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EVALUATION OF THE MONITOR - CTA AUTOMATIC VEHICLE MONITORING SYSTEM

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16. Abstract

In June 1972 the Urban Mass Transportation Administration requested that the Transportation System Center of DOT perform an evaluation of the CTA (Chicago Transit Authority) Monitor-Automatic Vehicle Monitor (AVM) system. TSC planned the overall evaluation, prepared the analytical data reduction, performed data evaluation and prepared conclusions and recommendations.

The CTA cooperated in the collection of the data according to the TSC plan and provided candid advice and commentary without which this evaluation would not have been possible.

The results of the evaluation show that until present system technical deficiencies have been corrected, the system cannot be considered to be fully operational. From the cost analysis it is concluded that this system appears to be a good public investment.

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PREFACE

This report represents the task outputs as detailed in the UMTA-TSC Program Plan Agreement (PPA) UM-311.

The Transportation Systems Center acknowledges the assisance and candid advice provided by the Chicago Transit Authority without which this evaluation would not have been possible.

The Center also appreciates the efforts of Messrs. David Hiatt (cost benefit analysis), Ronald Esposito (data reduction) and Bernie Kliem.

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1. INTRODUCTION

1.1 BACKGROUND

The need for centralized supervision of bus routes has long been recognized. Bus schedules are carefully constructed from passenger counts and running time checks conducted periodically throughout a year; but when the schedules are put into operation, limited and sometimes ineffective methods are available to check schedule adherence by the drivers.

Following the passage of the Urban Mass Transportation Act of 1964, funds were made available to the Chicago Transit Authority (CTA) for demonstration of a bus monitoring system. A contract was let in 1968 to design and build an AVM (automatic vehicle monitoring) system for the CTA. The system was built for demonstration purposes and was not a full scale system. In FY 72, the CTA requested funds from the government to expand the existing system. In late FY 72, UMTA requested that TSC evaluate the existing CTA-Monitor system to (1) determine the technical validity of the existing system and (2) to determine, based on (1) above, if the government would be justified expending capital grant funds for the completion of the Monitor-CTA system. The evaluation was conducted from July through mid-August of 1972.

1.2 REPORT FORMAT

To evaluate the existing system the following six tests and/or evaluations were conducted:

1) Management and Operations Evaluation;
2) Schedule and Headway Adherence Test;
3) System Response Rate Evaluation;
4) System Reliability Evaluation;
5) System Accuracy Test; and
6) Cost Benefit Evaluation.

This report is organized in sections according to the particular test or evaluation conducted. Generally, each section provides background information, test or evaluation procedures, results and conclusions, and recommendations. Finally, a section (Section 2), discussing the operation of the CTA-Monitor system, is provided for those readers who may not be familiar with the operation of this AVM system.

1.3 SUMMARY

The results of the tests and evaluations are summarized by report section below:

1.3.1 Management and Operations

The potential for increased management information is excellent; however, at this time, the CTA has not made use of information provided by the system for the following reasons:

1) System manpower shortage;

2) Difficulty in using data format and lack of confidence in output;

3) The system is only partially completed. (≈20%)

The existing system was not operational because the bus dispatchers have not assumed the necessary responsibility to make this AVM concept viable for the following reasons:

a) Union jurisdiction problems;

b) Low confidence in data presented;

c) Mode of operation, due to inadequate existing display and control system.

1.3.2 Schedule and Headway Adherence

The result of the tests indicated that generally no significant schedule and headway improvement was exhibited with the introduction of monitor buses on the test routes. However, a "% mean improvement" was generally shown, which may or may not be due to the monitor buses. Three factors contributed to these test results:

1) Biased data collected;

2) Dispatchers' inability to effectively control buses;

3) Time of test (July is the optimum month for buses to maintain good schedule and headway adherence due to general low traffic density).

1.3.3 System Accuracy

Results of the test indicate a mean accuracy error of +.5 minutes (the monitor system bus arrival calculated time is earlier than the actual arrival time) with a standard deviation of 1.6 minutes. Analysis of the factors contributing to the total system accuracy error indicated that the average error should have been approximately equal to zero seconds with a range of ±12 seconds. This mean accuracy error is indicative of possible problems with the buses' receiver transmitter unit and associated computer software.

1.3.4 System Response

Tests conducted during the owl shift (buses in service at 4 a.m.) indicated that the system valid response rate (the number of valid replies received by the computer from the monitor buses ÷ the number of interrogations made by the computer) is 52%. Further, on the average, 26% of the owl monitor bus population failed to respond at all during a given night. The low response rate was attributed in part to defects in the bus receiver-transmitter unit, thereby bringing into question the ability of the dispatcher to initiate schedule adherence action for the entire 500 monitor buses.

1.3.5 System Reliability

Analysis of the major subsystems showed that at the time of the test all subsystems' reliability except for one was adequate. The reliability of the bus receiver-transmitter was found to be inadequate. A "ball park" estimate of the Mean Time Between Failure (MTBF) for this unit was one year; whereas, the actual MTBF was found to be 80 days.

1.3.6 Cost Benefits

The results of the analysis indicate that from a purely financial viewpoint, the proposed expansion of the system represents a good investment. The present value of the "net differential" cost reductions which would be realized during the life of the system is $5,657,930, or the net savings of the expanded system is equal to the initial investment during the sixth year.

1.4 CONCLUSIONS

If the aim of the Monitor-CTA system is to maintain schedule adherence and headway at least as well as a non-monitor system, then from a financial point of view, the investment of government funds seems advisable. The cost benefit analysis has shown that mainly with the reduction of supervisors (point men and terminal telephone men), the proposed system will pay for itself in the sixth year whether the monitor system improves schedule and headway adherence or not.

However, TSC feels that the long term goal of the Monitor-CTA system is not to remain as status quo, but to show that this system can indeed improve schedule adherence and headway, in other words to become an operational command and control system.

The CTA-Monitor system must be considered non-operational until the time that the present system's technical and operational deficiencies are corrected. Therefore, before further investing government funds, it is suggested that the five recommendations outlined below (Section 1.5) be completed and re-evaluation of the Monitor-CTA system be conducted.

1.5 RECOMMENDATIONS

TSC recommends that the following steps, explained in more detail in the following section, be initiated in order to make the existing system operational.

1) Redesign the display and control hardware and software.

2) Train the CTA dispatchers to operate in an analysis rather than a reaction mode.

3) Employ more technical personnel on the program for software and hardware system support.

4) Improve reliability of the bus receiver-transmitter unit.

5) Conduct a series of schedule adherence and headway tests, following completion of the above four items, to determine if the monitor system does show schedule adherence and headway improvement.

2. THE MONITOR-CTA AVM SYSTEM[1]

2.1 INTRODUCTION

The "Monitor-CTA" project is the test of a system to automatically monitor a transit bus fleet from a central location. The system accepted by the CTA was a proximity Automatic Vehicle Monitoring (AVM) system, which locates a vehicle by its nearness to a fixed reference point. The operation of the monitoring system can be divided into three modes: Location, Interrogation, and Interpretation.

2.2 LOCATION

Location is accomplished by placing small low-powered radio transmitters at various points along the bus routes. These transmitters, called "signpost" transmitters, are usually located at the intersections of routes and at fairly even intervals in order to provide an efficient and economic coverage. Each signpost is assigned an identification number which is converted into a 10-bit binary code and wired into the signpost's location information generator. The generator uses this code to form a message consisting of a series of digital pulses. The message, which is being repeated continuously, is then fed into the telemetry transmitter, converted from pulse to tone, and modulated into a radio signal. As a bus passes a signpost, a signal is received by the buses signpost receiver unit which demodulates the signal back to a "chain" of tone signal messages. These are reconverted into pulses and fed into an error detector. When the message is determined to be correct, it is placed into the location information register, erasing the previous signpost number, and stored until the next signpost is passed.

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[1]This section is based on the Monitor-CTA Progress Report #2, April 1969.

Also located on the bus is an elapsed time generator and counter. The generator, once started, transmits a pulse every 12 seconds (.2 minute) and the counter counts the pulses and stores the count in a register. When the bus comes in range of a signpost, the count is reset to zero and the generator is stopped. This indicates that if an elapsed time count is zero, the bus is within the range of the signpost whose number is stored in the bus' location information register. Once the bus is out of signpost range, the generator restarts and a count begins. Calculations on how long a bus has been away from the signpost can then be made.

2.3 INTERROGATION

The interrogation cycle is controlled by the digital computer at the control center. From the vast amount of schedule information it has stored, the computer determines which buses must be located. One by one, at 66 2/3 millisecond intervals, the computer outputs the coded identification numbers through the computer interface to the vehicle address generator. The vehicle address generator converts the code to a series of pulses which are converted to tones by the telemetry transmitter which, in turn, are used to modulate the data transmitter. This is quite similar to the cycle described for the signpost. One base station radio transmitter is used to cover the entire metropolitan area.

Also, similar to the location cycle, is the data receiving process on the bus. All buses receive the data signal, demodulate it, convert it to tones, then to pulses, and check it for errors in the same manner as with the location signal. Unlike the location cycle events, the identification number from the error detector is then fed into the vehicle address comparator. This compares the number of the bus to be interrogated to the number (run number) which the bus operator has set into the equipment with the thumbwheel switches. If the numbers do not compare, which is true in all but one case, nothing else occurs until the next data signal is received and the cycle is repeated. On the one particular bus where the numbers do compare, a data transmission is initiated from the bus to the satellite stations.

In addition to the identification number, each message has a system address code. Once comparison shows agreement, this number is decoded and used to control equipment on the bus. Presently, it indicates a request for location data or voice communication; however, in the future, with additional equipment, it can request other data (passenger count, engine status, etc.) or control indications to the operator (time to leave terminal, ahead of schedule, etc.). The location information (last signpost number and elapsed time count) or other requested information is then coded into a series of pulses, processed and transmitted by the vehicle's data transmitter. As it is with all mobile radio transmitters, the range is less than that of a base station; therefore, to insure that the radio signals (both data and voice) are received from the vehicles, three satellite receivers which are connected to the control center, via cable, are located throughout the city.

Signals from the buses are received by one or more of these receivers and processed individually. Priority detection circuitry, which is monitoring the outputs of each error detector, then selects the first valid reply and sends the message to the computer interface, where it is inputed into the computer.

2.4 INTERPRETATION

Once the computer reads the reply from a bus, a schedule adherence check is made for the bus. First, a check is made to see if new information is available from the location information. If the signpost number is the same as the last interrogation, no new information can be ascertained because the bus has been checked by that point already. An exception to this is if the bus is still standing at the signpost; in this case, further checking may be accomplished. In all cases, the schedule adherence deviation is calculated and compared to the tolerance limits. These limits are set up to allow the bus operator a considerable leeway to content with usual traffic and passenger delays, yet give the dispatcher sufficient warning of a possible major interruption of service. If the deviation from the schedule is outside the allowable tolerances, a message is displayed at the dispatcher's console on a cathode ray tube (CRT) display and a permanent record made.

As mentioned previously, each mode of operation is occurring at the same time as the others. Each time a bus passes a signpost, the location cycle takes place. The interrogation cycle is continuous; it locates each bus on the street one by one and then repeats the cycle. Similarly, the interpretation cycle is processing the replies as they are received in a continuous chain.

2.5 OTHER FEATURES

Besides the monitoring operation, other features are integrated into the system. Two-way voice communication exists between the dispatcher and each bus. If the dispatcher wishes to talk to a particular bus, he simply "dials" that bus with a push-button type telephone device on the console. Another feature of the system is the emergency alarm. In the event of some emergency on the bus, such as a disturbance, sick or injured passenger, hold-up or the like, the operator has a foot switch which turns on the alarm. When the switch is pushed, the equipment automatically switches to the voice channel and transmits, continuously for two minutes, the identification and the location of the bus. During this transmission there is no audible or visual indication of any equipment operation on the bus. After two minutes has elapsed, the equipment automatically returns to normal operation.

3. MANAGEMENT AND OPERATIONS

3.1 INTRODUCTION

The management and operations evaluation of the Monitor-CTA AVM system was conducted through (1) meetings with responsible CTA personnel;[1] (2) actual monitoring of dispatchers using the system;[2] (3) actual monitoring of a street mobile supervisor; and (4) the review of appropriate operational manuals. Discussions were held primarily with the personnel responsible for the development and implementation of the Monitor-CTA system. The CTA's response to the TSC evaluation was in every way excellent and at all times candid especially about the problems they had encountered and planned end item achievement.

3.2 POTENTIAL BENEFITS

The Monitor-CTA offers many potential benefits to the CTA and to its customers. Although these may be unquantifiable at this stage of system development, they must be noted to present a complete picture of what the Monitor-CTA system will mean to the general public and to the management of the CTA. Ultimately, all decisions and actions should result in better service to the passenger, at a lower fare, with a very high level of safety. All other benefits must be secondary to these prime considerations. However, to provide the primary service, the CTA must operate as efficiently as possible, reducing and hopefully eliminating subsidies. The Monitor-CTA system enhances the efficient operation of the CTA and contributes directly to the safety of passengers.

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[1]Meetings were held with the CTA on the following dates: 5/23/72, 5/24/72, 5/25/72, 6/7/72, 6/19/72, 6/26/72, 6/27/72, 7/5/72, 7/19/72, 7/25/72, 7/26/72, 7/31/72, 8/2/72/ 8/3/72, 8/17/72, 8/24/72.

[2]The following list of dates and times represent time spent monitoring CTA operations from the dispatcher's room. 5/24/72 - 6 hours; 6/6/72 - 5 hours, 6/26/72 - 5 hours; 7/5/72 - 5 hours; 7/19/72 - 6 hours.

Also, service improvements occur through the improved surveillance of street conditions (bus movements), since the dispatcher's information is increased many fold. This information is then transmitted via voice to the bus drivers and mobile supervisor who takes necessary action to restore (if required) normal bus operation. This increased utility of the dispatcher and mobile supervisor is a direct benefit of the monitor system, since they have or should have the authority to affect operational changes.

The monitor system will support management decision making by providing data on schedules, changes to schedules, operator performance, bus maintenance, etc. More accurate planning can be performed by using the monitor data to establish trends that would be prohibitively costly to do manually. Improved schedule planning should result in fewer buses and operators required to provide a comparable or better level of service.

Provisions have been made in the Monitor-CTA system (with minor modifications) for a data collection system to be installed in the buses. The CTA plan for future installation in their buses is devices that will collect data on total passenger fare collection, bus speed, engine condition, fuel usage, number of stops, etc.

The emergency alarm feature of the system provides another unmeasurable benefit to the CTA operator and customer. Safety of operator and passenger is of major concern at the CTA. The system, by providing bus location, allows the dispatcher to have police and the mobile supervisor at the trouble point within minutes.[1] Obvious benefits, such as faster service for malfunctioned buses on the street, which are inherent with any radio equipped bus have been eliminated in the analysis of the Monitor-CTA system. The reason for this is that the CTA[2] has made a decision to install

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[1]July 5, 1972 - witness alarm in which police were on the scene in less than 2 minutes.

[2]Discussion with Mr. George Krambles, Operating Manager, CTA - July 6, 1972.

radios on the buses independent of the decision concerning future implementation of the Monitor-CTA AVM system. However, this decision cannot be completely separated due to the increased cost per radio if an AVM system is adopted (see Section 8).

3.3 SYSTEM MANAGEMENT

Although the CTA management is aware of the above managerial benefits and is striving to achieve these goals, at the present time few of these goals have been realized for the following reasons:

1) Manpower shortages associated with technical development;

2) The present data format and low confidence (in most cases unjustified) of system data output;

3) The partial system does not present total picture to management.

Perhaps the main reason the existing system is not an unqualified success, operationally, is that the level of staffing has been inadequate for system support during the developmental stages.[1] The present staff consists of a program manager, an engineer, one summer employee, and one bus driver. Using $200K of contracts/manyear as a leverage factor, the system should have been supported by three or four professionals over the two-year development phase. Also CTA's management acceptance of the Monitor-CTA generated reports has been justifiably low due to the data output format employed. Although the existing format is used by those CTA personnel directly involved in the AVM project, other managers who could make use of the potentially available information cannot, simply due to the inappropriate data format and the volume of information presented. However, it is anticipated that the CTA management, because of its positive view toward the system, will eventually take full advantage of this potentially available data, once the system is fully implemented.

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[1]This situation was emphasized by unclear status of funding, hiring freezes and a restrictive tight budget.

3.4 OPERATIONS

3.4.1 Dispatcher - Duties and Responsibilities

The Monitor-CTA system is designed such that a dispatcher may analyze the bus routes and operations in near real time and take the necessary action to restore service as required. The pre-monitor system required that the dispatcher react to problems as they arose. The introduction of the monitor system represents a considerable change in operations to the dispatcher.

At the present time, the dispatchers operating the Monitor-CTA system do not exercise the full authority that is inherent in the system for taking corrective actions to maintain schedules. This responsibility still resides primarily with the mobile and stationary supervisors located in the street. The dispatcher's reluctance to assume this responsibility is primarily from:

1) His lack of confidence in the data output (not completely justified);

2) The possibility of causing a labor union jurisdictional dispute (the union position regarding the use of the Monitor-CTA system is unclear);

3) His unfamiliarity with the change required in his mode of operations and

4) The data output format on his CRT display.

This situation is further complicated by the fact that the monitor system is only partially implemented. This requires that the dispatcher operate in two very different modes during a single shift. The duties and the responsibilities of the dispatcher are shown in Figures 3-1 and 3-2. These figures depict the difficult transition that the dispatcher is making from strictly a reaction mode (pre-monitor) to an analysis type of environment (monitor).

When fully implemented, the system will enhance the mobile supervisor's role without decreasing his level of authority. Stationary supervisors (point men) will not be required except in a

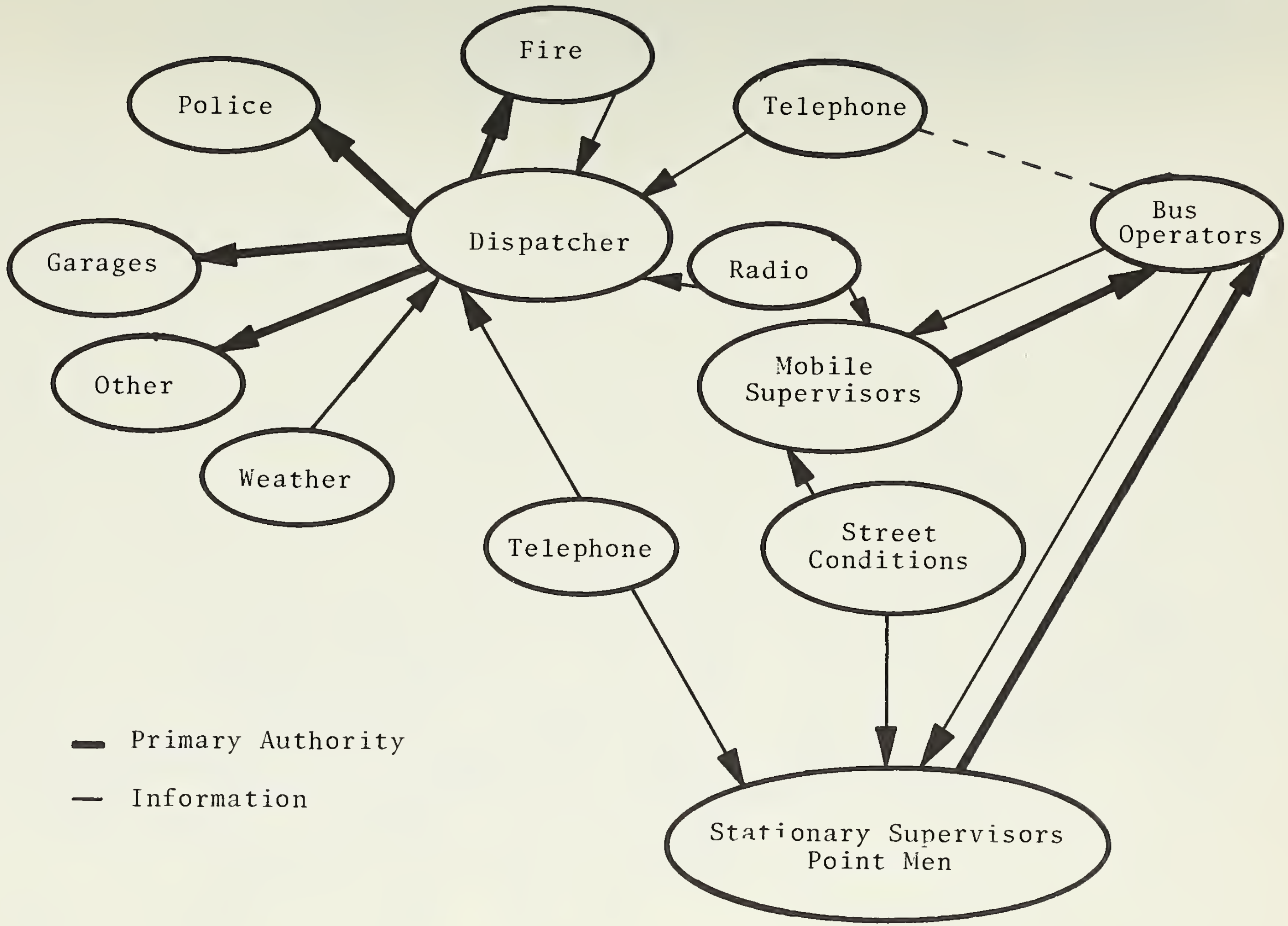

Figure 3-1 Current Operations

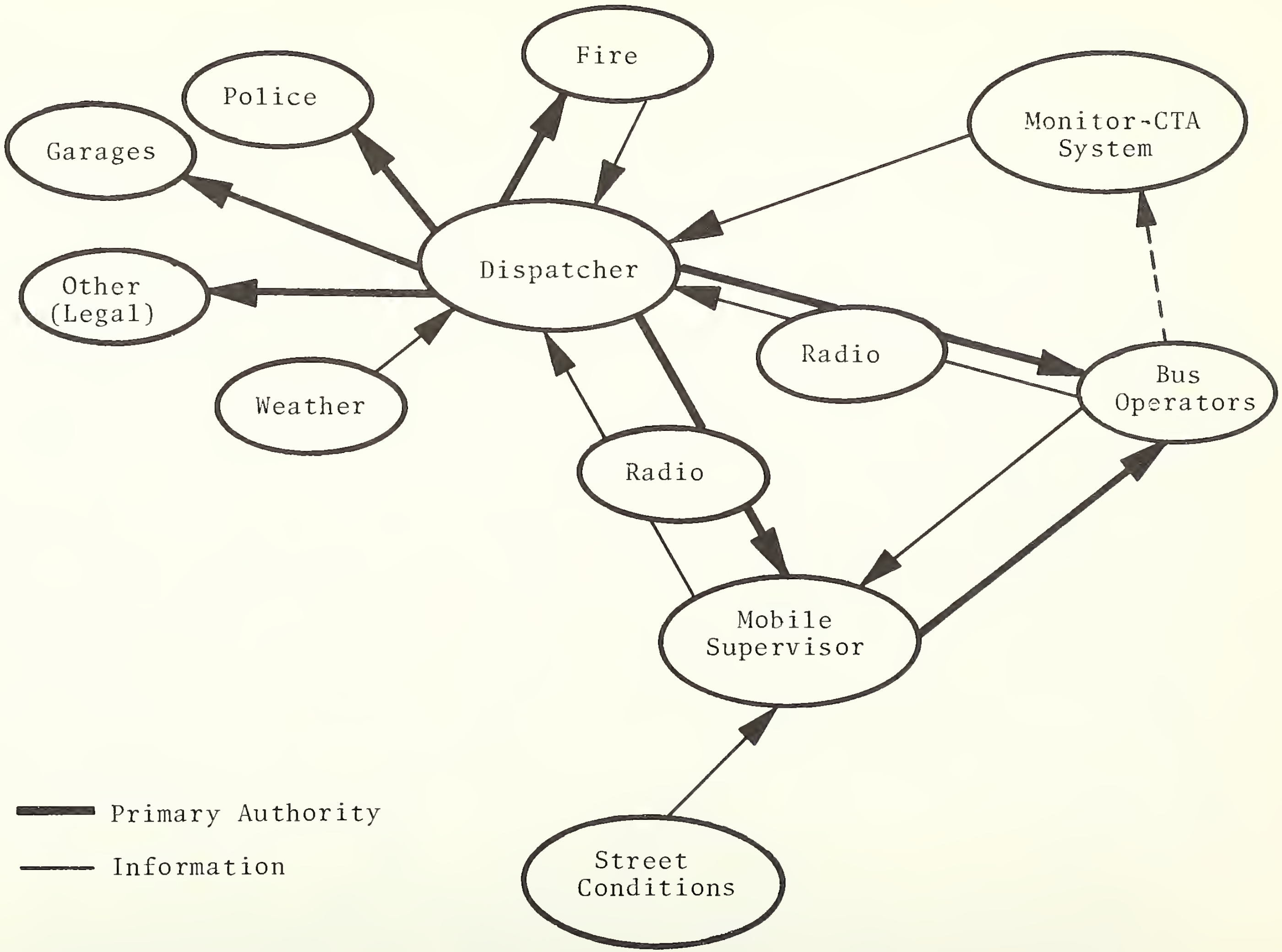

Figure 3-2 Monitor Operations

very few special situations (i.e., at Jefferson Park Terminal where many routes converge). With the improved surveillance of the monitor system, it is very likely that additional mobile supervision could be effectively utilized. In the fully implemented system, the team of dispatcher/mobile supervisor will be a more effective unit for insuring a high level of service!

The CTA plans to have each dispatcher (up to eight simultaneously when fully implemented) responsible for a number of garages and the routes that operate out of it. An alternative approach is to divide the city into areas. However, this approach has all but been abandoned since this would result in a severe handover problem between areas. Discussion with the dispatchers indicated that they preferred the approach where a dispatcher would work with the routes out of a garage.

The system, as presently being operated, requires that one dispatcher analyze buses on 60 routes out of 12 garages. This is beyond the capability of any dispatcher using the displays that are provided for him (see next section). If the number of routes was reduced, the operator could probably analyze a particular buses' performance and could take the necessary action to check operators that were deviating from schedule.

It was noticed that generally the dispatcher handled the emergency alarms with efficiency. However, it should be noted that the dispatcher was very cautious in his actions and refered to voluminous printed schedules to insure that the data in the monitor console was correct. The dispatcher's response time to alarms will probably decrease as he becomes more experienced and becomes more confident of the system.

3.4.2 Display and Controls

The dispatcher exercises his responsibilities through the Monitor-CTA console located in the dispatcher room on the 7th floor of the Merchandise Mart. Two dispatchers can sit at this console; however, only one dispatcher can use it at a time. Independent display capability is not designed into the system. The dispatcher obtains information through the following:

a) Data displayed on a cathode ray tube (CRT);

b) Digital displays;

c) Emergency alarm buzzer;

d) the RF radio channel;

e) A clock displaying CTT; and

f) A device for displaying a Chicago map in segments.

Dispatcher inputs are made through:

A computer entry keyboard;

Selective bus call module; and

RF voice channel or standard telephone.

The importance of the console capabilities cannot be overstated, since the information displayed on the console will be analyzed by the dispatcher and he takes appropriate action to control bus operations. The console and its inherent capabilities in the present Monitor-CTA system is a constraint on the ability of a dispatcher to analyze bus operations in a timely manner. The following critique of the console is submitted:

1) Selective Call - The selective call (which addresses the bus automatically) works well and reduces the voice communication required to contact a specified bus. Its location is often shielded by the computer entry device.

2) Digital Displays - The digital display (which shows the run number), although rather large and thereby occupying a high percentage of the console, functions very well and is of vital importance in emergency alarm situations because they are used to display the run number of a bus calling the dispatcher.

3) Alarm Buzzer - This function is necessary to alert a dispatcher if he has left the console (which he rarely does).

4) Manual Entry Device (MED) - A keyboard is provided through which the dispatcher communicates with the computer to call up new displays and run selected programs. The MED is awkward to use because of its physical construction and location. Although the dispatchers have learned to utilize the MED with about as much proficiency as is required, entry of a request is rather slow, and if a program is to be run several times, it proves annoying. This method of computer entry is not generally adequate for operations of the type dispatchers have to perform (i.e., several "program 30's").

5) Communications Panel - Entirely too much room on the console is occupied by the communications panel. Also, its central location on the console is not necessary and forces the CRT off to the side. In addition to the communications panel, a PBX type phone is provided for the dispatcher that again takes up too much space as compared with modern communications facilities. Its location also necessitates placing the MED on the work surface of the console.

6) CRT - The CRT is too small and located off to the right of the console. This is the most important display device the dispatcher has and it should have been placed in a central location.

7) Data Display - A choice of two CRT displays is provided for the dispatchers to use. One display provides information on out-of-tolerence (the tolerence can be set by the dispatchers) buses on all routes. The other display provides data on all buses on a selected route. The display of out-of-tolerence buses provides information on run numbers, last signposts, deviation (early or late), direction and route. Bus schedule information should also be provided on these displays, since the dispatcher must refer to printed schedules in almost every case to see if he is getting valid data. This

procedure becomes unwieldly. Often the dispaly has more information than can be displayed, which requires a paging of displays.

The procedure for computing the deviations may result in the display of two different deviations due to updating of data. A hard copy of the information in question would be advisable, since it is difficult to remember what the previous displayed information was. Without the hard copy the dispatcher often finds himself looking at updated data by the time he found the particular printed schedule. In some cases the bus may have been dropped altogether. Although this condition can be lived with, it is undesirable.

The selected route display may be called up by the dispatcher; it provides information with which to check bus operation on specific routes. The utilization of this routine is difficult since the CRT display does not show the buses in sequence or even by directional groupings. This makes headway evaluation nearly impossible except under very optimum conditions.

8) Street Map Display - A projection device is provided to show sections of a map of Chicago. The idea of the map is good even though the dispatchers are quite familiar with the streets and routes. The map display is located in such a position as to make use difficult; in addition the maps displayed are too small to read properly and tended to defocus. However this display would be a very useful tool for directing buses during emergencies.

9) Console Layout - The console configuration is sub-optimum for use by dispatcher. The CRT, which is the prime information device, is not centrally located. The MED should not be allowed to shield part of the console. The communications panel should be smaller and not be centrally located.

3.4.3 Training and Procedures

Comprehensive training is provided to the dispatchers and bus operators and the training plans have been integrated into the total CTA training effort. Revised training schedules are presented in Appendix A. Bus operator training has been effective in drastically reducing the false emergency alarm rate and the incidents of erroneous run numbers entered into the monitor equipment located on the buses. All the dispatchers that were observed (9 of 12) displayed a good understanding of the purpose and objectives of the monitor system. The procedures manual used by the dispatcher has been revised and edited repeatedly and is now a well organized and very effective document. (This document contains a list of software programs.)

Lack of a clear policy with regard to how the system should operate has made the procedures development more difficult. It is fully expected that the existing procedures will undergo many more changes until sufficient operational experience is gained. Since there are only a limited number of AVM systems in operation, relatively little experience is available to establish a policy of operation. Furthermore, since the system is only partly implemented, fixed policy regarding its use would be suspect. Therefore, a policy should be developed that gives guidance yet permits changes as required for an operational system.

3.5 RECOMMENDATIONS

Although the CTA personnel involved with the monitor project were found to be very capable, the vast majority of their time is spent with solving the day to day technical and operational problems with very little time available for system improvement. Therefore, additional personnel should be placed on this project until both the existing, operational and technical (discussed in the next sections) deficiencies are rectified.

The existing display and control system is inadequate for the evaluation of bus data and the initiating of corrective action.

Figure 3-3 Picture of the CTA-Monitor Console

The consoles should be redesigned with the following factors in mind:

1) Easy data entry;

2) Data presented to dispatcher in such a manner that simple analysis and quick control action is possible;

3) Optimize console layout, i.e., the different console subsystem should be strategically placed to optimize the dispatcher's performance.

Finally, the dispatchers, during their training period, should be required to take a more active role in controlling the monitor bus population.

4. SCHEDULE AND HEADWAY ADHERENCE

4.1 BACKGROUND

Buses deviate from their assigned schedules for two fundamentally different reasons. The most obvious reason is factors which influence bus headway; traffic movements and passenger density. Typically, these problems are highly unpredictable. Also, dynamic instability which results in the pairing of buses can be attributed directly to insufficient control over the progress of the buses along their routes. An automatic vehicle monitoring system theoretically offers an excellent means of dealing with the dynamic instability by the application of real-time control to the system. With the location of each bus continuously available at the central office, schedule deviations can be computed automatically and quickly. Through the radio return link, drivers would be instructed to skip a stop, wait at a stop, or take other corrective action which could rapidly alleviate the schedule deviation.[1]

A test was conducted to determine whether the monitor system improves schedule and headway adherence over a non-monitor system by comparing the buses actual time point arrival time to the buses schedule time point arrival time.

4.2 TEST PROCEDURES

Schedule and headway adherence data was collected during the month of July over a twelve-day period by the CTA under the direction of TSC. During the first six days of the test (July 5-7, 10-12) buses without "monitor" equipment operated over the selected bus routes. On the seventh test day (July 19) the non-monitor buses were replaced with monitor equipped buses and schedule and headway adherence data was collected for another six

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[1]Benefits and Costs of an Automatic Vehicle Monitoring System, MTR-6-64, MITRE, September 1971.

days (July 19-21, 24-26). Data was collected during both peak (6:00 - 9:00 a.m., 3:00 - 6:00 p.m.) and off-peak (9:00 a.m. - 3:00 p.m.) hours each day. Owl run (12:00 - 6:00 a.m.) data was not collected because of the limited CTA manpower available during these hours.

Bus routes were selected using the following criteria: 1) contain significant number of signposts; 2) variation in length; 3) different types of service provided (i.e. "feeder", "trunk line", "short hop, feeder",) and 4) represent typical bus routes for particular types of service. The table below represents the routes selected by TSC/CTA. Figure 4-1 represents the selected routes superimposed on a map of Chicago.

Route	# of Signposts	# of Signposts Used in Test	Route Length (Miles)	Type of Service[1]
Skokie	4	4	15	"feeder"
Kedzie-Cal	8	5	24	"trunk line"
Vincennes 111th	3	3	15	"short hop, feeder"

For the non-monitor tests, it was hoped that the entire bus population would not contain monitor equipment in order to insure that a bias in favor of a non-monitor bus system would not occur. However, due to bus scheduling difficulties, a few of the test buses did contain monitor equipment. During the non-monitor tests, no attempt was made by the dispatcher to control the monitor buses via the two-way radio. Also, the number of route supervisor personnel, i.e. mobile supervisors, point checkers, etc., were kept constant. Employees of the CTA Schedule and Traffic Department were used to collect data for this test. The time checkers were assigned specific routes, signpost location, and daily time periods

[1] "feeder" - a route which "feeds" passengers to a Rapid Transit
"trunk line" - a major route where passengers travel less than five miles
"short hop" - a route where passengers travel less than one mile

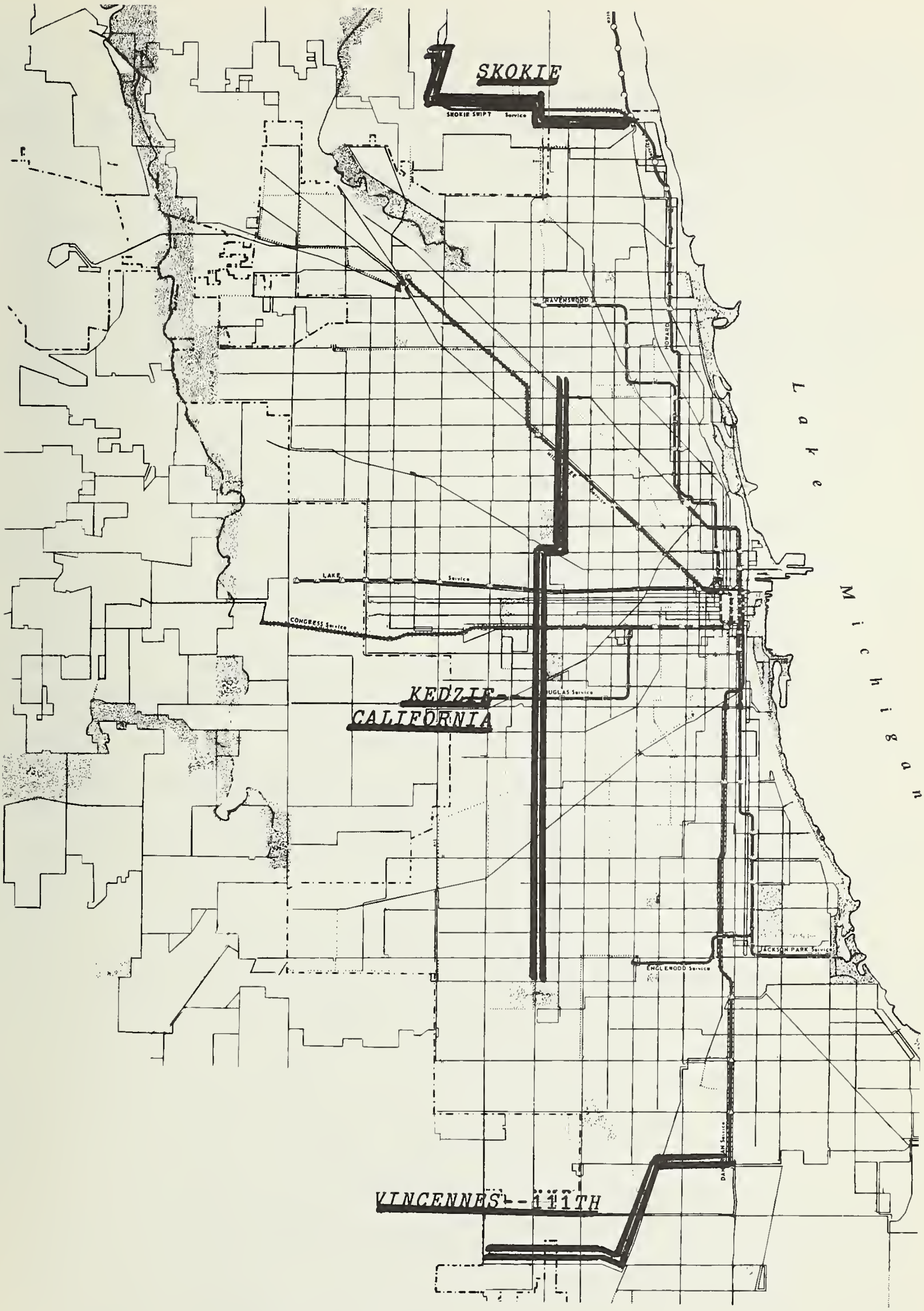


Figure 4-1 Test Bus Routes

in which to collect data. Each morning the time checkers would standardize their watches to the standard time by dialing the local "time" telephone number. Once positioned at the design signpost, the time checker would enter the following data as a CTA bus passed the signpost: 1) bus number; 2) run number; and 3) arrival time (to nearest 30 seconds). TSC had requested, via a test plan sent to the CTA, that the time checkers be positioned in such a way that they not be observed by the passing bus operator. However, well after the testing had begun, CTA informed TSC that due to operational procedures, it was not possible for the time checkers to take data unobserved by the bus operators. Bus operators who feel that they are being checked for schedule adherence probably tend to maintain better schedule adherence than if they are not being observed (especially those bus operators who tend to arrive at time points earlier than scheduled). The effect of time checkers collecting data along a route possibly creates a "mini-monitor" system. Only if non-CTA personnel were hired would TSC be assured that the data would be unbiased. Due to the time constraints involved in conducting this test, it was decided to continue the test with this built-in bias.

For the monitor tests, CTA was requested to run the maximum number of monitor equipped buses along the test routes. A 100% monitor equipped bus population could not be mustered due to bus scheduling procedures. Prior to this test, a CTA Service Bulletin was posted at the appropriate bus terminals informing the bus operators that the three test routes would be monitored 24 hours a day. A copy of one of these letters is in Appendix B. In addition, it was requested that the CTA dispatchers were to keep the monitor buses on schedule via the two-way radio as much as practically possible. The data was collected by the time checkers in the same manner as during the unmonitored tests. After the monitor data had been received by TSC, all non-monitor and monitor bus (with bad equipment) data was manually eliminated. The non-monitor and monitor data was separately inputed onto two discs of an IBM 370-155 computer. The raw data was inputed into the "computer error program" to eliminate typographical errors. The refined data was sorted by particular parameters; and schedule and headway adherence statistics were then generated using the "statistic data reduction" routines developed by TSC.

4.3 TEST RESULTS AND CONCLUSIONS

4.3.1 Schedule Adherence

Schedule adherence is defined as the bus arrival time deviation, whether early or late, from the schedule arrival time, or symbolically

$$|X_s - X_a| \text{ where:}$$

X_s = schedule bus time point arrival time

X_a = actual bus time point arrival time

Mean deviations from the schedule were calculated for each bus route by peak and off-peak hours, for both the non-monitor and monitor tests. The difference in mean deviation of the non-monitor and monitor tests was then compared for significance by use of the "two tailed" statistical "T" test at a 95% confidence level. Also, a percent mean and standard deviation improvement, defined below, were calculated:

Mean % Improvement	Standard Deviation % Improvement
$[(\overline{X}_{n/m} - \overline{X}_m) \div \overline{X}_{n/m}] \times 100$	$[(\sigma_{n/m} - \sigma_m) \div \sigma_{n/m}] \times 100$

where $\overline{X}$ = mean

σ = standard deviation

n/m = non-monitor test

m = monitor test

A positive percent improvement indicates a schedule adherence improvement with monitor equipped buses. These results are presented in Table 4-1. The histograms by route and time are presented in Figures 4-2 - 4-13.

The results of the "T" test indicate that no significant improvement of schedule adherence due to a monitor system was observed in 66% of the tests. During peak operating hours, a significant improvement to schedule adherence on routes with "monitor" buses occurred only on Vincennes. In fact, both Skokie and Ked/Cal exhibited poorer schedule adherence characteristics, as indicated by the mean % improvement, when operating with "monitor" buses. During off-peak operation, a significant improvement in schedule adherence occurred only on the Skokie route, but the other routes did not show overall improvement, which may or may not have been the result of the monitor system. The results of the test indicate the tendency of the monitor system to operate better during off-peak hours rather than peak hours. Three factors could have contributed to the above test results:

1) The data bias introduced during the non-monitor test, (i.e. collection of data by checkers,
2) Time of test (July is the month when passenger count and traffic are typically at a minimum)
3) The dispatcher's inability to effectively initiate schedule adherence control (see Section 3).

In conclusion, the test indicates that generally the monitor system performs as well as the non-monitor system; however, due to the above considerations, no conclusions can be made as to whether the monitor system is better than the non-monitor system in regard to improved schedule adherence.

4.3.2 Headway Adherence

Headway deviation is defined as the absolute value of the difference between actual headway and scheduled headway. (i.e. in time). The results of the test are presented in the Table 4-2 and

TABLE 4-1 SCHEDULE ADHERENCE DEVIATION

Time of Day	Route	Sample Size	Non-Monitor (minutes)		Sample Size	Monitor (minutes)		% Mean Improvement	σ% Improvement	Statistic "T" Test[1] (the monitor test shows significant schedule adherence improvement over non-monitor test)
			$\bar{X}$	σ		$\bar{X}$	σ			
Peak	Vincennes	526	2.30	2.55	659	1.71	1.97	+26	+20	yes
	Skokie	651	1.79	3.15	460	1.83	2.47	0^-	+25	no
	Ked/Cal	920	1.79	1.99	597	2.26	2.36	-26	-20	no
Off Peak	Vincennes	278	4.23	4.23	228	3.92	4.52	+7	-7	no
	Skokie	193	2.30	2.96	114	1.36	1.75	+41	+43	yes
	Ken/Cal	390	1.94	2.10	239	1.70	1.71	+12	+19	no

[1] The confidence level is 95%

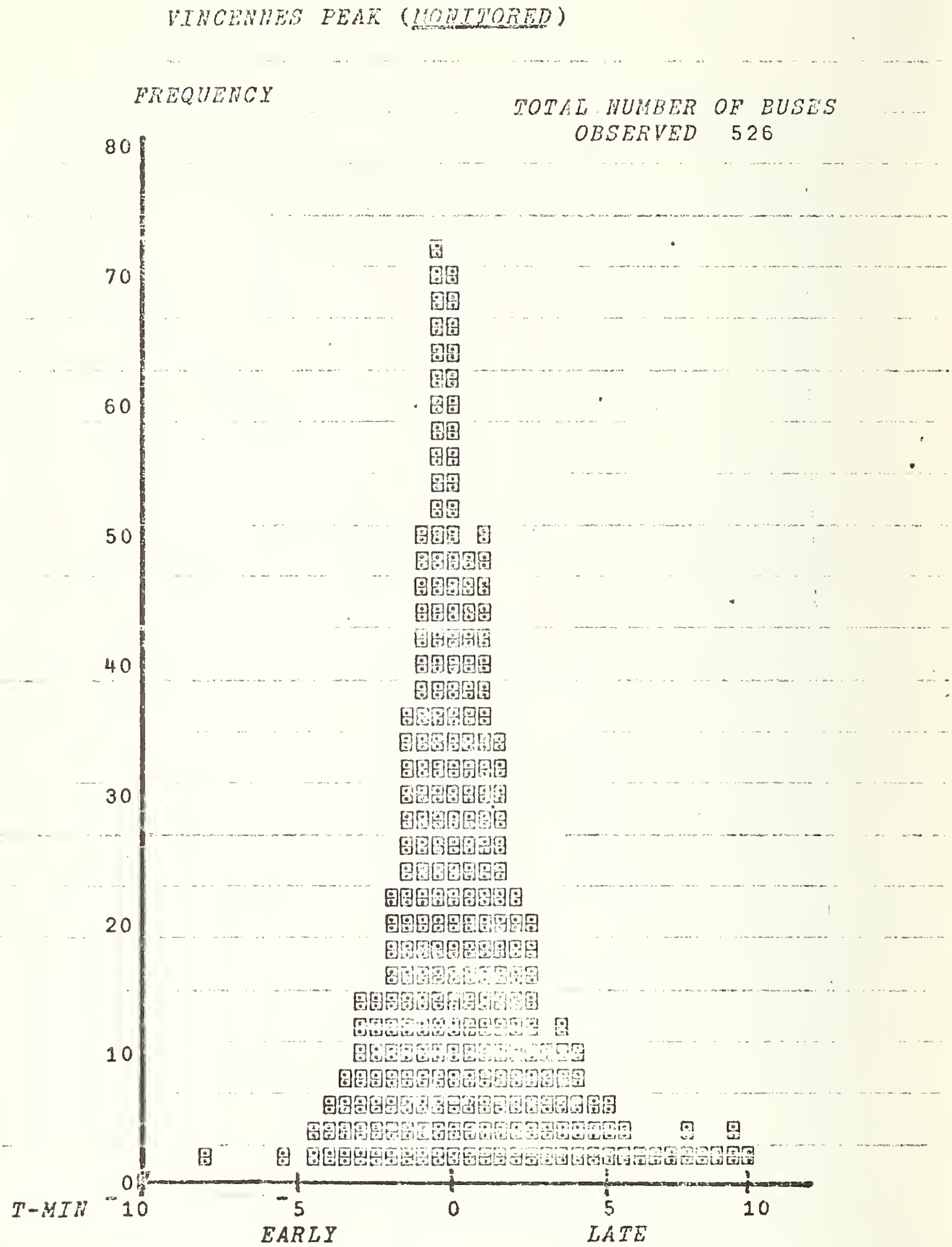


Figure 4-2 Schedule Adherence Vincennes Monitored Peak

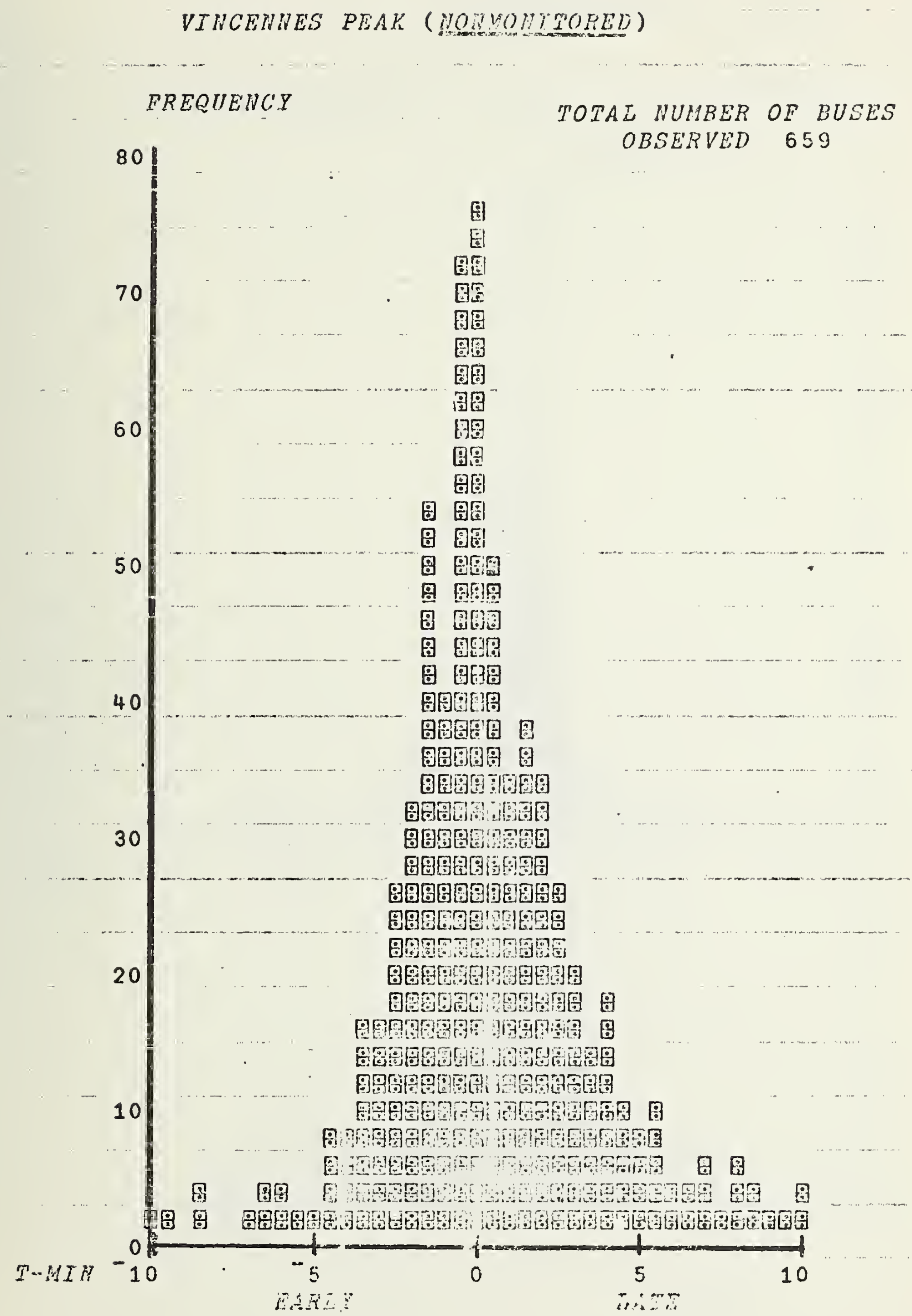


Figure 4-3 Schedule Adherence Vincennes Non-Monitored Peak

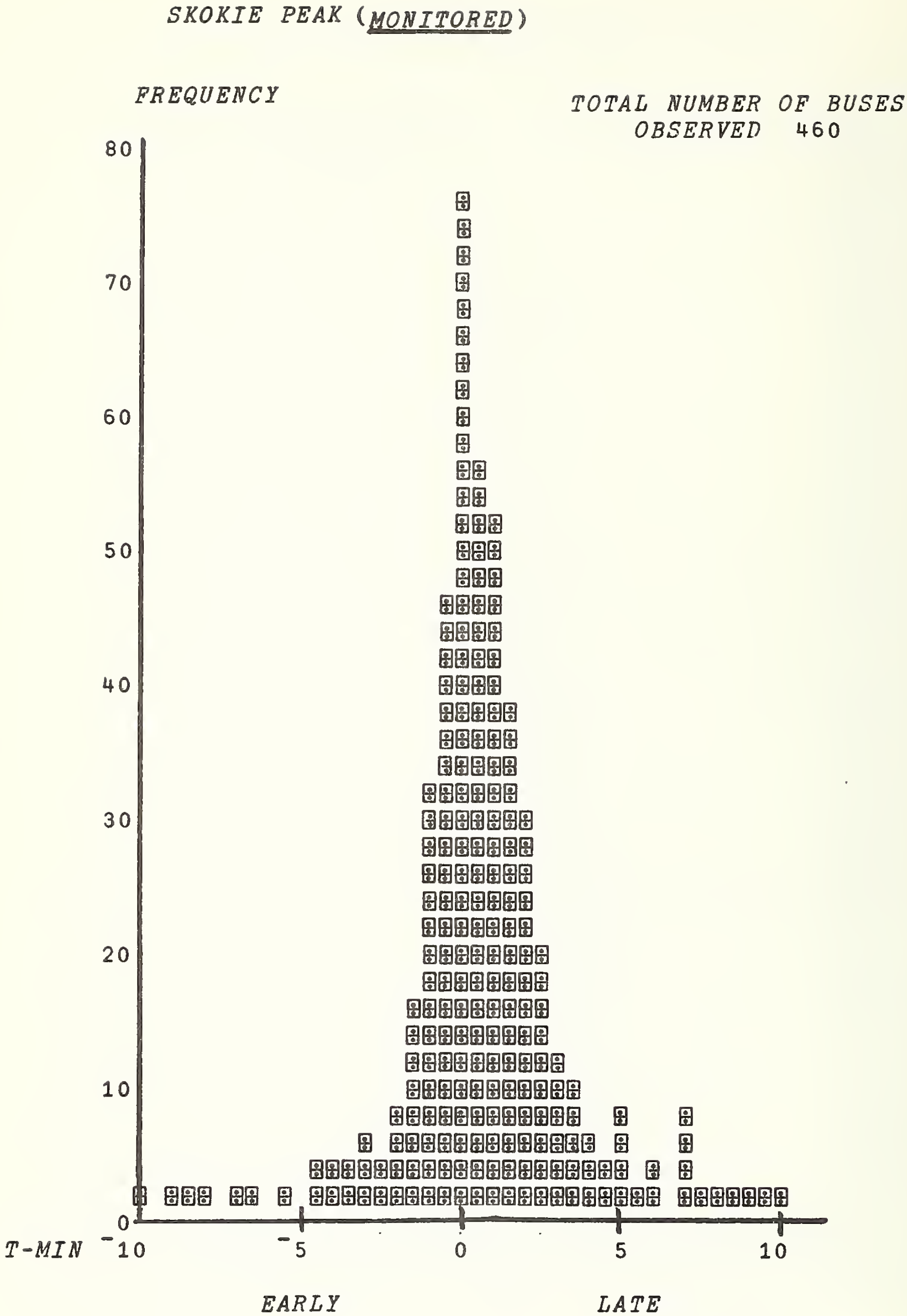


Figure 4-4 Schedule Adherence Skokie Monitored Peak

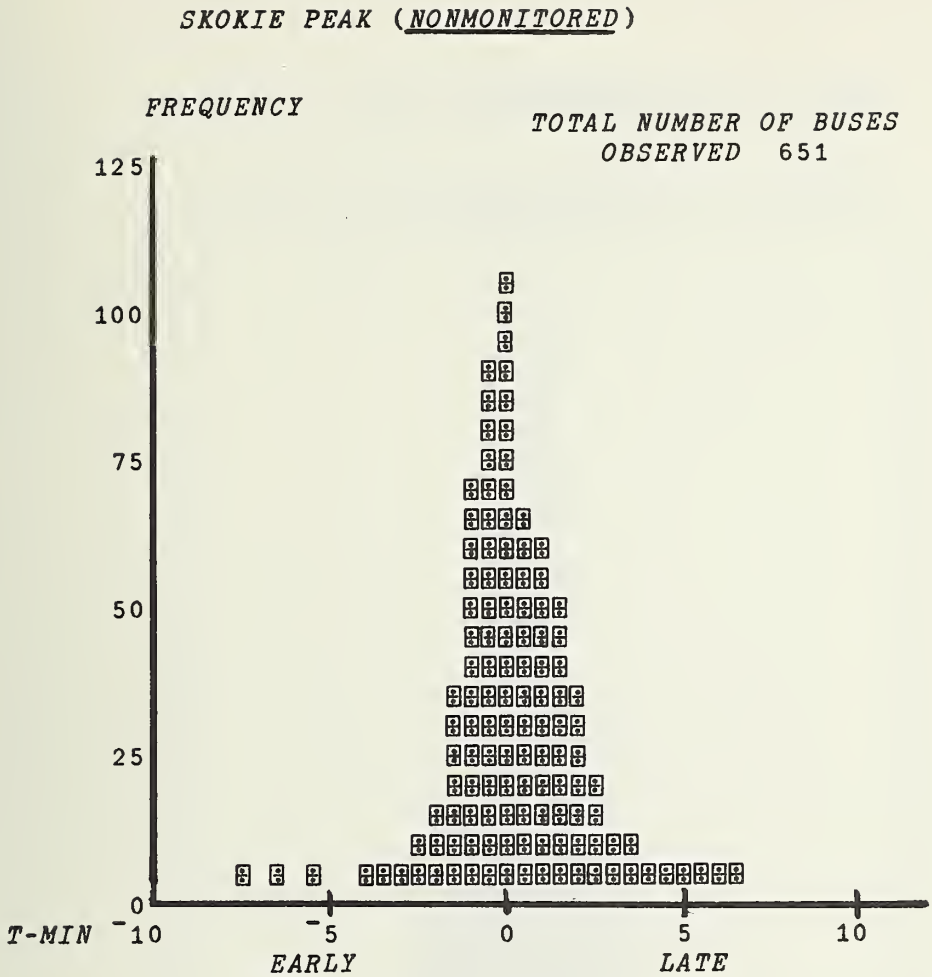


Figure 4-5 Schedule Adherence Skokie Non-Monitored Peak

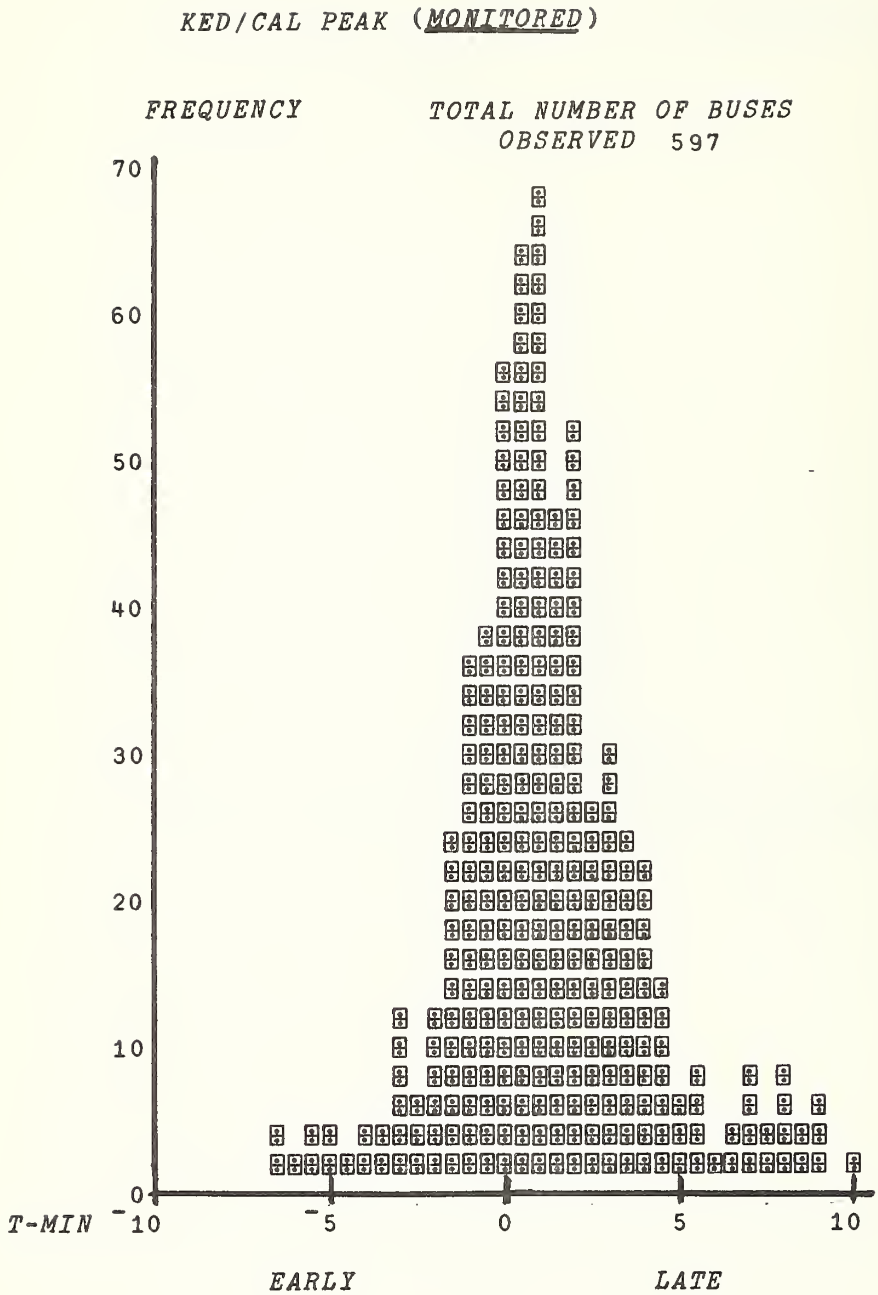


Figure 4-6 Schedule Adherence Ked/Cal Monitored Peak

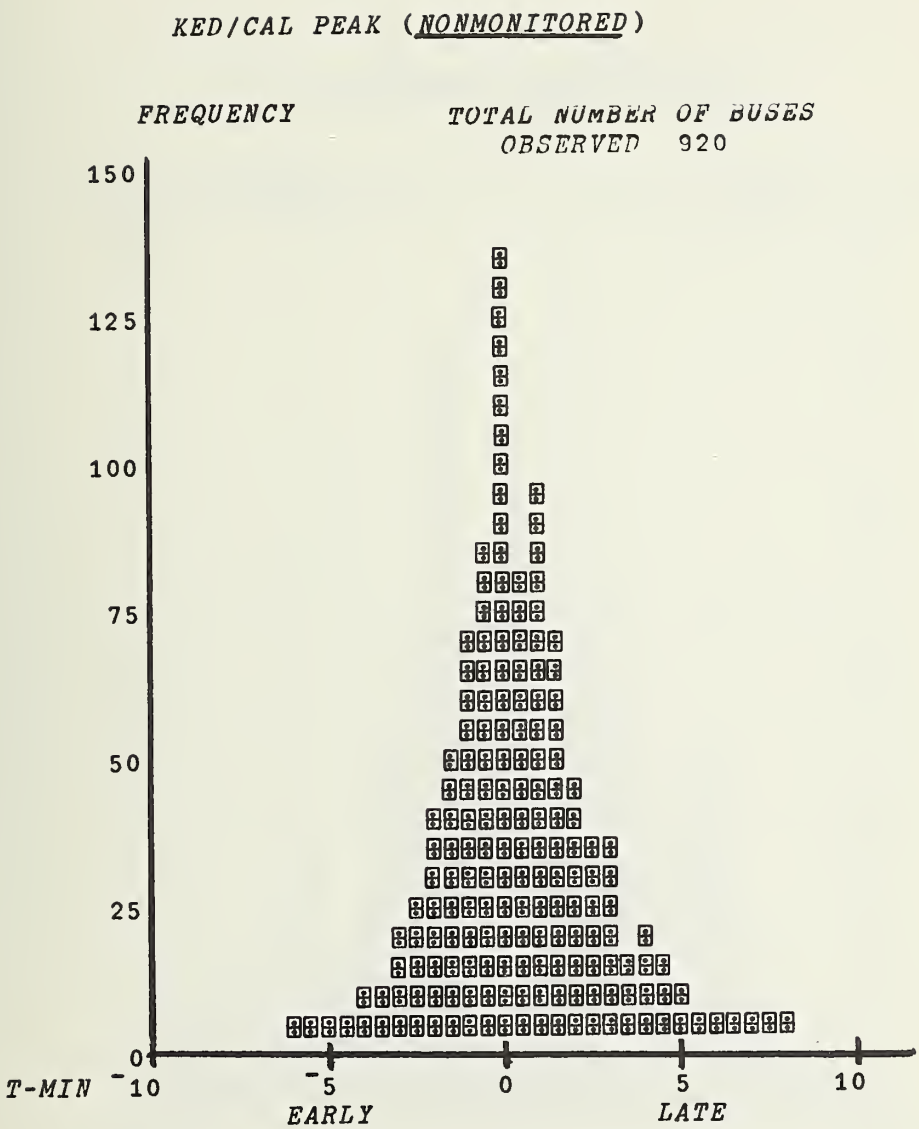


Figure 4-7 Schedule Adherence Ked/Cal Non-Monitored Peak

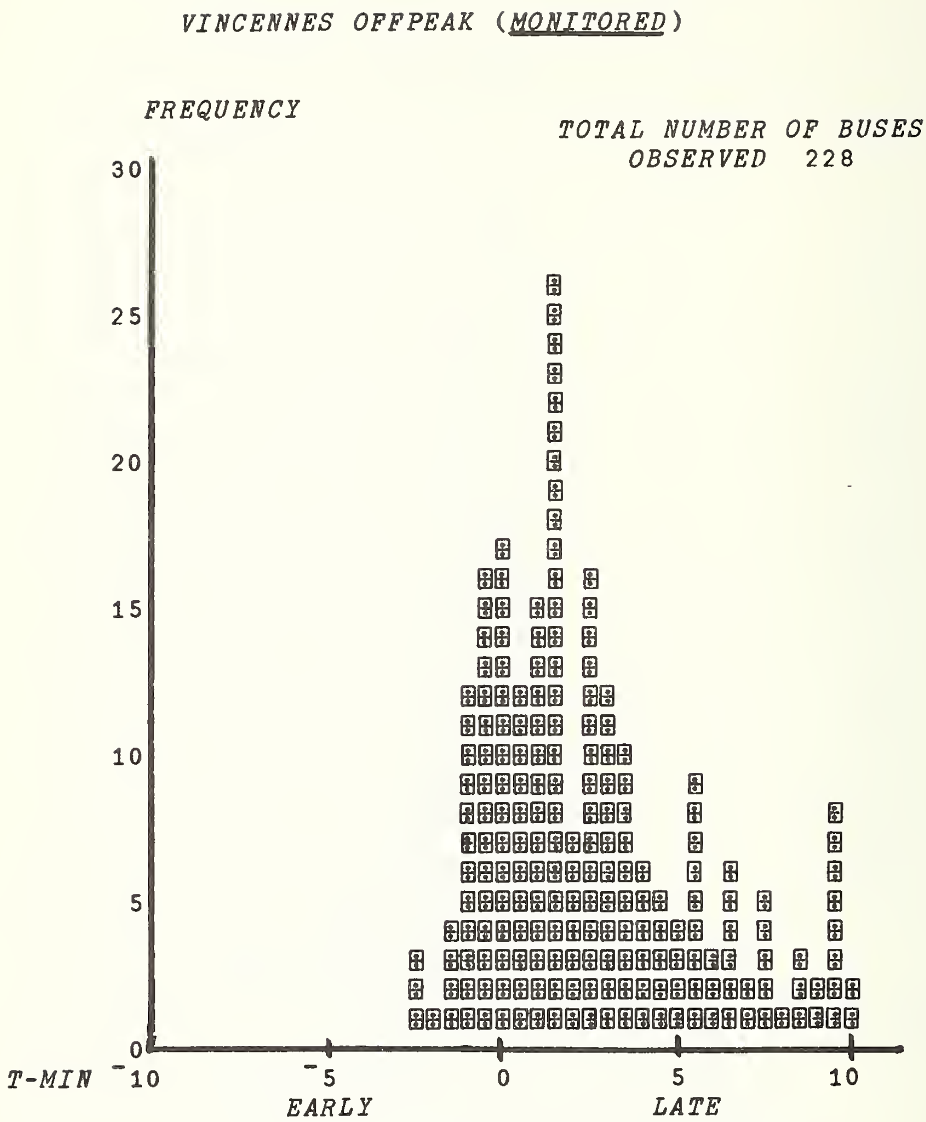


Figure 4-8 Schedule Adherence Vincennes Monitored Offpeak

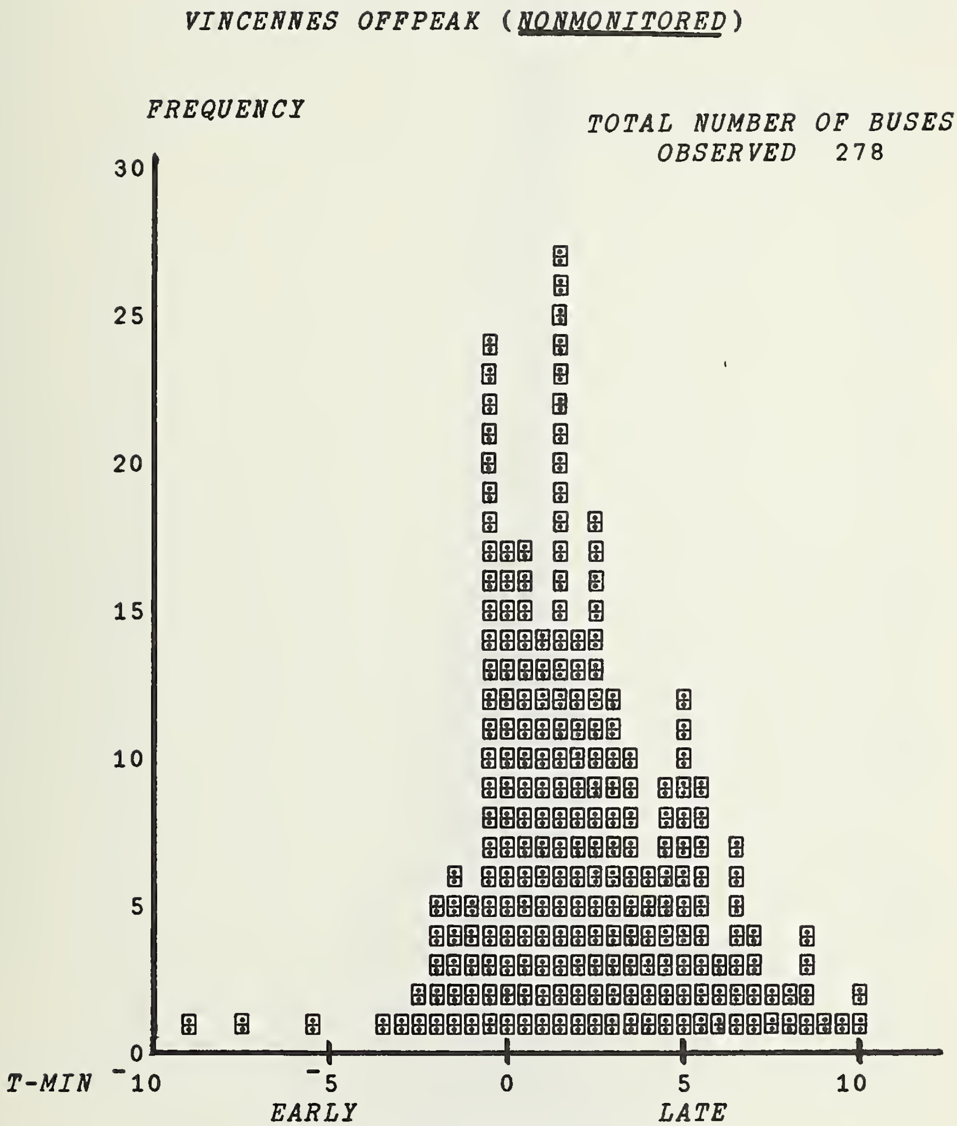


Figure 4-9 Schedule Adherence Vincennes Non-Monitored Offpeak

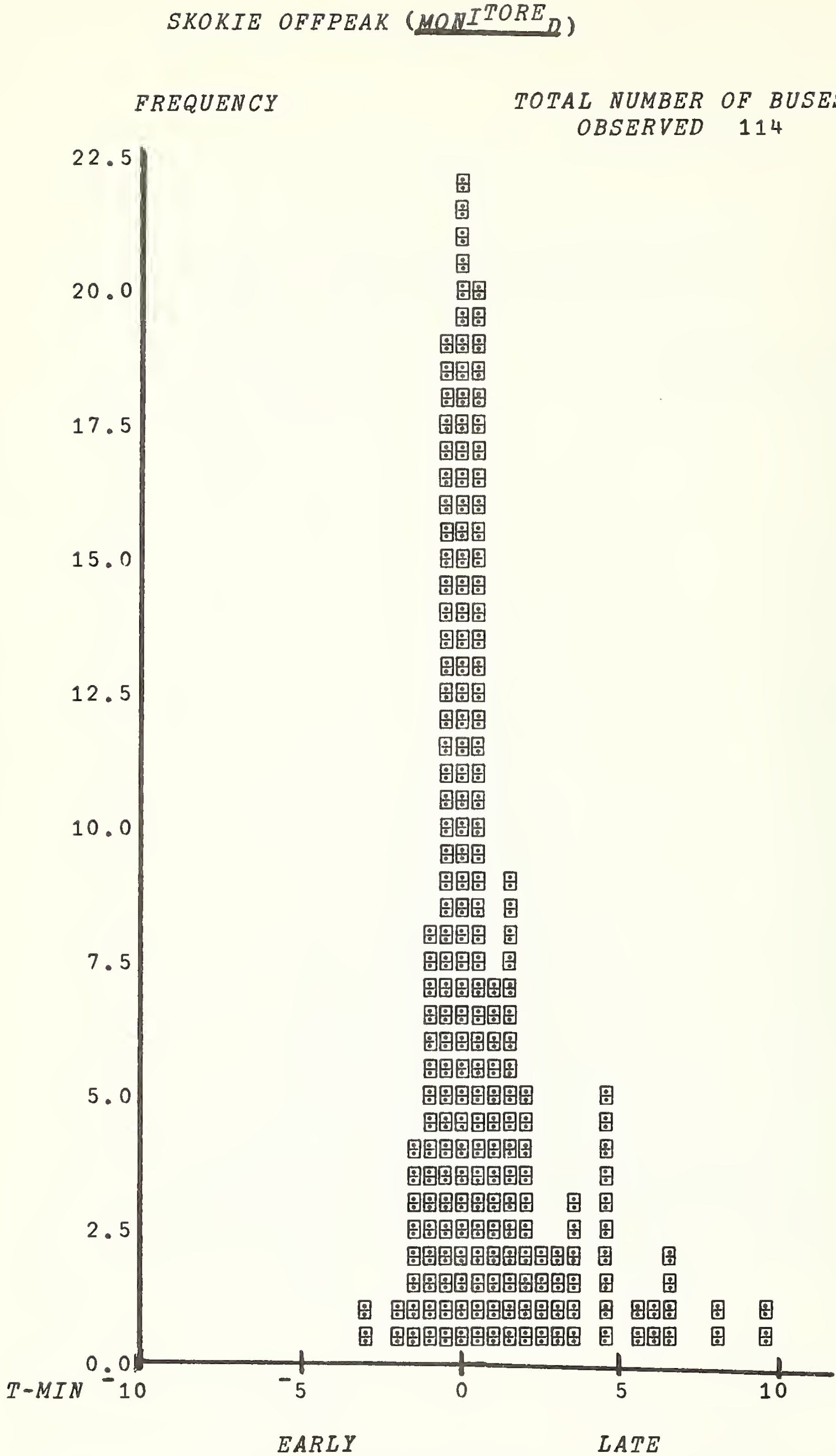


Figure 4-10 Schedule Adherence Skokie Monitored Offpeak

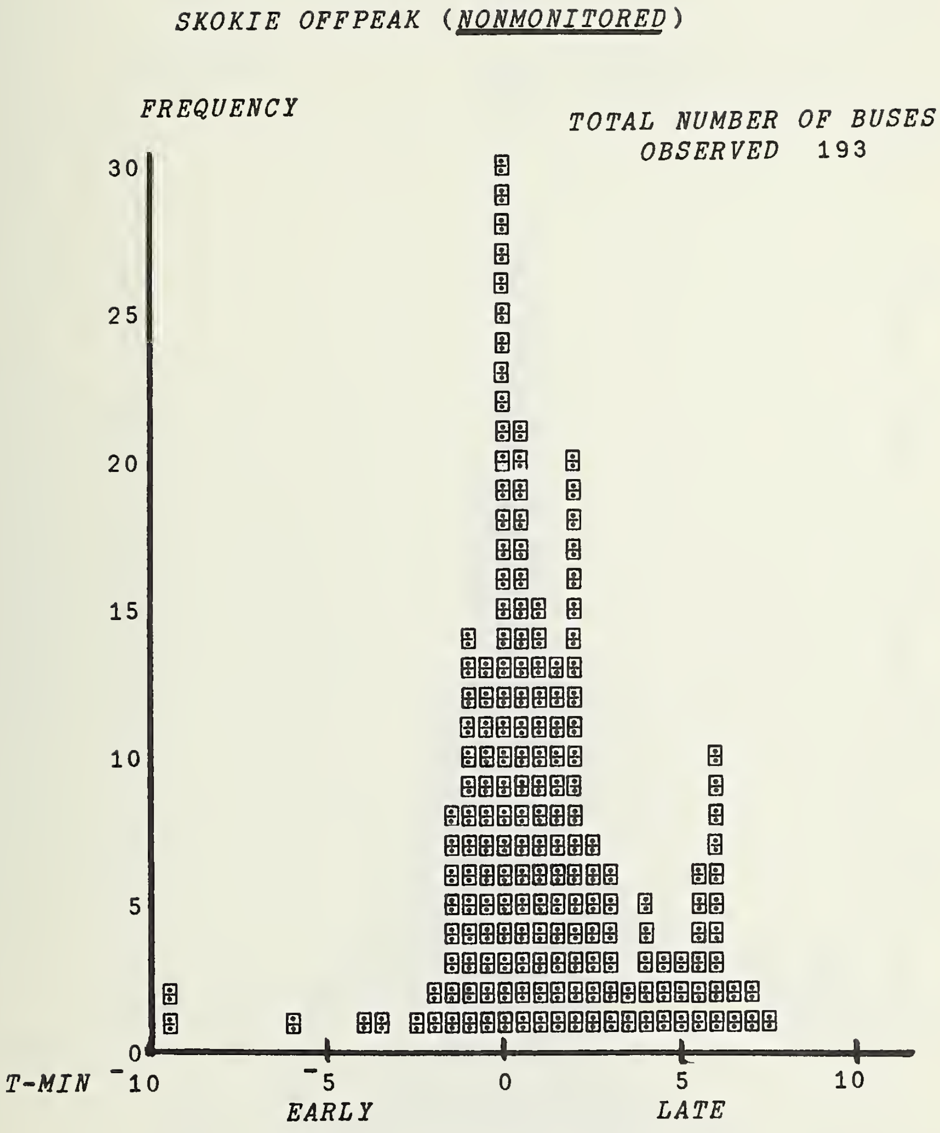


Figure 4-11 Schedule Adherence Skokie Non-Monitored Offpeak

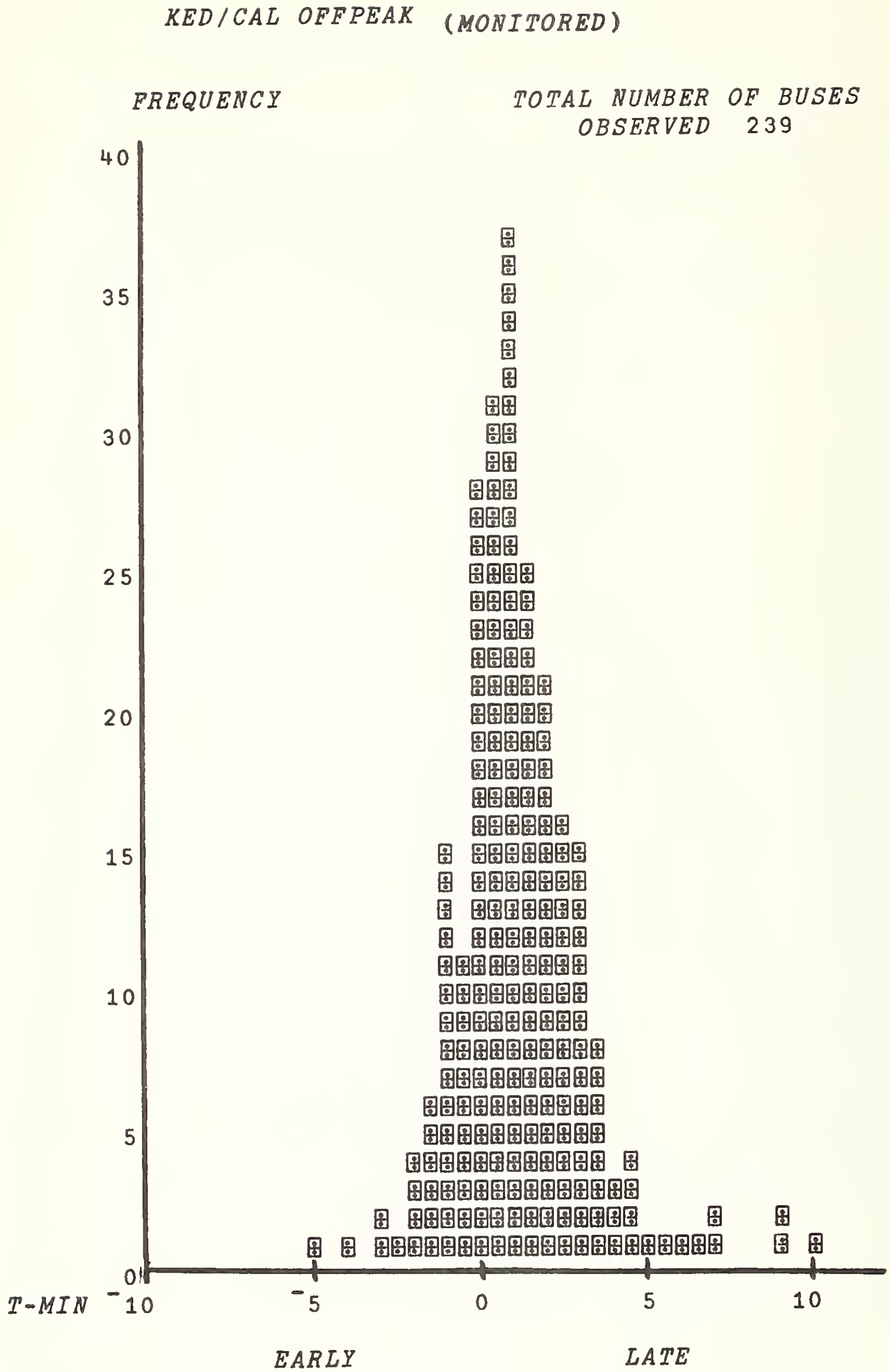


Figure 4-12 Schedule Adherence Ked/Cal Monitored Offpeak

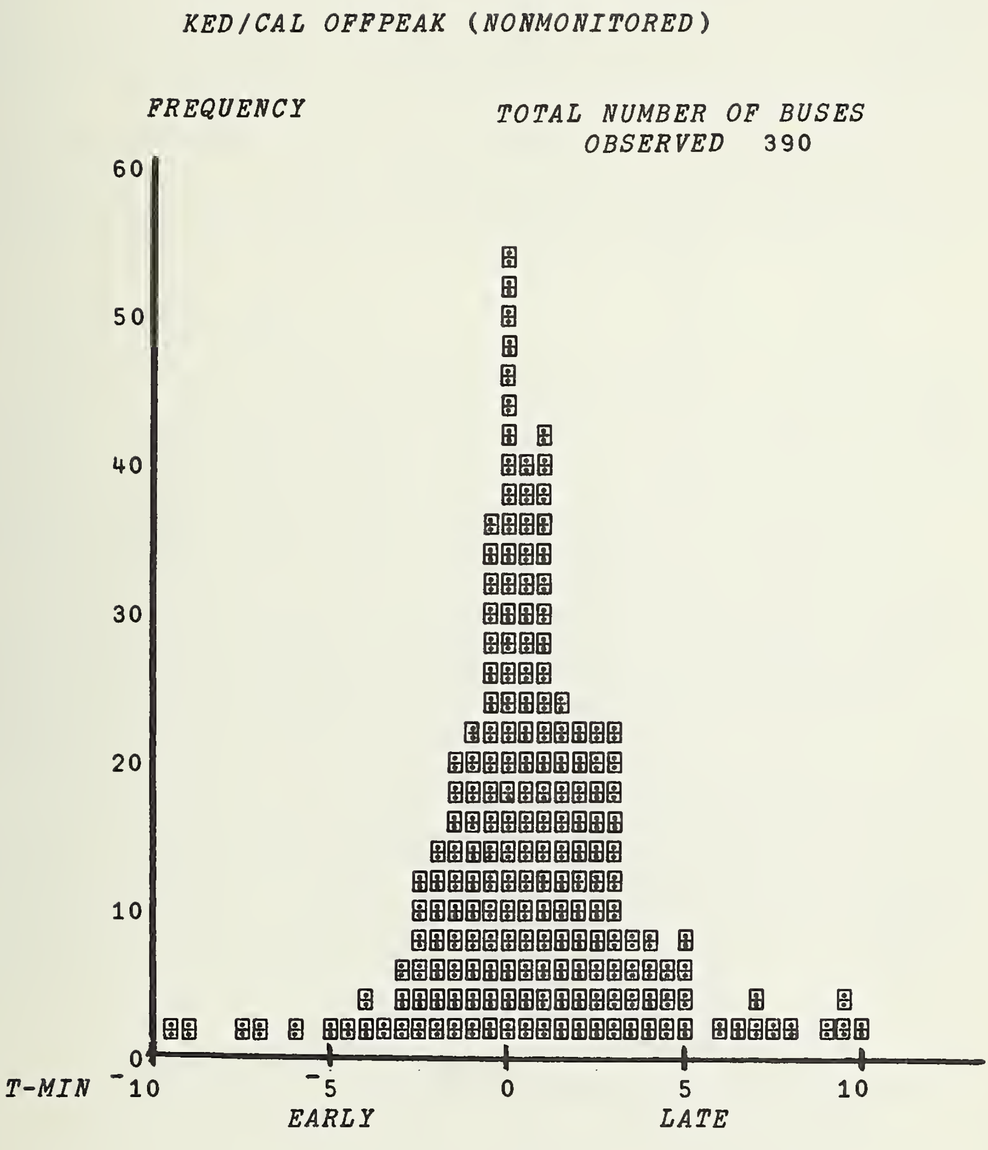


Figure 4-13 Schedule Adherence Ked/Cal Non-Monitored Offpeak

TABLE 4-2 SCHEDULE HEADWAY ADHERENCE DEVIATION

Time of Day	Route	Sample Size	Non-Monitor (minutes		Sample Size	Monitor (minutes)		% Mean Improvement	σ % Improvement	Statistic "T" Test[1] (the monitor test shows significant schedule adherence improvement over non-monitor test)
			$\bar{X}$	σ		$\bar{X}$	σ			
Peak	Vincennes	658	2.92	2.96	525	2.26	2.33	+21	+23	yes
	Skokie	650	2.72	4.10	459	2.53	3.05	+7	+24	no
	Ked/Cal	919	2.27	2.49	596	2.62	2.49	-13	0	no
Off Peak	Vincennes	227	4.66	4.25	277	4.23	4.59	+11	+7	no
	Skokie	196	2.36	2.80	113	1.87	1.94	+21	+32	no
	Ked/Cal	389	2.62	2.48	238	1.96	1.99	+23	+20	yes

[1] The confidence level is 95%.

the histograms by time and route are presented in Figures 4-14 - 4-25. The results of the "two tailed T" test at a 95% confidence level indicate that, as in the schedule adherence test, significant improvement of schedule adherence due to a monitor system was observed in only two of the six tests. However, both mean and standard deviation improvement was observed in three of the remaining four tests which may be attributed to the monitor system.

To conclude, the test indicated that the monitor system performs generally as well, although not significantly better, than the non-monitored system in improving headway adherence.

4.4 RECOMMENDATIONS

Since these tests showed that the monitor system does not, in general, improve schedule and headway adherence (due to the above three or other unknown factors), further tests should be conducted to determine that the CTA-Monitor system does in fact improve schedule and headway adherence.

To eliminate the bias introduced during the non-monitor tests, either non-CTA personnel should be hired to collect data, or data collection periods should be shortened to one-half hour and CTA personnel continue to be used.

Future tests should be conducted during different periods of the year in order to determine if the time of the year influences schedule adherence. Also, before any future tests are made, the operational deficiencies, as discussed in Section 3, should be corrected.

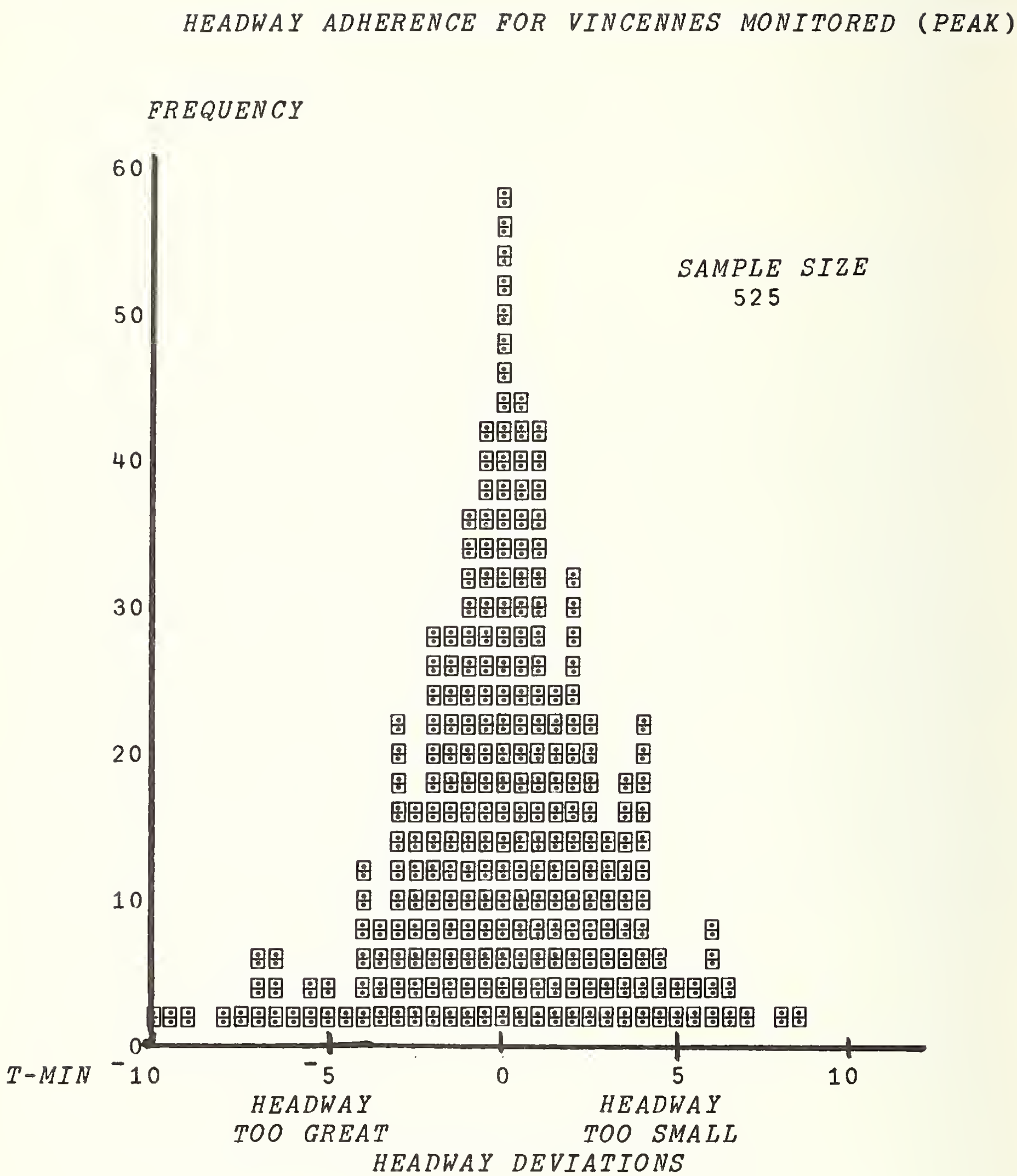


Figure 4-14 Headway Adherence Vincennes Monitored Peak

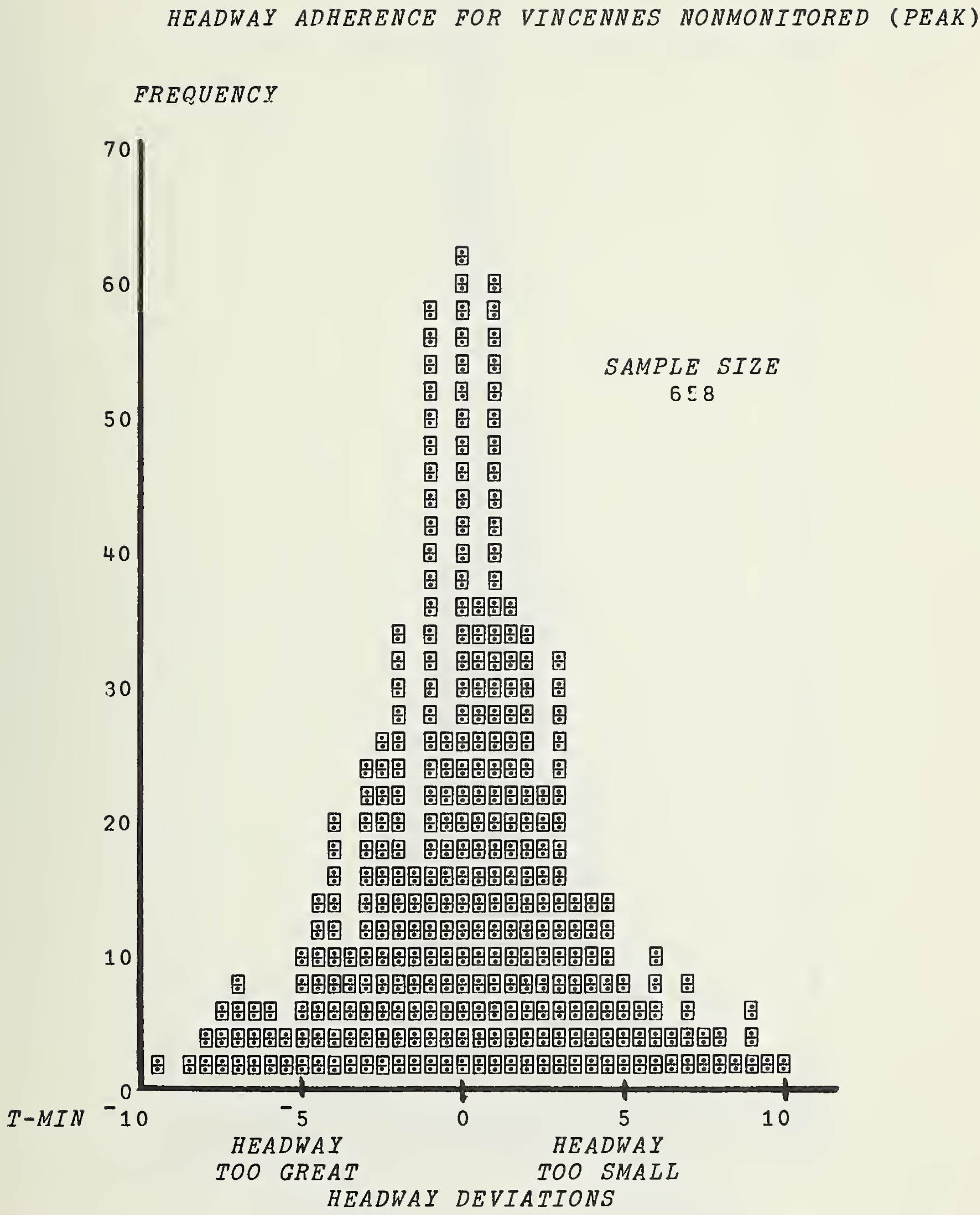


Figure 4-15 Headway Adherence Vincennes Non-Monitored Peak

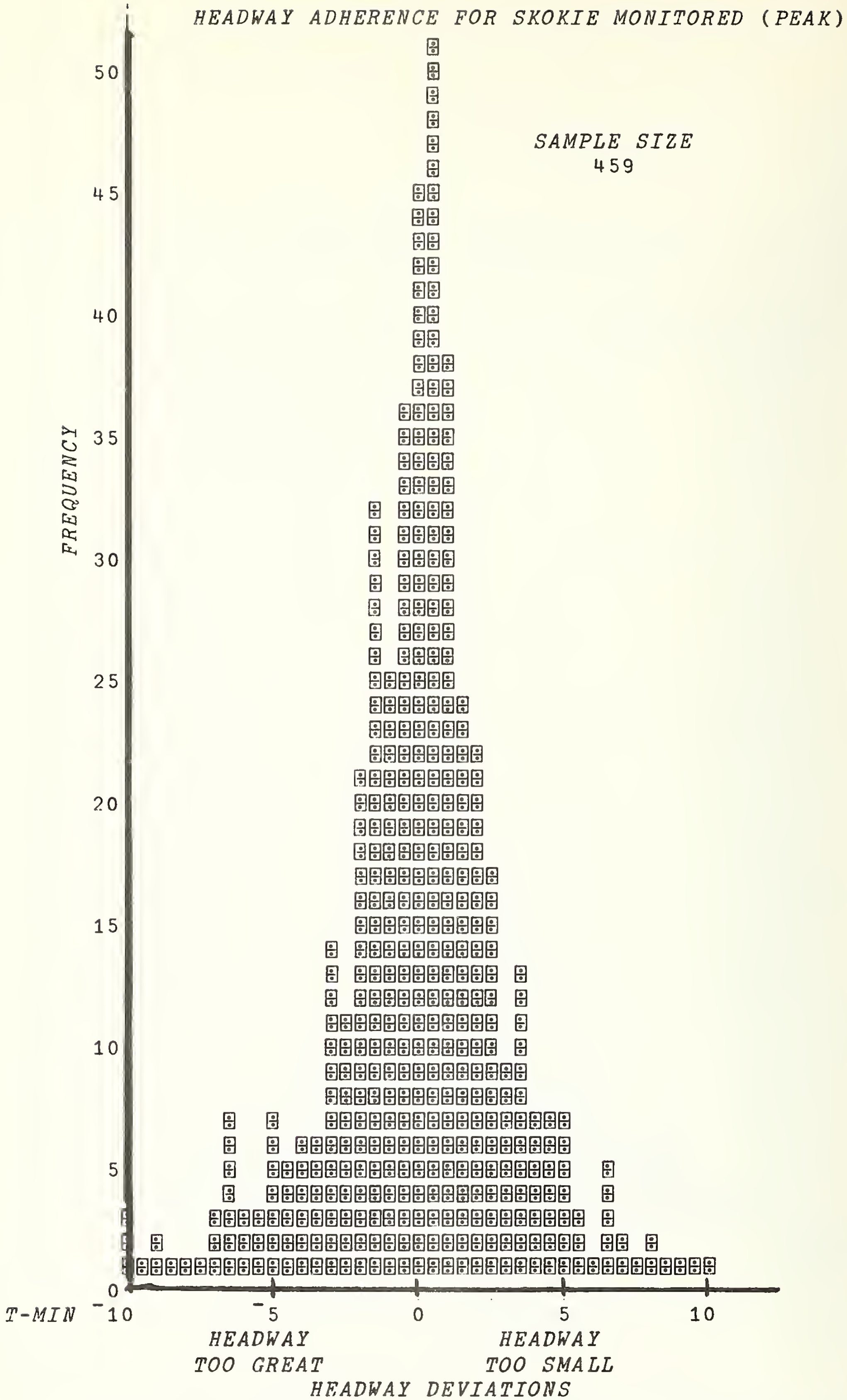


Figure 4-16 Headway Adherence Skokie Monitored Peak

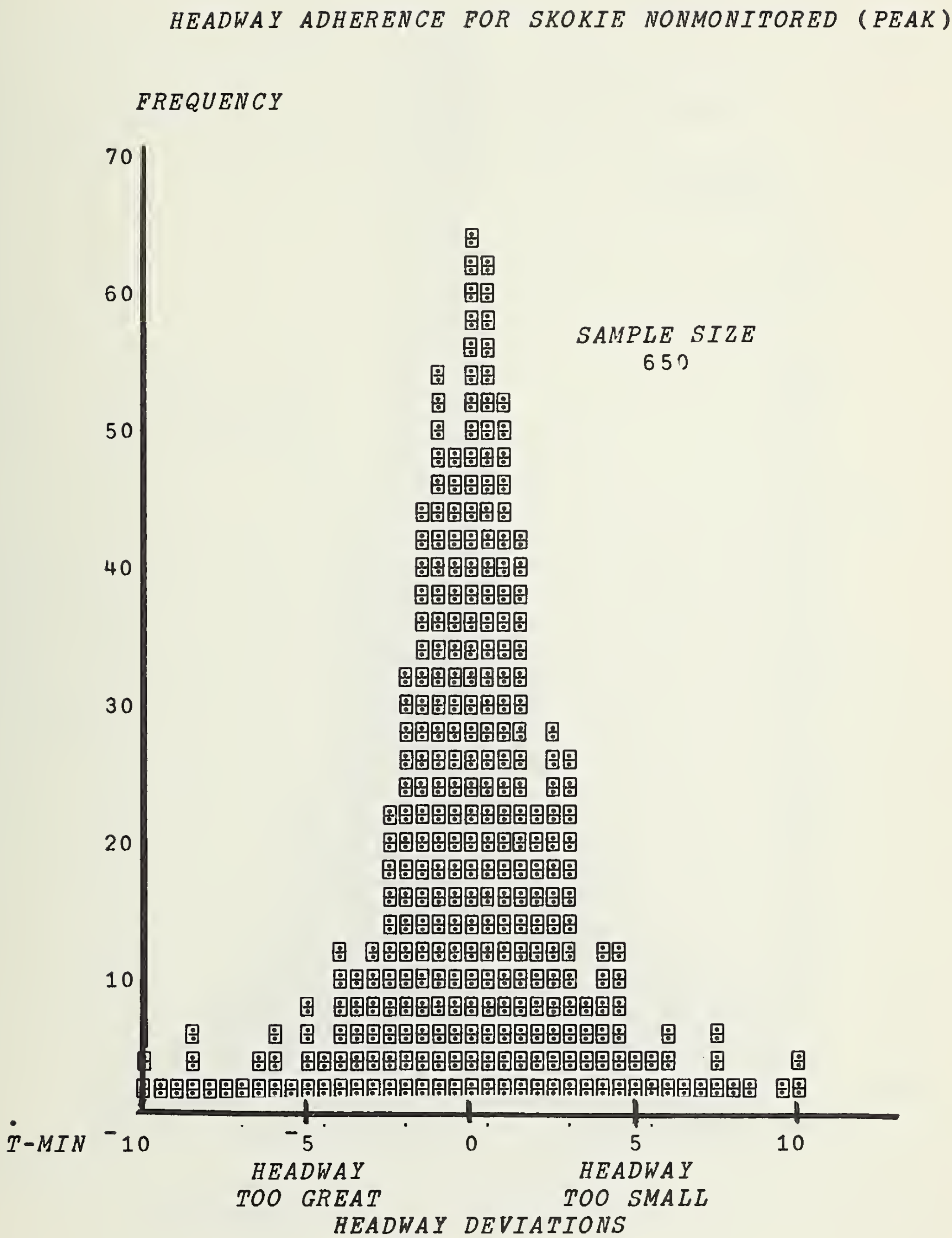


Figure 4-17 Headway Adherence Skokie Non-Monitored Peak

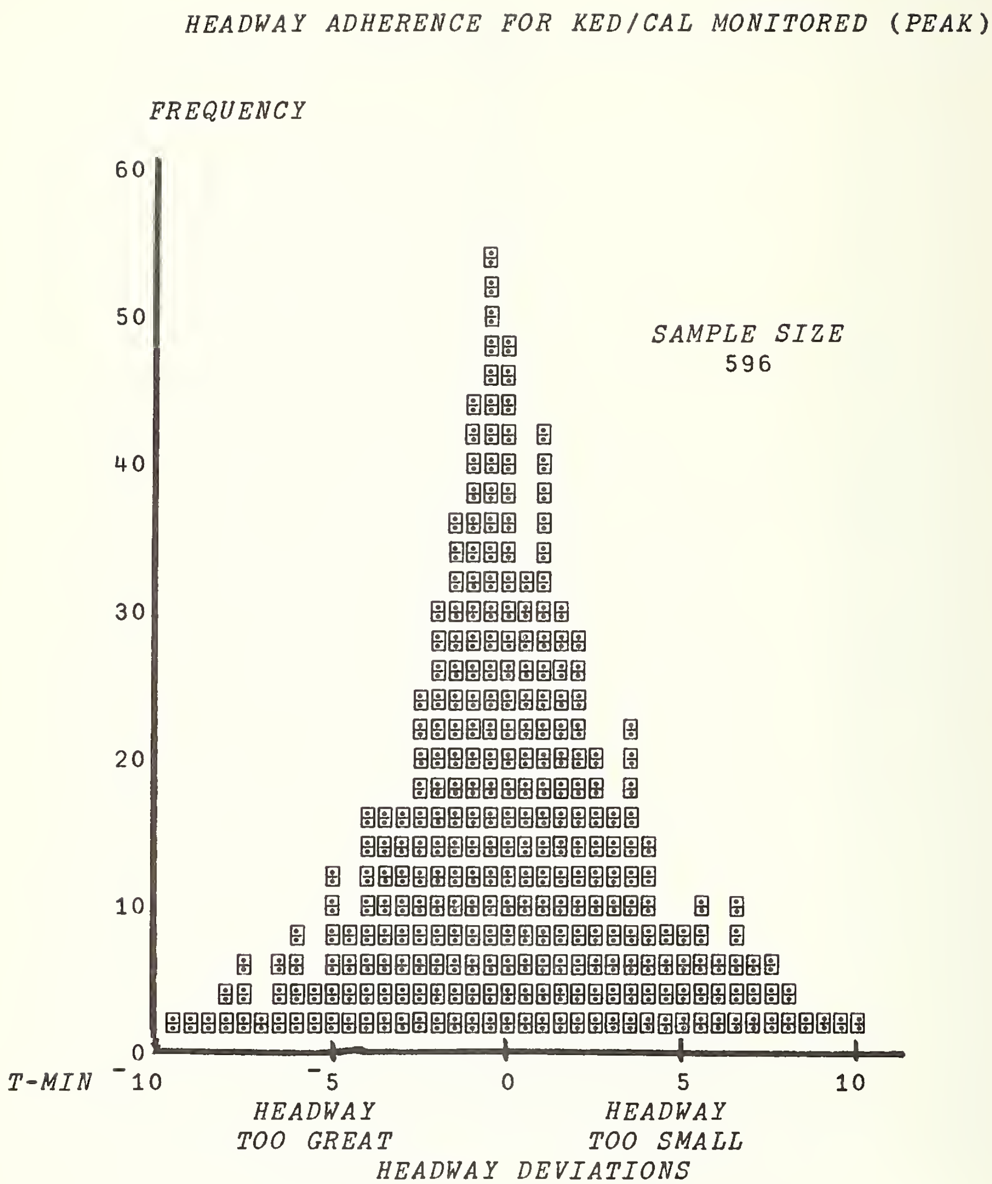


Figure 4-18 Headway Adherence Ked/Cal Monitored Peak

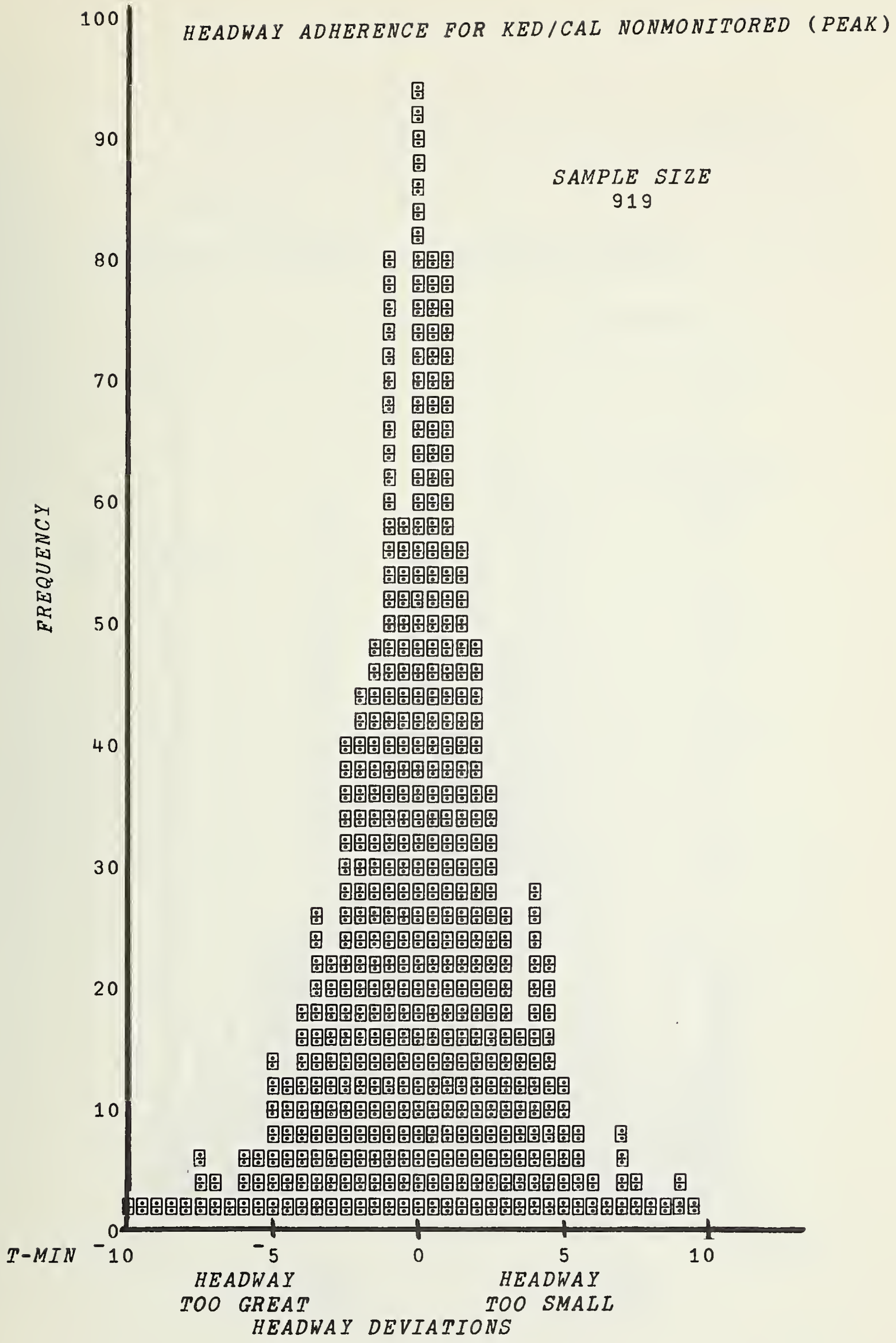


Figure 4-19 Headway Adherence Ked/Cal Non-Monitored Peak

Figure 4-20 Headway Adherence Vincennes Monitored Offpeak

Figure 4-21 Headway Adherence Vincennes Non-Monitored Offpeak

Figure 4-22 Headway Adherence Skokie Monitored Offpeak

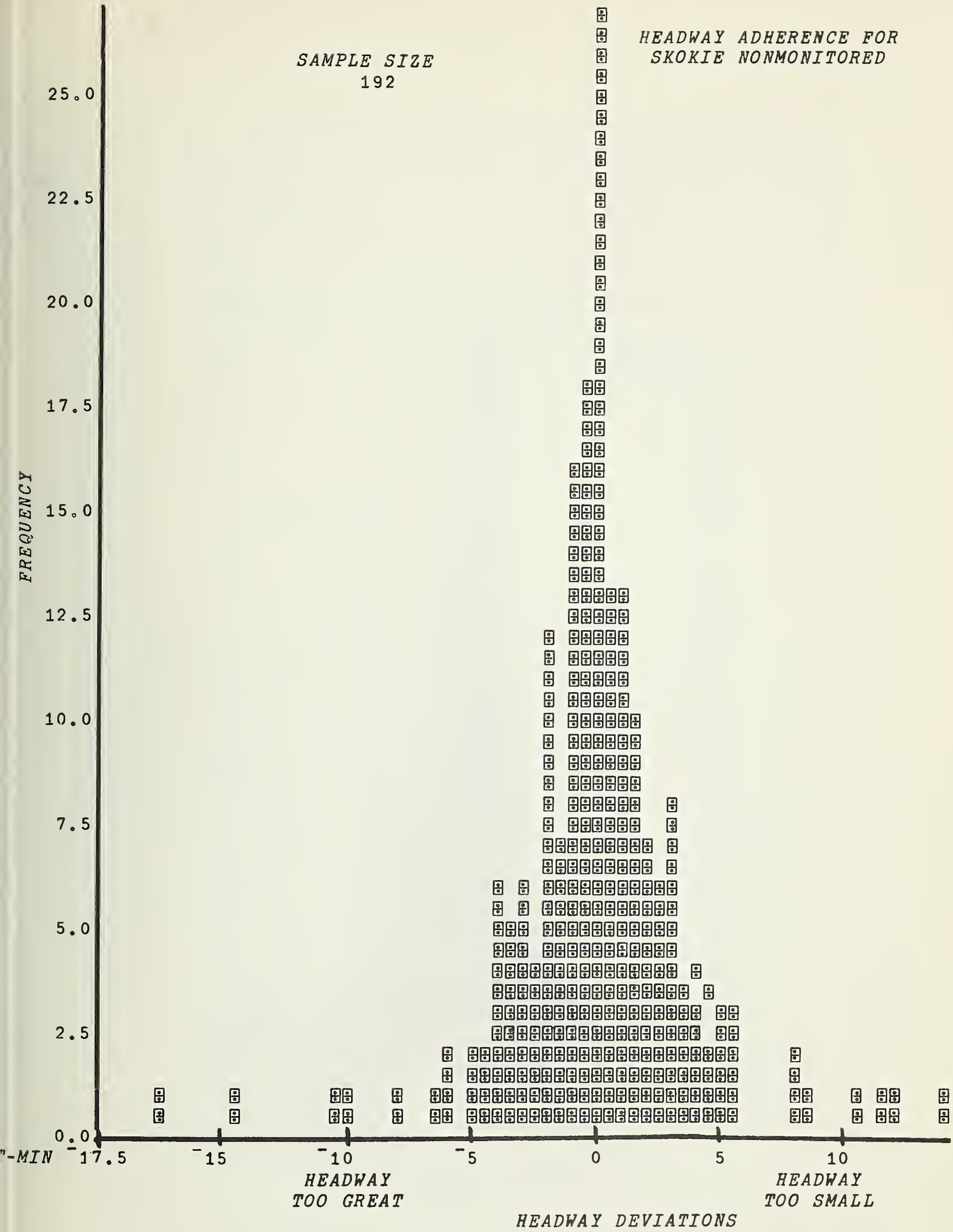


Figure 4-23 Headway Adherence Skokie Non-Monitored Offpeak

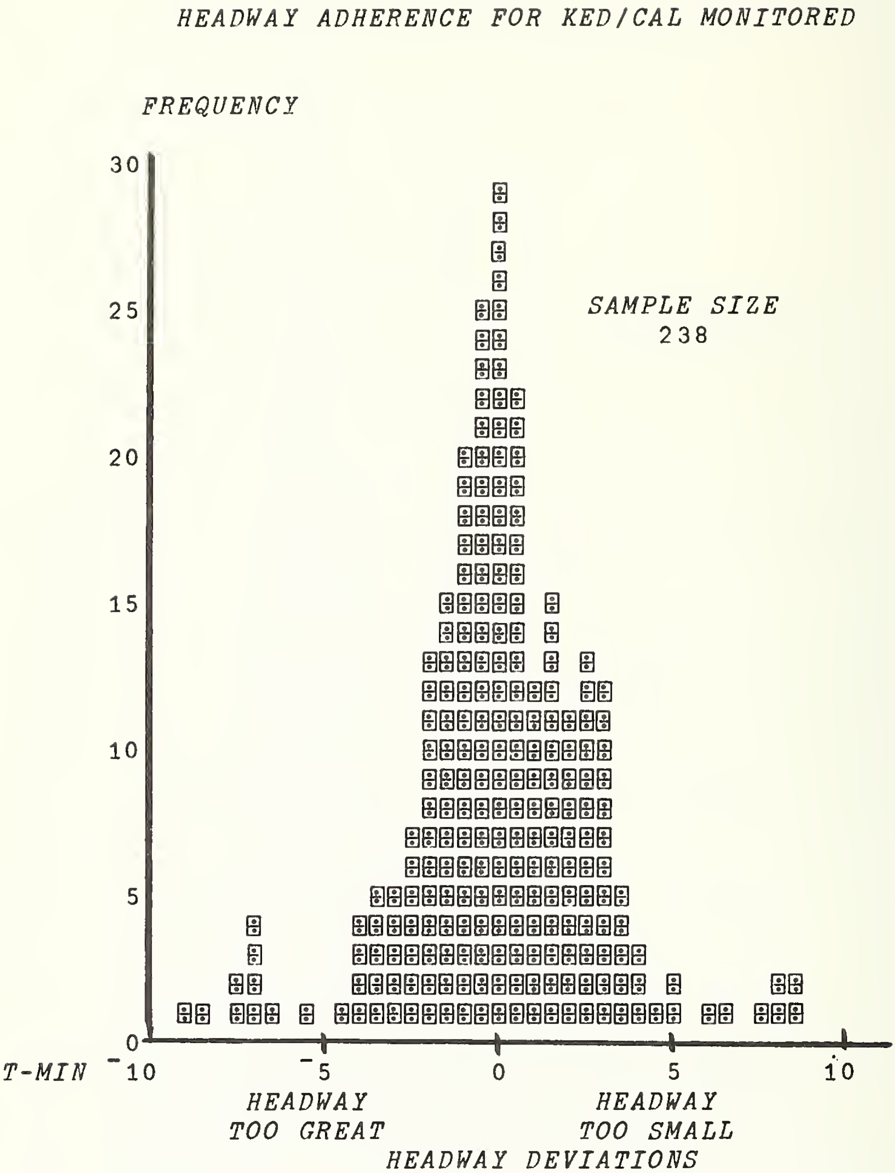


Figure 4-24 Headway Adherence Ked/Cal Monitored Offpeak

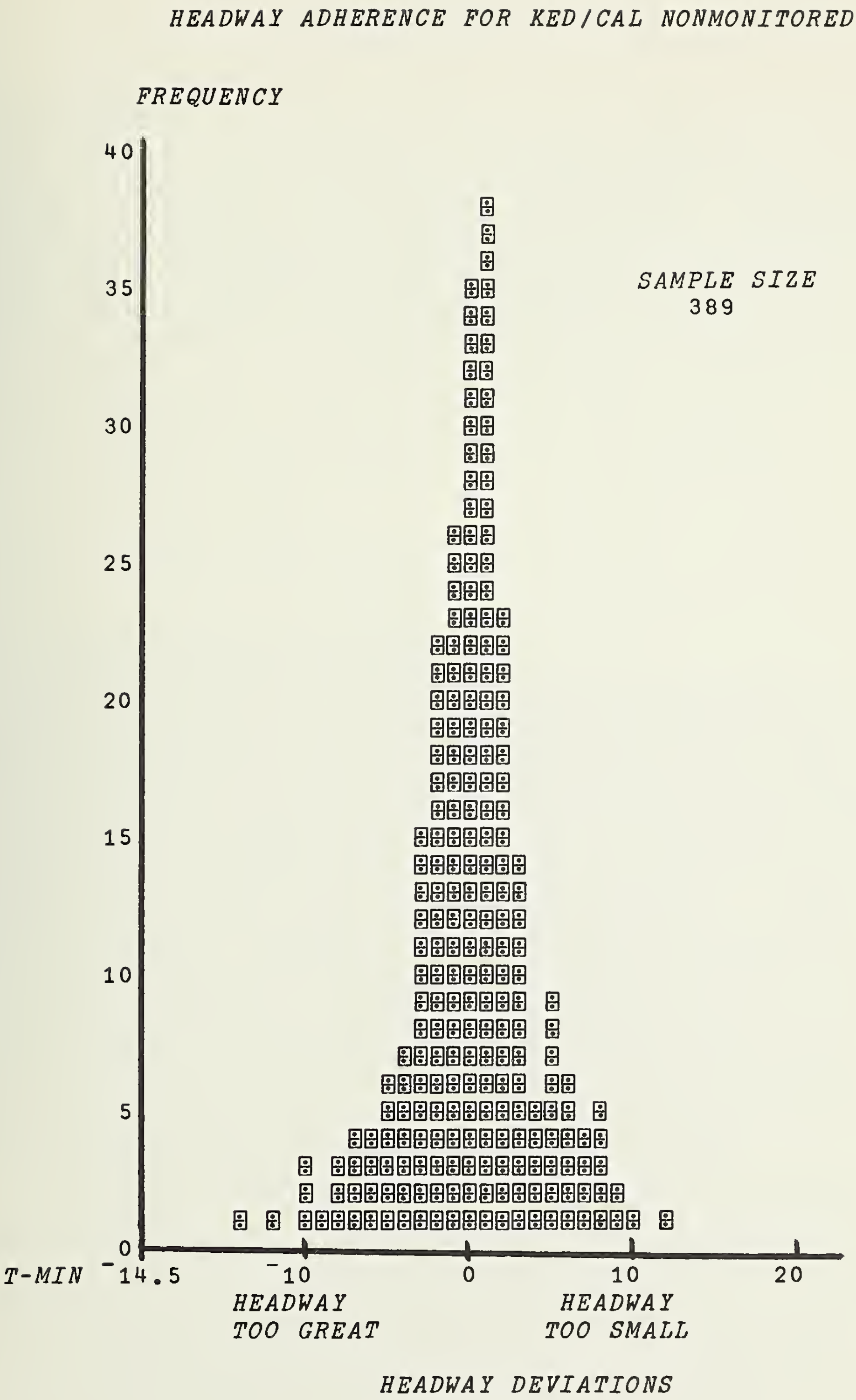


Figure 4-25 Headway Adherence Ked/Cal Non-Monitored Offpeak

5. SYSTEM ACCURACY TEST

5.1 BACKGROUND

The time that a bus passes a signpost is the basic measure of schedule adherence in the Monitor-CTA system. Therefore, it is of primary importance to know the accuracy with which the system is able to compute the signpost passing time. At least four sources of error occur in calculating the bus passing time:

1) Elapse Time Clock Error

2) Signpost Range Error

3) Software Error

4) Computer Clock Error

5.1.1 Elapse Time Clock Error

This error is due to either an electronic failure in the bus receiver-transmitter's elapse time clock and/or an elapse time error. If a bus enters the effective range of the signpost and the clock does not recycle to zero, or if a bus leaves the signpost range and the clock does not start, or if the clock intermittently starts and stops, errors between $-372 < \epsilon < +372$ (sec) or larger can occur. Further, if the clock is counting time too fast or too slow (the clock counts in 12 second intervals), system accuracy errors will also occur. Information supplied by the CTA indicates that in the past the clocks which did not keep time correctly were running too fast, thereby causing the monitor system to calculate the bus time point arrival too early.

An error of -12 to 0 seconds (a negative sign indicates the monitor calculated bus arrival time as later than the actual arrival time) occurs when a bus is interrogated by the central computer within 12 seconds after having left the signpost range. Although the clock starts the instant the bus leaves the effective signpost range, not until 12 seconds after leaving the range will the elapse time clock have registered a count of one. In addition, when the bus is more than 12 seconds out of the signpost range, an elapse time error occurs. This error occurs because the clock counts time in 12 second intervals. For example, a count of one indicates an actual time of between 12 to 24 seconds. Therefore, up to a 12 second error can occur. To compensate for this type of error, the computer is programmed to add 6 seconds to the elapse time, thereby decreasing the elapse time error $-6 < \epsilon < +6$ (sec).

5.1.2 Signpost Range Error

The second source of error is due to signpost range. To the computer, the bus appears to be at the signpost from the time it enters the effective range until 12 seconds after leaving its range. A test was conducted to determine the signpost range; the results of the test are presented in Appendix C. Results of this test indicate that if the bus is interrogated when it is within the signpost range an average error of $-23 < \epsilon < +23$ seconds can occur. In addition, when the bus is at least 12 seconds outside the effective signpost range i.e., the bus receiver-transmitter's elapse time clock contains a count of one or greater, an automatic average error of -23 sec. occurs.

5.1.3 Computer Software Error

This error is caused by at least two factors: (1) signpost location and (2) the inability of the central computer at certain times to know when a bus changes route direction at the terminal area.

The first software error is due to the location of the signpost and its relation to the nearest time point. The bus schedule is given for arrival times at the preselected time points and not the signposts. In many cases, it is impractical to place signposts at a time point; hence, signposts may be located up to a block away from the closest time point. In this case, a bus arriving at a time point correctly (time-wise) from one direction will appear late to the computer, while arrival from the other direction correctly on time, the bus would indicate an early arrival. This mean system accuracy error is generally equal to zero (the errors are of equal magnitude but of opposite sign); however, the system accuracy variance is not zero. This type of error can be corrected by modifications of the computer software.

The computer is programmed to change a bus' direction depending on the schedule terminal departure time and on information received from the route's last signpost. Due to several factors such as the computer receiving no replies from a bus passing the last route signpost, system accuracy errors can occur.

Information supplied to TSC from the CTA indicates that possibly other software errors exist; however, at this time, they have not been identified.

5.1.4 Computer Clock Error

Finally, the last source of error is due to an entry of the incorrect time into the computer. The monitor bus arrival time is calculated by the computer as follows:

CAL = (COMP - (CLOCK X 12) + 6)

where

CAL = calculated bus arrival time

COMP = computer time

(CLOCK X 12) = time as given by the elapse time counter (seconds)

Upon initializing the computer clock, two errors can occur: The first error is due to an incorrect wall clock time; the other error is due to the computer operator entering the time into the computer to the nearest minute. Combined, these errors could produce system accuracy errors of between ± 60 seconds, although greater errors are possible. For this test, an entry error of +20 seconds (early) was detected.

5.1.5 Error Summary

Table 5-1 presents a summary of the four sources of system accuracy errors:

TABLE 5-1 SYSTEM ACCURACY ERROR

Type of Error	Range of Error (sec)	Average or Known Error (sec)
1. Elapse Time Clock		
A. Electronic Failure	$-372 \leq \epsilon \leq +372$	Unknown
B. "0" in Register	$-12 \leq \epsilon \leq 0$	~ 0
C. Elapse Time	$-6 \leq \epsilon \leq +6$	0
2. Signpost Range		
A. Inside Range (ave)	$-23 \leq \epsilon \leq +23$	0
B. Outside Range (ave)	-23	-23
		Total -20*
3. Software		
A. Bus Direction	Unknown	Unknown
B. Signpost Time Point	$-20 \leq \epsilon \leq +20$	0
4. Computer	$-60 \leq \epsilon \leq +60$	+20
		Total 0 ± unknown

*Assumes that bus is outside of signpost range 90% of time.

The above table shows that on the average there is a known built-in system accuracy error of 0 seconds. In order to estimate the total system accuracy, a test was conducted in which comparisons of actual bus arrival times with monitor system calculated arrival times were made.

5.2 TEST PROCEDURES

System accuracy for a bus passing a signpost is defined as the actual bus arrival time minus the monitor system calculated arrival time. The actual bus arrival time data was collected by the time checkers during the monitor part of the schedule and headway adherence tests (see Section 4). At the time this data was manually being collected, the central computer was interrogating the monitor buses for arrival time information. This data was stored at the CTA on paper tape. The tape was then mailed to TSC and run through a computer paper tape reader which sorted the data by signpost locations. The monitor data points were then manually matched to the corresponding manual collected data points and inputed onto a third disc of an IBM 370-155 computer. The raw data was inputed into the "computer error program" to eliminate typographical errors. The refined data was sorted by particular parameters; and system accuracy statistics were then generated using the "statistics data reduction" routines developed by TSC.

5.3 RESULTS AND CONCLUSIONS

The results of the test are presented in the Figure 5-1 histogram. The precise cause of the +30 second mean system accuracy error cannot be pinpointed. The standard deviation of 1.63 minutes indicates that at least 95% (2σ) of all test buses exhibited system accuracy within +3.8 to -2.7 minutes. Reviewing Table 5-1, only two known sources of error, electronic failure of elapse time clock and software, could contribute to the value of σ.

5.4 RECOMMENDATIONS

In order to judge whether the system accuracy error calculated during the test is close to the minimum tolerence imposed by the system design, an estimate of the minimum possible system error was made (using the data presented in Table 5-1 as a guide) and is presented in Table 5-2. System accuracy errors were estimated for both an ideal system (all equipment software, operations are assumed

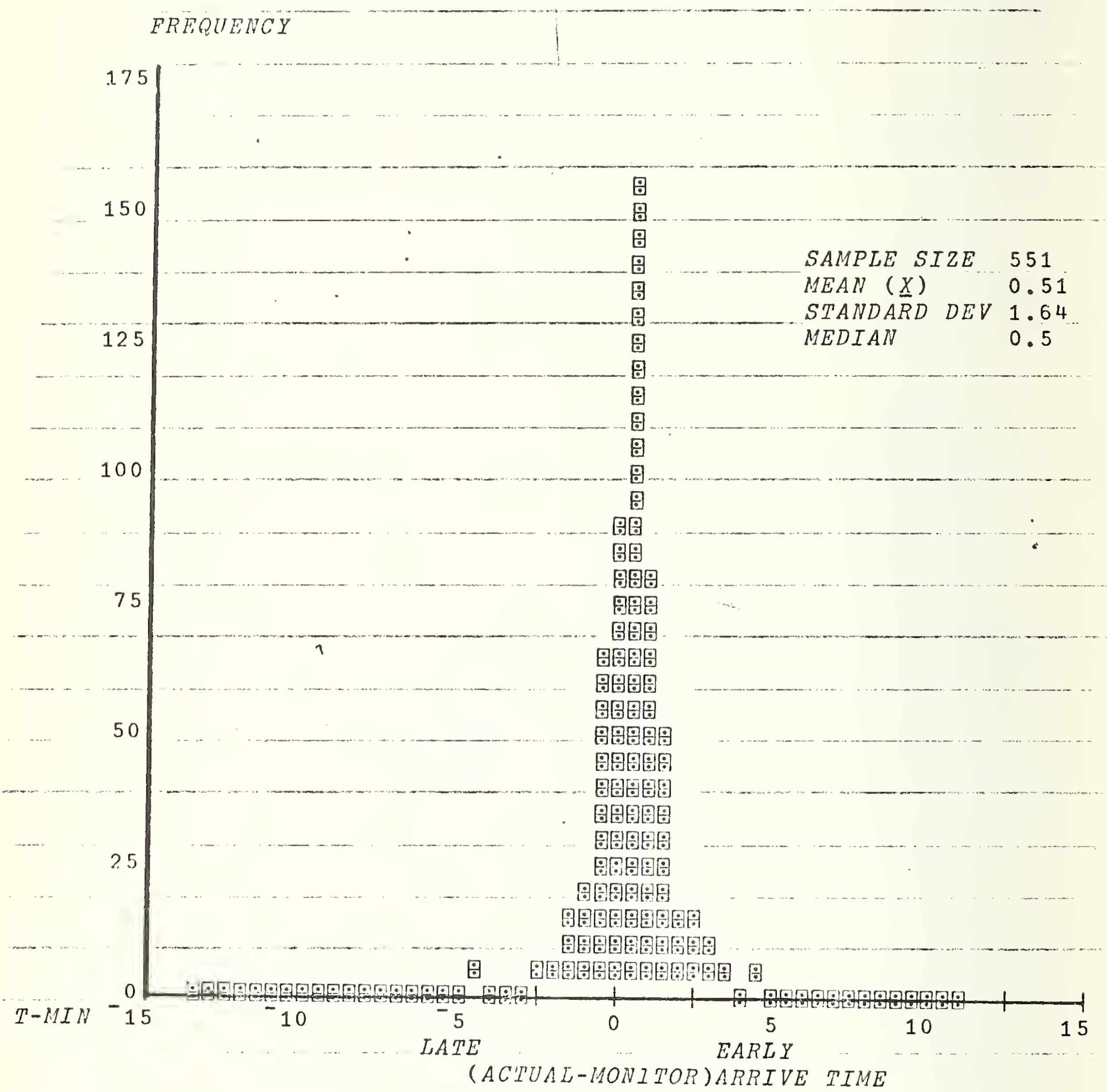


Figure 5.1 System Accuracy Test (Histogram)

to be perfect) and a realistic (the system from an engineering and operational viewpoint can never be perfect) CTA monitoring system. An estimate of the probability of these errors occuring is also presented.

The realistic system's mean error is approximately equal to zero, with a range of ± 18 seconds. Comparing these results with the system accuracy error observed during the test, the existing accuracy error was found to be too large. In order to reduce the present accuracy error, it appears that modifications of the existing software must be made and the problems associated with failures of the elapse time clock must be corrected.

TABLE 5-2 MONITOR-CTA SYSTEM ACCURACY TOLERANCE

Type of Error	"Ideal" Error		"Realistic" Error	
	Range(sec)	Probability of Occurance %	Range(sec)	Probability of Occurance %
1. Elapse Time Clock				
A. Electronic Failure	0	-	$-12 \leq \epsilon \leq +12$	~ 1
B. "0" in Register	$-12 < \epsilon \leq 0$	~ 1	$-12 < \epsilon \leq 0$	~ 1
C. Elapse Time	$-6 < \epsilon < +6$	100	$-6 < \epsilon < +6$	100
2. Signpost Range	$-6 \leq \epsilon \leq +6$	100	$-9 \leq \epsilon \leq +9$	100
3. Software				
A. Bus Direction	0	-	0	-
B. Signpost-Time-poing	0	-	0	-
4. Computer	0	-	$-10 < \epsilon \leq +10$	30
Estimated Average Range	$-12 \overset{+}{<} \epsilon < +12$		$-18 \overset{+}{<} \epsilon < +18$	

*Due to signpost receiver-transmitter threshold variance (see Appendix B).

6. SYSTEM RESPONSE EVALUATION

6.1 BACKGROUND

An important measure of performance of the CTA-Monitor System is the ability of the system to get back a valid reply when it initiates an interrogation. Figure 6-1 presents a schematic of the interrogation cycle. Every two minutes, the central computer sends an interrogation via a central radio transmitter to each operating monitor equipped bus ("A"). If the bus receiver-transmitter has a signpost stored in its memory, the receiver unit will respond to the computer's interrogation by sending a coded message, ("B") via a satellite receiver, back to the computer ("C"). (See Fig. 6-1.) The computer is programmed to analyze the message to determine if the response is valid.

If a bus has a high percentage of valid responses (number of valid responses ÷ total number of interrogations), the dispatcher will be continually receiving information concerning the bus identity and the updated time it passed the last signpost which will allow him to monitor the bus' progression along a route. However, if the bus' valid response rate is low (the bus is either not regularly replying to the interrogations or the replies are considered to be invalid by the computer), the dispatcher may or may not have enough data to effectively monitor and control the bus. Whether the dispatcher can effectively monitor and control buses with low valid response rates depends upon the sequence of the non-valid data returned to the computer. If the computer receives the non-valid data randomly, i.e., no two non-valid responses in a row, the dispatcher can in general effectively monitor and control the bus (although accuracy of the data and the dispatcher's time to control the bus may have diminished). The random non-valid replies are caused by either sporadic equipment failure and/or communication failures (a particular location on a route is blackened out due to the incoming interrogation not reaching the bus or the out-going reply not reaching the satellite radio receiver). On the other hand, if the computer receives non-valid data from a bus in a

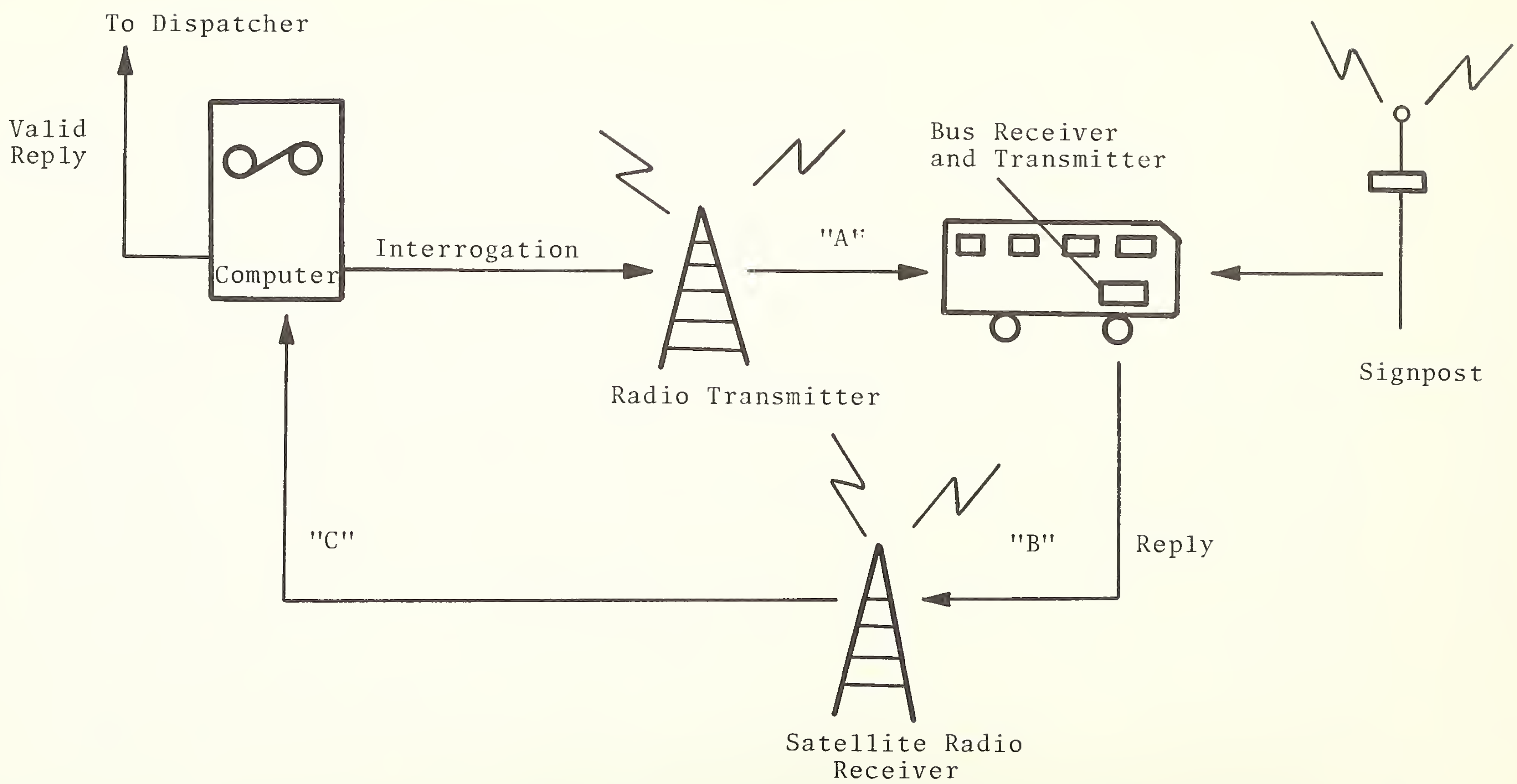


Figure 6-1 Bus Interrogation Cycle

"burst," i.e., two or more non valid responses in a row, the bus probably cannot be controlled by the dispatcher. For instance, if the bus traveling time between signposts is less than 12 minutes and if the computer receives 5 or 6 consecutive no replies from the same bus, the dispatcher will not have that data displayed on his monitor and therefore cannot determine the bus' location much less execute any bus control action. The burst non-valid replies are mainly caused by a failure of the receiver-transmitter unit or a failure of the communication equipment (main radio transmitter, satellite receiver.)[1] To conclude, buses operating with low response rates and in the burst mode cannot be effectively controlled.

An evaluation of the existing CTA-Monitor system was made to determine:

1) the system valid response rate

2) the cause of a low system valid response rate

3) the effect of this response rate on the system i.e., is the non valid reply occuring, on the average, in the random or burst mode.

6.2 TEST PROCEDURES

The CTA publishes a nightly summary of the valid and non-valid interrogations for those monitor equipped buses on the owl shift. A sample of data from the daily "Interrogation Summary" collected during July is presented in Figure 6-2. Interrogation data is provided for bus runs, routes, garages and bus system totals. The data provided by bus runs includes:

[1] A bus standing in an RF blackout area or a bus passing through two or more RF blackout areas can also cause a burst of non-valid replies.

ROUTE	NO. OF INTER.	BUS NO.		NO. OF REPLY / % REPLY	NO. OF CHANGES	NO. OF VALID REPLY / % VALID / % VALID/REPLY
ARCH	199	155	GARAGE 5	148/ 74%	32	146/ 73%/ 99%
ARCH	204	156	GARAGE 5	2/ 1%	1	2/ 1%/100%
ARCH	176	157	GARAGE 5	76/ 43%	41	56/ 32%/ 74%
ARCH	180	158	GARAGE 5	164/ 91%	10	155/ 86%/ 95%
ARCH	204	159	GARAGE 5	0/ 0%	0	0/ 0%/ 0%
ARCH	178	160	GARAGE 5	110/ 62%	10	103/ 58%/ 94%
ROUTE SUMMARY ARCH	1141			500 43%		462 40%
ARM	96	379	GARAGE 8	93/ 97%	2	89/ 93%/ 96%
ARM	69	380	GARAGE 8	52/ 75%	8	45/ 65%/ 87%
ROUTE SUMMARY ARM	165			145 87%		134 81%
ASH	158	438	GARAGE 4	103/ 65%	22	102/ 65%/ 99%
ASH	157	439	GARAGE 4	151/ 96%	6	145/ 92%/ 96%
ASH	150	440	GARAGE 4	124/ 83%	16	122/ 81%/ 98%
ASH	161	298	GARAGE 12	155/ 96%	4	153/ 95%/ 99%
ASH	191	299	GARAGE 12	185/ 97%	5	180/ 94%/ 97%
ASH	1[illegible]	300	GARAGE 12	2/ 1%	1	1/ 1%/ 50%
ROUTE SUMMARY ASH	979			720 73%		703 71%

Figure 6-2 Interrogation Summary (Example)

1) total number of times bus was interrogated by computer;
2) number of times bus replied;
3) number of times bus replied with valid data;
4) associated response rate percents;
5) number of times that data changed from valid response to non-valid.

This evaluation is based on the data contained in these interrogation summaries.

6.3 EVALUATION

6.3.1 System Response Rate

The totals for all buses operating on the owl shift during the month of July and a schematic of the resulting response rate percentages are shown in Table 6-1. As indicated in the Table 6-1B schematic, 48% of the computer interrogations were either invalid replies (6%) or no replies (42%). The cause of this high non-valid response rate and the significance to operational aspect of the system will be discussed in the next two sections.

6.3.2 Equipment

The 48% non-valid response rate (no replies + invalid replies) can be mainly attributed, as discussed previously, to three problem areas:

a) communication equipment failure
b) communication blackouts
c) bus receiver-transmitter equipment failure

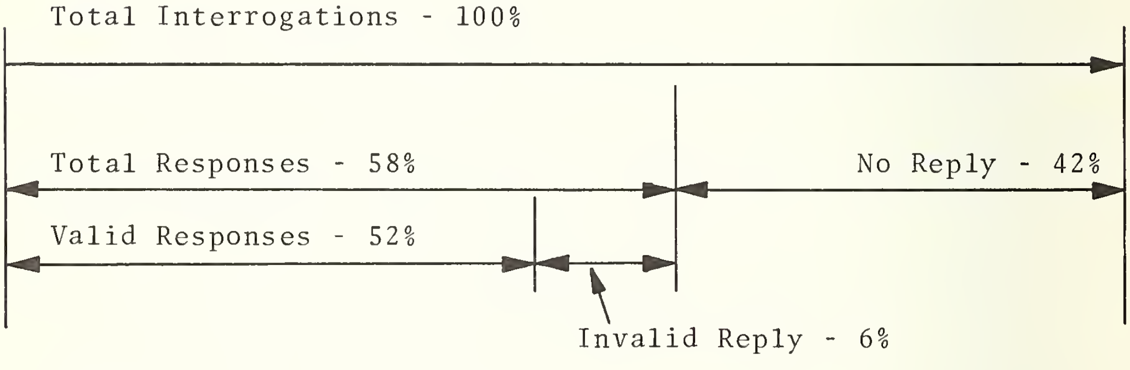
A sharp decrease in the daily ratio of valid response rates would indicate some type of communication equipment failure. The data plotted on Figure 6-3 indicates that no sharp decrease in the valid response rate occurred in July. Also, a recent test conducted by the CTA prime system contractor indicated that over 99% of the in-

TABLE 6-1 INTERROGATION SUMMARY

A. Interrogation Summary

No. of Test Days	Total No. of Computer Interrogations	Total No. of Bus Replies	Total No. of Valid Responses	Response Rate - % (2)/(1)	Valid Response Rate -% (3)/(1)
22	469,245	273,162	243,231	58	52

B. Percent Response Rate Schematic



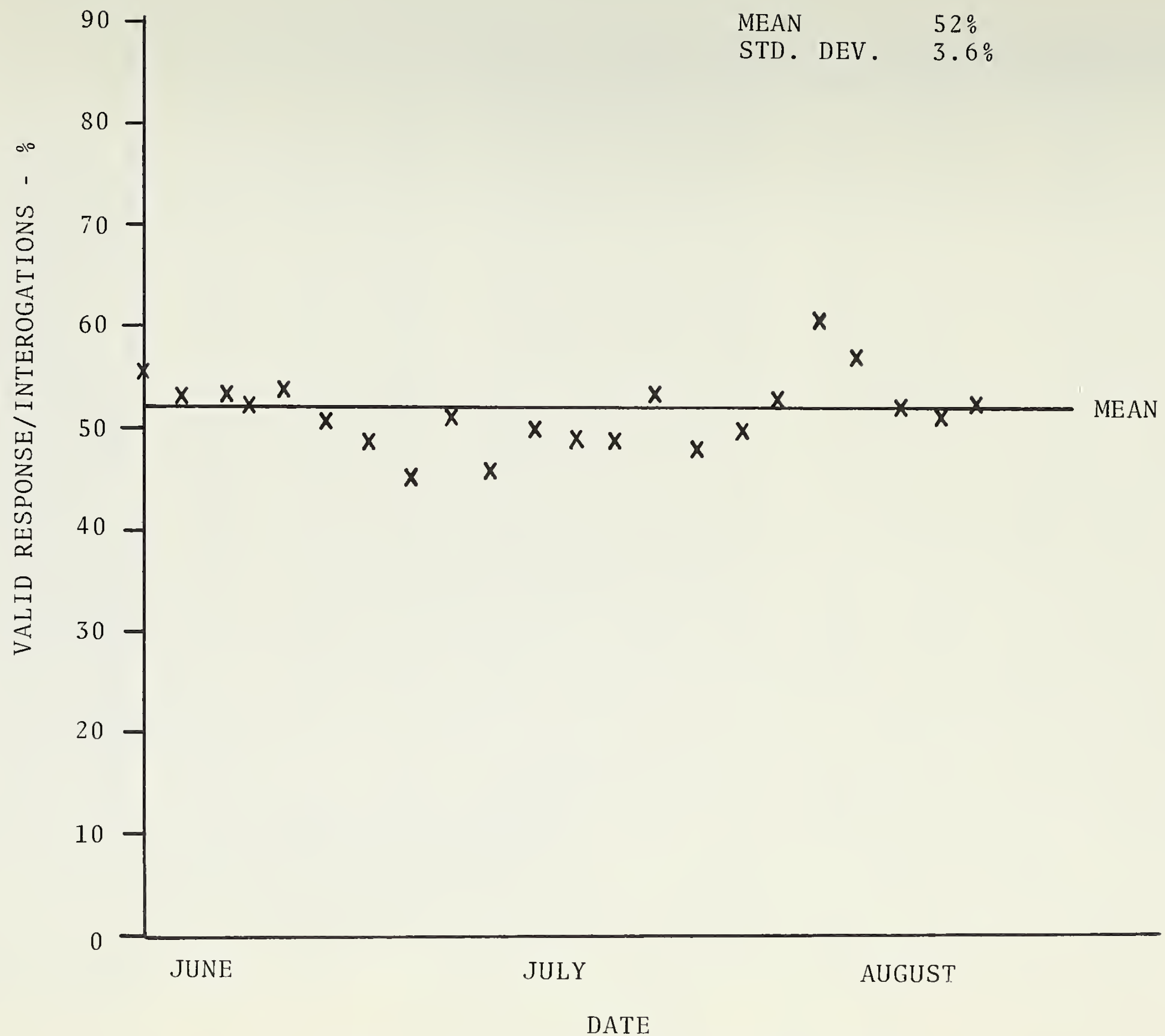


Figure 6-3 Daily Valid Response Rate

terrogations sent by the computer were received by the main transmitter and that over 99% of the replies received by the three satellite receivers from the buses were correctly sent back to the computer (see Appendix D). Therefore, a communication equipment failure between the computer, main transmitter and satellite stations can be eliminated as the cause for the high non-valid response rate. To determine which of the remaining two problem areas were the cause of the high rate, an analysis of the invalid reply (6%) and no reply (42%) data was made.

The 6% invalid reply rate data is due to errors contained in the coded message sent by the receiver-transmitter to the computer. Analysis of the data indicated that approximately 2% of this 6% is due to faulty signpost transmitters and the remaining 4% to a defective bus receiver-transmitter.

To determine what caused the 42% no reply rate, a sample of 724 bus runs were drawn from the July interrogation summaries. A histogram of the valid response rates for this sample is presented in Figure 6-4. Notice that the statistical "mode" (26%) occurs at the zero valid response rate. On the average, 26% of the "owl" monitor bus population is inoperative (zero valid response rate). Information supplied by the CTA (see Appendix E) indicated that of this 26% inoperative bus population that

1) approximately 2% of the 26% was attributable to the improper entry of the bus run number (a human error);
2) approximately 16% was due to bus receiver-transmitter failure;
3) the remaining 9% was attributed to either (1) or (2) above.

From Figure 6-4 histogram, one might expect that the bus receiver-transmitter failure could account for the other low response rates (5-30%), exhibited by 9% of the bus population; however, the interrogation summaries do not provide the needed detail to validate this hypothesis.

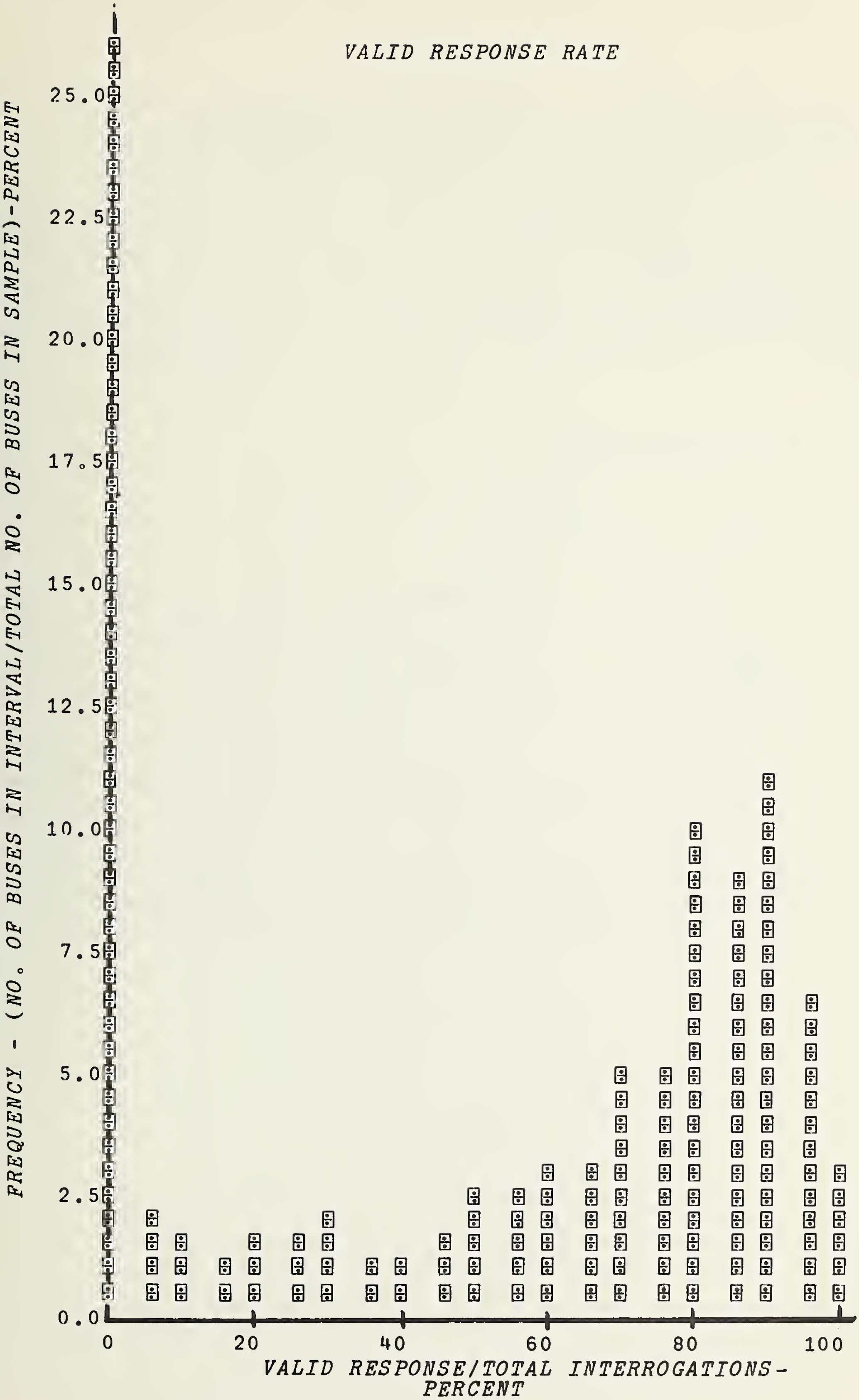


Figure 6-4 Valid Response Rate

Table 6-2 presents a summary of the analysis. At least 20% of the 48% non-valid responses can be attributed to failure of the monitor bus' receiver-transmitter units. Of the 15% caused by either bus receiver-transmitter failure or communication blackout, a sizable percentage may be due to communication blackout problems. TSC ran a series of tests using a Mobile Communication Test Van to uncover the problem associated with CTA monitor communication. The results of this investigation are discussed in Appendix D.

6.3.3 Random and Burst Mode

The data in the interrogation summaries does not provide detailed information on whether the computer receives random or burst no replies from the buses. However, by dividing a particular bus' total nightly no replies by the number of changes of state (the number of times a bus' valid data changes to no reply data), an average number of no replies in the burst mode can be determined. This ratio must be used carefully, because the burst rate is an average. For instance, if a bus had 100 no replies and 50 changes of state, the average length of no replies is 2; however, the maximum number could conceivably be equal to 51 no replies in one burst.

A sample of 100 buses was drawn from the interrogation summaries in order to determine the average length of consecutive no replies. The results of the analysis are presented in Table 6-3.

TABLE 6-2 BREAKDOWN OF THE 48% NON-VALID RESPONSE RATE BY EQUIPMENT FAILURE TYPE

Type of Equipment	% of Total Non-Valid Response Rate (48%)	
Signpost Transmitter	2	
Bus Receiver-Transmitter (4% + 16%)	20	
Bus Receiver-Transmitter and/or Wrong Run Number Entry	9	
Non-Equipment (Human Error)	2	
		33
Bus Receiver-Transmitter and/or Communication Blackout (48% - 33%)	15	
	48	

TABLE 6-3 AVERAGE NUMBER OF CONSECUTIVE NO REPLIES IN A BURST

No. of Buses	Average Response Rate - %	Average Number of Bursts Per Night	Average Number of No Replies in a Burst
49	85	15	1 to 2
18	58	10	3 to 10
33	4	15	> 10

33% of the sample bus population had an average response rate of 4% and failed to reply nightly at least 15 times for at least 10 consecutive interrogations. In effect, at least 33% of the monitor bus population could not be controlled at any time during the night by the dispatcher. 49% of the sample bus population failed to reply at least 15 times during the night; however, each failure resulted only in a average burst of 1 to 2 no replies. Therefore, at least 49% of the monitor bus population could be effectively controlled by the dispatcher. Finally, 18% of the sample bus population failed to reply at least 10 times for an average of 6.5 consecutive interrogations. The dispatcher's ability to initiate schedule adherence control over these buses during certain periods of time was diminished.

To conclude, the ability of the dispatcher to exercise effective control over the existing bus monitor population is in doubt.

6.4 RECOMMENDATIONS

In order to significantly upgrade the existing system, the deficiencies associated with the bus-receiver-transmitter units must be corrected. This step will not only have the obvious benefit of increasing the system valid response rate but also significantly decrease the average burst length of no replies. To determine the minimum system valid response rate that is required to make the existing system and proposed expanded system operational is beyond the scope of this effort; however, an analysis was done to estimate an order of magnitude range for a minimum system valid response rate. The following assumptions were made:

1) For the ideal system, all no replies received by the computer are random. (When the present system deficiencies are corrected, the no-reply data should tend to occur randomly.)

2) Signposts are located one or two miles apart. (In the existing system, signposts are located on the average at least two miles apart. In the expanded system, signposts may be located approximately one mile apart.)

3) The probability of a monitor bus not replying N times in a row is

   $(1 - V)^N$ where V = average system valid response rate

4) For a one mile signpost system

   a. Two no replies in a row, once a bus enters the signpost range, are sufficient to prevent dispatcher control action.

   b. When two no replies do occur in a row, the probability based on the two minute polling rate that they occur as stated in (4a) above is 1/3.

5) For a two mile signpost system

   a. Four no replies in a row, once a bus enters the signpost range, are sufficient to prevent dispatcher control action.

   b. When four no replies do occur in a row, the probability that they occur as stated in (5a) above is 1/6.

6) All buses have the same response rate.

The results of the analysis are presented in Table 6-4.

TABLE 6-4 AVERAGE SYSTEM VALID RESPONSE RATE REQUIREMENTS

Average System Valid Response Rate - %	Probability that at a Given Time a Monitor Bus Cannot be Controlled by the Dispatcher: For Signposts Located	
	One Mile Apart %	Two Miles Apart %
90	.3	0
80	1.3	0
70	3.0	.1
60	5.3	.4
50	8.3	1.0
40	12.0	2.2

The data shows that for the existing system, if the dispatcher is to control 99% of the bus population, the system valid response rate must be at least 50% (assuming no-replies occur randomly). For the expanded system, a valid response rate of between 80-90% would be necessary to assure effective bus control.

7. SYSTEM RELIABILITY

7.1 INTRODUCTION AND SUMMARY

The reliability of the Monitor-CTA system can be adversely affected if just one subsystem does not perform properly. Initial analysis of the subsystem reliability showed that, except for one subsystem-the bus' mobile unit, the reliability of the individual subsystems were good. However, due to the poor reliability of this one subsystem, the system as a whole cannot now be considered to be technically operational.

Initial analysis indicated that the reliability of the following subsystems was adequate at the time of the evaluation.

1) Computer hardware - Only five to six systems problems have developed since installation.

2) Computer software - The existing programs run reliability; however modification of present software, as noted in Section 3 and 5, is needed prior to implementation of the expanded system.

3) Consoles - No failures recorded - see operations sections for discussion.

4) Communication equipment

   a. Main transmitter and satellite receivers

   b. Land lines and data modems - initially a source of problems; however, they were corrected prior to the start of the evaluation.

   c. Signpost - Although 70 signposts were serviced from January through June, the work performed was primarily to adjust the level of RF power output; therefore, the signpost reliability can be considered to be good.

d. Mobile equipment (signpost receiver and a two-way voice/data unit) - Analysis of the interrogation summaries (Section 6) indicated the existence of a high rate of mobile equipment failure. The remainder of this section discusses this problem.

7.2 TEST PROCEDURES

In discussing the reliability and maintenance of the mobile equipment, prime consideration was given to the following:

1) Occurrences of failure

2) Time taken to repair equipment

3) Time that bad equipment remained on street

4) Loss of effectiveness due to inoperative equipment

5) Environmental effects on equipment

Data from the following sources was used in the analysis (examples of the data are presented in Appendix F).

a) Daily CTA shop records - listed by garage those buses with suspected bad mobile equipment. Records were not provided over weekends. The data contained in the shop records was inputed onto a disc on an IBM 370-155 computer. The data was then sorted by particular parameters and the appropriate reliability statistics were generated.

b) Reported bad timers records - data incomplete and not usable to determine failure rates; however, data was used to determine time which bad mobile units remained on street.

c) Computer log of failures of equipment - data recorded for the six-month period, January through June.

7.3 TEST RESULTS

The following statistics were generated from the data:

1) Failure record statistics (Table 7-1) - This table presents a summary of the results of the analysis.

2) Number of mobile equipment units in shop daily (Figure 7-1) - during the 45 day test period an average of 35.5 mobile units were in the shop each day. (Out of a total of 500 units.)

3) Length of time that equipment remained in shop (Figure 7-2) - This histogram shows that on the average a defective mobile unit remained in the shop for six days; however, six units were in the shop for at least 45 days.

4) Reliability Data

   a. by bus and fuel type (Table 7-2) - correlation between mobile unit failure and bus type and fuel type

   b. by garage (Table 7-3) - correlation between mobile unit failure and bus garage

7.4 CONCLUSIONS

The data clearly indicates that a high failure rate of the mobile equipment is occurring. The data presented in Table 7-1 shows that on the average an individual mobile unit fails every 80 days. This could be indicative of a design problem associated with the unit. Preliminary analysis indicates that a time counter in the mobile unit may be a large contributor to the failure rate; however, further analysis is required. Since no reliability specifications are available for this particular equipment, a ballpark estimate of the mean time between failure (MTBF) was made. It was determined that generally two-way radios, similar to those used in the mobile unit, have an MTBF of approximately two years. Even though the mobile unit used in the CTA system contains more components than a two-way radio, a ballpark estimate for the mobile unit's MTBF is one year. Repeating, this is an order of magnitude estimate only.

TABLE 7-1 MOBILE UNIT RELIABILITY SUMMARY
(DURING 45 DAY TEST PERIOD)

I. Failure Occurrences	Number of Units That Failed	Total Number of Failures
1. Number of units that failed one time	173	173
2. Number of units that failed two times	44	88
3. Number of units that failed three times	4	12
4. Number of units that failed four times	2	8
5. Total number of units that failed	223	
6. Total number of failures		281
7. Average number of unit failures per day (281 ÷ 45)		6.24 units/day
8. Average time between failure (24 ÷ 6.24)		3.84 hours/unit
9. Average time between failure of an individual unit [(3.84 X 500) ÷ 24]		80 days
II. Bus Population		
1. Average number of units in shop per day (see Figure 1)		35.5 units
2. Total number of buses which carry mobile units		500
3. Average % of bus population with mobile units in shop (due to electronic failures only)		7.1%
III. Other		
1. Average time to get defective unit off street into shop		4.8 days
2. Average shop time to repair a defective unit (Figure 7-2)		6.0 days

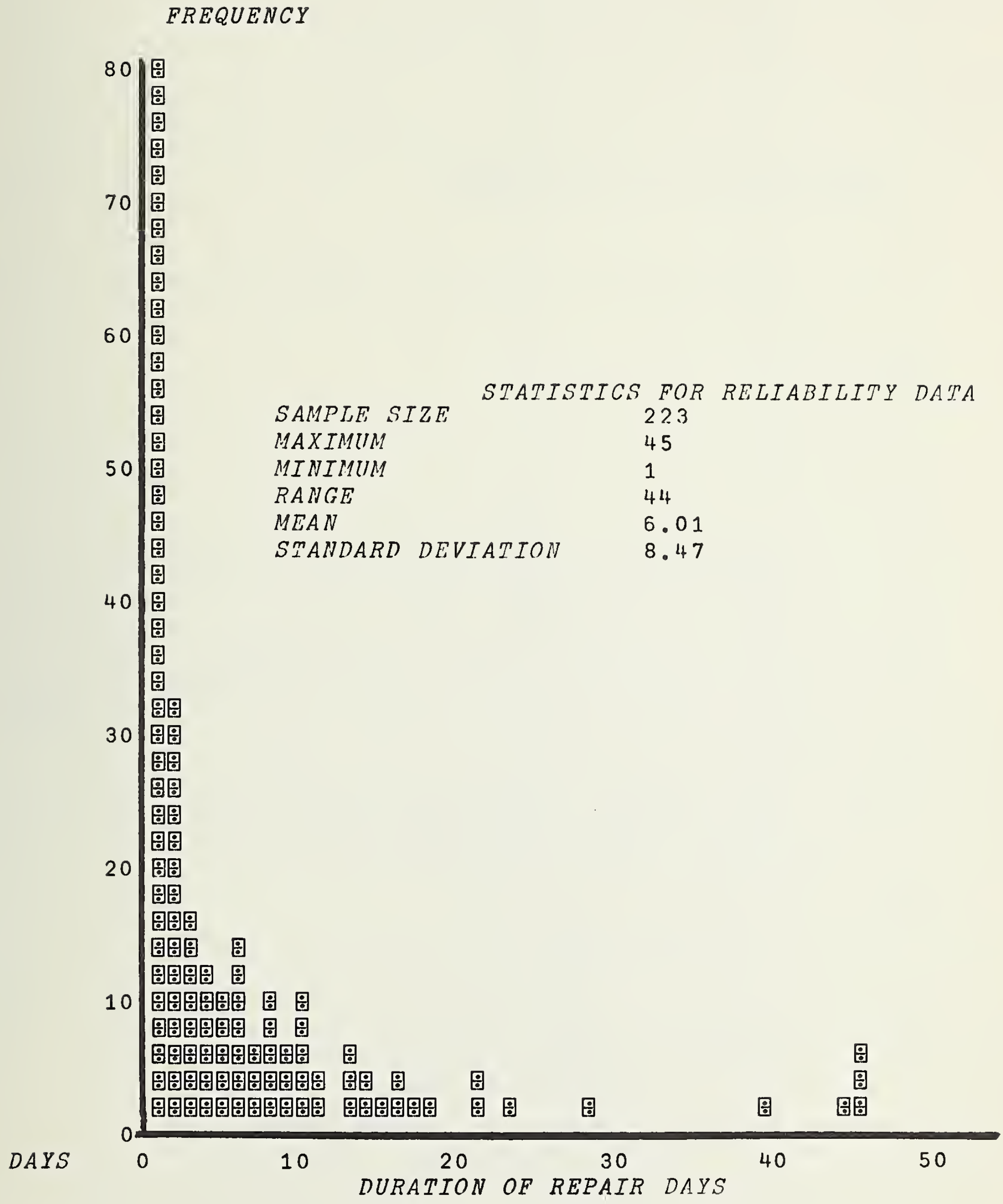


Figure 7-1 Bus Time In Shop

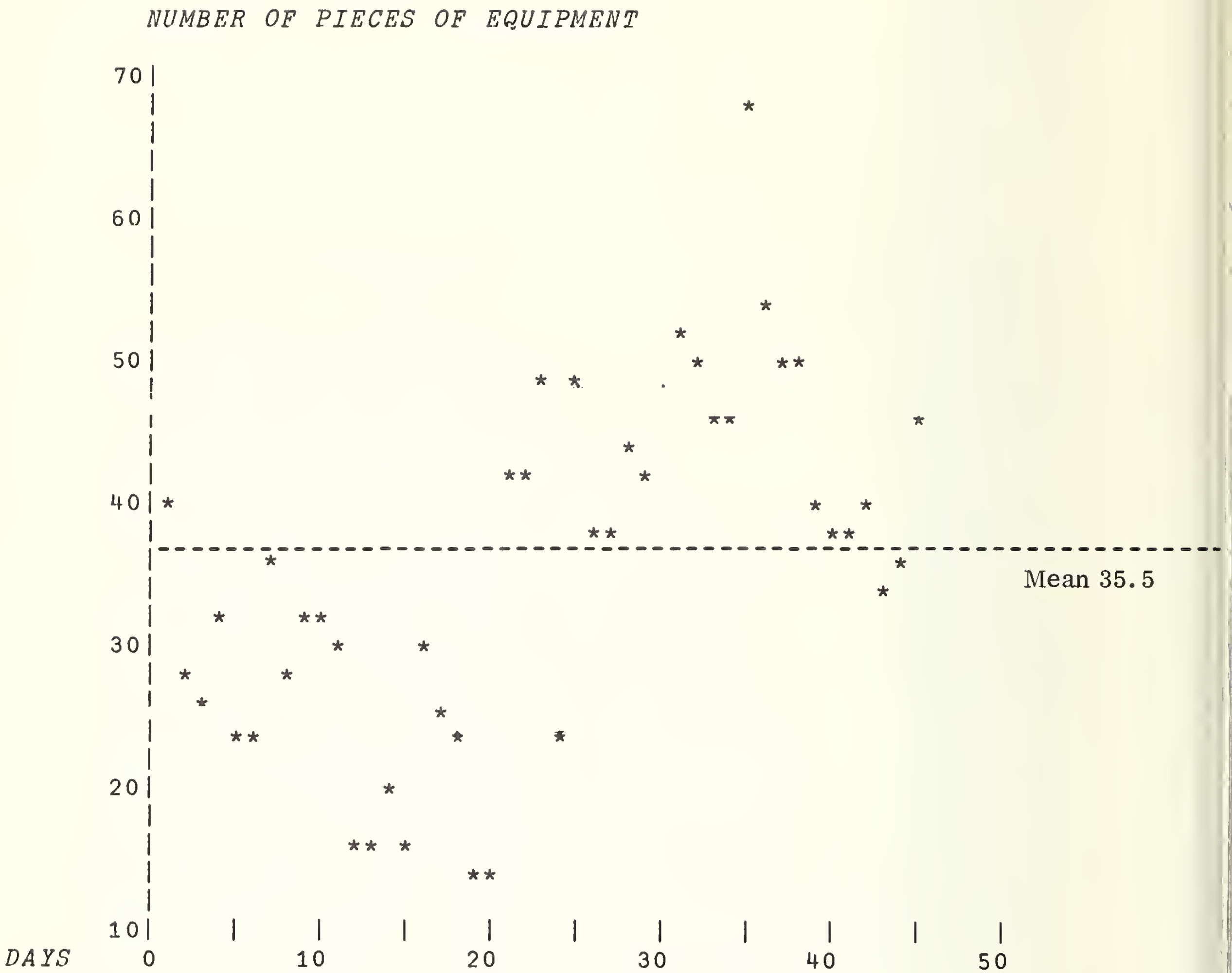


Figure 7-2 Equipment In Shop By Day

TABLE 7-2 MOBILE UNIT RELIABILITY BY BUS AND FUEL TYPE

Bus Type	Fuel Type	Total No. of Buses	Total No. of Monitor Buses	No. of Mobile Unit Failures 6/27-8/10	Failure Rate (5)÷(4) - %
GM 1961	Diesel	150	40	22	55
GM 1962-63	"	150	27	12	44
Flxible 1961	"	151	13	11	85
Flxible 1965	"	245	54	26	48
Flxible 1960	"	150	70	32	46
Flxible 1966-67	"	200	49	22	50
Flxible 1968-69	"	176	78	57	73
	Total Diesel	1222	331	182	55
Flxible 1956-57	Propane	150	63	37	59
Flxible 1958-59	"	150	10	2	20
Flxible 1963	"	150	95	60	63
	Total Propane	450	168	99	59

TABLE 7-3 RELIABILITY DATA BY GARAGE

Garage No.	No. of Monitored Buses	No. of Occurrences of Failures	Failure Rate (3) ÷ (2) - %
1	11	11	100
2	36	33	91.7
3	95	74	77.9
4	75	54	72
5	49	22	44.9
6	48	15	31.25
7	40	12	30
8	22	4	18.2
9	3	0	0
10	60	22	36.7
11	34	23	67.6
12	26	11	42.3

Finally, to check whether this 45 day test period was abnormal from a reliability point of view, shop records for January through June were examined and are summarized in Table 7-4. The data collected during the test period was found to be compatible with the preceding six-month records.

System effectiveness is defined as the number of buses whose monitor equipment is operating properly divided by the total monitor bus population or symbolically

$$\left(1 - \left(\frac{\text{BAD}}{\text{TOTAL}}\right)\right) \text{X100} \quad - \%$$

where

BAD = total number of inoperative buses (both in shop and on street)

Total = 500 CTA buses are monitor equipped

The total number of inoperative mobile units are calculated as follows:

1)	average in shop per day (Table 7-1)	35
2)	on the street during the owl shift (20% X 150) (see Section 6)	30
3)	In garage during the owl shift [(500 - (150 + 35)] X 20%][1]	63
	Total	128

Therefore, system effectiveness is no greater than 74% or at most, only 74% of the mobile bus fleet can be effectively operating on the streets of Chicago at one time.

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[1] Assumes that if 20% of buses operating during owl shift contain faulty mobile equipment, then approximately 20% of the remaining buses in the garage also contain defective equipment.

TABLE 7-4 FAILURE RECORD - JANUARY THROUGH JUNE

	Failures	Days	Daily Average
January	172	25	6.88
February	147	23	6.3
March	29	11	2.6
April	69	23	3.0
May	60	20	3.0
June	95	21	4.5
Test Period June 27 - Aug 10	281	45	6.24
Totals	853	168	5.12

The main reason for the low effectiveness is the amount of time required to get the defective unit in the shop. It was found that this time was approximately 4.8 days (Table 7-1). Further, probably several days pass from the time a unit actually fails until it is recorded. If the duration of time from an actual failure occurrence to the time the defective unit enters the shop could be decreased to one day, the effectiveness would increase to approximately 90%.

The possibility that the environment affects the reliability of the mobile unit was examined. The data from Table 7-3 shows that there is no apparent relationship between bus fuel type and mobile equipment failure rate. The effect of bus type (Table 7-3) and garage (Table 7-4) on the failure rate is not clear; a more detailed analysis would be required to ascertain if a relationship did indeed exist.

7.5 RECOMMENDATIONS

The obvious recommendation is that the reliability of the mobile unit should be improved. First, the exact cause(s) of this problem should be found. Preliminary analysis indicates that probably some component(s) in the mobile unit are experiencing high failure rates (in the past this has generally been the case). However, the possibility that environment effects, maintenance procedures, and tampering of the mobile units by bus operators contribute to the high failure rate, should not be ignored. Once the problem area is identified and necessary corrective action taken, a realistic estimate of the mobile unit reliability should then be made. This reliability estimate should be valuable to the CTA management in projecting future maintenance and manpower expenditures.

8. COST BENEFIT EVALUATION

The decision to implement a fully operational Automatic Vehicle Monitoring System must be based on a comparison of the net cost of the system with the potential benefits it offers the public served by the CTA. The net cost is best represented by the Net Present Value of the "differential" costs - those cost items which will be "different" as a result of the implementation of the AVM system. A majority of the CTA's cost items will be unaffected by this system and thus can be disregarded. The increased benefit provided to the public by this system will probably be difficult to measure or quantify, but the final decision must take into account all factors, both those which can be quantified and those which cannot.

The differential costs created by the AVM system are of two types - non-recurring and recurring. The non-recurring differential costs are those for the initial purchase of the required equipment and initial training of new radio operators. These costs are summarized in Table 8-1. The recurring differential costs are increases or decreases in annual charges for equipment maintenance, salaries, and rental of communications equipment. These costs are summarized in Table 8-2. (Tables 8-1, 2 were developed from the data contained in Appendix G.)

Several assumptions were required to determine the present day value of the cost changes that will occur over a period of years. First, it was assumed that the life of the system will be ten years and that the relative magnitude of the differential cost items will remain constant during that period. However, the absolute magnitude of the cost items will increase each year due to inflations, cost of living increases, etc. The recurring cost figures reported in Table 8-2 are valid only for the current year; thus, the second assumption was that all cost items would increase uniformly at an annual rate of 6%.

TABLE 8-1 NON-RECURRING COSTS

Item	Cost
1. Mobile equipment for 2700 buses at $475 each	$1,282,500
2. 500 signpost transmitters at $475 each	237,500
3. Fixed radio equipment for two data channels	25,000
4. Control Center equipment (consoles)	650,000
5. Control Center equipment (computer)	350,000
6. Installation of above equipment	153,000
7. Differential cost for 2000 monitor compatible radios of $325 per radio	650,000
8. Initial training of 10 new radio operators at $113 per man	1,130
	$3,349,130

TABLE 8-2 RECURRING COSTS[1]

Item	Current Annual Cost	Duration
1. Maintenance of communication equipment and signposts	$ 60,000	10 years
2. Maintenance of computer	12,000	10 years
3. System manager	20,000	10 years
4. Two system analysts/programmers	32,478	10 years
5. One programmer for first five years	15,436	5 years
6. One System Maintenance Coordinator/System Engineer	15,436	10 years
7. Ten additional radio operators at $18,800 each	188,000	10 years
8. Additional training for radio operators - two per year at $113 each	226	10 years
9. Fifty fewer supervisors (point men and terminal telephone men) at $17,125 each	(856,750)[2]	10 years
10. Four fewer schedule clerks at $17,135 each	(68,540)	10 years
11. Two fewer typists at $11,416 each	(22,832)	10 years
12. Reduction in annual overtime charges	(8,000)	10 years
13. Elimination of annual street telephone charges	(32,640)	10 years
14. Elimination of annual terminal reporting telephone charges	(12,914)	10 years

[1] Letters from the CTA containing this information are included in the addendum to this paper.

[2] Parentheses indicate cost reduction.

In comparing the differential costs to the initial investment for the system, one cannot simply add the net savings for each of the ten years; the money saved during future years must be discounted at some rate which reflects the time value of money and the opportunity costs borne by the economy for deferring other possible investments of public funds. The third assumption is that the appropriate discount rate is 10%, which is that recommended by OMB as the "public discount rate."

With these three assumptions, the data in Table 8-2 can be used to compute the present value of the differential savings produced by the AVM system. Combining the applicable, recurring differential costs for each year produces the yearly net differential costs in current prices. The actual net differential costs are determined by successively compounding these figures at the 6% annual growth rate. This produces the expected dollar values of the net savings provided by the AVM system in each year. The net present value of these savings is determined by successively discounting each of the yearly figures at the 10% discount rate and summing them.[1]

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[1] Given the net differential cost for each year n, C, in current prices, the actual net cost in year n is $G_n = C_n (1 + G)^n$, where g is the expected 6% annual growth factor. The present value of G_n is $PV_n = G_n/(1 + k)^n$ where k is the discount rate of 10%. Substituting the expression for G_n gives the expression for the present value of the net differential savings in year n (PV_n) in terms of current prices (C_n): $PV_n = \frac{C_n(1 + g)^n}{(1 + k)^n}$.

The cumulative net present value is thus: $NPV = \sum_{n=0}^{9} \frac{C_n(1 + g)^n}{(1 + k)^n}$. This is the expression graphed for successive values of n in Figure 1. As the slope indicates the value of cost savings in successive years decreases even though the absolute magnitude increases (k g). Note that the sum is taken from 0 to 9 rather than from 1 to 10 so that the first year's differential costs, which are already in current prices, are neither inflated nor discounted.

Figure 8-1 depicts the cumulative, discounted savings for the ten year period and indicates that, given the assumptions and cost figures stated above, these savings alone will offset the initial investments in the ninth year. Note that this represents a conservative estimate of the value of the savings due to the assumptions that (1) no reduction in the number of buses or operators would result and (2) all AVM compatible radios (which are each $325 more expensive than standard radios) would be purchased in the first year. If it was assumed that the radios would be purchased over a period of several years, the present value of this differential cost would be reduced, increasing the present value of the savings.

The results of this analysis indicate that from a purely financial viewpoint, the proposed AVM system represents a good investment. The present value of the net differential cost reductions which would be realized during the life of the system is $5,657,930; the savings during the full ten years thus exceed the required initial investment by $2,308,800. As Figure 8-1 demonstrates, the net savings equals the initial investment during the sixth year.

This selection of the 10% discount rate implies that a 10% "rate of return" is expected from the investment of public funds, or, that for every dollar of public money invested today, we demand $1.10 reduction in cost to the public per year. The fact that the expected net present value of this investment is positive indicates that it meets this criterion; in fact, it exceeds it by $2.3 million. The net savings predicted by this evaluation represent the minimum benefit which can be expected; any reductions in the number of buses or operators or other savings which result will make the system even more financially beneficial.

Were this system to provide no benefits to the public which the CTA serves other than the net savings, the estimated $2.3 million in excess savings would probably prove to be a sufficient

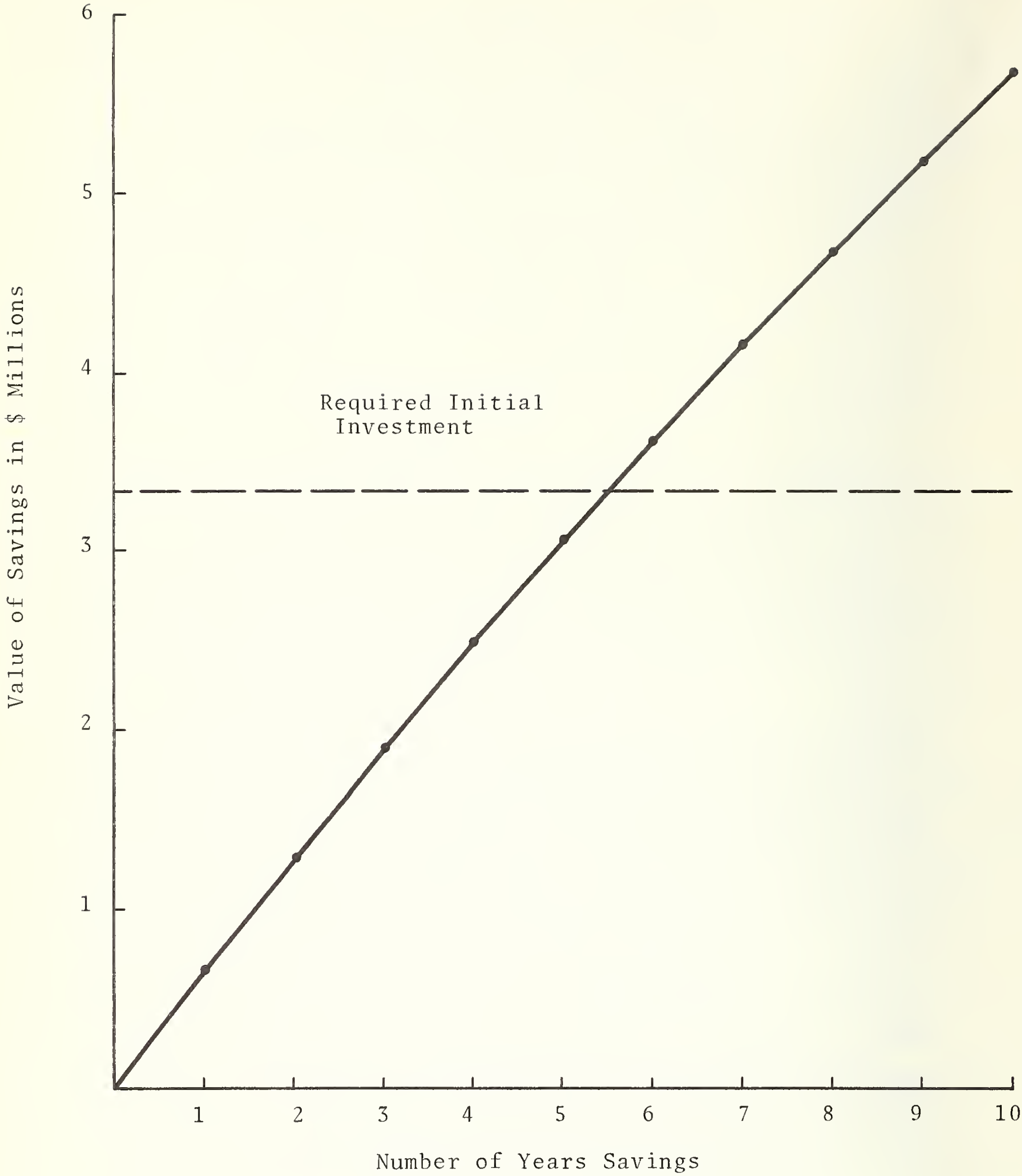


Figure 8-1 Discounted Present Value of Savings (Cumulative)

stimulus for its implementation. A public agency, however, must also consider the benefits of proposed alternatives to the public. The value of the undefinable benefits - greater convenience for the public as a result of improved schedule adherence, greater safety, and increased efficiency - are even more important considerations. Given that the investment in the system would result in a net saving at a 10% discount rate, the increase in the quality of service it would provide the public is an extremely cogent argument for its implementation.

APPENDIX A

TRAINING SCHEDULES

CTA 3687 REV. 11-67

CHICAGO TRANSIT AUTHORITY
TRANSPORTATION DEPARTMENT

STUDENT OPERATOR'S SCHEDULE

CLASS NO. ____________

______________________ NAME OF STUDENT   __________ BADGE NO.   __________ STATION

DAY	DATE	TIME	SUBJECT	LOCATION	TYPE OF INSTRUCTION
1st		7:30A to 4:00P	Orientation - Benefits and Pay Information, Personal Equipment, Responsibilities, Fare Structure, Fare Registration, Transfers, Introduction to Courtesy, Introduction to Defensive Driving, Transfers, Schedules, Trip Sheets, Defensive Driving Skills #1	Training Center 2660 N. Clark	Classroom Lecture
2nd		7:30A to 4:00P	Practice Operation Monitor (.5 hr)	Stations As Assigned	Lecture, Demonstration and Practice on Bus Not-In-Service
3rd		7:30A to 4:00P	Quiz 1, Fare Structure, Transfers, Trip Sheets, Defensive Driving Skills #2, Fire Extinguishers, Forms, Route Maps, Trip Sheets, Transfers, Accident Reports, Procedure for Reporting for Work	Training Center 2660 N. Clark	Classroom Lecture
4th		7:30A	Station Orientation	Home Station	Tour of Home Station
		8:30A	Practice Operation Monitor (.5 hr)	"	Lecture, Demonstration and Practice on Bus Not-In-Service
5th thru 10th		As Assigned	Practice Operation In Service on Various Routes as Assigned	"	Work with Line Instructor
11th		7:30A to 4:00P	Courtesy, Teamwork, Defensive Driving Skills #3, Final Examinations, Final Review	Training Center 2660 N. Clark	Classroom Lecture and Examinations
12th thru 14th		As Assigned	Practice Operation In Service on Various Routes as Assigned	Home Station	Work with Line Instructor
15th		As Assigned	Uniform and License Inspection	"	Inspection by Station Supt.
			Practice Operation In Service on Route as Assigned Monitor (On bus operations)	"	Work with Line Instructor

If unable to report for Instruction:
When scheduled to report at Training Center, Telephone Supervising Instructor, GR 7-1369, before 7:30 AM.
When scheduled to report at Home Station, Telephone Station before Reporting Time.

ARCHER VIrginia 7-1934	BEVERLY HIlltop 5-6121	FOREST GLEN SPring 4-2666	KEDZIE KEdzie 3-2410
KEELER SPaulding 2-8860	LAWNDALE LAwndale 1-5400	LIMITS LIncoln 9-1042	NORTH AVENUE DIckens 2-0660
NORTH PARK KEystone 9-4640	52nd STREET FAirfax 4-4600	69th STREET WAlbrook 5-2500	77th STREET TRiangle 4-7100

DAYS OFF - SUNDAYS and HOLIDAYS

T.&P.S.
4/72

Chicago Transit Authority
Training and Public Safety Department

RADIO-TELEPHONE OPERATOR TRAINING SCHEDULE

SESSION	TIME	SUBJECTS	LOCATION	TYPE OF INSTRUCTION
1	8:00 AM to 11:00 AM	Orientation; Description of Program; Film: "Instruction or Obstruction"; Radio Telephone Operator's Job Summary	Merchandise Mart	Lecture, Discussion
	11:30 AM to 2:45 PM	Tour of Operations Control Office; Preparing Radio-Telephone Operator Reports; Summary of Session.	Operations Control Office	Lecture, Demonstration
2	8:00 AM to 10:15 AM	Quiz I (General Information, Operations Control, Report Writing Problems); Review of Surface Supervisor Techniques in Restoration of Service; Tour of Station.	Forest Park Station	Written Quiz, Lecture, Demonstration
	10:15 AM to 11:45 AM	Tour of Yard; Tour of Rapid Transit Cars.	Harlem Yard	Lecture, Demonstration
	12:15 PM to 3:00 PM	Tour of Subway Facilities.	State Street Subway	Lecture, Demonstration
3	8:00 AM to 2:00 PM	Introduction to Procedures; Review of Radio-Telephone Operator Procedures; Using the Radio-Telephone System; Practice Operation; Review of Session; Quiz II (General Knowledge, Facilities and Equipment on Rapid Transit System).	Merchandise Mart	Lecture, Practice Operation, Written Quiz

SESSION	TIME	SUBJECTS	LOCATION	TYPE OF INSTRUCTION
4	8:00 AM to 12:30 PM	Review of Surface System Garage Locations; Rapid Transit Station Locations; Surface and Rapid Transit Routes; Review of "Employe's Guide to Equipment Trouble"; Quiz III (Problem Solving, Knowledge of Equipment).	Merchandise Mart	Lecture, Written Quiz
5	8:00 AM to 4:30 PM	Monitor-CTA: (Importance of system; description of system; voice communications; emergency alarm; radio control console operating procedures; display messages; operation of on-line keyboard).	Merchandise Mart	Lecture
		Tour of Monitor-CTA section.	Operations Control Office	Demonstration, Practice

NOTE: Sessions are held once a week.

The remainder of the training consists of a minimum of 120 hours on-the-job training under the supervision of a Regular Radio-Telephone Operator.

APPENDIX B

CTA-MONITOR BUS MEMORANDUM

METROPOLITAN TRANSIT CTA

CHICAGO TRANSIT AUTHORITY
TRANSPORTATION DEPARTMENT

SERVICE Bulletin

S198-72

S.S.	FILE	X
	POST	X
R.T.S.	FILE	
	POST	
	SPL.	
OTHER		

TO: All Operators, Skokie, Route #97

SUBJECT: Complete Radio Monitor Operations of all Runs

EFFECTIVE: Sunday, July 16, 1972

Effective Sunday, July 16, 1972, the Skokie, Route #97 will be completely monitored 24 hours daily from the Radio-Dispatcher's Office.

All Operators must accurately observe the "Scheduled Operation" of their runs at all times. If any run is behind schedule due to conditions beyond the control of the Operator, this will be registered in the Radio-Dispatcher's Office and, assistance will be given.

Any run operating ahead of schedule will be observed and, the Operator will be subject to discipline.

Operators must set the proper run number in the radio control box as soon as he is in service.

Extreme care must be taken so that the Emergency Alarm is never depressed unless an emergency exists and, assistance is needed.

Sup't of Transportation

7/5/72

CTA 3552 REV. 7-58

APPENDIX C

SIGNPORT RANGE ERROR

C-1 BACKGROUND

One of the errors that effect system accuracy is the signpost range error. As the bus enters the effective signpost range, the bus' signpost receiver elapse time counter is recycled to zero. As soon as the bus passes out of the signpost range, the counter is restarted (Figure C-1). To the computer, the bus appears to be at the signpost (the signpost range is assumed to be zero) from the time it enters its effective range up until 12 seconds after leaving the signpost range). Depending on when the bus is interrogated by the central computer, two types of errors can occur. When the bus is at least 12 seconds outside the signpost range, a type 1 time error (ϵ_1) occurs and is equal to signpost range ÷ average bus speed. This error will always be present whenever the bus is interrogated from the time the bus is at least 12 seconds outside the signpost range to the time it enters the next signpost range. If the bus is within the signpost range or has not been out of range for less than 12 seconds, a type 2 time error (ϵ_2) will occur and will be equal to $0 \leq \epsilon_2 < \epsilon_1 + 12$ sec. A test was conducted to determine the average and maximum (3σ) values of ϵ_1.

C-2 TEST PROCEDURES

The magnitude of the maximum (3σ) signpost range error is a function of :

a) signpost range;

b) the speed and duration of stops, if any, made by the bus within the signpost range;

c) the operational characteristics of the buses' signpost receivers.

---

[1] 3σ = 3 standard deviations

The operating characteristics of the signpost receiver affect the signpost range in two ways. The 500 bus receivers have different operating thresholds and each receiver has its own threshold sensitivity. Two buses passing the same signpost will capture the signal at different distances from the signpost. This is called the "receiver threshold variance." The threshold variance is due to (1) the signpost receiver's environment, type of bus (propane or diesel), bus electrical system, weather, etc. and (2) threshold band-signpost receivers have their own particular operating threshold. Also, the same bus making several passes at a given signpost will capture the signal at slightly different distances from the signpost. This is called the "receiver sensitivity." A test was conducted to determine the signpost receiver variance and sensitivity. Thirty-two monitor equipped buses were selected at random to make each a minimum of nine passes (three passes from three different directions) at a pre-selected signpost. Typically, a monitor bus would approach the test signpost at a low rate of speed (<5 mph) and stop upon capturing the signpost signal. A measurement of the signpost range was made by counting the number of streetlights between the bus and the signpost (streetlights are 85 ft. apart) and estimating the distances between the bus and the nearest streetlight and the signpost and nearest streetlight. The accuracy in using this measurement system was estimated to be $\pm$ 25 ft.

The average signpost range time error (ϵ_1) is a function of the individual signpost ranges and the buses' average speeds. If all signpost ranges could be set at exactly the same distance and this known distance could be incorporated into the existing computer program, the average error could be eliminated. However, it has not been practical for the CTA to set all the signpost ranges at the same distance. Therefore, a test was conducted to determine the average range and associative standard deviation for the signpost population. Bus 3536 was selected as the monitor equipped bus to perform these tests. During the signpost receiver test program, this bus had exhibited signpost receiver characteristics which were considered to be within the norm of the entire signpost receiver population. Bus 3536 made a minimum of nine passes (three passes from each of three of different directions) at each of 72 different signposts.

C-3 TEST RESULTS AND CONCLUSIONS

The results of these tests are presented in the table below:

Test	Mean $-\overline{X}$ (ft)	σ (ft)	3σ (ft)
signpost (sp) range	350	170	510
receiver variance (rv)		180	540
receiver sensitivity (rs)		20	60

The maximum (3σ) signpost range error will be equal to approximately

$$[(\overline{X}_{sp} + 3\sigma_{sp}) + 3\sigma_{rv} + 3\sigma_{rs}] \div \text{ ave bus speed}$$

This error, in terms of distance, is shown in Figure C-2 and is 1460 feet. The procedure of aligning the "signpost receiver variance" curve at the 3σ of the "signpost range" curve and the aligning of the "signpost receiver sensitivity" curve at the 3σ of the "signpost receiver variance" curve is not absolutely correct; however, by using this procedure an approximation of the maximum error can be calculated. For this analysis, the assumption is made that the average speed (v) of the bus while in the effective signpost range is 15 feet/sec. Therefore, the minimum (3σ) signpost range error is 98 seconds.

The average signpost range error is given by $\overline{X}_{sp}$ ÷ average bus speed and is equal to 23 seconds. The signpost receiver variance and "sensitivity" distribution were not used in calculating the average error because on the average, they are both equal to zero.

Figures C-3 and C-4 present curves showing the maximum (3σ) and average signpost range time error as a function of distance a bus travels from a signpost (d). The Figure C-3 curve presents the absolute signpost range time error (ϵ) in seconds while the Figure C-4 curve presents the instantaneous percent error $[\epsilon \div (d \div v)]_{\Delta T}$.

In conclusion, the following signpost range (SPR) errors occured as the buses are interrogated.

Error	Within SPR	Within 12 Secs After Leaving SPR	After 12 Secs After Leaving SPR
Ave. SPR (sec)	$-23 \leq \epsilon \leq +23$	$-35 < \epsilon \leq -23$	-23
Max. (3σ) SPR (sec)	$-98 \leq \epsilon \leq +98$	$-110 < \epsilon \leq -98$	-98

where "+" indicates early arrival error and

"-" indicates late arrival error.

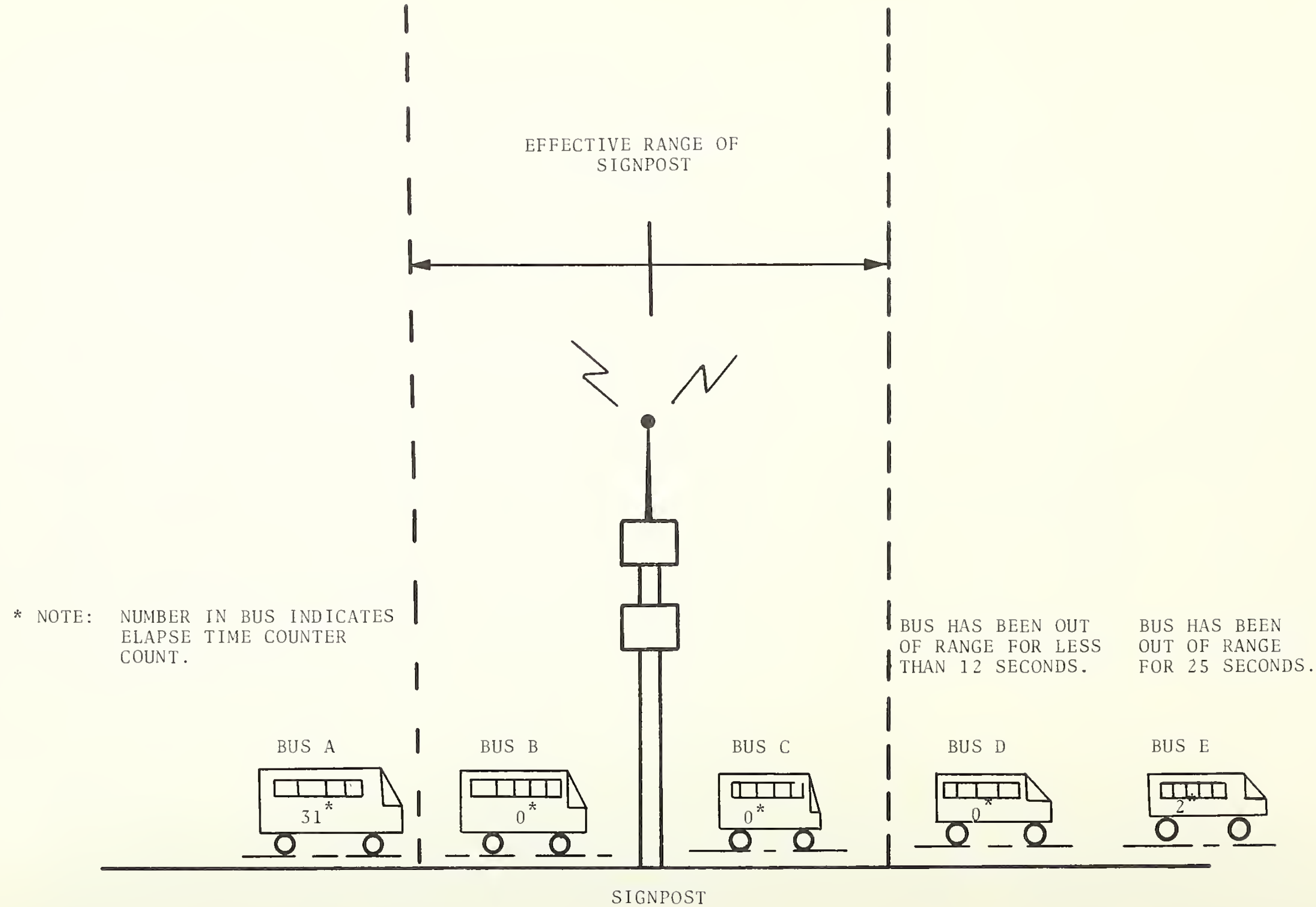

EFFECTIVE RANGE OF SIGNPOST
* NOTE: NUMBER IN BUS INDICATES ELAPSE TIME COUNTER COUNT.
BUS HAS BEEN OUT OF RANGE FOR LESS THAN 12 SECONDS.
BUS HAS BEEN OUT OF RANGE FOR 25 SECONDS.
BUS A
31*
BUS B
0*
BUS C
0*
BUS D
0*
BUS E
2*
SIGNPOST

Figure C-1

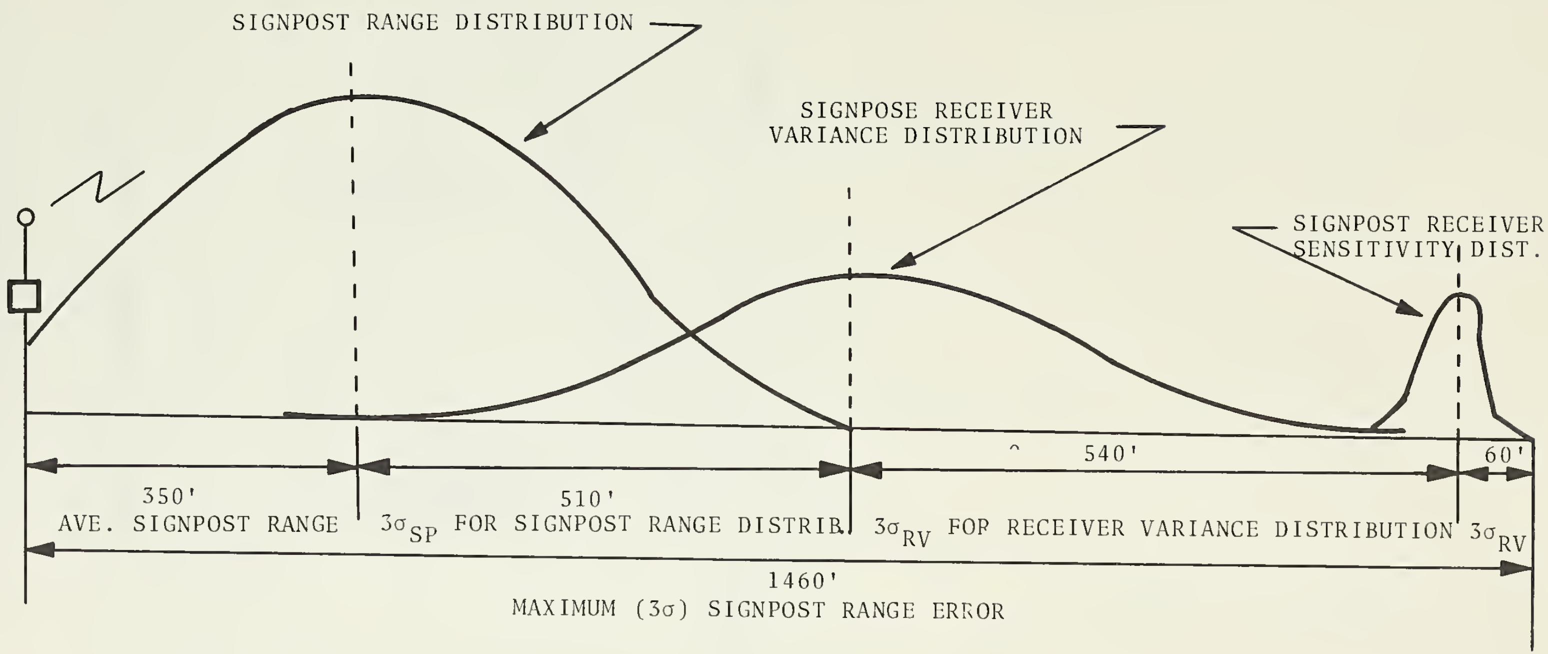

SIGNPOST RANGE DISTRIBUTION
SIGNPOSE RECEIVER VARIANCE DISTRIBUTION
SIGNPOST RECEIVER SENSITIVITY DIST.
350'
AVE. SIGNPOST RANGE
510'
3σSP FOR SIGNPOST RANGE DISTRIB.
540'
3σRV FOR RECEIVER VARIANCE DISTRIBUTION
60'
3σRV
1460'
MAXIMUM (3σ) SIGNPOST RANGE ERROR

Figure C-2

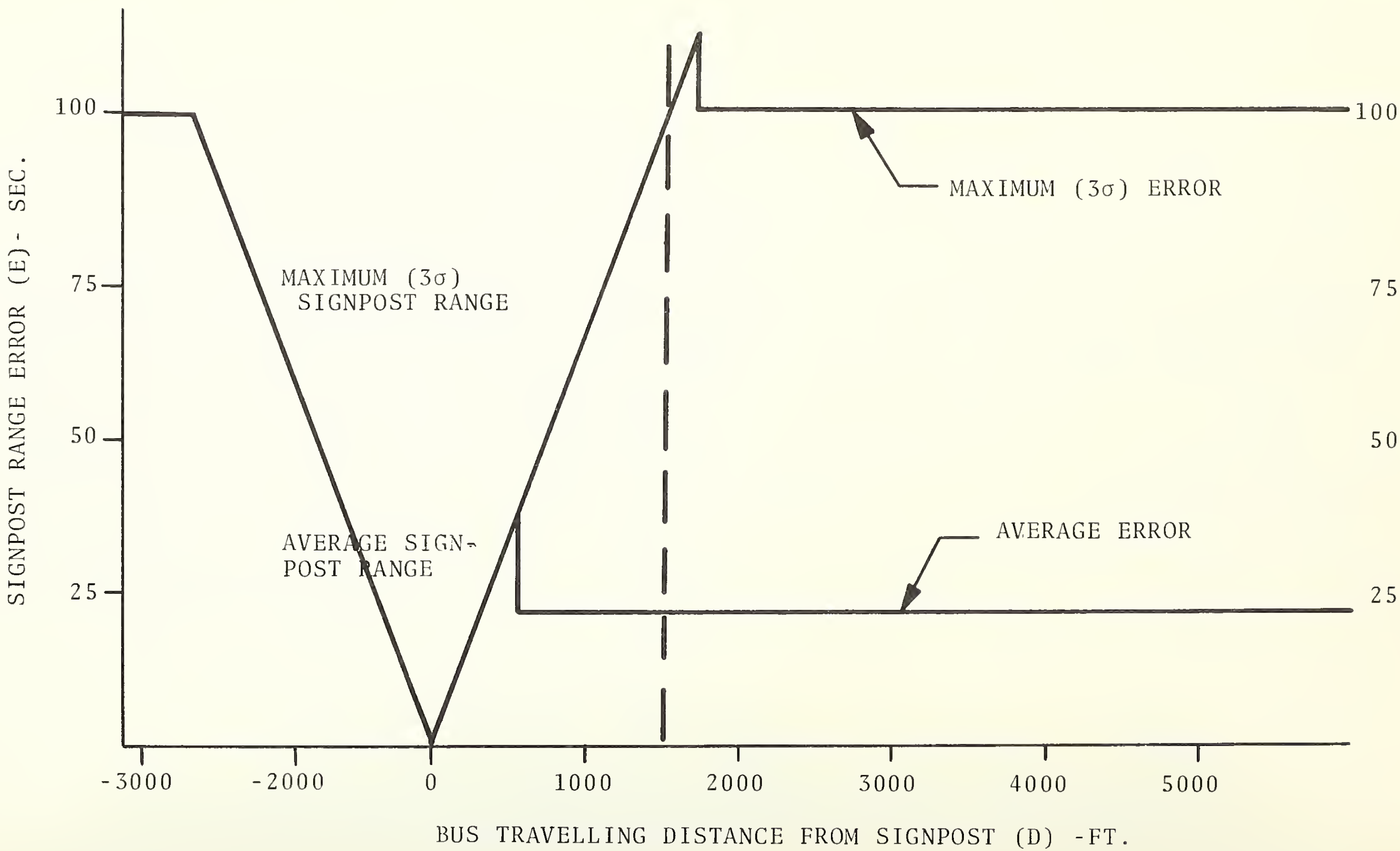
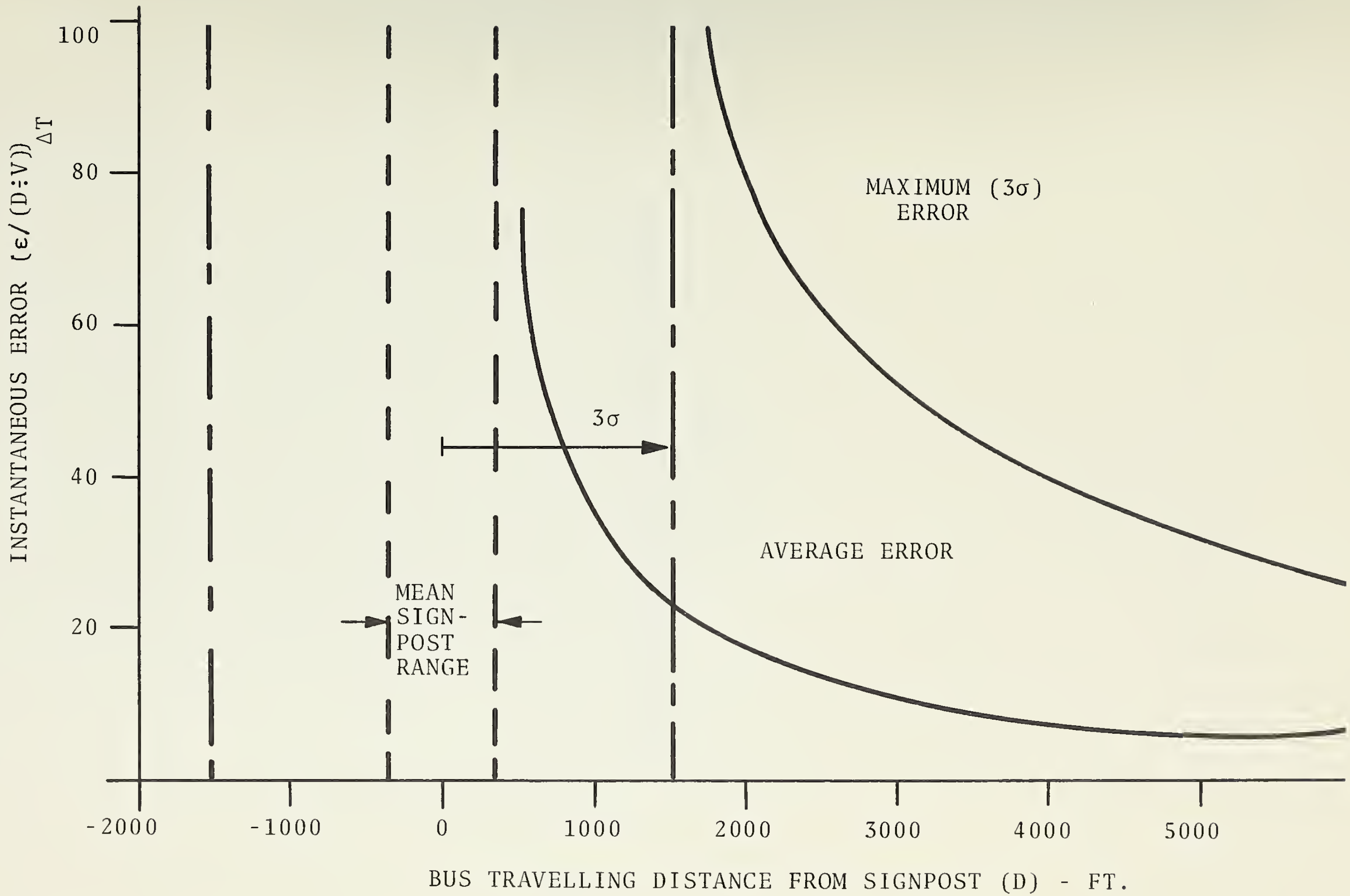

100
75
50
25
SIGNPOST RANGE ERROR (E)- SEC.
MAXIMUM (3σ)
SIGNPOST RANGE
AVERAGE SIGN-
POST RANGE
MAXIMUM (3σ) ERROR
AVERAGE ERROR
-3000
-2000
0
1000
2000
3000
4000
5000
BUS TRAVELLING DISTANCE FROM SIGNPOST (D) -FT.

Figure C-3



100
80
60
40
20
INSTANTANEOUS ERROR (ε/(D÷V))ΔT
-2000
-1000
0
1000
2000
3000
4000
5000
BUS TRAVELLING DISTANCE FROM SIGNPOST (D) - FT.
MAXIMUM (3σ) ERROR
AVERAGE ERROR
3σ
MEAN SIGN-POST RANGE

Figure C-4

APPENDIX D

COMMUNICATION RELIABILITY MEMORANDUMS

UNITED STATES GOVERNMENT

Memorandum

DEPARTMENT OF TRANSPORTATION
TRANSPORTATION SYSTEMS CENTER

DATE: September 19, 1972

In reply refer to: PA

SUBJECT: Telephone Line Quality Measurements

FROM: TEC/Richard E. Buck

TO: PA/Harold G. Miller

The telephone lines used to transfer CTA-AVM system data between the three satellite receiver stations and the control room are a combination of 19H88 and 22H88 lines having DC continuity. These telephone lines are a combination of CTA and Bell telephone lines. The modems used for data transmission and reception were designed and built by Motorola specifically for the CTA-AVM system. Since Bell Telephone Company only conducts quality tests on their own equipment, they would not test the CTA-AVM telephone data transmission system. Because telephone line quality measurements were necessary for a complete CTA-AVM system evaluation, a meeting was held with L. Bogan, J. Johnson and W. Nitschke of the Motorola Communication Division in Schaumberg, Illinois, to determine what could be done that would test the telephone data system quality. The results of this meeting were that a bus transceiver was installed at the satellite stations and directly connected to the input of the satellite transeiver. The 31 bit bus reply, containing a pre-set signpost location and interval timer information was repeatedly transmitted from the satellite station to the CTA control room via the telephone lines. The number of bus reply messages transmitted and the number of correct bus reply messages decoded at the control room were recorded.

With this test, not only were the telephone lines tested but also the telephone line modems, satellite transceiver and the control room receiver. The test was conducted for approximately two hours at both the South Side satellite station and the Lake Point Tower satellite station. The results of this test were that of the 30,000 bus messages sent from the South Side Station, 29,843 were correctly decoded for a reply rate of 99.5% or an error rate of 0.5%. Also, of the 20,0000 bus reply messages sent from the Lake Point Tower Station, 19,938 messages were correctly decoded for a reply rate of 99.7% or an error rate of 0.3%.

Although long term variations occur in telephone line quality, these variations would not appreciably change the measured error rates, and since these error

TSC F 1325.4

rates are well below the acceptable CTA-AVM system bus non-reply rates, further measurements on telephone line quality was not felt necessary.

Richard E. Buck

Richard E. Buck

APPENDIX E

CTA INTERROGATION INFORMATION

The following information was verbally received from the CTA on August 23, 1971. The information presented below concerns those buses which had "0" response rates during the indicated owl shift.

Date	(1) No. Buses with Wrong Run No.	(2) No. Buses with New Defect Found	(3) No. Buses with Old Defect Known and Reported	(4) No. Buses with Old Defect not Reported	(5) No. Buses with Either (1) or (2)
8/14	4	4	4	7	12
8/15	2	4	4	16	15
8/16	3	10	6	12	20
8/17	1	4	10	12	12
8/21	1	8	10	7	9
8/22	0	9	5	8	16

APPENDIX F

SAMPLE OF RELIABILITY DATA

RADIO'S IN SHOP ON 7-5-73 TUESDAY NIGHT 7-4-72

(Mobil units)

GAR	#1	#2	#3	#4	#5	#6
	8604	3010	3735	8807	3523	127
		3304	3748	8798	3522	3411
		176	3739	8795	3502	
		3007	3766	8799		
			3335	8843		
			3346	8839		
			3742			
			3334			
			3769			

GAR	#7	#8	#9	#10	#11	#12
		3705		8709	8026	
					8025	
					302	
					8006	

Example Data Sheet

69TH $\frac{04}{99}$

BUS	DEFECT	DATE REP'T	REPEAT DATES									
8827	ER E.T.	6/19/72	6/27	6/28	7/18	7/25						1
8815	ER E.T.	6/19/72	6/23	6/26	6/27	6/28	7/5	7/12	7/13	7/25	7/28	?
8825	ER E.T.	6/19/72	6/26	7/7	7/18	7/26	7/28					?
8845	ER E.T.	6/23/72	6/26	6/28	6/29	7/7	7/12	7/18	7/20	7/28		?
8832	FAST E.T.	6/23/72										?
8833	ER E.T.	6/23/72	6/26	6/27	7/14	7/28						8
8848	ER E.T.	6/23/72	6/28	7/7	7/21							13
8813	ER E.T.	6/23/72	6/26	7/5	7/28							?
8847	ER E.T.	6/26/72	6/27									32
8779	ER E.T.	6/26/72	6/28	6/29	7/5	7/12	7/13	7/18	7/20			?
8842	ER E.T.	6/29/72										?
8817	ER E.T.	7/ 5/72	7/20									?
8781	INC E.T.	6/28/72	7/18	7/20	7/25							?
8784	ER E.T.	7/20/72										1
8820	ER E.T.	8/ 9/72										
8838	ER E.T.	8/ 9/72										
8816	ER E.T.	8/16/72										

Eratic Timers

Example Data Sheet

REPORT DATE 08/07/72

BUS#	DATE	REPAIR WORK PERFORMED ON BUS RADIO EQUIPMENT	BEVERLY
0132	02/15/72	RADIO EQUIPMENT REPAIRED	LIMITS
0400	02/15/72	RADIO EQUIPMENT REPAIRED	LIMITS
0406	02/15/72	RADIO EQUIPMENT REPAIRED	77TH
3343	02/15/72	EQUIPMENT REPAIRED AT CHICAGO COMM	77TH
3343	02/15/72	EQUIPMENT REPAIRED AT CHICAGO COMM	LAWNDALE
3406	02/15/72	EQUIPMENT REPAIRED AT LOCATION BY CCS	ARCHER
3504	02/15/72	RADIO EQUIPMENT REPAIRED	ARCHER
3525	02/15/72	RADIO EQUIPMENT REPAIRED	ARCHER
3539	02/15/72	RADIO EQUIPMENT REPAIRED	ARCHER
3542	02/15/72	RADIO EQUIPMENT REPAIRED	ARCHER
3544	02/15/72	RADIO EQUIPMENT REPAIRED	77TH
3769	02/15/72	EQUIPMENT REPAIRED AT CHICAGO COMM	69TH
8775	02/15/72	RADIO EQUIPMENT REPAIRED	69TH
8777	02/15/72	RADIO EQUIPMENT REPAIRED	69TH
8779	02/15/72	RADIO EQUIPMENT REPAIRED	

Failures of Equipment (Jan. - June) Example Data Sheet

APPENDIX G

COST BENEFIT MEMORANDUM

CHICAGO TRANSIT AUTHORITY
MERCHANDISE MART PLAZA • P. O. BOX 3555, CHICAGO, ILLINOIS 60654 • AREA CODE 312 - 664-7200

August 1, 1972

Mr. Harold Miller
Project Coordinator
Transportation Systems Center
55 Broadway
Cambridge, Massachusetts

Dear Harold:

You have requested information on the cost of purchasing a fully implemented Monitor system and the maintenance thereof. The costs are expected to be as follows:

1. Mobile equipment for 2,700 buses at $475 each, totalling $1,282,500
2. 500 signpost transmitters at $475 each, totalling $237,500
3. Fixed radio equipment for two data channels - $25,000
4. Control Center equipment (consoles) - $650,000
5. Control Center equipment (computer) - $350,000
6. Installation of above equipment - $153,000

This yields a total one-time cost of $2,698,000.

The annual costs of this system are expected to be as follows:

1. Maintenance of communication equipment and signposts - $60,000
2. Maintenance of computer - $12,000

Total maintenance costs - $72,000.

On some items the cost is a differential above the cost of only a communications system.

Sincerely yours,

Martin J. Lukes
Project Manager
Monitor-CTA

MJL:cs

CHICAGO TRANSIT AUTHORITY

MERCHANDISE MART PLAZA • P. O. BOX 3555, CHICAGO, ILLINOIS 60654 • AREA CODE 312 - 664-7200

METROPOLITAN CTA TRANSIT

July 28, 1972

Mr. Harold Miller
Project Coordinator
Transportation Systems Center
55 Broadway
Cambridge, Massachusetts

Dear Harold:

You have requested information on the cost of managing a fully implemented Monitor system. This cost is expected to be as follows:

1.	System Manager - Annual cost -	$ 20,000.00
2.	Two permanent system Analysts/Programmers Annual cost including fringes -	32,477.80
	In addition to this, one Programmer would be required for approximately five years. Annual cost - including fringes -	15,436.33
3.	One system Maintenance Coordinator/System Engineer Annual cost - including fringes -	15,436.33
4.	Secretarial work would be a normal office function with costs not directly chargeable to system operation. Therefore, the cost for the system would be:	
	Annual cost for the first five years -	83,350.~~6~~46
	Annual cost thereafter -	67,914.13

The above costs do not include escalation.

Sincerely yours,

Martin J. Lukes,
Project Manager
Monitor-CTA

MJL:cs

CHICAGO TRANSIT AUTHORITY

MERCHANDISE MART PLAZA • P. O. BOX 3555, CHICAGO, ILLINOIS 60654 • AREA CODE 312 - 664-7200

July 26, 1972

Mr. Harold Miller
Project Coordinator
Transportation Systems Center
55 Broadway
Cambridge, Massachusetts

Dear Harold:

You have requested information on several items of potential savings accruing to CTA when Monitor-CTA is expanded to include the entire bus fleet. No savings has resulted during the demonstration period, or will result until the entire fleet is equipped. One substantial item which will result from better service regularity, a savings in equipment and total number of bus operators, is not included.

1. Field Supervisory Forces:

   The total Field Supervisory Force will be reduced by 50 men. The reduction is in the number of Point Men and Terminal Telephone Men. There will be no change in the total number of mobile supervisors.

   Each supervisor presently costs CTA $17,135 annually.

2. Schedule Department:

   The reduction within the Schedule Department will be 4 Schedule Clerks and 2 Typists.

   A Schedule Clerk costs CTA $17,135 annually.

   A Typist costs CTA $11,416 annually.

3. Radio Dispatchers:

   It is anticipated 10 additional Radio Dispatchers will be required to operate a total of 8 consoles.

   Each Radio Dispatcher costs CTA $18,800 annually.

4. Overtime pay of Bus Operators:

Overtime is paid operators for time worked beyond their scheduled time. This may result from traffic delays, fires, bus replacement, etc.

The annual savings in overtime paid to operators resulting from better regularity of service, faster response to bus replacements and related problems is estimated at $8,000.

5. A change in personnel resulting from the Monitor will also result in savings or costs in training the various groups of personnel. The attrition rate and training costs are as follows:

a. Bus Operators - 450 annually - $1,206 per man

b. Surface Supervisors - 6 annually - $77 per man

c. Radio Dispatchers - 2 annually - $113 per man

Sincerely yours,

Ralph W. Tracy,
Sup't of Operations

RWT:cs

CTA 8422

CHICAGO TRANSIT AUTHORITY

December 15, 1971

TO: Mr. M. J. Lukes

FROM: Mr. A. R. Sandberg

SUBJECT: Street and Terminal Reporting Telephones

In reply to your letter of November 23, 1971, in which you request the annual cost of all street telephones and terminal reporting telephones please be advised that for the twelve month period ending October 31, 1971, this cost has been computed to be:

a) Street Telephones	$32,639.64
b) Terminal Reporting Telephones	12,914.16
c) Total	45,553.80

A. R. Sandberg

JJH/sp

cc: File (2)