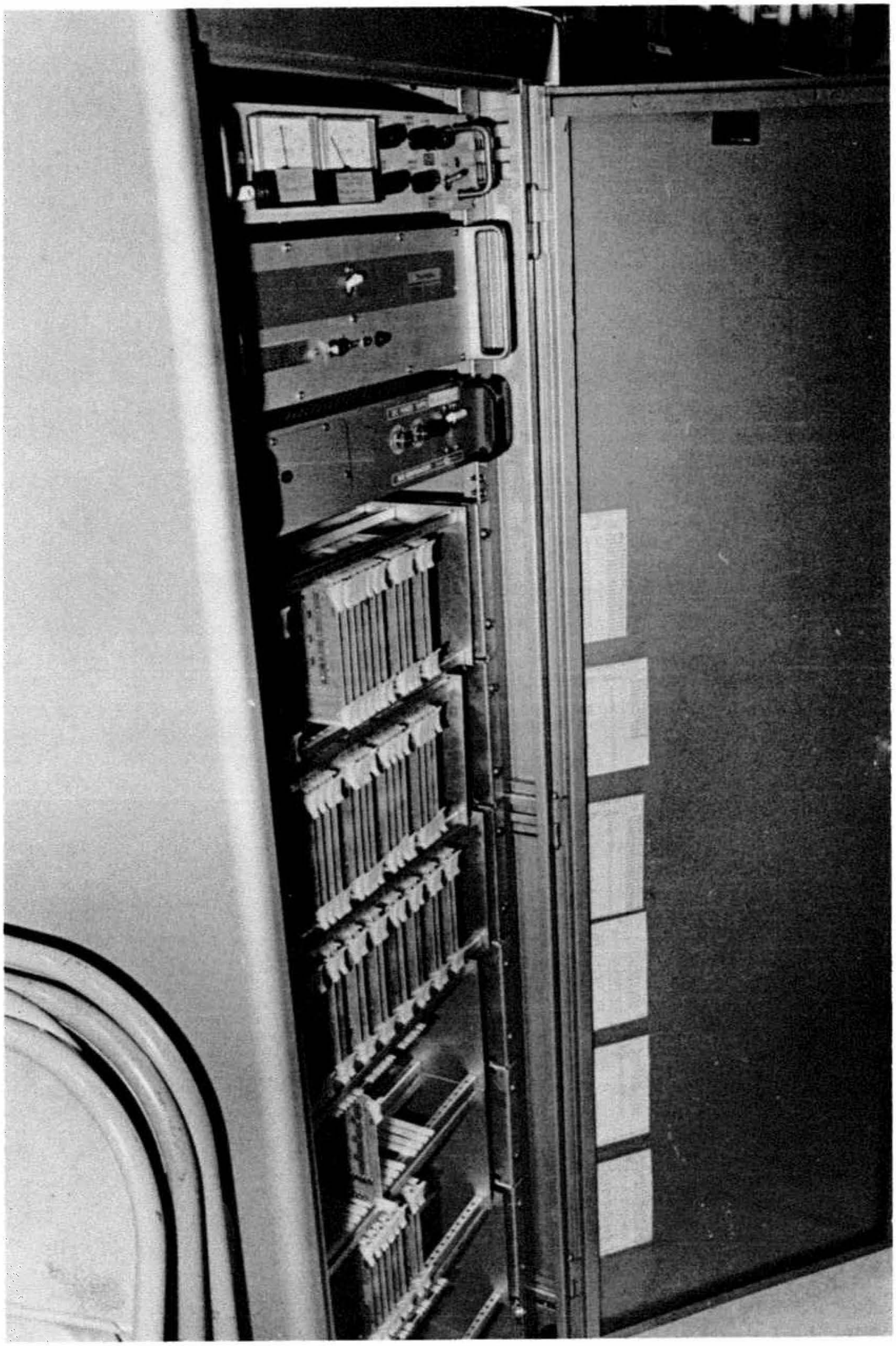

Figure 27. Map Electronics Cabinet

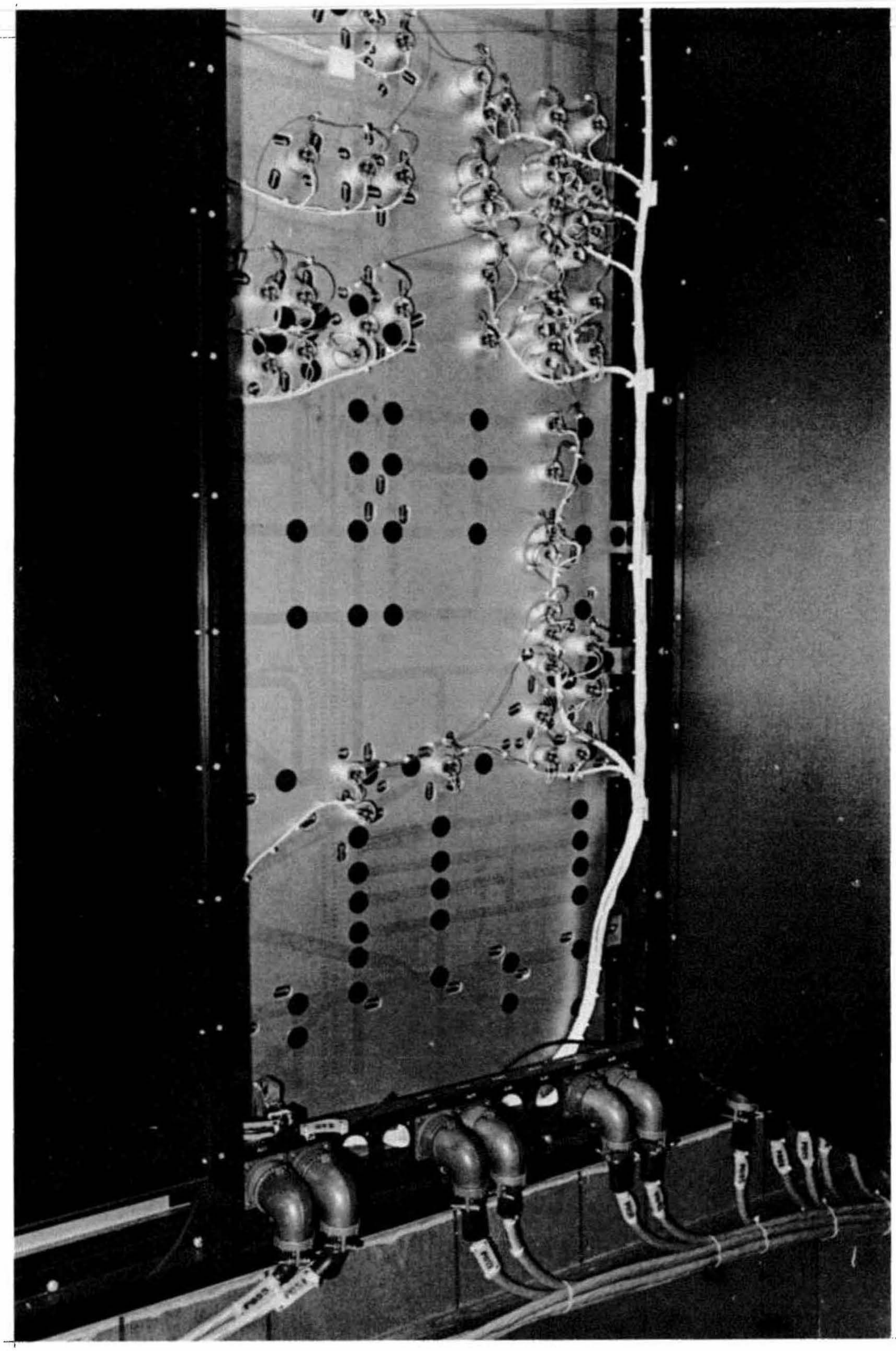

Figure 28. Rear of Map Display Showing Cables and Lamp Holders

address/location tables. When the board was isolated, an ohmmeter was used to check the resistances across the emitter, base, and collector combinations of the driver transistors for final component replacement.

4.1.2 CENTRAL POWER AND ENVIRONMENTAL EXPERIENCE

The computer system was housed in a temporary 50' x 50' building which was cooled by two 15-ton EPAC air conditioners. Incoming power was 240 volts/600 amp service. Twenty-five percent of the available 2500 square feet was used by the District of Columbia and the remaining seventy-five percent for UTCS/BPS.

The UTCS/BPS power requirements were estimated to be half the input service available. Power cables to the system were run in conduit under the raised floor, as were the power cables to the perphials.

Each system unit had its own circuit breaker, in addition to the main circuit fusing, in order to isolate it from possible chain power failures.

The air conditioner fed its cooled humidified forced air under the raised floor to each piece of equipment (where ducts were cut into the floor for air to enter the equipment cabinets).

Temperature in the control area was held to 72^{o}F at 45% humidity. Because of the uncontrolled environment of the temporary building (caused by entrance doors opening during the day and allowing warm air and dust to enter the computer area) temperature control and dust buildup were more uncontrollable then expected. Equipment was vacuumed more then once a week and temperature variations caused hot spots in the equipment area. A more desirable way of controlling this problem would have been to enclose and isolate the computer area from office and entrance ways as is planned for the permanent building. The computer system was usually run for 12-hour periods, so that the temperature variations occurred when the system was not in use.

4.2 SOFTWARE MAINTENANCE

The UTCS network was used as an evaluation vehicle for the advanced traffic control strategy development, and as such has undergone numerous revisions to accommodate new design concepts. Each control algorithm design or modification was developed, programmed, operated, tested, and evaluated in the UTCS real-time environment. The system manager was responsible for and performed all of the software maintenance and modifications associated with the support of the first generation UTCS network. The effort involved the implementation of data updates, modifications to the traffic control algorithms, and additions to the control program logic and to the system data base.

4.2.1 MULTIPLE SOFTWARE SYSTEM MAINTENANCE

Each first generation software system developed for testing and evaluation added to an expanding library of systems requiring software maintenance, separate system documentation, flow charts, coding listings, magnetic tape concerns of the system, and related pattern and history information. Thus each change, such as network configuration changes, had to be incorporated into each generation of software systems in order to maintain their operational readiness.

After each system evaluation, the associated documentation and source tapes were considered final. Pertinent items were retained in storage, but no further updates were made to that particular version of the system.

4.2.2 SYSTEM UPDATING

The software procedures followed for system updates are the same for either major or minor changes and are reflected in degree of effort only. Minor system or data base changes are initially made via either CPU #2, or the control panel prior to their incorporation into the system. This allowed for a test of the change before a permanent modification was made. Single programs or sets were updated using an update deck. However, once a system had been listed and attained some level of readiness, a save tape was made.

These procedures as well as the updating of traffic pattern data are described in the following section.

4.2.3 SYSTEM UPDATING PROCEDURE

A. Updating a Compressed Deck

The use of the Compressed Output, (CO), option of the MACRSYM card directs Macro-Symbol to produce a compressed deck from a source program which can then be used as input during a later assembly. Further details regarding these operations as well as terminology explanations are contained in Appendix C, Reference 4-2. Because compressed decks contain one-fourth to one-fifth as many cards as the source deck, they are significantly more manageable and faster to handle.

Macro-Symbol recognizes three update control commands:

+k where k is a line number corresponding to a line on the source or assembly listing produced from the compressed deck. The +k control card designates that all cards following the +k card, up to but not including the next update control card, are to be inserted after the kth line of the source program. The command +0 designates an insertion before the first line of the program.

+j,k where j and k are line numbers corresponding to line numbers on the source or assembly listing produced from the compressed deck, and j is less than or equal to k. This form designates that all cards following the +j,k card, up to but not including the next update control card, are to replace lines j through k of the source program. The number of lines to be inserted does not have to equal the number of lines removed; in fact, the number of lines to be inserted may be zero. In this case, lines j through k are deleted.

+END where END designates the physical end of an update packet. If the Symbolic Input, (SI), and Compressed Input, (CI), devices are the same, this command is optional, since Macro-Symbol terminates the update packet automatically on encountering the first compressed card. If the SI and CI devices are different, this command is necessary.

The + character of each update control command must be in column 1, followed immediately by the control information, with no embedded blanks. The first blank column terminates the control command, and comments may optionally follow the blank. The update control commands, with their associated update records, must occur in numeric sequence.

Compressed decks can be updated via an "update packet", which is the set of cards between the first + (update) command and the compressed deck. If any symbolic cards (a "symbolic deck") precede the first + command, they are treated as if they were preceded by an a + 0 card (see +k above); that is, they are inserted before the first line of the program.

The ranges of successive insert and/or delete control commands must not overlap, except that the following case is permissible: +j, k followed by +k, where j < k. Overlapping control commands cause an abort error.

As an example, consider the partial listing of Routine L (Figure 29) with the following modifications required:

a) The second element of the Stored Answer (STANS) array is to be moved to the end of the array.

b) A new element, having the value of 6, is to be added as the last element of the expanded STANS array.

c) The first operation performed by Routine L is to be a 'Store-doubleword' instruction.

```
200  16:46  AUG 02, '72                       ***** RTN. L  COMPUTER EVALUATION *****                2
                                                DEF      RTNL,RTNBJ,CPFLG,BPSDOWN
                                                 REF      SHTFLG
                                                REF      QMAST,KMAST,CRTFL1,CRTFL2,CRTDC1,CRTDC2
                                                 REF      LMAST,MAST,CPANOUT,BPSYSIF,WMINF,MASK                   RTNL
                                                SYSTEM   UTCSREG
   01 00000                       ARADD         RES      1            * ADD OF INPUT DATA CPU-1
   01 00001                       ARADD2        RES      1            * ADD OF INPUT DATA CPU-2
                                                BOUND    8
   01 00002                       EXVA1         RES      12           * RESULT OF CPU-1 CALCULATION
   01 0000E                       EXVA2         RES      12           * RESULT OF CPU-2 CALCULATION
   01 0001A                       INPUT         RES      8            * VARIABLE INPUT ARRAY
                                  *                                   * ARRAY OF STORED DATA
   01 00022    00000001 A         STDATA        DATA     1
   01 00023    00000002 A                       DATA     2
   01 00024    00000003 A                       DATA     3
   01 00025    00000004 A                       DATA     4
   01 00026    00000005 A                       DATA     5
   01 00027    00000006 A                       DATA     6
   01 00028    00000007 A                       DATA     7
   01 00029    00000008 A                       DATA     8
   01 0002A    00000000 A         CPFLG         DATA     0            * COMPARISON FLAG
   01 0002B    00000000 A         FLAG          DATA     0            * ENTRY FLAG FOR L1
   01 0002C    00000000 A         FLAG2         DATA     0            * ENTRY FLAG FOR BJ
   01 0002D    00000000 A         BPSDWN        DATA     0                 *SHT DOWN BPS FLAG         RTNL
                                  *                                   * ARRAY OF STORED ANS
                                                BOUND    8                                            RTNL
   01 0002E    FFFFFFFF A         STANS          DATA    X'FFFFFFFF'
   01 0002F    FFFFC19C A                        DATA    X'FFFFC19C'
   01 00030    00000702 A                        DATA    X'00000702'
   01 00031    FFFFC194 A                        DATA    X'FFFFC194'
   01 00032    00000016 A                        DATA    X'00000016'
   01 00033    00000001 A                        DATA    X'00000001'
   01 00034    00000404 A                        DATA    X'00000404'
   01 00035    00000200 A                        DATA    X'00000200'
   01 00036    00000003 A                        DATA    X'00000003'
   01 00037    0000000A A                        DATA    X'0000000A'
   01 00038    00000705 A                        DATA    X'00000705'
   01 00039    00000002 A                        DATA    X'00000002'
   01 0003A    00000005 A         BEGIN         DATA     5
                                  *                                   * TEMPORARY STORAGE
   01 0003B                       TEMR          RES      1
   01 0003C                       TEMR1         RES      1                                            RTNL
   01 0003D                       TEMR2         RES      1            *                               RTNL
   01 0003E                       TEMR3         RES      1            *                               RTNL
                                  *  ENTRY WHEN CPU1 AND CPU2 OPERATIONAL
   01 0003F                       RTNL          RES      0            *                               RTNL
   01 0003F    3500003C                          STW,0   TEMR1        SAVE EXIT FOR RTNL2 OR SHUTDOWN
   01 00040    3300002A                          MTW,0   CPFLG             *TST MODE OF OPERATION     RTNL
   01 00041    69300053                          BNEZ    RTNL2             *NO CPU 2, USED STR DATA   RTNL
   01 00042    2260000C A                        LI,R6   12
```

Figure 29. Partial Listing of Routine L (reduced)

The update packet to accomplish these changes would appear as:

Column 1	Column 10	Column 20
+29, 29		
+39		
	DATA	X'FFFFC19C'
	DATA	X'00000006'
+48, 48		
	STD, 0	TEMRI
+END		

B. Assembly Updates In Batch Mode

When batch assemblies consist of successive update packets from card input to compressed decks on the RAD or magnetic tape, the update packets are terminated by +END cards.

There must be a one-to-one correspondence between update packets and compressed programs. For example, three compressed decks on magnetic tape would require three update packets so that each compressed deck would receive its update in correct sequence. If only two of the compressed decks were to be updated (i.e., decks 1 and 3), the sequence integrity would be maintained by placing two +END cards after update packet 1. When the assembler reads the second +END card, it would update compressed deck 2 with an "empty" update packet and then update compressed deck 3 with update packet 3. At the conclusion of each update, the new (updated) version is written on the CO device.

Further details regarding these operations as well as terminology explanations are contained in Appendix C, Reference 4-2.

C. Manual Correction Procedure Using CPU 2 Control Panel

1. Set address of location to be examined/changed using the SELECT ADDRESS switches.

2. Actuate momentary DISPLAY toggle switch to the SELECT ADDR (down) position, and release to neutral (center). Current contents of the selected address can now be inspected in the DISPLAY light bank.

3. If contents of the location are to be modified:

   a. Define new bit configuration of the entire memory word using the DATA switches on the CPU Control Panel (Figure 30).

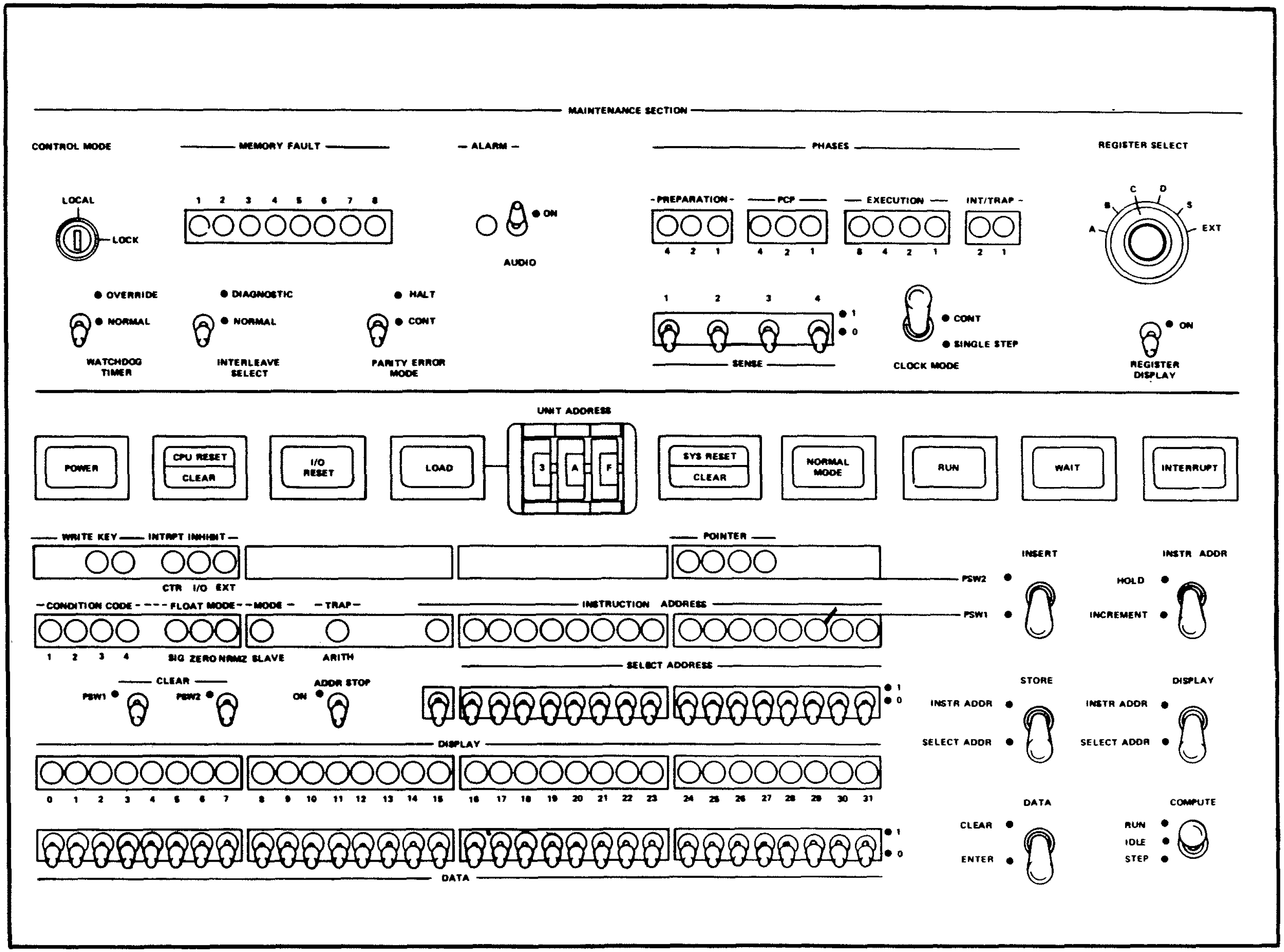

Figure 30. CPU Control Panel (Switch Configuration Before CPU #1/CPU #2 Start-Up)

b. Actuate momentary DATA toggle switch to CLEAR (up) position and then down to ENTER. The redefined configuration should now be indicated in the DISPLAY light bank.

c. Actuate momentary STORE toggle switch to the SELECT ADDR (down) position and return to neutral.

Note that if a CPU 1 address is desired, X'4000' must be added to the CPU 2 address of the CPU 1 address is between X'000' and X'3FFF'; X'4000' must be subtracted from the CPU 2 address if the CPU 1 address is between X'4000' and X'7FFF'. For all other CPU 1 addresses, the CPU 2 address is the same.

D. Procedure for Creating a Save Tape

A save tape of the entire software stored on the RAD may be created by mounting the magnetic tape with ring-in on tape drive 7TAE0. Next, input the following commands on the CPU1 TTY:

```
Key-In:   "TYC"
Type-In:  !JOB 1, SAVTP
          !RADEDIT
          :SAVE ALL
          !FIN
Key-In:   "CC"
```

E. Procedure for Loading a Pattern

A FORTRAN Pattern Program is available for loading patterns on the RAD. A sample case using this program was supplied with input card data for three of the existing Time of Day (TOD) street implementations.

The FORTRAN Pattern Program must be run as a background job. If the system is operating in the foreground traffic mode and not controlling on-street field equipment, the system can be placed in the background mode by the Key-in "RLS KING" on the CPU 1 TTY. Maximum background core is needed and made available by the key-in "FMEM 0".

The Pattern Program is segmented into a FORTRAN main program (UTCSIN), a FORTRAN subroutine (PTNRAD), and a Macro-Symbol Assembly language subroutine (PAT-OUT). The main program (UTCSIN) reads the basic pattern information and computes the required UTCS pattern parameters. These values are then passed to PTNRAD which formats them for storage on the RAD. The first input (Pattern Number and Options), specifies which pattern is being updated, whether a hexadecimal dump of the updated pattern is desired, and whether Volume and Occupancy History cards will be input. The second input, Offset and CIC Time of Day Flag, specifies which controllers are to be modified, the offset value (with resolution to one-half second), and the CIC Time of Day Flag. This input is used by PTNRAD in the following manner:

1. A card is read and the controller number (J) extracted.
2. The section (KSEC) containing controller J is determined.
3. The pattern corresponding to this section and the input pattern number (PTNN) are read into core by subroutine PATOUT, if it is not already resident.
4. Controller J's updated parameters, computed by UTCSIN, are inserted into the "boiler-plate" pattern.

This process continues until a controller number is read which corresponds to a different UTCS section. At that time, the current section's pattern is written to the RAD, by subroutine PATOUT, and the new section's pattern is read into memory. The source image of the routine is on magnetic tape (labeled PATGEN). The procedure for executing the program is as follows.

1. Key-In "FMEM 0"
2. Mount source tape PATGEN on E0.
3. Run the following JOB:

```
!JOB 1, PATGEN
!STDLB (SI, BO)
!FORTRANH SI, LS, GO, X (See Note 1)
!MACRSYM SI, LO, GO (See Note 2)
!STDLB (SI, C)
!OLOAD (MAP, PROG)
:ROOT (FIL, BT, GO, EOD), (ENTRY, 4MAIN)
!PAUSE KEY IN 'SYC'
!ROV
    PATTERN DATA CARDS
!FIN
```

NOTES:

1. The FORTRAN options LS and X may be deleted. If a listing of the program is not desired, delete the LS option. The X option controls the compilation of the program. When specified, it will generate a version of the program that will give a complete printout of all input and computed pattern parameters. If the X option is deleted, the program generated will only output notifications of data input errors or inconsistencies.

2. The Macro-Symbol LO option may be deleted if a listing of PATOUT is not desired.

3. For additional PATGEN documentation, see Appendix C, Reference 4-3.

4.2.4 SYSTEM MODIFICATIONS

In order to maintain control of the software effort, the FHWA formed a Software Modification Review Committee (SMRC) comprised of various FHWA divisions, the Washington DC-DOT, and the UTCS contractors as members. The committee was charged with recommending, reviewing, and approving system modifications.

SMRC also served as a forum for the discussion of UTCS-related concepts, the status of various projects, requests for assistance from the members, the dissemination of pertinent information to interested participants, and the scheduling of computer availability.

Figures 31 and 32 are pre-documentation and post-documentation SMRC forms. These forms highlighted, for the Committee, both the anticipated change and expected impact on the various systems.

Table 11 lists the SMRC-approved system change items. It indicates the control item number, and a brief description of the modification.

A 6-digit item number was assigned to each change request and was arrived at as follows: The first two digits represent the month (0-12); the third digit is year unit (3, 4, 5) nearest to the submittal date of the change request; the fourth digit is the system generation indicator (1 is first generation); and the last two digits specify and group the change requests submitted within the same month and year.

4.2.5 TRAFFIC PARAMETER EVALUATION

The criteria for relating alternate traffic systems' performance must be their effect on various aspects of the traffic network. All UTCS systems provide measures-of-effectiveness (MOE) data as output recorded on magnetic tape, CRT, and printouts.

Predocumentation of a Proposed Software Modification

A. Contractor/Agency: ____________________

B. Submitted by: ____________________ C. Date: __________

D. System Affected: 1-GC __________
2-GC __________
3-GC __________
1-GC (FORTRAN) ____
Other (Specify) ____________________

E. Routine to be Modified: ____________________

F. Variable(s) Added/Modified New Value(s) of Variable(s)

G. Documentation Volume and Page to be Modified (for signal timing changes, attach copy of revised timing sheets only): ____________________

H. Justification For and Objective of Modification:

I. Scope of Modification (include other routines which will be affected, how they will be affected and UTCS/BPS computer time requirement):

Figure 31. SMRC Pre-documentation Form

Software Modification Documentation

A. Contractor/Agency: ______________________________

B. Submitted by: ______________________ C. Date: ____________

D. Modification Implemented by: ______________ E. Date: ____________

F. System Affected: 1-GC ________ G. Computer Language: FORTRAN ___
2-GC ________
3-GC ________ ASSEMBLY ___
1-GC (FORTRAN) ________
Other (Specify) ______________

H. Routine Modified: ______________________________

I. Variable(s) Added/Modified   New Value(s) of Variable(s)

J. Documentation Volume and Page Affected: ______________________

K. Objective of Modification:

L. Discussion of Modification (Include exactly what was done, what was indirectly affected, and all other salient points of information):

M. Attach Listing Indicating Changes

Figure 32. SMRC Post-documentation Form

TABLE 11. SMRC APPROVED SYSTEM CHANGE ITEMS

Predocumentation Number Assigned	Description
11311.1	413-Simulator 1 second, change
11312.1 11312.2 11312.3	Routine I) Moving controllers PATGEN) #21, & #23 to Routine Y) Section 1
11313.1 11313.2	Routine I) Bus data P.O. Routine H) format changes
11314.1	Source Edit - dating changes
01411.1	PATGEN Data Base changes
	Routine Y; Block length changes
03411.1 03411.2	Routine Y) Variable intervals PATEGN) at end of phase(s)
03412.1	Power Interruption Routine
03413.1 03413.2	Routine BC; Bus counts not being incremented correctly
04411.1 04412.1	Correct errors found in the implementation of 11312.2 and .3
07411.1	Correct error found in the implementation of 03411.1
07412.1	Correct error found in Interval Table for controller #16
07413.1	Routine Y; Patterns/TOD changes
07414.1	Routines H, I; Correct overflow
07415.1	Routine Y; Change number of detectors on link for two links
09411.1	Routine H; Put current pattern numbers onto MOE output tape
09412.1 09412.1	Routine H; Correct no MOE record output when LP hangs up
09413.1 09413.2	Routines H, Y; MGVD installation modifications
03511.1 03511.2	Routines A, N, Y, and PATGEN; modified to allow 16 Radio Synch Pulse Signal inputs
03512.1	Routine H; correct bias in volume MOE output
09511.1 10511.1	Routine Y; to add 18 detectors, modifying data base
10512.1	PATGEN; to add check for and printout of minimum green violations

Two utility routines were developed to facilitate the processing of the UTCS 15-minute MOE data tapes. The first routine, the Master Tape Maintenance program, is used to create a master tape. This program will merge individual daily or weekly tapes with the existing files on the master tape. Each physical tape will become one file on the master tape. It is essential that these individual tapes be added to the master tape in chronological order.

The end of the master tape is signaled by a double EOF. Each individual tape to be merged with the master tape is also assumed to be terminated in this manner. The procedure for adding a file to the master tape is as follows:

a. Mount the master tape (write ring in) on tape unit E1.

b. Mount the tape to be merged on tape unit EO.

c. Position the master tape beyond the last file it currently contains, using the SFIL utility directive (e.g., if the master tape contains n files input a !SFIL 7AE1, n through the TTY).

d. Run the job deck for the tape creation routine.

The routine will then read the input tape, delete the 15-minute failure records, write the individual MOE records on the master tape, and log all of the dates of the merged records on the line printer. When the end of the input tape is sensed (EOF, EOF), the program will write a double EOF on the master tape and rewind the input tape.

The second routine, the MOE Master Tape Processor, allows the selection of data from the master tape in various modes. Data may be extracted corresponding to any or all of the seven MOEs for any complement of links. Data selection can be made in two ways:

- By date
- Between two dates

The input data can be in any of the following forms:

• Month, Day, Time	(e.g. FEB 22 1100)
• Month, Day	(e.g. FEB 22)
• Month, Time	(e.g. FEB 1100)
• Month	(e.g. FEB)
• Time	(e.g. 1100)

The only restriction is that in selecting between two dates, the input form of both dates must be identical (e.g. FEB 22 to MAR 05 is valid, while FEB 22 to MAR 05 1100 is invalid). Portions of the date can be omitted simply by leaving their respective input fields blank.

NOTE: When extracting data between two dates, the year cannot be overlapped, that is, a date selection such as NOV 10 to JAN 05 is not allowed. The overlap must be accomplished by successive runs of the program.

The desired MOE's are selected by number with the following definitions:

- 1 = VOLUME
- 2 = OCCUPANCY
- 3 = QUEUE
- 4 = STOPS
- 5 = SPEED
- 6 = TRAVEL TIME
- 7 = DELAY

The link numbers to be examined are input 16 per card. Note that the date fields input are entirely blank, data will be selected for all desired links from every record on the master tape.

All data extracted is printed, by link, for each record encountered whose date matches the input criterion. After all data has been logged for the input date(s), the routine generates a summary consisting of totals and averages for the requested MOEs (Figure 33).

4.2.6 PROGRAM INVENTORY

Table 12 represents the status of the various card decks and magnetic tapes that are available at the Washington, D.C., UTCS Traffic Control Center.

4.3 FIELD EQUIPMENT

Field equipment was comprised of a controller cabinet housing pre-timed, or semi-actuated controllers, vehicle detectors, system adapters, and associated communication modules. The systems manager personnel maintained all electronic equipment and the District of Columbia signal shop maintained the controller and associated field wiring (Figure 34).

Maintenance was performed when a failure was experienced by the central operator, at which time contractor personal would check all equipments associated with the UTCS system, at that particular location. The computer controlled system locations, by controller number, are designated in Figure 35. The division of intersections into sections is also shown in the figure.

SPERRY DIVISION

GENERALIZED MANIFEST

DATA PROCESSING CENTER

PURPOSE	PREPARED BY	EXT.	DATE	PAGE OF
INPUT DATA FORMATS				

1st Input - Selection Mode (SKEY) (I5)

X

2nd Input - Selection Dates (DATE, DATE1) (3A4, 4X, 3A4)

MON DD HHMM MON DD HHMM

3rd Input - MOE Selections (MOES) (7I5)

X X X X X X X

4th Input - LINK NUMBERS (LINK) (16I5)

XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX XXX

5th Input - TERMINATION CODE (Terminates Link Input)

999

SPERRY RAND DPC 100

Figure 33. MOEs Summary (Sheet 1 of 3)

SPERRY DIVISION

GENERALIZED MANIFEST

DATA PROCESSING CENTER

PURPOSE	PREPARED BY	EXT.	DATE	PAGE OF
SAMPLE DATA DECKS: Selection by single date (SKEY=1)				

```
    1                                       (SKEY = 1 FOR SINGLE DATE SELECTION)
MAR 07                                      (DATE TO SCAN FOR - MARCH 7, ANY TIME)
    1    2                                  (MOES - VOLUME, OCCUPANCY)
    1    10   16   23                       (LINKS DESIRED)
  999                                       (LINK TERMINATOR)


    1
MAR      0800                               (DATE TO SCAN FOR - MARCH 8AM, ANY DAY)
    1    3    5                             (MOES - VOLUME, QUEUE, SPEED)
   11    13   21   107  256  270
  999


    1
         0800                               (DATE TO SCAN FOR - 8AM, ANY MONTH/DAY)
    1    2    3    4    5    6    7         (MOES - ALL)
   11    13   21   107  256  270
  999
```

SPERRY RAND DPC 100

Figure 33. MOEs Summary (Sheet 2 of 3)

SPERRY DIVISION

GENERALIZED MANIFEST

DATA PROCESSING CENTER

PURPOSE	PREPARED BY	EXT.	DATE	PAGE OF

SAMPLE DATA DECKS: Selection by multiple dates (SKEY=2)

```
    2                                   (SKEY = 2 FOR MULTIPLE DATE SELECTION)
 FEB 05 1100       MAR 10 0700          (SCAN BETWEEN FEB 5 11AM & MAR 10 7AM)
    1    3    3    4    5    6    7     (MOES - ALL)
   10   10   30   40   50   60   65   70   75   80   85   90   95  100  110  120
  130  140  150  175                    (LINKS DESIRED - 2 CARDS)
  999                                   (LINK TERMINATOR)

    2
 FEB 10            JUN 06               (SCAN BETWEEN FEB 10 & JUN 6, ANY TIME)
    1    2    3    4    5    6    7
   10   12   13
  999

    2
         0800               1900        (SCAN BETWEEN 8AM & 7PM, ANY MONTH/DAY)
    1    2    3    4    5    6    7
   10   13   16  260
  999
```

SPERRY RAND

DPC 100

Figure 33. MOEs Summary (Sheet 3 of 3)

TABLE 12. PROGRAM INVENTORY

Item (Name)	Format	Description	Status
1. UTCS/X Save Tape	Tape	UTCS System (KING) for expanded networks	Latest version of System, Patterns, History Data, and RBM Operating System
2. UTCS/X/DS Save Tape	Tape	UTCS System (KING) with Single Detector additions requested by the FHWA	Latest version of System, Patterns, History Data, and RBM Operating System
3. UTCS/X/CL Save Tape	Tape	UTCS System (KING) with Cycle Length (> 190 Sec) modifications requested by D.C. Traffic Dept.	Latest version of System, Patterns, History Data, and RBM Operating System
4. UTCS/X Update Tape	Tape	Used to list or update System	Coincidence with associated Save Tape
5. UTCS/X/SD Update Tape	Tape	Used to list or update System	Coincidence with associated Save Tape
6. UTCS/X/CL Update Tape	Tape	Used to list or update System	Coincidence with associated Save Tape
7. UTCS/X Rad Source Save Tape	Tape	Source programs for expanded network system	Current as of 6/3/76
8. UTCS/X/SD Rad Source Save Tape	Tape	Source programs for expanded network system with Single Detector additions	Current as of 6/3/76
9. UTCS/X/CL Rad Source Save Tape	Tape	Source programs for expanded network system with Cycle Length modifications	Current as of 6/3/76
10. CØC Module 4/4/72	Tape	CRT interface program	Current

Table 12. Program Inventory (Cont)

Item (Name)	Format	Description	Status
11. UTCS/CIC Update Tape 7/17/74	Tape	Used to list and/or update System programs for FHWA version of CIC algorithm on pre-expansion network	Frozen per 7/17/74
12. UTCS/CIC Update Deck	Card	Used in conjunction with Update Tape to produce system	Frozen per 3/75
13. UTCS/CIC/MGVD Update Deck	Card	Used in conjunction with Update Tape to produce system MGVD Mods	Frozen per 3/75
14. UTCS/MGVD Update Deck	Card	Used in conjunction with Update Tape to produce system MGVD Mods added	Frozen per 3/75
15. UTCS/PBPS Rad Source 7/16/74	Tape	Source programs for FHWA version of BPS Algorithm used per expansion network	Frozen per 7/16/74
16. UTCS/PBPS Update Tape 7/16/74	Tape	Used to list or update System	Frozen per 7/16/74
17. UTCS/PBPS Update Deck	Card	Used to generate UTCS/ PBPS System	Frozen per 3/75
18. UTCS/PBPS/MGVD Update Deck	Card	Used to generate UTCS/ PBPS System with MGVD Mods	Frozen per 3/75
19. Pattern Generation Program (PATGEN)	Tape & Cards	Expanded network timing patterns. Program is on tape with date input via cards.	Current as of 5/76

Table 12. Program Inventory (Cont)

Item (Name)	Format	Description	Status
20. PATGEN for Cycle Length modifications	Tape & Cards	Modified item 19 to allow longer cycle length and internal values	Current as of 6/76
21. History Data Generation (HISBUF) Program	Cards	Expanded network historic link values	Current as of 5/76
22. MØE Master tape Merge Program	Cards	Expanded network MOE date files are separated from the 15 minute MOE data tape and merged onto a new tape with only MOE data files	Current as of 6/76
23. MOE Master Tape Processor	Cards	Scans and analyses MOE data in concise printed format	Current as of 6/76
24. Source Edit Program	Cards	Program will allow modification to Source programs	Current
25. Update and Assembly Listing Deck	Cards	This program generates an assembly listing on the system line printer and a new update tape	Current
26. Sample Update Deck	Cards	Update deck which has no updates in it (as sample)	Current
27. UTCS/1st Gen. Update Tape 7/17/74	Tape	Used to list and/or update System programs for pre-expansion network	Frozen per 7/17/74
28. UTCS/1st Gen. (Current) Update Deck	Card	Used in conjunction with Update Tape to produce system	Frozen per 3/75

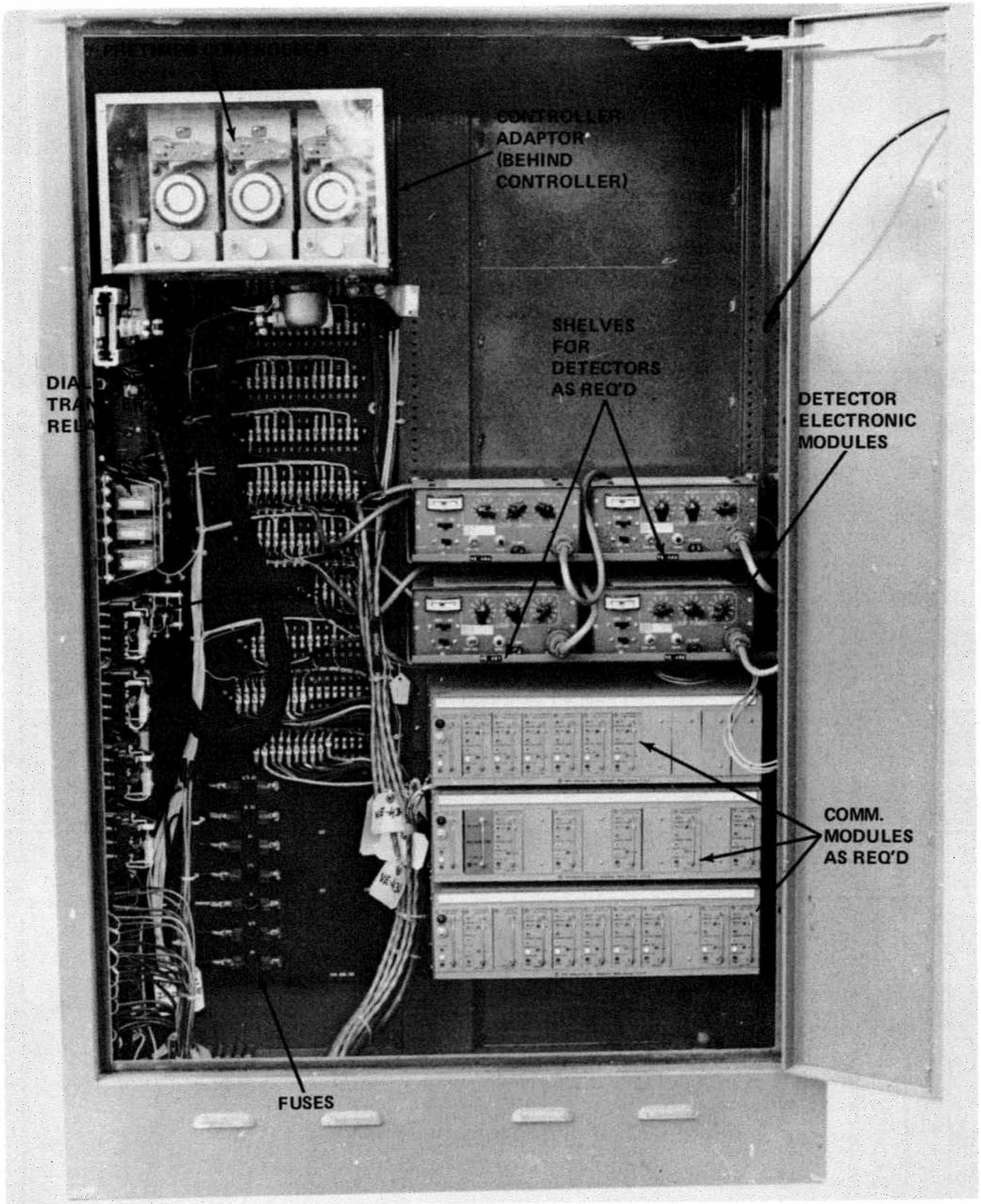

Figure 34. UTCS Pre-Timed Controller Cabinet Installation

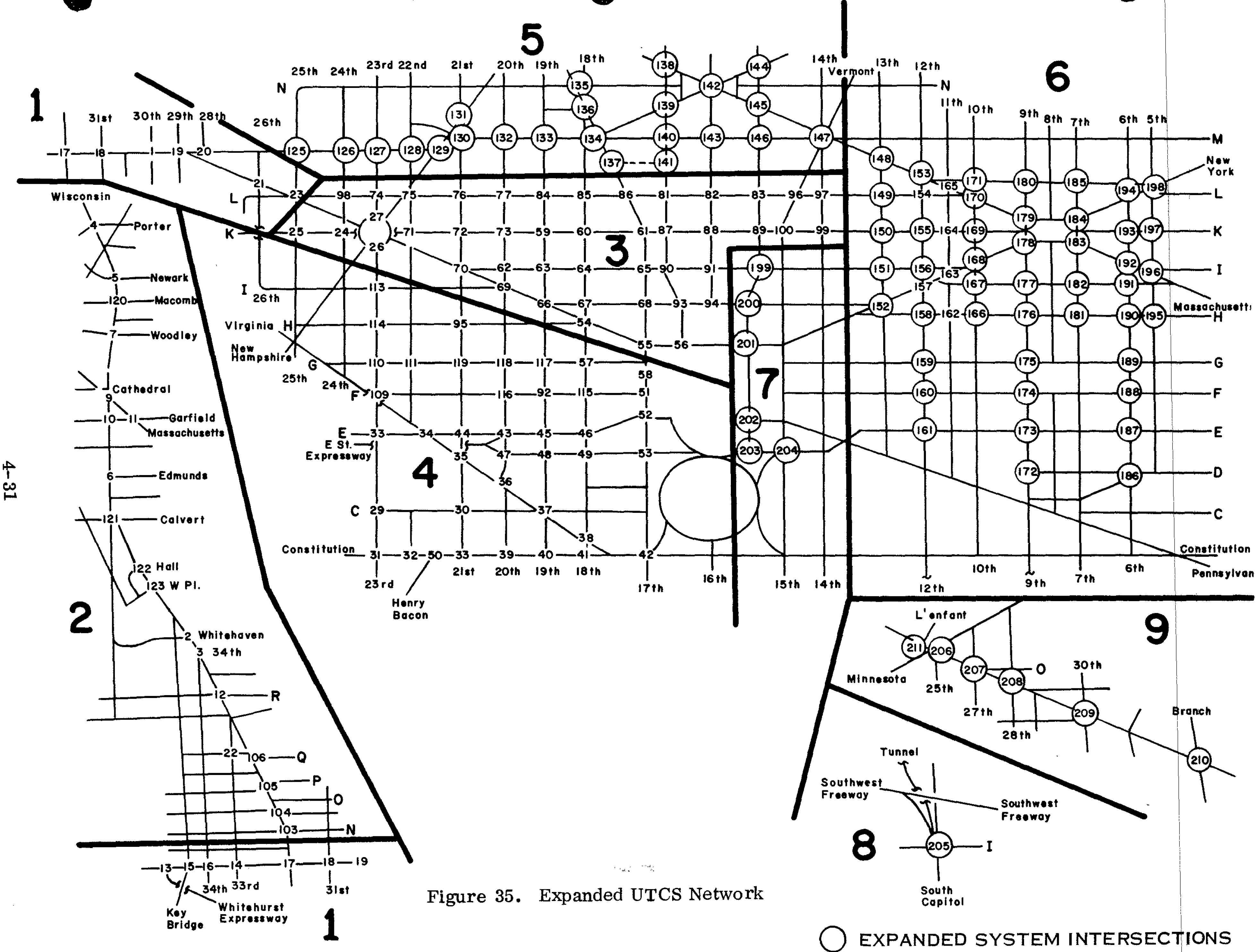

Figure 35. Expanded UTCS Network

The initial equipment design provided for a hostile environment, vibration, and high reliability. These design concepts, coupled with the philosophy that disturbing operating equipment can cause system perturbances and that the cost of continually visiting controller cabinets is high, led to the conclusion that a scheduled preventive maintenance program would not be instituted for field equipment.

4.3.1 MAINTENANCE PROCEDURES

When an equipment malfunction was indicated at Central, the operator's initial check was to determine if the condition was caused by a failure in control center equipment. Upon determination that a field (rather than a control center) problem did exist, a repair crew was dispatched to the location. The first item checked when a controller malfunction is indicated is to determine if the proper signal appears at the telephone input pair. If not, the Telephone Co. was called to repair the data line problem. If the signal did exist, the 12 vdc power supply is checked to determine if the electronics are receiving the correct power source.

Failures experienced in controller cabinets, other than direct signal controller problems, can be categorized into four basic groups, as experienced by the field repair crews. These are loss of main street green returns, loss of computer control, vehicle detector subsystem failure, and bus detector subsystem failure. See Figure 34 for Controller Cabinet configuration.

In the case of loss of main street green return to the control center, the use of a portable oscilloscope is used to trace the signal loss from the source through the communications equipment and to the telephone lines. The usual causes of this condition were a bad telephone pair or an inoperative 2 frequency transmitter. Data line problems, as mentioned above, were called to the attention of the Telephone Co. and the transmitter modules were replaced with field spares. Module repair was performed at a later date at the repair facility.

The loss of computer control at a particular location was usually traced to a lack of, or faulty advance signals from the computer interface adapter to the controller cam shaft motor. This condition can be checked by the use of a voltmeter on the terminal board for the presence of 115 VAC. The lack of this voltage usually indicated an adapter failure.

Vehicle detector failures where relatively simple to detect and repair. The front panel meter on the vehicle detector electronics was used to indicate the condition of the loop. The inability to properly tune the detector electronics usually indicated that an inspection should be made of the loop installation. Failed vehicle detector electronics were also verified by using the front panel meter. The lack of meter movement, when vehicles were crossing the associated loop, usually indicated a bad detector unit. Vehicle detector subsystem failures were also seen as a lack of transmission from the 2-frequency transmitters to central. The vehicle detector subsystem is composed of a vehicle loop, detector electronics, 2 FS transmitter and telephone line. The final Vehicle Detector Status Table is included in Appendix A.

The bus detector subsystem experienced minimal failures. Failures were detected by the placement of a bus transmitter, mounted on the service vehicle, over the bus loop and locating the malfunction.

The field equipment associated with the Bus Priority System are installed in the roadway, at the intersection, and on the bus.

The intersection-related installation includes the roadway antenna (loop), which is coupled to the bus receiver and 3FS communications transmitter, located in the controller cabinet.

The bus installation includes the transmitter (mounted beneath the bus, on the right side, forward of the rear wheels, the interconnecting cable and a selector switch mounted on the steering column.

The UTCS has been operating for approximately 42 months, in Washington, D.C. The BPS, however, has been in operation intermittently for approximately 20 months. During the BPS operating period, buses were reassigned to new routes and the new rail transit system construction eliminated many of the BPS areas. These conditions created a situation where only limited testing, of the BPS equipment, was possible.

Two types of Bus Detector Transmitter tests were performed at the terminals. One test was used to determine if the transmitter was working after it was installed and while it was still on the lift. The other test provided a daily operational check on the operation of the transmitter as the bus entered the garage. A test facility, simulating a street installation, was installed in the path of the entering bus. The driver as he passed over the test loop, would observe a traffic signal associated with the test. If the signal did not light he would note the condition on his trip report form and the repair would be made.

The number of bus equipment failures, as shown in section 3.4 was small in comparison to the 450 installations. The two items which malfunctioned were the transmitter and the interconnecting cable.

The BPS field equipment was comprised of the bus antenna and receiver. The 3-frequency receiver was connected to the communications equipment for transmission to Central.

The bus loop was a near field antenna, constructed in the field by forming a loop of #14 wire separated by one-inch plastic spacers for the required width of roadway. The roadway installation was performed in the same manner as for the vehicle loops. Roadway deterioration and construction caused the failure of 3 bus loops, as noted in paragraph 3.6.2.

The 3-frequency receiver mounted in the communications chassis proved to be very reliable, as shown in section 3.4.

4.3.2 REPAIR STRATEGY AND TECHNIQUES

As stated in previous paragraphs, repair to field equipment was initiated by a call from the central operator to the field crew. Field equipment repairs were made on a unit replacement basis and unit repairs performed at the repair facility.

The field crew had a complement of each module for field replacement; this included at least one of every frequency used in the Communication transmitters and receivers, 12 volt power supplies, detector units, and adapters. The test equipment complement included an oscilloscope, a voltohmmeter, loop tester, assorted hand tools, and splicing material used in making loop splices.

The largest field repair costs were associated with the repair of vehicle detector loops. The installation of a rail transit system in the District, coupled with the large number of loops required for the research activity, were the prime reasons for this high repair cost.

A trial program consisting of only repairing the damaged section of the loop or loop lead-in without degrading its performance, was initiated in order to reduce the cost of loop repairs. Where large sections of the loop was damaged, or where the roadway was in disrepair the entire loop was replaced.

Repairs were accomplished by removing the damaged section by sawing along the original installation. The wires protruding from the existing installation were bared and replacement wires were spliced to them using the technique specified in Appendix C, Reference 4-4. The saw cut was then refilled with the original type sealer (Bondo). Loop integrity was then checked for resistance to ground and for comparison against its original inductance measurement. This loop repair method has proven successful, with no loop failures due to this type of repair.

An enclosed vehicle loop installation technique, for high loop mortality areas, was developed as part of the UTCS network expansion. The street in which the loops were to be installed had a cobblestone surface and soft base. In addition, the lane in which the loops were to be installed had abandoned trolley tracks running its entire length.

Tunneling under the tracks would have been very costly due to the reinforced concrete foundation the tracks rested on. Movement of the cobblestones, however slight, would in time shear the loop wires.

A loop configuration, as shown in Figure 36, was developed. The wire loop was formed by threading it in 1-inch PVC conduit prior to permanently coupling the corner PVC elbows to the conduit. A "T" connector was used at the lead in exit point. The cobblestones were removed and a small slot made for insertion of the conduit. Small sections of the trolley tracks were cut with a torch and removed. The formed loop was placed in position (Figure 37), backfilled and the cobblestones were replaced.

The sidewalk end of the lead-in conduit was inserted in a slightly larger elbow which was connected to the sidewalk splice box.

In effect the enclosed loop installation "floated" so that roadway motion would be transmitted along the entire loop installation rather than at a single point.

The vehicle detector electronics was tuned without the trolley tracks having any effect on its operation. To date, the installation has been highly successful, relatively inexpensive compared to other alternatives, and provided a means for placing a loop in an otherwise inaccessible location.

When field maintenance was performed, two-way communication was maintained between the central operator and the repair crew to facilitate troubleshooting, alignment procedures, and to confirm the completion of the repair.

Figure 36. Enclosed Loop Configuration

Figure 37. Enclosed Loop Installation

SECTION 5

MAINTENANCE MANAGEMENT

5.1 RESPONSIBILITIES

The maintenance of UTCS included the responsibility for routine and preventive maintenance and for emergency repairs. System maintenance, in the UTCS context, encompassed software as well as hardware responsibility, and included system refinement, additions, deletions, and data base updates. The system manager had prime responsibility for maintaining the system. This function included coordination of all activities, subcontractors, and other agencies. Figure 38 provides an overview of the functions and responsibilities performed by the UTCS system manager. They include the following.

- Software Maintenance. Software maintenance, as fully described in Section 4.2, provided the overall programming and analystical support for UTCS.

- Control Center Maintenance. The control center equipment is divided into two categories for maintenance purposes: (1) the computer and its associated peripherals, and (2) other than EDP-related equipment (such as the map display, control panel, CRT, and communications). Computer maintenance was performed by the equipment supplier. Other equipments were maintained by system manger personnel.

- Main Repair Depot. The main repair depot was located at the system manager's facility and was the center for the majority of equipment repairs and installation preparation. The depot also housed the spares equipment.

- Field Maintenance. The responsibility for field maintenance was assumed by the system manager and included repairs by his field crew and the notification, coordination, and monitoring of other subcontractors.

- Maintenance Control. Maintenance control includes all administrative functions associated with the system. The updating of all drawings, tables, and manuals; inventory, and warranty control; obtaining construction permits; and processing invoices are representative tasks associated with this function.

5.2 FACILITIES AND RESOURCES

The facilities and resources required to support the UTCS operation and maintenance functions are shown in Figure 38.

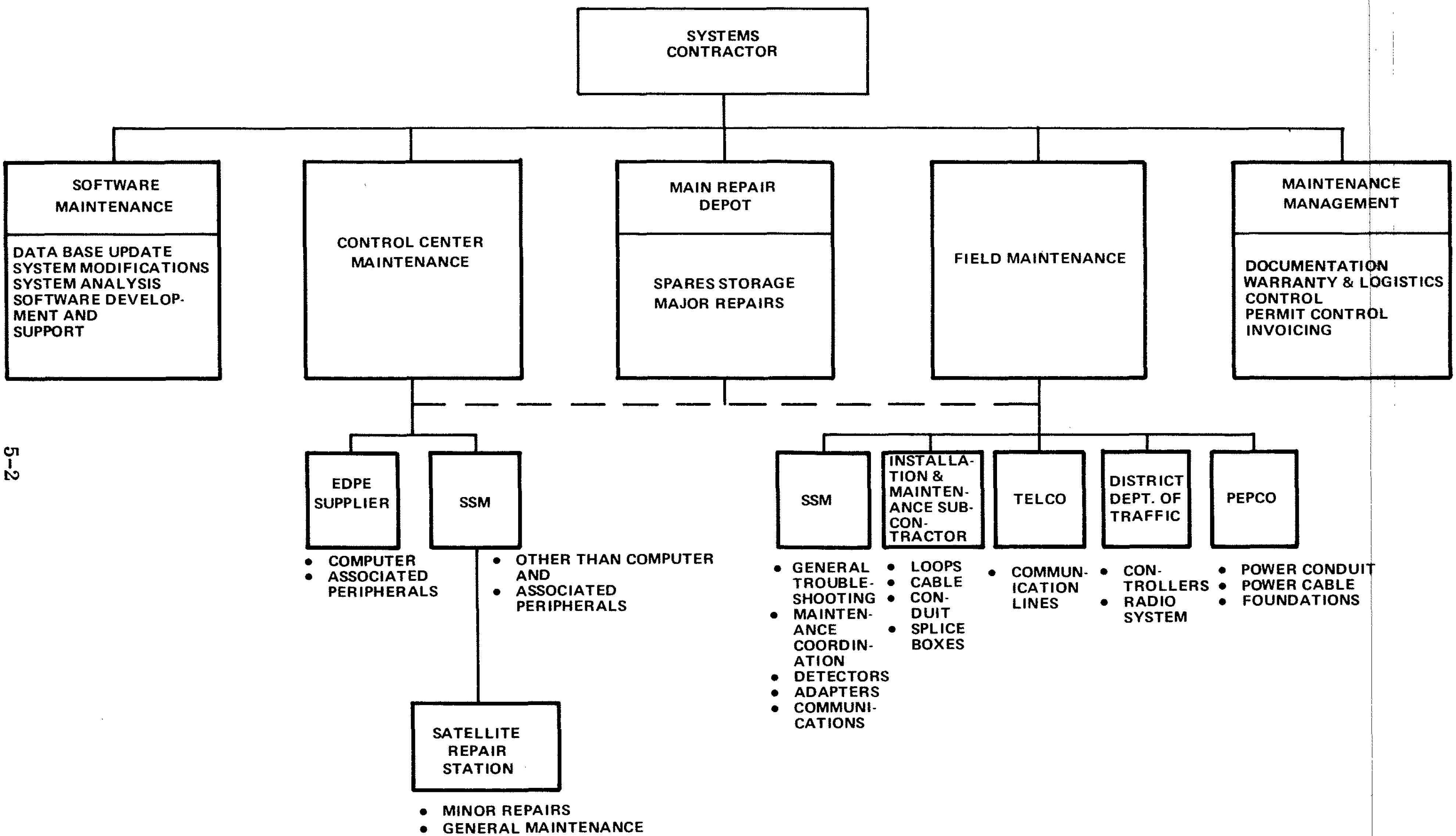

Figure 38. System Maintenance Responsibilities

5.2.1 FACILITIES

All UTCS-related equipment was stored and repaired at the system manager's local facility. The one exception was the storage of spare traffic signal controllers and cabinets which were located at the DC-DOT warehouse after the installation phases. This facilitated the controller repair function which was the District's responsibility. Prior to the initial installation, the controllers and cabinets were stored, prepared, and tested at the system manager's depot.

The maintenance management tasks, as specified in section 5.1.5, were controlled from the system manager's local office, as were repairs to the electronic equipment.

The general space requirements and usage were.

- Large storage area
  - Controllers
  - Cabinets
  - Cable
  - Splice Boxes
- Small storage
  - Detector Electronics
  - Communication Modules
  - Controller Adapters
  - Bus Transmitters
  - Miscellaneous Components
- Equipment Repair and Preparation Area
- Office, File and Drafting Area

5.2.2 RESOURCES

The UTCS/BPS program, because of its research and operational nature, used the resources of various Federal Agencies, the District of Columbia, private concerns, and the systems manager.

Extensive data collection was required during the course of the program. This necessitated the assistance of the University of Maryland staff and students for data collection and reduction. For a short time their participation provided a large labor pool at relatively low cost, while not requiring reassignment of Federal, District, or system manager personnel.

FHWA and District radar speed meters and traffic counters were also used during the data collection and evaluation phases of the program. Federal and system manager computer facilities were used for off-line data processing. The system manager installed a 413 Univac computer at the control center for the purpose of system simulation. Various signal patterns and system programs could thus be run and debugged prior to on-street testing and evaluation.

The total UTCS/BPS maintenance function required both standard and specialized test equipment, and included the following.

Equipment	Quan.
H.P. Model 400D VTVM	1
Tektronix Model 323 Oscilloscope	2
Mosley Strip Recorders Model 680	2
H.P. Model 412A VTVM	1
H.P. Model 200CD Wide Range Oscilloscope	2
Standco Model B-5 Megger	1
Model LT-100 ACE Corp. Loop Tester	1
Decatur Modd DLT-150 Loop Analyzer	1
Decatur DST-300 Loop Sensitivity Tester	1
Simpson Model 260-5P Multimeter	4
H.P. Model 211A Signal Generator	1
H.P. Model 650A Audio Oscillator	1
Simpson Model 260 Multimeter	3
Controller Preparation Display Panel	2
UTCS Map Tester	1

Transportation for system maintenance was provided by the system manager and included both a standard sedan and a van. Experience gained during the course of the program indicated that a van type vehicle had greater utility for equipment and spare parts storage and access, weather protection, and provided a protected, on-street site for minor repairs.

Two way radio communications proved necessary for all phases of the UTCS/BPS program. Relatively long messages and continuous transmissions were required for the tune up, checkout, and evaluation tasks. A frequency of 166.025 MHz assigned to the Fairbank Research Station was used with units at the control center, all program related vehicles, and three portable units. District of Columbia radio units were also installed at the control center and in the vehicles for direct transmission to the District shops, repair vehicles, and surveillance crews.

5.3 STAFFING

The UTCS Operations and Maintenance program, for staffing purposes, was categorized in the following manner.

- Administration
- Control Center Operation
- Software Support
- System Analysis
- Field Support

5.3.1 ADMINISTRATION

The administrative responsibility for UTCS rested with the resident Program Manager, whose tasks included: staff assignments and direction, task scheduling, overall program and financial status, inventory control, subcontractor control, invoicing, and liaison between governmental and private agencies.

5.3.2 CONTROL CENTER OPERATION

The Control Center staffing was dependent upon the activity in progress. Normal system operation during the development phases required that a central operator be on duty to provide support during a flexible and varying 8-hour work day. Tasks which included data collection for a specific study, on system evaluation required control center coverage for a 7 am to 7 pm shift.

The central operator's responsibilities included bringing the system on-line, preparation for data logging, continual surveillance of system operability and performance, malfunction detection, monitor system repairs, maintaining the system log and providing Central to field communications.

5.3.3 SOFTWARE SUPPORT AND SYSTEM ANALYSIS

The average manpower effort allocated to the software maintenance and system analysis support by the systems manager due to the R & D nature of the program, was one man-month per month. The degree of complexity of the specific task to be performed, plus the established schedule, dictated the labor effort actually expended.

When system availability permitted, the software effort was performed at the control center. At other times the initial effort was performed at the system manager's facility using their computer systems and support personnel, if required.

5.3.4 FIELD SUPPORT

The field support task was primarily dedicated to the maintenance of on-street equipment; but also included data collection and assistance in various system and timing pattern evaluations. The field team was comprised of two men for the initial 111 intersection system, and was increased to three men for the expanded 201 intersections.

Field maintenance tasks included subcontractor monitoring, equipment repairs and adjustments, and coordinating the efforts of the various utility companies. Bench repairs of electronic modules were performed by both the field repair team and the control center staff.

In summary the total UTCS maintenance and operations staff included:

- 1 Program Manager
- 1 Programmer, on a half-time basis
- 1 System Analyst on a half-time basis
- 4 Field Engineers for operation and maintenance

It should be noted that the field engineering staff were engineering graduates and were well versed in a variety of tasks including some software maintenance. This is not the usual case for a typical municipality, where personnel of various disciplines may be required to perform the same function.

5.4 SUBCONTRACTOR MANAGEMENT

5.4.1 SUBCONTRACTOR AGREEMENTS

The maintenance of UTCS, as for most systems, requires that subcontractors with specialized capabilities be used. Maintenance of UTCS required that selection procedures and negotiations be conducted and final subcontractor agreements executed for the major maintenance services shown in Table 13.

The subcontractor agreements established the unit (or total) costs associated with their specific responsibilities, the specifications to which the service was performed, periods of performance and response time, equipment and materials to be supplied, and the method of reporting and billing.

5.4.2 SUBCONTRACTOR MONITORING

Equipment repairs or routine preventive maintenance was performed by the firms subcontracted by the system manager.

TABLE 13. MAJOR MAINTENANCE SUBCONTRACTORS AND SERVICES

Subcontractor	Responsibility
Chesapeake & Potomac Telephone Co. (1)	Line Lease & Maintenance
Potomac Electric Power Co. (1)	Conduit, Cable, manhole maintenance & controller cabinet, or foundation replacement
Xerox Data Services (1) (2)	Computer & peripheral maintenance
Welsbach Electric Corp; (1) (3) Truland Electric Corp; (1) (3) Hawkins Electric Corp. (3)	Vehicle and Bus loop Maintenance; splice box Replacement; Loop lead in cable replacement
Hazeltine Corp.	CRT maintenance
Multicomm. Corp.	Teletype maintenance
Safety First Co.	Fire protection
Washington Metropolitan Area Transit Authority	Bus mounted, BPS component maintenance

(1) Also used for system installation, modifications, and expansion

(2) Now Honeywell Systems

(3) Each utilized during different periods.

All field repairs requiring street construction, such as conduit or loop replacement, were subject to District of Columbia permit applications and review, which was carried out by the system manager. These and other repairs were performed at the direction of the system manager, upon the detection of a malfunction.

Once initiated, the repair request was monitored for contract stipulated response time and completeness of the repair. The field engineers inspected and tested all repairs to verify both system integrity and invoice validity.

The subcontractors were repeatedly queried about the material supplies which they provided. When necessary, assistance was provided by the system manager to obtain long lead items in a shorter time.

5.4.3 COORDINATION OF ACTIVITIES

Many system repairs or modifications required the services of more than one subcontractor or agency. As an example, the relocation of a controller cabinet due to construction in the area necessitated that the system manager prepare the required plans and coordinate with: the District of Columbia Engineers, Permits Division and Signal Shop; the Potomac Electric Power Co. whose ducts and manholes are utilized; the Chesapeake and Potomac Telephone Co. for the relocation of their termination box and lines; and the construction subcontractor. Additionally, various groups, within each agency, were involved during the modification, including contracts, accounting, engineering, construction, and inspection.

Checklists and schedules were maintained by the system manager as part of the overall job.

5.4.4 FINANCIAL CONTROLS

Prior to beginning the program, estimates were made of the tasks to be performed in order to set a limit of liability for each subcontractor agreement. All invoices were checked against actual services rendered, and continuous audits were made of the rate of expenditures. Cost-to-complete analyses were periodically performed to determine the financial posture of each subcontractor as well as of the total program.

5.5 DOCUMENTATION

The two basic forms of documentation, maintained by the system manager were contract deliverable and non-deliverable items. Contract deliverable items were the final output or results of a contracted task where as non-deliverable items were internal working documents.

Deliverable documentation consisted of the following items:

- Monthly progress reports
- Vehicle detector placement table
- Field equipment placement table
- As-built installation drawings
- System tapes and listings
- Software manual addendums
- Equipment inventory
- System cross reference directing (Rolodex File)
- Communications system cross reference
- Other UTCS/BPS manual modifications

Items included in the non-deliverable documentation category, but which were used by all associated with the system were:

- Vehicle loop detector status table
- Central operators log
- System tape inventory
- Off-line programs

Other forms of documentation included:

- Special task reports
- Equipment malfunction reports
- Data base tables

5.6 MAINTENANCE COSTS

This section provides a guideline to the costs involved for the maintenance of UTCS/BPS. As previously noted throughout this report, this particular system was primarily operated as a research laboratory, with goals and procedures differing from a strictly operational system and within an already structured maintenance organization.

5.6.1 EXCLUDED ITEMS

- Personnel - The minimum level of effort required for the operation and maintenance of the system is one central operator and a field maintenance crew of three, supported by a field installation team (when required) and a computer service agency. The various Traffic Organizations due to their diverse structures, size, and available talent will, as a rule, provide staffing within their own particular framework. For these reasons, and because of varying labor rates for each category, manpower costs were not included in this estimate.

- Transportation - The cost of rolling stock will be dependent upon the type and availability of the vehicle used for system maintenance, and was not included in this estimate.

- Utility Costs - Except for telephone line lease costs the rates applied to the system for electricity, water, heat, etc., are not included. These costs vary dramatically depending upon the facility housing the system. A separate building will naturally incur higher total utility costs than will a room in an existing building which has heat, hot water, sanitary hook-up, air conditioning, etc.

The approximate annual cost of power for the 50' x 50' temporary building, housing the UTCS/BPS equipment was $18,000. This cost included two 15-ton air conditioners, hot water heater, lighting, heat and other District of Columbia activities. The power consumption of the system alone was a small fraction of the total building drain.

• Facility - Other costs associated with the operation of the system facility are not included in this maintenance cost estimate for the same reasons mentioned above.

• Other Items - Costs relating to the specific R&D aspect of system maintenance, such as labor or subcontractor overtime premium rates, are not included in the estimate. Spare units which would ordinarily be purchased from annual capital budgets and dependent upon specific city needs are not included. Repairs to system field equipment, performed by (and charged to) other service agencies due to building or rail transit construction, are not included.

5.6.2 INCLUDED MAINTENANCE COSTS

Table 14 lists the recurring maintenance costs associated with this particular system for the periods specified.

5.7 SPARES, COMPONENTS, INVENTORY

5.7.1 SPARES

The spares complement purchased for the initial UTCS/BPS installation, was approximately 10% of all items. The exceptions were that no computer or peripheral spares were purchased, since the Xerox maintenance agreements covered those items. Vehicle detectors and communications equipment, were purchased for operations on specific frequencies. A broad spectrum of spares were purchased which included all required frequencies and made up the 10% spares total.

Additional spares for the expanded system were held to 5%.

All spare units, except for controllers and cabinets, were stored at the system manager's facility. Spare controllers and cabinets were maintained at the District Signal Shop warehouse.

Cable splice boxes and other construction materials were maintained by the installation subcontractor.

5.7.2 COMPONENTS

During the initial maintenance period, it was determined that a lower spares inventory could be maintained by purchasing specific electronic components. This provided the capability of modifying vehicle detector and communications equipment for use on various operating frequencies. Both the field maintenance vehicle and repair depot storage requirements and related costs were greatly reduced by use of this method.

Repair components such as transformers, transistors, capacitors, resistors, relays etc., were maintained at the system manager's facility. Some long lead items which would normally cause unit failure were purchased from the manufacturer. Standard electronic components were purchased, as required, from a local electronics equipment supplier.

TABLE 14. INCLUDED MAINTENANCE COSTS

ITEM	12/72-7/75 Initial System	7/75-7/76 Expanded System
Loop Repairs (1)	$30,126	$ 6,354
Telephone Line Lease (2)	30,516	70,200
Xerox Maintenance	91,428	38,856
Teletypewriters	750	300
CRTS	800	400
Fire Protection	100	100
Belden Cable	400	100
Splice Boxes	150	75
Central Supplies (3)	750	300
Consumeables (4)	4,980	1,992
Components (5)	1,500	600
Vendor Repair items	800	300
Total	$162,300	$119,577

Average Monthly Cost For Initial System (111 intersections) =

$$\frac{\$162,300}{30 \text{ mo.}} = \$5,410$$

Average Monthly Cost For Expanded System (201 intersections) =

$$\frac{\$119,577}{12 \text{ mo.}} = \$9,965$$

NOTES

(1) Based on 19 splicebox replacements, splices and 3,271 feet of saw cut for both vehicle and bus loop repair for initial system; and 9 splice box, splices and 1,285 feet of saw cut for expanded system. Three subcontractors were engaged during the 42-month period at a varying cost per foot of saw cut.

(2) $672/month until 5/75 and approximately $5,850/month after that.

(3) Includes items such as control panel and map display lamps and line printer and teletype ribbons.

(4) Includes items such as fuses, electrical tape, connectors, wire, etc.

(5) Includes items such as transistors, transformers, resistors, capacitors, etc.

5.7.3 INVENTORY

Table 15 accounts for all items other than those comprising the computer subsystem. The quantities include equipment purchased for the intial installation, system expansion, and spares.

Table 16 lists all equipment installed at the control center.

The IN-3 Tables in Appendix B show the UTCS field equipment placement and inventory.

TABLE 15. UTCS NON-EDPE INVENTORY

Item	Manufacturer	Model	Total Purch.	Installed				Spares								Total
				Cent.	Field	Metro	Sub-Total	Cent.	SSM	D.C. H & T	D.C. Trans.	FHWA	Vend. Repr.	Non-Recov	Sub-Total	
2 FSK Rcvr.	RFL	HB-35600	874	794	-	-	794	77	3	-	-	-		-	80	874
2 FSK Trans.	RFL	HB-24335-5	873	-	803	-	803	-	54	4	-	-		12	70	873
3 FSK Rcvr.	RFL	HB-35605	364	-	199	-	199	139	22	2	-	-	-	2	165	364
FS Rcvr/Filter	RFL	HB-60100	365	-	199	-	199	142	19	2	-	-	-	3	166	365
3 FSK Trans.	RFL	HB-2433T-34	365	201	-	-	201	10	152	-	-	-	-	2	164	365
Power Supply	RFL	HB-35610	313	-	239	-	239	-	63	-	-	1	-	10	74	313
Dual Amp.	RFL	HB-14717-3	42	42	-	-	42	-	-	-	-	-	-	-	-	42
Comm. Chassis	RFL	Type A	275	-	262	-	262	-	9	2	-	-	-	2	13	275
"B" Chassis	RFL	Type B	29	-	0	-	0	-	28	-	-	1	-	-	29	29
Comm. Rack	RFL	- - -	13	13	-	-	13	-	-	-	-	-	-	-	-	13
BPS Rcvr.	EDO-Aire	- - -	155	-	-	-	-	-	153	-	-	2	-	-	155	155
BPS Trans.	EDO-Aire	- - -	500	-	-	364	364	-	9	-	40	87	-	-	136	500
BPS Switch	Signal Stat.	- - -	500	-	-	450	450	-	-	-	50	-	-	-	50	500
Controller Cab.	Marbelite	N	231	-	199	-	199	-	-	24	-	-	-	8	32	231
19 ckt. Cont.	Marbelite	M-30	175	-	167	-	167	-	-	6	-	-	-	2	8	175
40 ckt. Cont.	Marbelite	M-40	30	-	25	-	25	-	-	4	-	-	-	1	5	30
EB Panel	Marbelite	- - -	54	-	46	1	47	-	6	1	-	-	-	-	7	54
Cont. Adapter	Marbelite	- - -	213	-	199	-	199	-	11	2	-	-	-	1	14	213
Veh. Detector	Decatur	LHA	622	-	567	-	567	-	47	-	-	2	-	6	55	622
Splice Box	Ford Meter	- - -	534	-	503	-	503	-	21	2	-	-	-	8	31	534
Map Tester	SSMD	- - -	1	-	-	-	-	1	-	-	-	-	-	-	1	1
BPS Link Sim.	SSMD	- - -	1	-	-	-	-	1	-	-	-	-	-	-	1	1
Cont. Test Pan.	SSMD	- - -	2	-	-	-	-	-	2	-	-	-	-	-	2	2
Map Prototype	SSMD	- - -	1	-	-	-	-	-	-	-	-	1	-	-	1	1
80 ckt. Cont.	Marbelite	M-80	2	-	1	-	1	-	-	1	-	-	-	-	1	2

TABLE 16. UTCS/BPS CONTROL CENTER EQUIPMENT COMPLEMENT

Equipment	Manufacturer	Type/Model Number	System Qty
Two Way Access	Xerox	8255	4
Three Way Access	Xerox	8256	4
External Interface Feature	Xerox	8270	2
Multiplexer Input/Output Processor	Xerox	8273	1
Additional Eight Multiplexer Channels	Xerox	8276	1
Keyboard/Printer and Controller	Xerox	7012	2
Card Reader (400 CPM)	Xerox	7122	1
Card Punch (100 CPM)	Xerox	7165	1
Rad Controller	Xerox	7201	1
Rad Storage Unit 1.5 MB	Xerox	7203	1
Rad Storage Unit 3.0 MB	Xerox	7204	1
20 KC Magnetic Tape Control	Xerox	7361	2
20 KC Magnetic Tape Unit	Xerox	7362	3
BCD Option	Xerox	7365	2
Buffered Line Printer, 600 LPM	Xerox	7440	1
Interprocessor Interrupt Feature	Xerox	7700	1
Computer Interface Unit	Xerox	7901	3
IOP to DIO Adapter	Xerox	7929	1
Digital I/O Adapter	Xerox	7930	3
Digital I/O Expander	Xerox	7931	9
Stored Output Module (8 Bit)	Xerox	7950	75
Digital Input Module (16 Bit)	Xerox	7951	102
Frequency Control Unit	Xerox	7969	1

Table 16. UTCS/BPS Control Center Equipment Complement (Cont)

Equipment	Manufacturer	Type/Model Number	System Qty
Frequency Source Unit	Xerox	7970	2
Communication Controller	Xerox	7612	1
Timing Module	Xerox	7612	1
Send Module	Xerox	7615	2
EIA Interface	Xerox	7621	2
CRT Terminal	Hazeltine	H 2000	2
Control Panel	Artisan	UTCS Special	1
Map Logic Unit	TEC	UTCS Special	1
Map Graphics Unit	TEC	UTCS Special	1
Control Console	TAB	UTCS Special	1

SECTION 6

APPLICABILITY OF EXPERIENCE TO OTHER CITIES

The UTCS/BPS in Washington, D.C., while unique in its research perspective, is nevertheless similar in many respects to any computerized traffic control system of similar size installed in a major city. The system has all of the elements common to systems of this type, except for its extensive surveillance capability and large computer capacity. Therefore, much of the experience in maintaining and operating this system is typical and applicable to other cities having or considering similar installations. Although the operation of the system was principally for developing and evaluating advanced control strategies, the experience gained from performing all normal functions and exercising the system in all of its many modes of operation produced many useful guidelines. Further, the field equipment and installation is similar to that of most other systems, making maintenance, reliability, and repair experience directly applicable. Since one of the objectives of the UTCS/BPS research was to provide guidelines and disseminate information to prospective users, more attention than normal was given to the assimilation of this data. Consequently, the experience presented herein is probably the most extensive documented so far relating to systems of this type.

This section of the report discusses some of the specific operating and maintenance aspects applicable to other cities. The items are grouped according to the same four areas of discussion presented in Sections 2 to 4 of this report: namely, System Operating Experience, Equipment Experience, Maintenance Experience, and Maintenance Management.

6.1 SYSTEM OPERATING EXPERIENCE

Operation of the UTCS/BPS for the 3-1/2-year period from November 1972 to June 1976 was predominantly in support of the control strategy research effort. As a result, most system operating tasks, particularly those in the control center, focused on the software development activities of the various contractors involved in the effort. It has been estimated that over half of the central operator's time was applied to these activities. This is, of course, an unusual distribution of his time and would not normally be expected in a predominantly operational situation. Following are some of the aspects of the system operating experience learned from UTCS/BPS which should be considered.

6.1.1 FACILITIES

The UTCS/BPS was housed in a temporary building with an area measuring approximately 2500 square feet (50' x 50').

This area, even with the atypically large and extensive data processing complement, proved to be more than adequate. A typical operational system should be accommodated readily in half of this area, unless some unusual requirements exist. The control center had a raised floor which proved necessary to permit the extensive system cabling to be routed without unsightly and hazardous obstacles. The raised floor also facilitated air conditioning of the room and the equipment by serving as a distributing chamber for the cooled air.

One problem encountered was that entrance and exit doors of the building opened directly into the computer facility, creating severe temperature variations and significant amounts of dust and dirt, necessitating frequent cleaning. Consideration should be given to isolating the control center room from the entrances by partitions or separated rooms if possible. In this same regard, it was found that using the control center room as an office facility detracted from its utility as an operations center and permitted unauthorized personnel access to the center. If possible, considerations should be given to maintaining the control center separate from any office facilities in it own controlled-access area.

The UTCS/BPS control center was equipped with a fire protection system which protected the major computer system components. Individual smoke sensors were installed and an extinguishing system was piped to the various equipments. Such protection is relatively inexpensive and should be considered in the control center design.

Since the UTCS/BPS was always operated in an attended mode and around-the-clock traffic operations were never assumed, no auxiliary power system was incorporated. Where power failure is a frequent possibility, consideration of a backup power source should also be made. To avoid overloads and minimize equipment drop-out, attention should be given to the power distribution system of the control center. Each unit should have an individual circuit breaker and startup of any peripheral should not disturb the operation of any other operating equipment.

The temporary UTCS/BPS control center employed two large air conditioners located in the room. These units produced a significant amount of noise and were particularly disturbing during lecture periods and demonstrations. If room air conditioning is used, attempts should be made to locate the units outside the center itself with the cooling air directed into the rooms.

Continuous operation of a system requires supplies of expendable materials (e.g., tapes, cards, paper) and the use of various stored program material (disks, tapes, etc.). In time, these items can grow to occupy considerable space, and a proper place for their storage and easy access will prove a great convenience.

6.1.2 STAFFING

The UTCS/BPS was operated and maintained by a full-time staff of four on-site personnel. It should be noted, however, that these were all graduate engineers with capabilities for flexible assignment to any task - from operating the system to repairing components. The system was operated, for the most part, on a 12-hour, 5-day basis.

The staff requirements for an operational system will depend mainly on how the system is to be used, the maintenance structure of the agency, and the capabilities of the assigned personnel. The experience of UTCS/BPS indicates that for a normal, single-shift operation (peak-to-peak attended), a staff of three people should be adequate. A system operator with some simple programming capability and a field maintenance technician can normally carry out all required functions. The third man serves as the central operator's backup and can assist the field technician in certain troubleshooting activities. This staff would have to be augmented if any special evaluation or data assimilation tasks were performed and if the system operation were extended to more than a single shift or the system size and amount of field equipment to be maintained was enlarged. The system operator will, in addition to monitoring the system and traffic status, perform simple maintenance functions such as lamp replacement, tape and paper replenishment, and periodic diagnostic checks. Often overlooked, however, are the many associated necessary tasks such as record keeping, parts procurement, vendor warrantee processing, utilities coordination, etc. It is important that the coordinating responsibility for operations and upkeep of the system be clearly designated to an individual. It should be this individual's responsibility to establish and enforce procedures for such things as:

- Operation in emergency situations (weather, power losses, etc.)
- Operations for special traffic situations (accidents, special events, etc.)
- Coordination with police for traffic control and emergency operations
- Correction of malfunctions, in both central and field equipments, including recordkeeping

- Procedures for alerting appropriate personnel to system and/or traffic status during regular and after hour periods
- Incorporation of system update and changes, including data base equipment for all elements of the system and software.

The system operator should maintain a log of all activities by all users of the system. This is essential not only for tracing the operational history of performance but also is vital to the maintenance and troubleshooting area of activity.

6.1.3 CONFIGURATION CONTROL

One of the major activities of the UTCS/BPS operating staff was keeping the equipment and software status continuously current. Although this requirement was more pronounced in this project, it is nevertheless a consideration in any such system because of the often separated functions of field maintenance and traffic operations. Therefore, a well coordinated change procedure that keeps the traffic engineering and maintenance personnel informed of all changes is essential. All updates should be documented and highlighted when they occur. A reference library should be maintained in the control center of all systems and software configuration changes.

6.1.4 DOCUMENTATION AND RECORDKEEPING

A computerized traffic control system affords a visibility into, and control of, operations not possible with conventional systems. However, to usefully collect and apply this information requires a systematic procedure of recordkeeping and documentation. In the UTCS/BPS, the following items of reporting were found to be useful:

- System Operation Log
- Computer Maintenance Log - (maintained by the computer maintenance personnel, but monitored by the system operator to verify maintenance procedures)
- Field Equipment Status Log
- Software Log
- End-of-day Reports

The system reference documentation should also be kept current and accessible in the control center. This includes:

- Tape library file

- Program listings
- System operator and maintenance manuals
- Other cross-referenced listings, usually established by the operators according to individual preference and which are aids for ready reference to required data.

6.1.5 PUBLIC AWARENESS AND DISSEMINATION OF INFORMATION

Installation of a modern computerized traffic control system in any city is a major advance and one requiring public awareness of the benefits and support for its success. The media and the public are often made aware of the installation of such systems at their inception, but are not kept informed of the operation or performance of the system during its use. A definite procedure for communication with the media (press, TV, radio) can keep the public informed of the status and improvements achieved and can serve as a source of motorist aid or public service information.

6.2 EQUIPMENT EXPERIENCE

The UTCS/BPS uses standard, available off-the-shelf equipment typically specified for urban traffic control systems. The only specially developed items are the bus priority transmitter and detector (for which there were no commercially available equivalents at the time the system was implemented). However, equivalents are available from several manufacturers that are similar to those used in the BPS. Only in the quantity of detectorization and in the capacity and scale of the computer system does the UTCS/BPS differ from systems typically installed in other relatively large cities.

The equipment experience of the UTCS/BPS, both in the field and in central, has been very good. In 3-1/2 years of operation, very few major malfunctions have occurred to significantly disable the operation or degrade its performance. Most equipment failures have been isolated occurrences in which repair and restoration of operation has been no more difficult, unusual, or burdensome than for any conventional traffic signal system of comparable size. Failures in central have been mostly in the computer peripherals, with only a few (notably the mass storage disc units) causing the system to become inoperable. This successful experience has been due to several factors including complete and careful specification of requirements; selection of available, proven, and tested equipments; attention to proper installation; and maintenance. The system's status reporting capability and the assignment of adequate, competent personnel contributed significantly to the high uptime and continuous level of performance that was demonstrated.

Section 3 reported the failure rates and reliability of equipments and subsystems of the UTCS/BPS. With the proper adjustments for quantities and operating time, these results may be applied to other installations to estimate expected reliability. In addition to the reliability, some other aspects of the equipment experience were learned from UTCS/BPS.

6.2.1 CONTROL PANEL AND MAP DISPLAY

The Control Panel of the UTCS/BPS is the principal system/operator interface. The unit is designed around the traffic engineer-operator and permits control of the system and determination of status in readily understandable language. The Control Panel has proven to be a useful device to which new personnel can easily adapt. It is a convenient, useful, and trouble-free element which was a valuable tool in determining system and equipment status and which facilitated maintenance activities. At relatively small cost, this unit should be considered in the design of such systems.

A dynamic map display has considerable impact in demonstrating the status of the traffic signal system and the condition of traffic to both operating and observing personnel. This element has also proven to be a very powerful aid in troubleshooting the system, debugging and refining control techniques, and evaluating performance. As the main focus of attention in the control center, it must be kept in good operating condition. The main requirement for maintenance is the servicing of indicator lamps, and therefore ease of access and simplicity of replacement is essential. The UTCS/BPS Map Display was mounted in a partition wall which permitted easy access from the rear. The rear of the map was marked with the street network so that location of components was facilitated. Other techniques for providing access are available but attention to this factor should not be overlooked. Also, an important consideration in the design of the map display is the lamp life. Proper attention to lamp rating and power supply characteristics are essential as are the factors of turn-on transient and replacement with power on.

6.2.2 RECORDKEEPING

Keeping track of equipment configuration and operating experience is essential for a number of maintenance functions. In addition to logging malfunctions, a good system of records can indicate recurring problems, trends in performance, and sparing needs.

The Trouble/Failure Reports (TFRs) used in UTCS/BPS are a good example of a systematic failure reporting technique. Regardless of the technique used, complete and detailed records (including serial numbers, locations, dates, repair action or disposition, and other pertinent data) can be invaluable when tracing past history. Another technique which proved very useful was the storage of an equipment dossier in each field intersection cabinet. In a protective envelope, records of controller and cabinet modifications, controller timing, communication channel designations, and other pertinent data are available at the site when maintenance activities are required.

6.3 MAINTENANCE EXPERIENCE

The maintenance tasks for the UTCS/BPS were coordinated by the system manager and carried out by various agents including the system manager's on-site personnel, the computer service subcontractor, the local power utility, the local telephone utility, the District of Columbia DOT personnel, a construction contractor, and various equipment suppliers. Such an array of participating groups is not unusual and leads to the first consideration of maintenance – responsibility. With many interacting elements in the system and the need for systematic identification and isolation of malfunctions and direction of repair, a focal point of responsibility is essential. As in the case of system operation, procedures and records are vital.

Maintenance is broadly taken to include repair of malfunctions, periodic preventive servicing, incorporation of changes and updates, and component repair and warrantee servicing. Following are some of the aspects of maintenance experience learned from UTCS/BPS which should be considered:

6.3.1 CENTRAL MAINTENANCE

Because of the specialized nature of the computer system and its associated peripheral devices, maintenance of these elements should be provided by the computer manufacturer or a qualified computer service organization under a service contract arrangement. The service contract will cover both regularly scheduled periodic maintenance and emergency maintenance with an agreed upon maximum call response time. Under such an agreement, periodic updates of operating system software are often provided and the specialized equipment knowledge and user support are always accessible. Regularly scheduled preventive maintenance ahould be arranged for a specific time when the system can be dropped into standby. In UTCS/BPS, for example, Friday afternoons were found to be convenient, but this may vary with the specific city's conditions.

Other central equipments, including the map display, control panel, and central communications, were found to be serviceable, under normal conditions, by the system operator. With a little experience, certain key components or modules can be spared and, with the aid of system diagnostic procedures and the proper documentation, malfunctions can be readily located and repaired. Good recordkeeping of spares inventory, warrantee servicing, and sources of key replacement items can materially help in this task and avoid the inconvenience of an unrepairable malfunction at a critical operating time.

Software maintenance includes the incorporation of updates to the program itself or, more often, to the system data base. The system operator should maintain good records of the data base changes and system revisions and store the tapes or other media until they are positively of no further value. A library of the tapes and other media provides for eacy access and chronological history of the system development and growth.

6.3.2 FIELD MAINTENANCE

A repair strategy for field equipment must be established to define responsibilities and determine at what level repairs are to be made. In UTCS/BPS it was decided that no preventive maintenance or routine servicing of field equipment would be done on the premise that, once established as operating properly, the least amount of tampering was best. When field repairs were necessary, replacement was on a unit basis (e.g., detector, adapter, communication receiver, controller) in the field. The unit was then returned to a depot for repair or, if necessary, cycled back to the supplier for warrantee servicing. The level of depot service is a function of the capabilities of the service technicians available, but with a little training and experience it was found that many units could be repaired by simple component replacement, thus saving significant costs and requiring fewer unit and module spares.

In this same regard, the mean time needed to repair malfunctions in the field is dependent on the routine or procedure used by the system staff. In UTCS/BPS, there were at least two technicians continuously assigned to maintaining the field equipment in a high level of operability. On an almost daily basis, the team operated in the field attending to problems logged by the system operator or, on occasion, verbally communicated in real time from the control center. As a result, the response time to correct problems was short, averaging, as indicated in the Section 3 analysis, 1.5 hours for most field problems. This response time will, in most cases, be somewhat higher for a typically operational system, reflecting the procedure used and including the normal factors of recognizing a problem, assigning a responsibility for its repair, dispatching the service and then accomplishing the repair.

One item found to be essential was a two-way communication link between the field and the control center. In the UTCS/BPS, a radio communication system was established with a base station at the control center and mobile car radios in the field. Other techniques are available (e.g., voice line to intersections) but in any case, a communication link is a cost effective and time saving aid in troubleshooting a system and in evaluating operation and performance.

6.4 MAINTENANCE MANAGEMENT

Maintenance management refers to the overall approach to planning, providing, coordinating, and documenting the maintenance functions of a computerized traffic control system. While actually a recognized or implicit part of any system's operation, maintenance management is more critical to the effective functioning of a computer controlled system because of the greater interaction of system elements.

The effectiveness of a good maintenance operation starts with the assignment of personnel. Experience indicates that a normally experienced technician can readily learn enough about a system's operation to isolate and identify most malfunctions and to service most equipments. Attention must be given, however, to the early assignment of the personnel, so that they can be trained, and to the retention of these personnel in this assignment. This is often difficult since the very training and experience provided leads to other opportunities for personal advancement and turnover may be high. Recognition of this factor, however, can help to alleviate its effect by providing for replacement training and establishing good training and system documentation.

The logistics of maintenance include many factors. As noted earlier, a replacement level philosophy must be established which then leads to a repairing and sparing approach. Spare components and equipments can be established based on projected reliability of equipment and turn-around time for repairs. Also to be considered is the provision of standard and special test equipment, facilities for storage and repair, and vehicles for field maintenance. In UTCS/BPS, a small van was found to be a convenient vehicle -- large enough to carry replacement units and test equipment and small enough to travel on urban streets and park easily without blocking traffic. A van also afforded a weather-protected location for doing on-site test and repairs. As noted earlier, two-way communication was found to be essential and in UTCS/BPS, the maintenance vehicles were radio-equipped.

In most cases, the maintenance of a system involves one or more utilities (power company, telephone company) as well as a construction or electrical contractor who repairs or replaces loop detectors, conduit and cable, cabinet knockdowns, etc. Necessary tasks in effective maintenance management include establishing arrangements for providing the required services (including clearly defined procedures for responding and unit costs of services), monitoring and verifying their completion, validating invoices, and updating as-built drawings, if required.

The practices for budgeting maintenance operations will vary from city to city. However, it should be recognized that a computer-controlled signal system will have more requirements and interconnects than a conventional system. With more equipment installed, the greater likelihood is incurred of cabinet knockdowns by motorists and detector loop and conduit destruction from contractor and utility activities. Proper consideration should be given to budgeting for this restoration and replacement.

Appendix A

VEHICLE DETECTOR STATUS TABLE

The following report on system detector status incorporates the installation of new detectors on H and I Street one-way changes, M Street new loops, and Connecticut Avenue additions. Contents of status reflects system as of 5/1/76.

An explanation of notations used in the "detector" columns are as follows:

1 = Operable

2 = To be repaired

3 = Cannot be repaired

4 = Installed

5 = Removed

6 = Will not be repaired (See note K)

Notations used in "other" and "remarks" columns of Detector Status:

Belden cable bad

Conduit bad

Splice Box missing

Loop Wipeout

a = One-way change

b = Metro

c = MGVD

d = FHWA takeout

e = CIC takeout

f = Obstruction/Construction

g = software inhibited

h = manually placed in standby

i = manually placed in standby because of parking in off and AM peak

j = repaired since 10/27/75

k = permanent system removal, will not be repaired

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS IN USE	SYSTEM STATUS REMOVAL PER.	SYSTEM STATUS REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
001/501	S/B Wisc @ W	Q_2	L2	X			1	1		
002/500	S/B Wisc @ W	Q_1	L2	X			1	1		
003/496	N/B Wisc @ W	Q_1	L2	X			1	1		
004/497	N/B Wisc @ W	Q_2	L2	X			1	1		
005/499	E/B W @ Wisc	Q_2	L2	X			1	1		
006/498	E/B W @ Wisc	Q_2	L2	X			1	1		
007/488	W/B Calvert @ Wisc	Q_1	L2	X			1	1		
008/489	W/B Calvert @ Wisc	Q_2	L2	X			1	1		
009/490	N/B Wisc @ Calvert	Q_1	L2	X			1	1		
010/491	N/B Wisc @ Calvert	Q_2	L2	X			1	1		
011/009	SE/B Mass @ Wisc	Q_1	L2	X			1	1		
012/007	E/B Cathedral @ Mass	V_1	L1	X			1	1		
013/011	SE/B Mass @ Wisc	Q_3	L2	X			1	1		
014/008	SE/B Mass @ Wisc	V_1	L1	X			1	1	i	
015/010	SE/B Mass @ Wisc	Q_2	L2	X			1	1		
016/014	S/B Wisc @ Mass	Q_3	L2		X		5	5	g	d,f
017/493	E/B Calvert @ Wisc	Q_2	L2	X			1	1		
018/013	S/B Wisc @ Mass	Q_2	L2		X		6	1	h	k(2/76)
019/492	E/B Calvert @ Wisc	Q1	L2	X			1	1		
020/012	S/B Wisc @ Mass	Q_1	L2		X		6	1	h	f,k (2/76)
021/494	S/B Wisc @ Calvert	Q_1	L2		X		6	1	h	f k (2/76)
022/034	SE/B Mass @ Garfield	Q_3	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE	LANE	SYSTEM STATUS: IN USE	SYSTEM STATUS: REMOVAL PER.	SYSTEM STATUS: REMOVAL TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
023/002	NW/B Mass @ Wisc	Q_1	L2	X			1	1		
024/005	N/B Wisc @ Mass	Q_1	L2		X		6	1	h	f k (2/76)
025/024	S/B Wisc @ Garfield	Q_2	LT		X		6	1	h	f k (2/76)
026/495	S/B Wisc @ Calvert	Q_2	L2	X			1	1		
027/022	S/B Wisc @ Garfield	V_1	L1		X		6	1	h	f k (2/76)
028/023	S/B Wisc @ Garfield	Q_1	LT		X		6	1	h	f k (2/76)
029/137	S/B 17 @ Const.	Q_3	L2	X			1	1		
030/006	N/B Wisc @ Mass	Q_2	L2		X		6	1	h	f,k (2/76)
031/136	S/B 17 @ Const	Q_2	L2	X			1	1		
032/015	W/B Garfield @ Wisc	Q_1	L1	X			1	1		
033/031	E/B Garfield @ Mass	Q_2	L1	X			1	1		
034/017	N/B Wisc @ Garfield	Q_1	L2	X			1	1		
035/019	N/B Wisc @ Garfield	Q_3	L2		X		5	5	g	d,f
036/128	W/B Const @ 17	Q_3	L3	X			1	1		
037/018	N/B Wisc @ Garfield	Q_2	L2		X		6	1	h	f ,k (2/76)
038/231	W/B K @ 18	V_1	L2	X			1	1		
039/021	E/BGarfield @ Wisc	Q_2	L2	X			1	1		
040/020	E/B Garfield @ Wisc	Q_1	L2	X			1	1		
041/016	W/B Garfield @ Wisc	Q_2	L1	X			1	1		
042/030	E/B Garfield @ Mass	Q_1	L1	X			1	1		
043/001	NW/B Mass @ Wisc	V_1	L1	X			1	1		
044/003	NW/B Mass @ Wisc	Q_2	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS			DETECTOR			REMARKS/DATE
			IN USE	REMOVAL					
				PER.	TEM.	LOOP	ELEC.	OTHER	
045/033	SE/B Mass @ Garfield	Q_2 L2	X			1 1	1		
046/004	NW/B Mass @ Wisc	Q_3 L2	X			1	4		c=old assignment
047/032	SE/B Mass @ Garfield	Q_1 L2	X			1	1		
048/025	W/B Garfield @ Mass	Q_1 L1	X			1	1		
049/027	NW/B Mass @ Garfield	Q_1 L2	X			1	1		
050/026	W/B Garfield @ Mass	Q_2 L1	X			1	1		
051/028	NW/B Mass @ Garfield	Q_2 L2	X			1	1		
052/029	NW/B Mass @ Garfield	Q_3 L2	X			1	1		
053/042	S/B Wisc @ R	Q_2 L2	X			1	1		
054/041	S/B Wisc @ R	Q_1 L2	X			1	1		
055/040	E/B R @ Wisc	Q_2 L1	X			1	1		
056/039	E/B R @ Wisc	Q_1 L1	X			1	1		
057/035	W/B R @ Wisc	Q_1 L1	X			1	1		
058/036	W/B R @ Wisc	Q_2 L1		X		6	1	h	f,k (2/76)
059/038	N/B Wisc @ R	Q_2 L1	X			1	1		
060/037	N/B Wisc @ R	Q_1 L1	X			1	1		
061/052	E/B M @ Key Bridge	Q_2 L2	X			1	1		
062/050	E/B M @ Key Bridge	V_1 L1	X			1	1		
063/051	E/B M @ Key Bridge	Q_1 L2	X			1	1		
064/503	E/B K @ 10	V_1 L2	X			1	1		
065/047	N/B Key Bridge @ M	Q_1 L3	X			1	1		
066/044	N/B Key Bridge @ M	Q_1 L1	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
067/049	N/B Key Bridge @ M	Q_3 L3	X			1	1		
068/046	N/B Key Bridge @ M	Q_3 L1		X		1	1	g	
069/048	N/B Key Bridge @ M	Q_2 L3	X			1	1		
070/045	N/B Key Bridge @ M	Q_2 L1	X			1	1		
071/502	W/B K @ 10	V_1 L3	X			1	1		
072/105	W/B Const @ 20	V_1 L3		X		6	1	h k(2/76)	
073/043	W/B M @ 34	V_1 L3		X		5	5	g	K (2/76)
074/060	E/B M @ Wisc	Q_1 L2	X			1	1		
075/057	N/B Wisc @ M	Q_1 L2	X			1	1		
076/058	N/B Wisc @ M	Q_2 L2	X			1	1		
077/063	S/B Wisc @ M	Q_1 L2	X			1	1		
078/054	W/B M @ Wisc	Q_1 L2	X			1	1		
079/062	E/B M @ Wisc	Q_3 L2	X			1	1		
080/061	E/B M A Wisc	Q_2 L2	X			1	1		
081/059	E/B M @ Wisc	V_1 L1	X			1	1		
082/065	S/B Wisc @ M	Q_3 L2	X			1	1		
083/419	E/B H @ 17 (W)	V_1 L2	X			1	1		new assignment move from H/Conn/Jack,H E/B @ Conn/Jackson
084/064	S/B Wisc @ M	Q_2 L2	X			1	1		
085/068	E/B M @ 31	V_1 L2		X		6	1		k, 3/76
086/053	W/B M @ Wisc	V_1 RT	X			1	1		
087/055	W/B M @ Wisc	Q_2 L2	X			1	1		
088/056	W/B M @ Wisc	Q_3 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS			DETECTOR			REMARKS/DATE
				IN USE	REMOVAL					
					PER.	TEM.	LOOP	ELEC.	OTHER	
089/485	E/B Macomb @ Wisc	Q_2	L2	X			1	1		
090/484	E/B Macomb @ Wisc	Q_1	L2	X			1	1		
091/067	W/B M @ 31st	Q_2	L2	X			1	1		
092/069	E/B M @ 29	V_1	L2	X			1	1		
093/331	N/B 20 @ L	V_1	L3	X			1	1		
094/072	SE/B Penn @ 28	V_1	L2	X			1	1		
095/066	W/B M @ 31	Q_1	L2	X			1	1		
096/071	SW/B M @ Penn	V_1	L2	X			1	1		
097/242	N/B 17 @ I	Q_1	L2		X		6	1	g	K, (2/76)
098/244	N/B 17 @ I	Q_3	L2		X		5	5	g	d,b,f
099/070	NW/B Penn @ 28	V_1	L2	X			1	1		
100/075	SE/B Penn @ 26	V_1	L2		X		6	1		h,k (2/76)
101/073	NW/B Penn @ 26	V_1	L2	X			1	1		
102/304	W/B 20 @ K	V_1	L3	X			1	1		
103/074	E/B L @ Penn	V_1	L2	X			1	1		
104/487	S/B Wisc @ Macomb	Q_2	L2	X			1	1		
105/486	S/B Wisc @ Macomb	Q_1	L2	X			1	1		
106/483	N/B Wisc @ Macomb	Q_2	L2	X			1	1		
107/482	N/B Wisc @ Macomb	Q_1	L2	X			1	1		
108/080	S/B 25 @ Penn	V_1	L2	X			1	1		
109/076	E/B L @ 24	V_1	L2	X			1	1		
110/077	NW/B Penn @ 25	V_1	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE	LANE	SYSTEM STATUS: IN USE	REMOVAL: PER.	REMOVAL: TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
111/078	N/B 25 @ Penn	V_1	L2		X		6	1	h	f,k (2/76)
112/079	SE/B Penn @ 25	V_1	L2	X			1	1		
113/084	S/B 24 @ Penn	V_1	L2	X			1	1		
114/081	NW/B Penn @ 24	V_1	L2	X			1	1		
115/082	W/B K @ 24	V_1	L1	X			1	1		
116/083	N/B 24 @ K	V_1	L2	X			1	1		
117/505	E/B K @ Circle Main	V_1	L2	X			1	1		
118/504	E/B K @ Circle Acc	V_1	L2	X			1	1		
119/095	S/B 23 @ Const.	Q_2	L2	X			1	1		
120/094	S/B 23 @ Const.	Q_1	L2	X			1	1		
121/085	W/B Const @ 23	Q_1	L3	X			1	1		
122/088	N/B 23 @ Const	Q_1	L2	X			1	1		
123/096	S/B 23 @ Const	Q_3	L2		X		6	1		h,k(2/76)
124/090	N/B 23 @ Const	Q_3	L2	X			1	1		
125/089	N/B 23 @ Const	Q_2	L2	X			1	1		
126/093	E/B Const @ 23	Q_3	L2	X			1	1		
127/092	E/B Const @ 23	Q_2	L2	X			1	1		
128/480	W/B Macomb @ Wisc.	Q_1	L2	X			1	1		
129/091	E/B Const @ 23	Q_1	L2		X		6	1	h	f,k (2/76)
130/086	W/B Const @ 23	Q_2	L3	X			1	1		
131/087	W/B Const @ 23	V_1	LT	X			1	1		
132/172	E/B Const @ H. B.	Q_2	L3	X			1	1		

VEHICLE NUMBER	LOCATION	USE	LANE	SYSTEM STATUS: IN USE	SYSTEM STATUS: REMOVAL PER.	SYSTEM STATUS: REMOVAL TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
133/097	W/B Const @ 22	V_1	L3	X			1	1		
134/171	E/B Const @ H. B.	Q_1	L3	X			1	1		
135/168	N/B H.B. @ Const	Q_1	L1	X			1	1		
136/101	E/B Const @ 21	V_1	L3	X			1	1		
137/103	E/B Const @ 21	Q_2	LT	X			1	1		
138/166	W/B Const @ H. B.	Q_1	L4	X			1	1		
139/165	W/B Const @ H. B.	V_1	L2	X			1	1		
140/170	N/B H. B. @ Const	Q_3	L1	X			1	1		
141/169	N/B H. B. @ Const	Q_2	L1	X			1	1		
142/167	W/B Const @ H. B.	Q_2	L4	X			1	1		
143/102	E/B Const @ 21	Q_1	LT	X			1	1		
144/481	W/B Macomb W Wisc	Q_2	L2	X			1	1		
145/098	W/B Const @ 21	Q_1	L3	X			1	1		
146/099	W/B Const @ 21	Q_2	L3	X			1	1		
147/104	S/B 19 A Va.	V_1	L3	X			1	1		
148/264	N/B 17 @ H	Q_2	L2	X			1	1		
149/114	S/B 19 @ Const	Q_3	L2		X		5	5	g	f,d
150/117	S/B19 @ Const	Q_3	LT		X		5	5	g	f,d
151/106	E/B 21 @ Const	V_1	L3	X			1	1		
152/100	W/B Const @ 21	Q_3	L3	X			1	1		
153/111	E/B Const @ 19	Q_2	L3	X			1	1		
154/113	S/B 19 @ Const	Q_2	L2		X		6	1		f,k (2/76)

VEHICLE NUMBER	LOCATION	USE,	LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
155/116	S/B 19 @ Const	Q_2	LT		X		6	1	h	f ,k (2/76)
156/112	S/B 19 @Const	Q_1	L2	X			1	1		
157/115	S/B 19 @ Const	Q_1	LT	X			1	1		
158/110	E/B Const @ 19	Q_1	L3	X			1	1		
159/107	W/B Const @ 19	Q_1	L3	X			1	1		
160/125	E/B Const @ 18	Q_3	LT	X			1	1		
161/108	W/B Const @ 19	Q_2	L3	X			1	1		
162/124	E/B Const @ 18	Q_2	Lt	X			1	1		
163/122	E/B Const @ 18	V_1	L2	X			1	1		
164/109	W/B Const @ 19	Q_3	L3	X			1	1		
165/123	E/B Const @ 18	Q_1	LT	X			1	1		
166/119	W/B Const @ 18	Q_1	L3	X			1	1		
167/120	W/B Const @ 18	Q_2	L3	X			1	1		
168/118	W/B Const @ 18	V_1	RT	X			1	1		
169/132	E/B Const @ 17	Q_1	L3	X			1	1		
170/135	S/B 17 @ Const	Q_1	L2	X			1	1		
171/126	W/B Const @ 17	Q_1	L3	X			1	1		
172/129	N/B 17 @ Const	Q_1	L2	X			1	1		
173/134	E/B Const @ 17	Q_3	L3		X		5	5	g	f ,d
174/133	E/B Const @ 17	Q_2	L3	X			1	1		
175/121	W/B Const @ 18	Q_3	L3	X			1	1		
176/127	W/B Const @ 17	Q_2	L3		X		1	1		c, e (2/76)

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS: IN USE	SYSTEM STATUS: REMOVAL PER.	SYSTEM STATUS: REMOVAL TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
177/131	N/B 17 @ Const	Q_3 L2	X			1	1		
178/130	N/B 17 @ Const	Q_2 L2	X			1	1		
179/449	W/B K @ 14	Q_1 L2	X			1	1		
180/142	S/B 21 @ E (N)	V_1 L3	X			1	1		
181/138	W/B E (N) @ 20	V_1 L2	X			1	1		
182/139	W/B E (N) @ 20	V_1 L3	X			1	1		
183/450	W/B K @ 14	Q_2 L2	X			1	1		
184/158	S/B 19 @ E (S)	V_1 L3	X			1	1		
185/146	S/B 19 @ E (N)	V_1 L2	X			1	1		
186/148	S/B 19 @ E (N)	Q_2 L3		X		6	1	h	f ,k (2/76)
187/147	S/B 19 @ E (N)	Q_1 L3	X			1	1		
188/143	W/B E (N) @ 19	Q_1 L3	X			1	1		
189/451	W/B K @ 14	Q_3 L2	X			1	1		
190/144	W/B E (N) @ 19	Q_2 L3	X			1	1		
191/145	W/B E (N) @ 19	Q_3 L3	X			1	1		
192/474	N/B 18 @ F	Q_3 L2	X			1	1		
193/150	W/B N.Y. @ 18	V_1 L3	X			1	1		
194/155	E/B E (S) @ 20	V_1 L3	X			1	1		
195/154	E/B E (S) @ 20	V_1 L2	X			1	1		
196/141	N/B 20 @ E (N)	V_1 L3	X			1	1		
197/140	N/B 20 @ E (N)	V_1 L2	X			1	1		
198/157	E/B E (S) @ 19	V_1 L3	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
199/156	E/B E(S) @ 19	V_1 L2	X			1	1		
200/153	N/B 20 @ E(S)	V_1 L3	X			1	1		
201/152	N/B 20 @ E(S)	V_1 L1	X			1	1		
202/164	E/B E(S) @ 18	Q_3 L3	X			1	1		
203/163	E/B E(S) @ 18	Q_2 L3	X			1	1		
204/162	E/B E(S) @ 18	Q_1 L3	X			1	1		
205/151	N/B 18 @ New York	V_1 L2	X			1	1		
206/182	E/B E(S) @ 17	Q_3 L2		X		5	5	g	d,f
207/159	N/B 18 @ E(S)	Q_1 L2	X			1	1		
208/161	N/B 18 @ E(S)	Q_3 L2	X			1	1		
209/160	N/B 18 @ E(S)	Q_2 L2	X			1	1		
210/174	E/B F @ 17	V_1 L2	X			1	1		
211/176	S/B 17 @ New York	V1 L2	X			1	1		
212/173	N/B 17 @ F	V_1 L2	X			1	1		
213/184	S/B 17 @ E(S)	Q_2 L2	X			1	1		
214/181	E/B E(S) @ 17	Q_2 L2		X		6	1	h	c,e (2/76)
215/180	E/B E(S) @ 17	Q_1 L2		X		6	1	h	c,e (2/76)
216/175	N/B 17 @ New York	V_1 L2	X			1	1		
217/183	S/B 17 @ E(S)	Q_1 L2	X			1	1		
218/177	N/B 17 @ E(S)	Q_1 L2	X			1	1		
219/178	N/B 17 @ E(S)	Q_2 L2	X			1	1		
220/179	N/B 17 @ E(S)	Q_3 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS			DETECTOR			REMARKS/DATE
				IN USE	REMOVAL					
		USE	LANE		PER.	TEM.	LOOP	ELEC.	OTHER	
221/251	NW/B Penn @ H	Q_1	L2	X			1	1		
222/252	NW/B Penn @ H	Q_2	L2	X			1	1		
223/435	N/B Vermont @ L	V_1	L2	X			1	1		
224/259	N/B 18 @ H	V_1	L2	X			1	1		
225/185	NW/B Penn @ 18	Q_1	L2	X			1	1		
226/186	NW/B Penn @ 18	Q_2	L2	X			1	1		
227/191	E/B H @ 18	V_1	L2	X			1	1		
228/193	SE/B Penn @ 18	Q_2	L2	X			1	1		
229/192	SE/B Penn @ 18	Q_1	L2	X			1	1		
230/203	SE/B Penn @ 17	Q_3	L2	X			1	1		
231/206	S/B 17 @ Penn	Q_3	L2	X			1	1		
232/187	NW/B Penn @ 18	Q_3	L2		X		3	5	g	b,d,f
233/205	S/B 17 @ Penn	Q_2	L2	X			1	1		
234/452	N/B 14 @ K	Q_1	L2	X			1	1		
235/204	S/B 17 @ Penn	Q_1	L2	X			1	1		
236/453	N/B 14 @ K	Q_2	L2	X			1	1		
237/265	N/B 17 @ H	Q_3	L2		X		5	5	g	b,d,f
238/195	W/B Penn @ 17	Q_1	L2	X			1	1		
239/202	SE/B Penn @ 17	Q_2	L2	X			1	1		
240/201	SE/B Penn @ 17	Q_1	L2	X			1	1		
241/454	N/B 14 @ K	Q_3	L2		X		5	5	g	b,d,f
242/207	E/B Penn @ Jackson	V_1	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
243/196	W/B Penn @ 17	Q_2 L2	X			1	1		
244/197	W/B Penn @ 17	Q_2 L2	X			1	1		
245/208	S/B Jackson @ Penn	V_1 L2		X		1	5	g	a
246/424	N/B Jackson @ H	Q_3 L2	X			1	1		
247/508	E/B Indep @ 14	V_1 L2	X			1	1		
248/509	S/B 14 @ Indep	V_1 L2	X			1	1		
249/507	N/B 14 @ Indep	V_1 L2	X			1	1		
250/506	W/B Indep @ 14	V_1 L2	X			1	1		
251/443	N/B 14 @ L	Q_3 L2	X			1	1		
252/189	N/B 18 @ Penn	Q_2 L2	X			1	1		
253/190	N/B 18 @ Penn	Q_3 L2	X			1	1		
254/209	W/B G @ 18	Q_1 L3	X			1	1		
255/210	W/B G @ 18	Q_2 L3	X			1	1		
256/211	N/B 18 @ G	Q_1 L2	X			1	1		
257/212	N/B 18 @ G	Q_2 L2	X			1	1		
258/198	N/B 17 @ Penn	Q_1 L2	X			1	1		
259/213	S/B 17 @ F	V_1 L2	X			1	1		
260/199	N/B 17 @ F	Q_2 L2	X			1	1		
261/200	N/B 17 @ Penn	Q_3 L2	X			1	1		
262/218	E/B K @ 19	Q_2 L2	X			1	1		
263/217	E/B K @ 19	Q_1 L2	X			1	1		
264/219	S/B 19 @ K	Q_2 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE,	LANE	SYSTEM STATUS			DETECTOR			REMARKS/DATE
				IN USE	REMOVAL PER.	REMOVAL TEM.	LOOP	ELEC.	OTHER	
265/214	W/B K @ 19	Q_1	L2	X			1	1		
266/230	E/B K @ 18	Q_3	L2	X			1	1		
267/238	W/B 19 @ I	V_1	LT	X			1	1		
268/455	N/B 14 @ K	V_1	LT	X			1	1		
269/229	E/B K @ 18	Q_2	L2	X			1	1		
270/215	W/B K @ 19	Q_2	L2	X			1	1		
271/216	W/B K @ 19	Q_3	L2	X			1	1		
272/228	E/B K @ 19	Q_1	L2	X			1	1		
273/222	W/B K @ 18	Q_1	L2	X			1	1		
274/237	E/B K @ 17	Q_3	L3	X			1	1		
275/223	W/B K @ 18	Q_2	L2	X			1	1		
276/373	N/B 18 @ K	V_1	L3	X			1	1		
277/371	N/B 18 @ L	Q_2	L2	X			1	1		
278/372	N/B 18 @ L	Q_3	L2	X			1	1		
279/225	N/B 18 @ K	Q_1	L3	X			1	1		
280/236	N/B K @ 17	Q_2	L3	X			1	1		
281/224	W/B K @ 18	Q_3	L2	X			1	1		
282/235	N/B K @ 17	Q_1	L3	X			1	1		
283/248	S/B 17 @ I	Q_3	LT		X		5	5	g	b,d,f
284/232	N/B 17 @ K	Q_1	L2		X		6	1	h	b,k (2/76)
285/247	S/B 17 @ I	Q_2	LT	X			1	1		
286/405	N/B 15 @ K	Q_2	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
287/406	N/B 15 @ K	Q_3 L2		X		5	5	h	b,d
288/395	N/B 16 @ K	Q_2 L2	X			1	1		
289/478	W/B G @ 21	V_1 L2	X			1	1		
290/411	N/B Conn @ I	V_1 L2		X		1	1		k, (2/76)
291/479	S/B 21 @ G	V_1 L2	X			1	1		
292/473	N/B 18 @ F	Q_2 L2	X			1	1		
293/476	E/B F @ 18	Q_2 L2	X			1	1		
294/475	E/B F @ 18	Q_1 L2	X			1	1		
295/257	S/B 19 @ Penn	Q_2 L2	X			1	1		
296/472	N/B 18 @ F	Q_1 L2	X			1	1		
297/477	E/B F @ 18	Q_3 L2	X			1	1		
298/149	S/B 19 @ E(N)	Q_3 L3	X			1	1		
299/226	N/B 18 @ K	Q_2 L3		X		6	1	g	k, (2/76)
300/227	N/B 18 @ K	Q_3 L3		X		6	1	g	f,k (2/76)
301/469	S/B Vermont @ K	Q_1 L2	X			1	1		
302/239	N/B 18 @ I	Q_1 L2		X		1	1		k, (2/76)
303/403	W/B K @ 15	V_1 L2	X			1	1		
304/465	N/B 15 @ K	Q_1 L2	X			1	1		
305/462	W/B K @ Vermont	Q_1 L2	X			1	1		
306/233	N/B 17 @ K	Q_2 L2	X			1	1		
307/245	S/B 17 @ I	V_1 L2		X		6	1	g	f,k (2/76)
308/246	S/B 17 @ I	Q_1 LT		X		6	1	g	k, (2/76)

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
309/234	N/B 17 @ K	Q_3 L2		X		5	5	g	d,f
310/269	S/B 17 @ H	Q_3 L2		X		5	5	g	f,d
311/268	S/B 17 @ H	Q_2 L2	X			1	1		
312/243	N/B 17 @ I	Q_2 L2	X			1	1		
313/254	SE/B Penn @ 19	Q_2 L2	X			1	1		
314/272	NW/B Penn @ 20	Q_3 L2	X			1	1		
315/253	SE/B Penn @ 19	Q_1 L2	X			1	1		
316/256	S/B 19 @ Penn	Q_1 L2	X			1	1		
317/249	W/B H @ Penn	V_1 L2	X			1	1		
318/194	SE/B Penn @ 18	Q_3 L2	X			1	1		
319/250	W/B H @ Penn	V_1 L3	X			1	1		
320/240	N/B 18 @ I	Q_2 L2	X			1	1		
321/241	N/B 18 @ I	Q_3 L2	X			1	1		
322/458	E/B K @ 14	Q_3 L2		X		5	1		f, h ,k(2/76)
323/258	W/B H @ 18	V_1 L2	X			1	1		
324/457	E/B K @ 14	Q_2 L2		X		1	1		k(2/76)
325/267	S/B 17 @ H	Q_1 L2		X		6	1	g	f,k (2/76)
326/261	W/B H @ 17	Q_2 L2	X			1	1		
327/260	W/B H @ 17	Q_1 L2	X			1	1		
328/262	S/B 34 @ M	V_1 L2	X			1	1		new assignment moved from H/17,H st E/B @ 17
329/266	N/B 17 @ H	V_1 L3	X			1	1		
330/263	N/B 17 @ H	Q_1 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
331/206	S/B 17 @ Penn	Q_3 L2	X			1	1		
332/271	NW/B Penn @ 20	Q_2 L2	X			1	1		
333/466	N/B 15 @ K	Q_2 L2		X		1	2		f,k,3/76
334/279	W/B I @ Penn	V_1 L2	X			1	1		
335/467	N/B 15 @ K	Q_3 L2		X		5	5	h	d,f
336/303	N/B 20 @ K	Q_3 L2	X			1	4		c,old assignment
337/302	N/B 20 @ K	Q_2 L2	X			1	1		
338/282	NW/B Penn @ 21	Q_3 L2		X		5	5	g	d,f
339/276	SE/B Penn @ I	Q_1 L2		X		6	1	g	b,k (2/76)
340/275	E/B I @ Penn	V_1 L2	X			1	1		
341/273	N/B 20 @ Penn	Q_1 L2	X			1	1		
342/274	N/B 20 @ Penn	Q_2 L2	X			1	1		
343/255	SE/B Penn @ 19	Q_3 L2	X			1	1		
344/270	NW/B Penn @ 20	Q_1 L2	X			1	1		
345/285	SE/B Penn @ 21	Q_3 L2	X			1	1		
346/284	SE/B Penn @ 21	Q_2 L2	X			1	1		
347/283	SE/B Penn @ 21	Q_1 L2	X			1	1		
348/278	SE/B Penn @ 21	Q_3 L2		X		5	5	g	d,f
349/281	NW/B Penn @ 21	Q_2 L2		X		6	1	g	f,k (2/76)
350/277	SE/B Penn @ 20	Q_2 L2		X		6	1	g	f,k (2/76)
351/286	S/B 21 @ Penn	Q_1 L2	X			1	1		
352/280	NW/B Penn @ 21	Q_1 L2		X		1	1	g	b,k (2/76)

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
353/288	N/B 22 @ Penn	V_1	L2	X			1	1		
354/289	E/B Penn @ 22	V_1	L2	X			1	1		
355/295	E/B K @ 22	Q_3	L2	X			1	1		
356/294	E/B K @ 21	Q_2	L2	X			1	1		
357/293	E/B K @ 21	Q_1	L2	X			1	1		
358/287	S/B 21 @ Penn	Q_2	L2		X		1	1		k, (2/76)
359/290	W/B K @ 21	Q_1	L2	X			1	1		
360/307	E/B K @ 21	Q_3	L2	X			1	1		
361/297	S/B 21 @ K	Q_2	L2		X		1	1		k, (2/76)
362/296	S/B 21 @ K	Q_1	L2		X		1	1		k, (2/76)
363/306	N/B K @ 20	Q_2	L2	X			1	1		
364/291	W/B K @ 20	Q_2	L2	X			1	1		
365/292	W/B K @ 20	Q_3	L2	X			1	1		
366/305	N/B K @ 20	Q_1	L2	X			1	1		
367/301	N/B 20 @ K	Q_1	L2	X			1	1		
368/445	E/B L @ 14	Q_2	L2	X			1	1		
369/299	W/B K @ 20	Q_1	L2	X			1	1		
370/300	W/B K @ 20	Q_2	L2	X			1	1		
371/471	S/B Vermont @ K	Q_3	L2	X			1	1		
372/330	N/B 20 @ K	Q_3	L2	X			1	1		
373/470	S/B Vermont @ K	Q_2	L2	X			1	1		
374/309	E/B L @ 24	V_1	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE,	LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
375/437	S/B Vermont @ L	V_1	L2	X			1	1		
376/438	W/B L @ 14	Q_1	L2		X		5	5	g	a
377/439	E/B H @ 17(W)	V_1	L2	X			1	1		new assignment moved fromL/14, L St E/B @ 14
378/315	E/B L @ New Hamp.	V_1	L2	X			1	1		
379/461	S/B 14 @ K	Q_3	L2	X			1	1		
380/310	S/B 23 @ L	V_1	L2	X			1	1		
381/308	E/B L @ New Hamp	V_1	L3		X		1	5	g	a,f
382/314	NE/B New Hamp @ L	V_1	L2	X			1	1		
383/441	N/B 14 @ L	Q_1	L2		X		6	1		3/76,k
384/313	N/B 22 @ L	V_1	L2	X			1	1		
385/312	E/B M @ 33	V_1	L2	X			1	1		new assignment moved from L/22/NH
386/321	E/B L @ 21	Q_3	L2		X		1	4		c, old assignment k, (2/76)
387/311	NE/B New Hamp @ 22	V_1	L3		X		5	5	g	a
388/320	E/B L @ 21	Q_2	L2	X			1	1		
389/319	E/B L @ 21	Q_1	L2	X			1	1		
390/298	S/B 21 @ K	Q_3	L2	X			1	1		
391/322	S/B 21 @ L	Q_1	L2	X			1	1		
392/316	W/B M @ Key Bridge	Q_1	L3	X			1	1		new assignment moved from L/21
393/334	E/B L @ 21	Q_3	L2	X			1	1		
394/324	S/B 21 @ L	Q_3	L2	X			1	1		
395/323	S/B 21 @ L	Q_2	L2	X			1	1		
396/333	E/B L @ 20	Q_2	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
397/317	W/B M @ Key Bridge	Q_2 L3	X			1	1		new assignment moved from L/21
398/318	SE/B Conn @ L	V_1 L2	X			1	1		new assignment moved from L/21
399/332	E/B L @ 20	Q_1 L2	X			1	1		
400/460	S/B 14 @ K	Q_2 L2	X			1	1		
401/328	N/B 20 @ L	Q_1 L2	X			1	1		
402/329	N/B 20 @ L	Q_2 L2		X		1	1		k, (2/76)
403/442	N/B 14 @ L	Q_2 L2	X			1	1		
404/325	W/B L @ 14	Q_1 L2		X		5	5	g	a
405/363	E/B L @ 19	Q_3 L2	X			1	1		
406/326	E/B L @ 19	V_1 L3		X		5	5	g	a
407/434	E/B I @ 16	V_1 L2	X			1	1		
408/444	E/B L @ 14	Q_1 L2	X			1	1		
409/510	SE/B Mass. @ 22	V_1 L2	X			1	1		
410/446	S/B 14 @ L	Q_1 L2	X			1	1		
411/511	W/B Fla. @ Q	V_1 L2	X			1	1		
412/447	S/B 14 @ L	Q_2 L2	X			1	1		
413/513	NW/B Mass. @ 22	V_1 L2	X			1	1		
414/512	SW/B RI @ M	V_1 L3	X			1	1		
415/515	NE/B RI @ 17	V_1 L2	X			1	1		
416/516	S/B 17 @ M	V_1 L3	X			1	1		
417/517	W/B H @ 16	V_1 L2		X		5	5	g	a Dummy Link
418/514								g	Dummy link assignment
419/378	E/B L @ 17	V_1 L3		X		5	5	g	a
420/379	E/B I @ 17	V_1 L2	X			1	1		
421/448	S/B Ver @ L	Q_3 L2	X			1	1		
422/440	W/B L @ 13	Q_3 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS: IN USE	SYSTEM STATUS: REMOVAL PER.	SYSTEM STATUS: REMOVAL TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
423/348	E/B L @ 16	Q_3 L2		X		5	5	g	f,d
424/463	W/B K @ 15	Q_2 L2	X			1	1		
425/338	S/B 17 @ L	V_1 L2	X			1	1		
426/337	E/B L @ 17	V_1 L2	X			1	1		
427/464	W/B K @ Ver	Q_3 L2	X			1	1		
428/390	S/B 17 @ K	Q_3 L2	X			1	1		
429/389	S/B 17 @ K	Q_2 L2	X			1	1		
430/336	N/B 17 @ L	V_1 L2		X		6	1		3/76,k
431/335	SE/B Conn @ L	V_1 L2	X			1	1		new assignment moved from L/17
432/347	E/B L @ 16	Q_2 L2	X			1	1		
433/456	E/B K @ 14	Q_1 L2	X			1	1		
434/346	E/B L @ 16	Q_1 L2	X			1	1		
435/349	S/B 16 @ L	Q_1 L2	X			1	1		
436/339	W/B L @ 16	Q_1 L2		X		5	5	g	a
437/459	S/B 14 @ K	Q_1 L2	X			1	1		
438/402	S/B 16 @ K	Q_3 L2	X			1	1		
439/342	N/B 16 @ L	Q_1 L2	X			1	1		
440/401	S/B 16 @ K	Q_2 L2	X			1	1		
441/345	N/B 16 @ L	V_1 L3		X		6	1		fk, (2/76)
442/343	N/B 16 @ L	Q_2 L2	X			1	1		
443/351	S/B 16 @ L	Q_3 L2	X			1	1		
444/350	S/B 16 @ L	Q_2 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
445/352	S/B 16 @ L	V_1 L3	X			1	1		
446/357	S/B 15(W) @ L	V_1 L2	X			1	1		
447/414	N/B 16 @ I	Q_2 L2	X			1	1		
448/431	S/B 16 @ H	Q_1 L2	X			1	1		
449/415	N/B 16 @ I	Q_3 L2	X			1	1		
450/410	S/B 15(W) @ K	V_1 L2	X			1	1		
451/355	N/B 15(W) @ L	V_1 L3	X			1	1		
452/354	N/B 15(W) @ L	V_I L2	X			1	1		
453/340	E/B L @ 15	V_1 L3		X		5	5	g	a
454/356	E/B L @ 15	V_1 L2	X			1	1		
455/341	E/B I @ 18	V_1 L2	X			1	1		new assignment: moved from L/16
456/436	E/B L @ Ver.	V_1 L2	X			1	1		
457/353	SE/B Conn @ K	V_1 L2	X			1	1		new assignment:moved from L/15
458/362	E/B L @ 19	Q_2 L2	X			1	1		
459/327	E/B I @ 19	V_1 L2	X			1	1		new assignment: moved from L/20
460/361	E/B L @ 19	Q_1 L2	X			1	1		
461/364	S/B 19 @ L	Q_1 L2	X			1	1		
462/358	W/B M @ 33	Q_1 L2	X			1	1		new assignment: moved from L/19
463/376	E/B L @ 19	Q_3 L2	X			1	1		
464/221	S/B 19 @ K	Q_3 L2	X			1	1		
465/220	S/B 19 @ K	Q_2 L2	X			1	1		
466/366	S/B 19 @ L	Q_3 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS: IN USE	SYSTEM STATUS: REMOVAL PER.	SYSTEM STATUS: REMOVAL TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
467/365	S/B 19 @ L	Q_2 L2	X			1	1		
468/375	E/B L @ 18	Q_2 L2	X			1	1		
469/359	W/B M @ 33	Q_2 L2	X			1	1		new assignment: move from L/19
470/360	W/B L @ 18	Q_3 L2		X		5	5	g	a
471/374	E/B L @ 18	Q_1 L2	X			1	1		
472/370	N/B 18 @ L	Q_1 L2	X			1	1		
473/367	W/B M @ 34	Q_1 L2	X			1	1		new assignment:moved from L/18
474/382	E/B L @ 17	Q_3 L2	X			1	1		
475/381	E/B L @ 17	Q_2 L2	X			1	1		
476/368	W/B M @ 34	Q_2 L2	X			1	1		new assignment:moved from L/18
477/369	W/B L @ Conn.	Q_3 L2		X		5	5	g	a
478/380	E/B L @ Conn	Q_1 L2		X		1	1		11-75, 1-76 k, (2/76)
479/428	W/B H @ 16	Q_1 L2	X			1	1		
480/377	W/B L @ Conn	Q_1 L2		X		5	5	g	a
481/429	W/B H @ 16	Q_2 L2	X			1	1		
482/430	E/B H @ 16	V_1 L2	X			1	1		new assignment:from H/16 takeout
483/423	W/B Jackson Pl @ H	Q_2 L2	X			1	1		
484/421	W/B H @ Conn	Q_2 L2	X			1	1		
485/387	E/B K @17	V_1 L3		X		6	1	h	k, (2/76)
486/388	S/B 17 @ K	Q_1 L2	X			1	1		
487/383	W/B K @ 17	Q_1 L2	X			1	1		
488/399	W/B K @ 16	Q_3 L2		X		5	1	g	d
489/384	W/B K @ 17	Q_2 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
490/389	E/B K @ 16	Q_2 L2	X			1	1		
491/412	S/B 17@ I	V_1 L2	X			1	1		
492/385	W/B K @ 17	Q_3 L2	X			1	1		
493/397	E/B K @ 16	Q_1 L2	X			1	1		
494/400	S/B 16 @ K	Q_1 L2	X			1	1		
495/344	N/B 16 @ L	Q_3 L2	X			1	1		
496/391	W/B K @ 16	Q_1 L2	X			1	1		
497/409	E/B K @ 15	Q_3 L2	X			1	1		
498/425	S/B Conn. @ H	Q_1 L2	X			1	1		
499/394	N/B 16 @ K	Q_1 L2	X			1	1		
500/416	S/B 16 @ I	V_1 L2	X			1	1		
501/418	S/B 16 @ I	Q_2 LT	X			1	1		
502/392	W/B K @ 16	Q_2 L2	X			1	1		
503/408	E/B K @ 15	Q_2 L2	X			1	1		
504/393	W/B K @ 16	Q_3 L2	X			1	1		
505/407	E/B K @ 15	Q_1 L2	X			1	1		
506/420	W/B H @ Conn	Q_1 L2	X			1	1		
507/468	E/B K @ 15(E)	V_1 L2	X			1	1		
508/404	N/B 15 @ K	Q_1 L2	X			1	1		
509/422	N/B Jackson Pl @ H	Q_1 L2	X			1	1		
510/ 417	W/B 16 @ I	Q_1 LT	X			1	1		
511/386	N/B 17 @ k	V_1 L2	X			1	1		
512/396	N/B 16 @ K	Q_3 L2		X		5	5	g	d,f

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS: IN USE	REMOVAL: PER.	REMOVAL: TEM.	DETECTOR: LOOP	DETECTOR: ELEC.	DETECTOR: OTHER	REMARKS/DATE
513/433	S/B 16 @ I	Q_3 L2	X			1	1		
514/427	S/B Conn @ H	Q_3 L2	X			1	1		
515/413	N/B 16 @ I	Q_1 L2	X			1	1		
516/426	S/B Conn @ H	Q_2 L2		X		6	1		h,k (2/76)
517/432	S/B 16 @ H	Q_2 L2	X			1	1		
518/518	W/B M @ 23	V_1 L3	X			1	1		
519/519	S/B 23 @ M	V_1 L2	X			1	1		
520/520	NE/B New Hamp.	V_1 L2	X			1	1		
521/521	W/B M @ 21	V_1 L3	X			1	1		
522/522	SW/B New Hamp. @ 21	V_1 L2	X			1	1		
523/523	S/B 21 @ New Hamp.	V_1 L2	X			1	1		
524/524	W/B M @ Conn/RI	V_1 L2		X		6	1	Belden bad g	f,k (2/76)
525/525	NW/B Conn @ M	V_1 L2	X			1	1		
526/526	N/B 18 @ Conn.	V1 L2		X		6	1	h	b,f,k (2/76)
527/527	SE/B Conn @ M	V_1 L2		X		6	1	h	b,f,k (2/76)
528/528	SE/B Mass @ 17	V_1 L2	X			1	1		
529/529	S/B 17 @ Mass	V_1 L2	X			1	1		
530/530	NW/B Mass @ Scott	V_1 L2	X			1	1		
531/531	SW/B RI @ Scott Cr	V_1 L2	X			1	1		
532/532	SE/B Mass @ ScottCr	V_1 L2	X			1	1		
533/533	NW/B Mass @ 15	V_1 L2	X			1	1		
534/534	N/B 15 @ Mass	V_1 L2	X			1	1		
535/535	SE/B Mass @ 15	V_1 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS			DETECTOR			REMARKS/DATE
				IN USE	REMOVAL					
					PER.	TEM.	LOOP	ELEC.	OTHER	
536/536	W/B M @ 15	V_1	L2	X			1	1		
537/537	NW/B Mass @ 13	V_1	L2	X			1	1		
538/538	N/B 13 @ Mass	V_1	L2	X			1	1		
539/539	S/B 13 @ Mass	V1	L2	X			1	1		
540/540	S/B 13 @ L	V_1	L2	X			1	1		
541/541	N/B 13 @ I	V_1	L2	X			1	1		
542/542	W/B K @ 12	V_1	L2	X			1	1		
543/543	N/B 12 @ K	V_1	L3	X			1	1		
544/544	E/B K @ 12	V_1	L2	X			1	1		
545/545	SW/B N.Y. @ 12	V_1	L3	X			1	1		
546/546	NE/B N.Y. @ 12	V_1	L3	X			1	1		
547/547	W/B E @ 12	V_1	L3	X			1	1		
548/548	N/B 12 @ E	V_1	L3	X			1	1		
549/549	N/B 11 @ I	V_1	L2	X			1	1		
550/550	S/B 11 @ I	V_1	L2	X			1	1		
551/551	W/B L @ 11	V_1	L3	X			1	1		
552/552	N/B 11 @ L	V	L2	X			1	1		
553/553	SE/B Mass @ 11	V_1	L2	X			1	1		
554/554	S/B 11 @ L	V_1	L2	X			1	1		
555/555	W/B H @ 10	V_1	L2	X			1	1		
556/556	E/B H @ 10	V_1	L2	X			1	1		
557/557	S/B 10 @ H	V_1	L2	X			1	1		
558/558	S/B 9 @ E	V_1	L2	X			1	1		
559/559	W/B I @ 9	V_1	L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE	SYSTEM STATUS IN USE	REMOVAL PER.	REMOVAL TEM.	DETECTOR LOOP	DETECTOR ELEC.	DETECTOR OTHER	REMARKS/DATE
560/560	E/B I @ 9	V_1 L2	X			1	1		
561/561	S/B 9 @ I	V_1 L3	X			1	1		
562/562	NE/B N.Y. @ 9	V_1 L2	X			1	1		
563/563	SE/B Mass @ 9	V_1 L3	X			1	1		
564/546	S/B 9 @ Mass	V_1 L3	X			1	1		
565/565	W/B L @ 9	V_1 L3	X			1	1		
566/566	S/B 9 @ L	V_1 L3	X			1	1		
567/567	NW/B Mass @ &	V_1 L2	X			1	1		
568/568	N/B 6 @ E	V_1 L3	X			1	1		
569/569	N/B H @ 6	V_1 L2	X			1	1		
570/570	N/B 6 @ H	V_1 L2	X			1	1		
571/571	N/B 6 @ I	V_1 L3	X			1	1		
572/572	NW/B Mass @ 6	V_1 L2	X			1	1		
573/573	SE/B Mass @ 6	V_1 L2	X			1	1		
574/574	N/B 6 @ N.Y.	V_1 L3	X			1	1		
575/575	NE/B N.Y. @ 6	V_1 L3	X			1	1		
576/576	S/B 5 @ Mass	V_1 L2	X			1	1		
577/577	W/B K @ 5	V_1 L2	X			1	1		
578/578	N/B 5 @ K	V_1 L2	X			1	1		
579/579	SW/B N.Y. @ 5	V_1 L2	X			1	1		
580/580	W/B Penn @ E Exec.	V_1 L3	X			1	1		
581/581	N/B E. Exec @ Penn	V_1 L2	X			1	1		

VEHICLE NUMBER	LOCATION	USE, LANE		SYSTEM STATUS IN USE	REMOVAL PER.	TEM.	DETECTOR LOOP	ELEC.	OTHER	REMARKS/DATE
582/582	E/B Penn @ Exec	V_1	L3	X			1	1		
583/583	S/B Madison Pl@ Penn	V_1	L2	X			1	1		
584/584	W/B E. @ E. Exec	V_1	L2	X			1	1		
585/585	E/B E @ 15	V_1	L2	X			1	1		
586/586	N/B S. Capitol @ I	V_1	L2	X			1	1		
587/587	E/B I @ S. Capitol	V_1	L2	X			1	1		
588/588	S/B S. Capitol @ I	V_1	L2	X			1	1		
589/589	S/B (E/B) Freeway Ramp @ I	V_1	L2	X			1	1		
590/590	S/B (W/B) Freeway Ramp @ I	V_1	L2	X			1	1		
591/591	NW/B Penn @ Minn	V_1	L2	X			1	1		
592/592	NE/B Minn @ Penn	V_1	L2	X			1	1		
593/593	SE/B Penn @ Minn	V_1	L2	X			1	1		
594/594	SE/B Minn @ Penn	V_1	L2	X			1	1		
595/595	NW/B Penn @ Branch	V_1	L2	X			1	1		
596/596	N/B Branch @ Penn	V_1	L2	X			1	1		
597/597	SE/B Penn @ Branch	V_1	L2	X			1	1		

Appendix B

FIELD EQUIPMENT PLACEMENT AND INVENTORY

TABLE IN-3

FIELD EQUIPMENT COMPLEMENT SUMMARY

ORIGINAL SYSTEM

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
CB001	M & 30 St	FT-19	0	0	1	0	1	Wire to	CB019	
CB002	Wisc & Whitehaven	FT-19	0	0	1	0	1			
CB003	Wisc & 34 St	FT-19	0	0	1	0	1	Wire to	CB002	
CB004	Wisc & Porter	FT-19	0	0	1	0	1	Wire to	-	Wisc/Van Ness
CB005	Wisc & Newark	FT-19	0	0	1	0	1	Wire to	-	Wisc/Van Ness
CB006	Wisc & Edmunds	Semi	0	0	1	0	1	Wire to	CB009	
CB007	Wisc & Woodley	FT-19	0	0	1	0	1	Wire to	-	Wisc/Van Ness
CB009	Wisc & Mass	FT-40	6		1		14			
EB002	Mass bet. Cath & Klingle	None	5	0	0	0	0			Comm in CB009
EB003	Wisc N. Of Cath.	None	3	0	0	0	0			Comm in CB009
CB010	Wisc & Garfield	FT-19	5		1		11	Wire to	CB009	B Ø Xmtr
EB004	Wisc S. of Garfield	None	1	0	0	0	0			Comm in CB010
EB005	Wisc & Garfield W.. Side	None	3		0	0	0			Comm in CB010
CB011	Mass & Garfield	FT-19	10	0	1	0	13	Wire to	CB009	
EB007	Mass & 35 St.	None	2	0	0	0	0			Comm in CB011
CB012	Wisc & R St.	FT-19	6		1		9	Wire to	CB002	

Table IV 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
EB008	Wisc & R. E. Side	None	2		0	0	0			Comm in CB012
CB013	M & 36 St.	FT-19	0	0	1	0	1	Wire to CB015		
CB014	M & 33 St.	FT-19	4	0	1	0	6	Wire to CB019		B Ø Xmtr
CB015	M & Key Bridge	FT-19	6	0	1	0	10	Wire to CB019		B Ø Xmtr
EB009	M & Key Bridge	None	4	0	0	0	0			Comm in CB015
CB016	M & 34 St.	FT-19	4	0	1	0	6	Wire to CB019		B Ø Xmtr
CB017	M & Wisc	FT-40	5		1		12	Wire to CB019		B Ø Xmtr
EB010	M W. of Wisc	None	3		0	0	0			Comm in CB017
EB011	Wisc & Prospect	None	2		0	0	0			Comm in CB017
CB018	M & 31 St.	FT-19	6		1		7	Wire to CB019		
CB019	M & 29 St.	FT-19	2	0	1	0	3			
CB020	Penn & 28 St.	FT-40	2	0	1	0	5	Wire to CB020		B Ø Xmtrs
CB021	Penn & 26 @ L	FT-19	2	0	1	0	3	Wire to CB023		
CB022	Q & 33 St.	FT-19	0	0	1	0	1			
CB023	Penn & 25 @ L	FT-19	6	0	1	0	7			
CB024	Penn & 24 St.	FT-40	4	0	1	0	6			B Ø Xmtr
CB025	K & 25 St.	Semi	2	0	1	0	3			
CB026	Wash Circle SW Side	FT-40	0	0	1	0	1			

Table IV 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
CB027	Wash Circle NE Side	FT-19	0	0	1	0	1			
CB028	E St. W/B & 23 St.	FT-40	0	0	1	0	1			
CB029	C St. & 23 St.	FT-19	1	0	1	0	2			
CB030	C St. & 21 St.	FT-19	0	0	1	0	1			
CB031	Const. & 23 N. Side	FT-19	5	0	1	0	11			B Ø Xmtr
EB013	Const. & 23 S Side	None	2	0	0	0	0			Comm in CB031
EB014	Const. W. of 23 St.	None	2	0	0	0	0			Comm in CB031
CB032	Const. & 22 St.	FT-19	5	0	1	0	6			
CB033	Const & 21 St.	FT-19	4	0	1	0	6			B Ø Xmtr
CB034	Virginia & E St.	FT-19	0	0	1	0	1			
CB035	Virginia & 21 St.	FT-19	0	0	1	0	1			
CB036	Virginia & 20 St.	FT-19	0	0	1	0	2			B Ø Xmtr, Comm in CB037
CB037	Virginia & 19 @ C St.	FT-40	1	0	1	0	3			B Ø Xmtr
CB038	Virginia & 18 St.	FT-19	0	0	1	0	1			
CB039	Const. & 20 St.	FT-19	3		1		5			B Ø Xmtr
CB040	Const.& 19 St.	FT-19	8		1		9			
CB041	Const. & 18 St.	FT-19	8		1		10			B Ø Xmtr
CB042	Const. & 17 St.	FT-19	6		1		13			

Table IV 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	Communications 3F Tr.	Communications 2F Tr.	Radio Rec.	Radio Dec.	Remarks
EB016	Const. W. of 17 St.	None	3		0	0	0			Comm in CB042
EB018	Const. E. of 17 St.	None	2		0	0	0			Comm in CB042
EB019	Const. S. of 17 St.	None	2	0	0	0	0			Comm in CB042
CB043	E St. W/B & 20 St.	FT-19	0	0	1	0	1			
CB044	E St W/B & 21 St.	FT-19	1	0	1	0	2			
CB045	E St. W/B & 19 St.	FT-19	3	0	1		8			
EB020	E St. W/B & 19 St. E. Side	None	4		0	0	0			Comm in CB045
CB046	N.Y. & 18 St.	FT-19	5		1		6			
CB047	E St. E/B & 20 St.	FT-19	8	0	1	0	9			
CB048	E St. E/B & 19 St.	FT-19	1	0	1	0	2			
CB049	E St. E/B & 18 St.	FT-19	5		1		8			
EB021	E St. E/B & 18 St. S. Side	None	2		0	0	0			Comm in CB049
CB050	Const. & H.B. Drive	FT-19	7	0	1	0	8			
CB051	F St. & 17 St.	FT-19	2	0	1	0	3			
CB052	N.Y. & 17 St.	FT-19	2	0	1	0	3			
CB053	E St. E/B & 17 St.	FT-19	5	0	1	0	9			B Ø Xmtr
EB022	E St. E/B & 17 St. S. Side	None	2	0	0	0	0			Comm in CB053
CB054	Penn & 18 St.	FT-19	5		1		11			

Table IV 3 – Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
EB023	Penn & 18 St. S.Side	None	5		0	0	0			Comm in CB054
CB055	Penn & 17 St.	FT-19	6		1		10			
EB024	Penn & 17 St. (CB2)	None	3		0	0	0			Comm in CB055
CB056	Penn & Jackson	FT-19	3		1		4			
CB057	G & 13 St.	FT-19	5		1		6	Wire SY		
CB058	Executive & 17 St.	Semi	4	0	1	0	5			
CB059	K & 19 St.	FT-19	5		1		9			
EB026	K & 19 St. (CB2)	None	3		0	0	0			Comm in CB059
EB027	K & 18 St. (CB2)	None	4		0	0	0			Comm in CB060
CB60	K & 18	FT-19	5		1		10			
CB061	K, Conn & 17 St.	FT-19	6	0	1	0	7			
CB062	I & 20 St.	FT-19	5		1		6	Sy		
CB063	I & 19 St.	FT-19	2	0	1	0	3			
CB064	I & 18 St.	FT-19	3		1		4			
CB065	I & 17 St.	FT-19	8		1		11			8 Ø Xmtr
CB066	Penn, 19 & H St.	FT-40	7		1		9			8 Ø Xmtr
CB067	H & 18 St.	FT-19	4		1		5			
CB068	H & 17 St.	FT-19	8		1		10			8 Ø Xmtr
CB069	Penn & 20 St.	FT-19	7	0	1	0	8			

Table IV 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
CB070	Penn & 21 St.	FT-19	6		1		9			
EB029	Penn & 21 St. (CB2)	None	2		0	0	0			Comm in CB070
CB071	Penn & 22 St.	FT-40	2	0	1	0	4			B Ø Xmtr
CB072	K & 21 St.	FT-19	6		1		9			
EB030	K & 21 St. N. Side (CB2)	None	2		0	0	0			Comm in CB072
CB073	K & 20 St.	FT-19	8		1		9			
CB074	L & 23 St.	FT-19	3	0	1	0	4			
CB075	L, N. H. & 22 St.	FT-40	3	0	1	0	5			B Ø Xmtr
CB076	L & 21 St.	FT-19	6		1		8			
EB033	21 St. N. of L St.	None	1		0	0	0			Comm in CB076
CB077	L & 20 St.	FT-19	7		1		8			
CB078	Mass & 22 St.	None	2	0	0	0	2			
CB102	Indep & 14 St.	None	4	0	0	0	4			
CB081	L & 17 St.	FT-19	5	0	1	0	6			
CB082	L & 16 St.	FT-19	5		1		12			
EB012	L & 16 St. S. Side	None	5		0	0	0			Comm in CB082
EB006	16 N. of L St.	None	1		0	0	0			Comm in CB082

Table IV 3 - Field Equipment Complement Summary (Continued)

					Communications			Radio		
Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	3F Rec.	3F Tr.	2F Tr.	Rec.	Dec.	Remarks
CB083	L & 15 St.	FT-19	5	0	1	0	6			
CB084	L & 19 St.	FT-19	5		1		8			
EB001	19 N. of L	None	2		0	0	0			Comm in CB084
CB085	L & 18 St.	FT-19	4		1		6			
CB086	L & Conn Ave.	FT-19	2	0	1	0	3			
CB087	K & 17 St.	FT-19	8		1		9			
CB088	K & 16 St.	FT-19	6		1		10			
EB015	K & 16 St. (CB2)	None	3		0	0	0			Comm in CB088
CB089	K & 15 St.	FT-19	8		1		9			
CB090	I, 17 & Conn Ave.	FT-19	3		1		4			
CB091	I & 16 St.	FT-19	2		1		7			8 Ø Xmtr
EB017	I & 16 St. S. Side (CB2)	None	3		0	0	0			Comm in CB091
CB092	F & 19 St.	FT-19	0	0	1	0	1			
CB093	H. Conn. & Jackson	FT-19	6		1		7			
CB094	H & 16 St.	FT-19	5		1		6			
CB095	H & 21 St.	FT-19	0		1		1			
CB096	L & Vermont	FT-19	5	0	1	0	6			
CB097	L & 14 St.	FT-19	5		1		9			
EB025	L & 14 St. W. Side	None	3		0	0	0			Comm in CB097

Table IV 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	Communications 3F Tr.	Communications 2F Tr.	Radio Rec.	Radio Dec.	Remarks
CB098	L & 24 St.	FT-19	0	0	1	0	1			
CB099	K & 14 St.	FT-19	9		1		14			
EB028	K on NE Mall	None	3		0	0	0			Comm in CB099
CB100	K, 15 St. & Vermont Ave	FT-19	7		1		10			
EB031	I & 15 St. (CB2)	None	2	0	0	0	0			Comm in CB100
EB032	Indep & 14 St. SW Side	None	1	0	0	0	0			Comm in CB102
EB034	Indep & 14 St. E. of 14 St.	None	1	0	0	0	0			Comm in CB102
CB103	Wisc & N St	FT-19	0	0	1	0	1	Wire to CB002		
CB104	Wisc & O St.	FT-19	0	0	1	0	1	Wire to CB002		
CB105	Wisc & P St.	FT-19	0	0	1	0	1	Wire to CB002		
CB106	Wisc & Q St.	FT-40	0	0	1	0	1	Wire to CB002		
CB109	Virginia & 23 St.	FT-19	0	0	1	0	1	Wire		
CB110	G & 23 St.	FT-19	0	0	1	0	1			
CB111	G & 22 St.	FT-19	0	0	1	0	1	Wire		
CB113	I & 23 St.	FT-19	0	0	1	0	1			
CB114	H & 23 St.	FT-19	0	0	1	0	1	Wire		

Table I'' 3 - Field Equipment Complement Summary (Continued)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F Tr.	2F Tr.	Radio Rec.	Dec.	Remarks
CB115	F & 18 St.	FT-19	4		1		7			
EB035	F & 19	None	2	0	0	0	0			Comm in CB115
CB116	F & 20 St.	FT-19	0	0	1	0	1	Wire		Future Use
CB117	G & 19	FT-19	0	0	1	0	1			
CB118	G & 20 St.	FT-19	0	0	1	0	1			
CB119	G & 21 St.	FT-19	2	0	1	0	3			
CB120	Wisc & Macomb	FT-19	4		1		8	Wire to -		Wisc/Van Ness
EB037	Wisc & Macomb (CB2)	None	4		0	0	0			Comm in CB120
CB121	Wisc & Calvert (S/E)	FT-40	4		1		10	Wire to CB009		B Ø Xmtr
EB036	Wisc & Calvert (N/W)	None	4		0	0	0			Comm in CB121
CB122	Wisc & Hall Place	Semi	0	0	1	0	1	Wire to CB009		
CB123	Wisc & W Place	FT-19	6		1		7	Wire to CB009		

TABLE IN-3

FIELD EQUIPMENT COMPLEMENT SUMMARY

EXPANDED SYSTEM

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F TR	2F TR	Radio Rec. - Dec	Remarks
CB092	F & 19th St.	FT 19-18	0	0	1	0	1		
CB095	H & 21st St.	FT-19-18	0	0	1	0	1		
CB098	L & 24th St.	FT-19-18	0	0	1	0	1		
CB125	M & 25th St.	FT-19-18	0	0	1	0	1		
CB126	M & 24th St.	FT-19-18	0	0	1	0	1		
CB127	M & 23rd St.	FT-19-16	1	0	1	0	2		
CB128	M & 22nd St.	FT-19-16	1	0	1	0	2		
CB129	M & New Hampshire	FT-19-16	1	0	1	0	2		
CB130	M & 21st St.	FT-19-16	1	0	1	0	2		
CB131	New Hampshire & 21st	FT-19-16	2	0	1	0	3		Comm. in CB 130
CB132	M & 20th St.	FT-19-18	0	0	1	0	1		
CB133	M & 19th St.	FT-19-18	0	0	1	0	1		
CB134	M. Conn & Rhode Island	FT-40-16	2	0	1	0	4		BØ Xmtr
CB135	N, Conn & 18th St.	FT-40-16	0	0	1	0	2		BØ Xmtr
CB136	Jefferson, Conn, 18th	FT-40-16	0	0	1	0	2		Comm. in CB 135, BØ Xmtr
CB137	Conn & DeSales St.	FT-19-18	1	0	1	0	2		

TABLE IN-3 (cont.)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F TR	2F TR	Radio Rec. - Dec. Remarks
CB138	Massachusetts & 17th	FT-19-16	3	0	1	0	4	
CB139	Rhode Island & 17th	FT-19-18	3	0	1	0	4	
CB140	M & 17th St.	FT-19-18	0	0	1	0	1	
CB141	DeSales & 17th St.	FT-19-18	0	0	1	0	1	
CB142	Scott Circle	FT-80-16	0	0	1	0	4	Comm. in CB 138, BØ, CØ, DØ, Xmtr
CB143	M & 16th St.	FT-19-18	0	0	1	0	1	
CB144	Rhode Island & 15th	FT-19-16	1	0	1	0	2	
CB145	Massachusetts & 15th	FT-19-18	3	0	1	0	4	
CB146	M & 15th St.	FT-19-18	2	0	1	0	3	
CB147	Thomas Circle	FT-40-16	0	0	1	0	2	BØ Xmtr
CB148	Massachusetts & 13th	FT-19-16	3	0	1	0	4	
CB149	L & 13th St.	FT-19-18	1	0	1	0	2	
CB150	K & 13th St.	FT-19-16	1	0	1	0	2	
CB151	I & 13th St.	FT-19-16	0	0	1	0	1	Comm. in CB 156
CB152	H, 13th & New York	FT-40-16	1	0	1	0	4	BØ, CØ Xmtr
CB153	Massachusetts & 12th	FT-19-18	1	0	1	0	2	
CB154	L & 12th St.	FT-19-16	0	0	1	0	1	

TABLE IN-3 (cont.)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F TR	2F TR	Radio Rec. - Dec.	Remarks
CB155	K & 12th St	FT-19-18	0	0	1	0	1		
CB156	I & 12th St.	FT-19-16	1	0	1	0	2		
CB157	New York & 12th St.	FT-19-18	1	0	1	0	2		
CB158	H & 12th St.	FT-19-16	0	0	1	0	1		
CB159	G & 12th St.	FT-19-16	0	0	1	0	1		
CB160	F & 12th St.	FT-19-16	0	0	1	0	1		
CB161	E & 12th St.	FT-19-16	2	0	1	0	3		
CB162	H & 11th St.	FT-19-18	2	0	1	0	3		
CB163	I, New York & 11th St.	FT-40-16	2	0	1	0	3		Comm. in CB 157
CB164	K & 11th St.	FT-19-16	2	0	1	0	3		
CB165	Massachusetts, L & 11th	FT-40-16	1	0	1	0	4		Comm. in CB 153, BØ, CØ Xmtrs
CB166	H & 10th St.	FT-19-18	1	0	1	0	2		
CB167	I & 10th St.	FT-19-18	1	0	1	0	2		
CB168	New York & 10th St.	FT-19-18	0	0	1	0	1		Comm. in CB 167
CB169	K & 10th St.	FT-19-18	2	0	1	0	3		
CB170	Massachusetts & 10th	FT-19-18	0	0	1	0	1		
CB171	L & 10th St.	FT-19-18	1	0	1	0	2		Comm. in CB 170

B-12

TABLE IN-3 (cont.)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F TR	2F TR	Radio Rec. - Dec	Remarks
CB172	D & 9th St.	FT-19-18	0	0	1	0	1		
CB173	E & 9th St.	FT-19-18	1	0	1	0	2		
CB174	F & 9th St.	FT-19-18	0	0	1	0	1	Comm. in CB 173	
CB175	G & 9th St.	FT-19-18	0	0	1	0	1		
CB176	H & 9th St.	FT-19-18	0	0	1	0	1	Comm. in CB 175	
CB177	I & 9th St.	FT-19-18	2	0	1	0	3	Comm. in CB 178	
CB178	New York, K & 9th st.	FT-19-16	2	0	1	0	3		
CB179	Massachusetts & Mt. Vernon & 9th St.	FT-19-18	1	0	1	0	2		
CB180	L & 9th St.	FT-19-18	3	0	1	0	4		
CB181	H & 7th St.	FT-19-18	0	0	1	0	1		
CB182	I & 7th St.	FT-19-18	0	0	1	0	1		
CB183	Massachusetts, K, & 7th	FT-19-16	1	0	1	0	2		
CB184	New York, Mt. Vernon & 7th St.	FT-19-16	0	0	1	0	1		
CB185	L & 7th St.	FT-19-16	0	0	1	0	1	Comm. in CB 184	
CB186	Indiana, D & 6ht St.	FT-40-16	0	0	1	0	2	BØ Xmtr	
CB187	E & 6th St	FT-19-18	1	0	1	0	2		
CB188	F & 6th St.	FT-19-18	0	0	1	0	1		

TABLE IN-3 (cont.)

Cabinet Number	Intersections Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	Communications 3F TR	Communications 2F TR	Radio Rec - Dec	Remarks
CB189	G & 6th St.	FT-19-18	0	0	1	0	1		
CB190	H & 6th St.	FT-19-18	2	0	1	0	3		
CB191	I & 6th St.	FT-19-18	0	0	1	0	1		
CB192	Massachusetts & 6th	FT-19-18	1	0	1	0	2		Comm. in CB 191
CB193	K & 6th St.	FT-19-18	1	0	1	0	2		
CB194	New York, L & 6th	FT-40-16	1	0	1	0	2		
CB195	H & 5th St.	FT-19-18	1	0	1	0	2		Comm. in CB 190
CB196	Massachusetts,I & 5th	FT-19-16	2	0	1	0	3		
CB197	K & 5th St.	FT-19-18	2	0	1	0	3		
CB198	New York,L & 5th	FT-40-16	1	0	1	0	2		Comm. in CB 194
CB199	Vermont, I & 15th	FT-19-16	0	0	1	0	1		Comm. in CB 200
CB200	Madison Pl.H & Vermont	FT-19-16	0	0	1	0	1		
CB201	E.Executive,Madison Pl. & Penn	FT-19-16	4	0	1	0	5		
CB202	E.Executive,Alex Ham.	FT-19-18	0	0	1	0	1		Comm. in CB 203
CB20	E&S Executive Ave.	FT-40-16	0	0	1	0	2	BØ Xmtr	
CB204	E & 15th St.	FT-19-16	2	0	1	0	3		
CB205	South Capitol & I St.	FT-19-18	5	0	1	0	7	BØ Xmtr	

TABLE IN-3 (cont.)

Cabinet Number	Intersection Description	Controller Type	Veh. Det.	Bus Det.	Communications 3F Rec.	3F TR	2F TR	Radio Rec - Dec	Remarks
CB206	Pennsylvania & Minn.	FT-19-16	4	0	1	0	6	Comm. in CB 211 BØ Xmtr	
CB207	Pennsylvania & 27th	FT-19-16	0	0	1	0	1		
CB208	Pennsylvania & 28th	Semi	0	0	1	0	1		
CB209	Pennsylvania & 30th	Semi	0	0	1	0	1		
CB210	Pennsylvania & Branch	FT-40-16	3	0	1	0	4		
CB211	Pennsylvania & L'Enfant Square	FT-40-18	0	0	1	0	1		

Appendix C

REFERENCES

Section	Reference	Description
1	**1**	**Available UTCS/RPS Published Reports (listed below)**

Volume	Title	Number	Price
I	Systems Description	PB 188 963	$ 3.00
IA	Bus Priority System Description	PB 190 847	3.00
II	UTCS/BPS Programming Specs.	PB 190 848	3.00
III	UTCS/BPS System Equipment Specs.	PB 190 849	3.00
IV	Vehicle Detector Tests	PB 188 966	3.00
	Bus Detector Development Program	PB 204 084	3.00

Urban Traffic Control and Bus Priority System

Volume	Title	Number	Price
I	Design and Installation	PB 214 788	9.00
II	Operator's Manual	PB 214 641	5.45
III	Maintenance Manual	PB 217 317	3.00

Urban Traffic Control and Bus Priority System Software Manual

Volume	Title	Number	Price
I	Functional Description and Flow Charts	PB 220 867	9.00
II	Variable Definitions; Algorithm and Off-Line Software Descriptions	PB 220 868	6.00
	Set of 2 volumes	PB 220 866	14.00

Urban Traffic Control System - FORTRAN IV Software

Volume	Title	Number	Price
I	Software Documentation	PB 225 352/4	8.00
II	Interface Manual	PB 225 351/6	6.25
	Set of 2 volumes		13.00

Urban Traffic Control System - Second Generation Software

Title	Number	Price
Traffic Adaptive Network Signal Timing Program (TANSTP)	PB 241 870/AS	10.00

Urban Traffic Control System - Third Generation Software
Variable Cycle Signal Timing Program: Phase I

Volume	Title	Number	Price
1	Development of Third Generation Control	PB 241 717/AS	4.25
2	Optimization of Traffic Signals in Networks by Mixed Integer Linear Programming	PB 241 718/AS	7.00
3	CYRANO: Cycle-Free Responsive Algorithms for Network Optimization: Moderate, Congested and Light Flow Regimes	PB 241 719/AS	7.25
4	Prediction Algorithms, Software and Hardware Requirements, and Logical Flow Diagrams	PB 241 720/AS	7.50
	Set of 4 volumes	PB 241 716/SET	22.00

Evaluation of First Generation UTCS/BPS Control Strategy

Volume	Title	Number	Price
	Executive Summary	PB 244 110/AS	3.75
1	Technical Report	PB 244 111/AS	7.00
2	Technical Appendices	PB 244 112/AS	7.00
	Set of 3 volumes	PB 244 109/SET	15.00

SIGOP

	Title	Number	Price
SIGOP	Traffic Signal Optimization Program Computer Program to Calculate Optimum Coordination in a Grid Network of Synchronized Traffic Signals	PB 173 738	6.00
SIGOP	Traffic Signal Optimization Program Users Manual	PB 182 835	6.00
	Field Tests and Sensitivity Studies	PB 182 836	6.00
SIGOP	Source Tape	PB 222 295	250.00/year* U.S. 312.50/year* Foreign
	SIGOP/TRANSYT Evaluation San Jose, California	PB 213 415	7.25

*Tapes are leased rather than sold.

TRANSYT

	Title	Number	Price
TRANSYT	TRANSYT Method for Area Traffic Control (Users Manual)	PB 224 084/AS	5.25
TRANSYT	Source Tape (including Users Manual)	PB 224 085/AS	250.00

UTCS-1 Simulation

Volume	Title	Number	Price
1	Technical Report	PB 230 760/AS	6.75
2	Subroutine Documentation I	PB 230 761/AS	5.75
3	Subroutine Documentation II	PB 230 762/AS	5.50
4	Users Manual	PB 230 763/AS	5.75
5	Applications Manual	PB 230 764/AS	3.75
	Application of Network Simulation Models to the Analysis of Urban Intersection Performance	PB 236 507/AS	4.00
	Simulation of Urban Bus Operation on Signalized Arterials	PB 236 795/AS	9.00

Systems Analysis Methodology in Urban Traffic Control Systems

Title	Number	Price
Final Report	PB 185 422	8.50
Addendum: Annotated Bibliography	PB 184 952	4.25
Phase II	PB 207 861	7.00

Vehicle Detection

Title	Number	Price
Phase I: SPVD Development	PB 244 134/AS	5.50
Phase II: MGVD Development	PB 244 135/AS	5.50
Locating Detectors for Advanced Traffic Control Strategies		
Handbook	PB 251 182/AS	4.00
Technical Report	PB 251 177/AS	7.75

All reports are available from:	National Technical Information Service 2585 Port Royal Road Springfield, Virginia 22151

All prices listed are subject to change.

Implementation Packages

Title	Number
Urban Traffic Control System Hardware	76-1
Inductive Loop Detectors: Theory and Practice	76-2
Traffic Control System Handbook	
Executive Summary	76-3
Handbook	76-10

Implementation Packages are available from:

Federal Highway Administration
Office of Development
Implementation Division (HDV-21)
Washington, D. C. 20590

Section	Reference	Description
3	1	Preliminary Analysis of UTCS Failure and Repair Experience F. Agresti; SMD Internal Memorandum, 15 January 1975
3	2	Revised Analysis of UTCS/BPS Failure and Repair Experience F. Agresti; SMD Internal Memorandum, 29 January 1975
3	3	Reliability Analysis of a Computerized Urban Traffic Control System; N.D. Signpurwalla and W. G. Marchal; George Washington University Report, under NASA Grant NGR-09-010-030 and NSF Institutional Grant GU3287, 1971
4	1	UTCS Operators Manual; Appendix C; Status Reports and Displays
4	2	Xerox Sigma 5/7 Macro-Symbol and Real-Time Batch Monitor (RBM) Reference Manuals
4	3	UTCS Software Manual Volume II; Section 4
4	4	FHWA Implementation Package 76-2; Inductive Loop Detector - Theory and Practice