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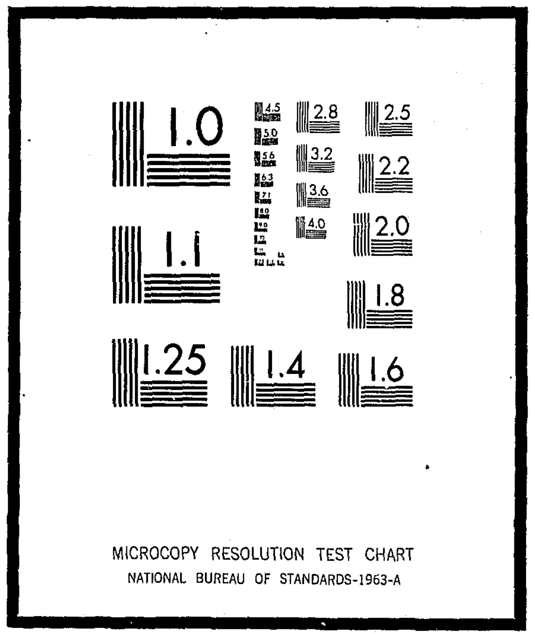

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SAN FRANCISCO
REMOTE TERMINALS
DECODING
AUTO THEFT INQUIRY SYSTEMS
MATHEMATICAL MODEL
DIGITAL COMMUNICATIONS
TELECOMMUNICATIONS

ANNOTATION:
DIGICOM IS A TWO-WAY DIGITAL COMMUNICATIONS SYSTEM AUGMENTING THE VOICE RADIO.

ABSTRACT:
THE OFFICER IN THE VEHICLE ENTERS A DIGITAL MESSAGE ON THE DIGICOM UNIT AND TRANSMITS IT AS A TONE-CODED BURST OVER THE VOICE CHANNEL TO THE BASE STATION. AT THE BASE STATION, THE INFORMATION IS DECODED AND ENTERED INTO A MINICOMPUTER WHICH TRANSFERS AND DISPLAYS THE DIGITAL INFORMATION TO THE DISPATCHER OR TO THE PIN/AUTOSTATIS (POLICE INFORMATION NETWORK/ AUTOMATIC STATEWIDE AUTO THEFT INQUIRY SYSTEM) OPERATOR. DIGITAL INFORMATION FROM THE BASE STATION ORIGINATES AT THE COMPUTER OR IS ENTERED VIA A KEYBOARD. WHEN THE CHANNEL IS CLEAR THE COMPUTER OUTPUTS THE DIGITAL MESSAGE TO AN ENCODER FOR TRANSMISSION OVER THE VOICE CHANNEL TO THE PATROL CARS. VOICE TRAFFIC ORIGINATING WITH THE DISPATCHER OR FIELD PERSONNEL IS MONITORED BY THE COMPUTER. THIS CAPABILITY PROVIDES EXACT DATA ON CHANNEL CONGESTION AND ASSURES THAT THE DIGITAL SYSTEM IS SECONDARY TO VOICE AT ALL TIMES. AFTER EACH DIGITAL TRANSMISSION, THE COMPUTER CHECKS IF ANYONE HAS INITIATED VOICE CONTACT. IF SO, DIGITAL TRANSMISSIONS ARE STOPPED UNTIL THE CHANNEL IS AVAILABLE. (AUTHOR ABSTRACT)

SAN FRANCISCO digicom SYSTEM

OJECT 007 FINAL REPORT

Sociosystems Laboratory

Sylvania Electronic Systems Western Division / P.O. Box 188 Mountain View, California 94040 / (415) 966-3373

FINAL REPORT

SAN FRANCISCO DIGICOM SYSTEM

A Program to Evaluate the Effectiveness of Digital Communications for Law Enforcement Agencies

Grant No. DF-007

July 1970

Submitted to Mr. Alfred J. Nelder, Chief of Police, San Francisco, California

Ronald Adams
Program Manager
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This study was performed under a grant from the United States Department of Justice, Law Enforcement Assistance Administration, to the City of San Francisco, California, Police Department.

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FOREWORD

Sylvania Electronic Systems would like to express appreciation to Alfred J. Nelder, Chief of the San Francisco Police Department for his assistance and cooperation. His continued interest, encouragement and suggestions contributed greatly to the overall effectiveness and success of this project.

No report would be complete without giving due recognition to the field and communications/dispatcher personnel of the San Francisco Police Department. Their patience during the initial stages and their continuous constructive criticism, suggestions, and comments are greatly appreciated.

This effort has resulted in a successful and meaningful project only because it received the wholehearted and cooperative support of the officers and men of the San Francisco Police Department.

1.0 RADIO CHANNEL CONGESTION — A SERIOUS PROBLEM

Congestion on the radio frequencies assigned to law enforcement agencies is hampering effective communication. A number of factors may be identified as contributing to the development of radio channel congestion over the past several years:

- An increase in patrol activities — special crime prevention units are frequently deployed.
- An increase in the number of patrolmen assigned to field duty.
- A dramatic increase in the quantity of vehicle license plate numbers checked through computer files.
- An increase in the number of want/warrant checks run on persons.
- A proliferation of computerized data bases which can be accessed via the radio channel-dispatcher link by the field personnel.
- A well-known crime rate increase which has caused radio traffic to increase proportionally.

Radio channel congestion caused by the above factors and the factors themselves also impact on general police operations. These secondary effects typically result in:

- Over-burdened dispatchers who no longer can deal effectively with the demands placed upon them.
- Increased standby time of field personnel who must wait their turn to communicate with the base station.
- A sacrifice of personal safety when officers forego making routine want/warrant checks on vehicles and persons.
- A loss in command and control due to a lack of knowledge of the current status of field personnel. An officer may neglect to change status if the channel is over-crowded.

Faced with the consequences of over-loaded radio channels, it is desirable to investigate methods of improving the utility of assigned frequencies before adding more dispatchers and purchasing new radio equipment.

2.0 DIGITAL COMMUNICATIONS — A POSSIBLE SOLUTION TO RADIO CHANNEL CONGESTION

The San Francisco Police Department, under a $100,000 grant from the Law Enforcement Assistance Administration, contracted with Sylvania's Sociosystems Laboratory to investigate the potential of digital communications for law enforcement.

Specifically, can digital communications:

- Significantly reduce channel congestion?
- Reduce the workload on the dispatcher?
- Provide increased personal security for field officers?
- Provide increased efficiency in the areas of command and control?
- Simplify the routine operations of dispatchers and radio car operators?
- Provide greater information throughout without increasing channel congestion?
- Improve the responsiveness of the communications system?; i.e., shorten the time between inquiry and response.
- Provide data for resource allocation in a computer-compatible and real-time form?

In addition to investigating the usefulness of digital communications, a major project goal was to present the results in a form that would be useful to any law enforcement agency. This "model" approach would allow most departments to confidently predict the improvement to their own specific communication system.

Hardware evaluation was not a project goal because equipment of this type is not generally available. It was expected that requirements for such equipment would be identified and could be used by anyone considering the manufacture of such devices.

3.0 PLAN FOR EVALUATING DIGITAL COMMUNICATIONS

The project which became known as digicom was undertaken as a joint effort by the San Francisco Police Department, the San Francisco Department of Electricity and Sylvania's Sociosystems Laboratory. The Police Department, in addition to contributing personnel, facilities, and equipment, provided the necessary guidance to assure that the project was germane to police operations. Department of Electricity personnel contributed manpower and facilities to help install and maintain the system during evaluation. Sylvania supplied the hardware and technical personnel to evaluate the effectiveness of digital communications.

In considering possible digital devices, several levels of sophistication came to mind:

1. Small pushbutton status-only devices requiring very little base station equipment.
2. Larger units capable of sending status and 6 to 10 preset radio codes and requiring more base station equipment.
3. Mobile units that both send and receive preset digital messages and hence require base station equipment that can send and display the messages.
4. Mobile units that can send and receive preset codes and send license plate numbers to the base station. The base station would require even more sophisticated equipment to display the necessary information.
5. Mobile units that can send preset codes, text messages, and received radio codes and text messages.

Available funding did not permit the design and fabrication of quantities of each type of equipment for evaluating the corresponding digital capability. Rather, a plan was developed which called for hardware that would permit the sequential evaluation of increasingly sophisticated digital communication levels. Equipment designed to do this offers a convenient method of determining the [illegible]ity of many "types" of digital devices but should not be evaluated as an operational piece of equipment. For example, the question "can license plates be sent digitally?" is not the same as "should a keyboard be used to enter license plates to be sent digitally?" Equipment designed to answer the first question need not and should not be used to answer the second question. The digicom project has addressed the question of "concept evaluation" and not "human factors" evaluation.

At the beginning of the project, a plan was devised for evaluation of five levels of digital capability:

Level 1: Mobile-to-base status messages without acknowledgment and requiring no base station message readout.

Level 2: Mobile-to-base status and preset messages with message display required at the base station.

Level 3: Mobile-to-base-status and preset messages and base-to-mobile preset messages. Base station requires preset message entry and display capability.

Level 4: Preset messages mobile-to-base and base-to-mobile with the added capability to send digital license plates mobile-to-base. Base station requires sophisticated alpha-numeric display capability.

Level 5: Level 4 with an added digital code to be used wherever voice communication is desired mobile-to-base.

The equipment at the base station was designed to be a non-interfering add-on to present equipment. Because digicom was not being purchased by the San Francisco Police Department, it was undesirable to modify or replace existing equipment. Operational evaluation is compromised somewhat in doing this because the dispatcher is using equipment designed to evaluate the concept of digital communication and not designed to support him in an optimum fashion. Similar problems exist with the mobile equipment designed to be installed on a non-interfering basis. A permanent installation integrated into the patrol car would be desirable for operational evaluation.

3.1 Project Implementation

Actual project implementation deviated significantly from the planned program. The major causes of the deviation were associated with the delay between award announcement by LEAA and receipt of the necessary papers by the San Francisco Police Department, the unplanned delay associated with the selection of a subcontractor by San Francisco, and the 11-week delay in getting an experimental license from the FCC.

A request for a contract extension was granted by LEAA to offset the first two factors. The delay associated with obtaining a license for operating digital equipment was more serious. Six weeks of program time were lost waiting for the license. Rather than remain idle, the decision was made to install all the mobile units and do the testing later when RCC approval was received. In retrospect, that was a very poor decision because it was necessary to modify all the mobile units. Modifications were made at the radio shop — which was open from 8:00 a.m. to 5:00 p.m. — and modification could only be made to one unit at a time and only if it could be spared from the field. Another four weeks were lost making modifications to the mobile units.

The situation was further complicated by the fact that the men were trained to operate the equipment and briefed on the plan for experimental evaluation six weeks before they were able to start using the system. As a result, retraining was necessary and a number of the men felt the equipment didn't work.

In addition to the above unplanned and unexpected difficulties, the usual planned-for but unexpected problems also developed. For example, how do you find a good ground on the fourth floor of the Hall of Justice in the Communications Bureau and what do you do when the fan on the tape deck makes too much noise to permit placing the system in the room where it was planned?

The above complications are identified in the hope that other agencies may plan and develop schedules that allow for or eliminate such difficulties. Although late getting started, the project was completely successful in accomplishing the goals and objectives.

3.2 Digicom Training and Project Coordination

Training for the project began on December 17, 1969 when Sylvania conducted a briefing for staff members of the Police Department. The concept of digital communications and the goals and limitations of the project were presented.

The more formalized training was prepared and conducted by a member of the Sociosystems Laboratory. It started with the preparation of separate operating manuals for dispatchers handling the base stations equipment, and for the radio car officers who would be using the mobile unit equipment. These manuals, each of approximately 30 pages, used both text and drawings to explain the purpose and concepts of the project as well as detailed operating instructions.

Eight 2-hour training sessions were conducted during January for the members of three districts involved in the project. Approximately 270 radio car officers and supervisors received training in the operation of the mobile equipment. Each man was issued a copy of the operator's manual and had an opportunity to use a specially prepared model of the equipment to be in the police car.

The concept of digital communications and goals and limitations of the project were discussed and audience participation was encouraged to help eliminate misunderstanding and negative attitudes in those who would be participating.

The Commander of the San Francisco Police Department Communications Bureau was present at each of these sessions. He coordinated the training effort and also conducted some specialized supervisory training at the conclusion of each of the regular sessions.

All members of the Communications Bureau received instruction in the project concepts and in the operation of the base station equipment. Special training was conducted for the communications supervisors. They in turn conducted additional daily training for the dispatchers on each shift. Each dispatcher rotates through all operating positions; therefore it was desirable to emphasize the training for each study phase as the operator takes over the digicom dispatcher position or the PIN/AUTOSTATIS (Police Information Network/Automatic Statewide Auto Theft Inquiry System) position.

In addition to the formal training, each officer was encouraged to practice as often as possible. This included setting up license plates or going through the sequences necessary for various operational situations, such as status changes, requests for backup units, or emergency procedures. This practice by both radio car officers and dispatchers did not interfere with normal activities as long as the "transmit" button was not pushed. Supervisors were expected to handle retraining when necessary and also train new officers of those coming from other non-trained districts.

Evaluation questionnaires were distributed on two occasions and various department orders and clarifying memos were circulated explaining the approaching project phases and changes in the scheduling or operating procedures.

The problems affecting training for the project seemed to arise from two main areas: the lack of information about the purpose of the project, and the difficulty of reaching personnel on all three shifts. The first area varied from the officer who was disappointed over the system limitations when he found voice was not completely eliminated and only license numbers (not suspect names) could be checked, to the officer who thought the only "real" purpose of the system was to keep an

3.2 (Continued)

eye on the policeman so that he would have to work harder. The second area was complicated by the frequent shift changes which make it difficult to contact each officer in any series of meetings. The formal training sessions overcame this problem by scheduling eight meetings on 4 days, including a shift change weekend. This method was too expensive and too slow for the day-to-day explanation of changes, and misunderstandings; therefore another dual approach was taken. Whenever possible, regular departmental information channels were used — memos, bulletin boards and official broadcasts. However, the most effective tool seemed to be the assignment of technical personnel by Sylvania. These men were needed at various times to make modifications to the hardware and software, and to perform necessary maintenance functions. Careful selection of the men plus close supervision resulted in a continuous two-way flow of information about the positive and negative reactions to the system, the hardware, procedures, and suggestions for changes and future applications. This free interchange of information at street level plus the active interest of some of the high-ranking members of the department contributed heavily to the successful completion of the project.

3.3 Scheduled Evaluation Periods

Five different phases of evaluation were planned to determine the effectiveness of increasingly sophisticated digital communications systems.

PHASE 1: DIGITAL STATUS MESSAGES MOBILE-TO-BASE

On March 22, 1970, an evaluation period using a limited capability of the digicom units was undertaken. During the test and integration period it became obvious that digital operation mobile-to-base without acknowledgment was not operationally feasible. Normal police operations require acknowledgment of all messages; noise on the channel invalidated some transmissions, and in the simplex system sometimes it is not possible to tell when someone else is on the channel. Level 1 was modified to evaluate status-only message capability but with base-to-mobile acknowledgment in the form of a digital 10-4. The evaluation period continued for 10 days and then the system capability was expanded.

PHASE 2: EXPANDED PRESET DIGITAL CODES MOBILE—TO—BASE WITH ACKNOWLEDGMENT

The significant difference between Phase 1 and Phase 2 is the type of equipment required at the base station. Level 1 could be implemented with nothing more than a status board that can be operated via a digital controller. Level 2 requires that some display exist for digital messages sent from the mobile unit. A printer or electroluminescent panel would be suitable. For evaluation, the video terminal described previously was used.

Operation at Level 2 for a short period revealed that the preset digital messages, other than status, were not used frequently enough to warrant separate evaluation. Phase 3 was implemented shortly thereafter.

PHASE 3: TWO—WAY SYSTEM USING PRESET CODES

Implementation of Level 3 requires that a data entry system exist for the dispatcher to send digital codes to mobile units. The mobile unit must be capable of receiving and displaying digital codes and a method of acknowledgment mobile-to-base must be supplied. In San Francisco, responses to license plate checks and want/warrant checks do not originate with the dispatcher; hence, a data entry point for the PIN/AUTOSTATIS operator was required.

3.3 (Continued)

Data was collected for 10 days during Phase 3 before proceeding to Phase 4.

PHASE 4: FULL TWO—WAY SYSTEM INCORPORATING DIGITAL LICENSE PLATE CHECKS

The ability to send California passenger vehicle license plates digitally was the most exciting aspect of the program. Success meant that it was feasible to provide the officer on the street with a direct link to large masses of computerized data bases.

To accomplish this requires an elaborate increase in equipment complexity. The mobile unit must allow entry and display of license plate numbers. At the base station the tasks involved in processing this type of request require a small computer for information transfer and processing.

Because of the sophistication of Level 4, data was collected for over a month before consideration was given to Phase 5.

PHASE 5: COMPLETE DIGITAL SYSTEM WITH DIGITAL CONTROL OF VOICE TRAFFIC

Requiring any field unit that wanted to make a non-emergency voice transmission to first send a digital 10-11 offered a method for complete control of the voice channel. Operationally, this procedure represented such a dramatic change in policy that it was not felt to be practical. Dispatchers have, over a period of years, operated in an aural environment and would have great difficulty changing over to a visual-aural environment. Field personnel accustomed to simply picking up the mike and transmitting would also have difficulty adjusting. Because of this and because of the enormous effort already made by everyone in evaluating the equipment, Phase 5 was abandoned and Phase 4 continued for the remainder of the period.

The availability of enormous quantities of data from the digicom system on magnetic tape provided a valuable foundation for evaluation of the program.

The next section briefly reviews the operation of the San Francisco Police Department Bureau of Communications.

4.0 OVERVIEW OF SAN FRANCISCO POLICE COMMUNICATIONS BUREAU

The Communications Bureau is responsible for coordination of the activities of the Police Department and other Public Safety Agencies. Specifically, the Bureau is tasked to provide:

1. Emergency and routine telephone answering of complaints from the general public.
2. Radio communication for the Police Department and other Public Safety Agencies (Department of Public Health, Harbor Police, etc.).
3. Telecommunications for the Police Department.

Five normal operating frequencies are available for police use and are assigned as follows:

Channel 1: Companies "F", "G", "H", "I" and certain unmarked cars from the Juvenile and Central Warrant Bureaus.

Channel 2: Companies "B", "C", and "D".

Channel 3: Traffic Units and Ambulance (D.P.H.).

Channel 4: Companies "A" and "E", Investigative Units, Headquarters Units, and Harbor Police Units.

In addition, the department operates special Crime Prevention (CP) units and a Tactical (Tac) unit which operate on the frequencies of the area they are working in.

Departmental call-signs and designators are as follows:

Unit	Spoken	Written
Central Station	"Central"	"A"
Southern Station	"Southern"	"B"
Potrero Station	"Potrero"	"C"
Mission Station	"Mission"	"D"
Northern Station	"Northern"	"E"
Park Station	"Park"	"F"
Richmond Station	"Richmond"	"G"
Ingleside Station	"Ingleside"	"H"
Taraval Station	"Taraval"	"I"
Traffic Bureau	"Traffic"	"K"
Inspectors Bureau	"Inspectors"	"Insp."
Juvenile Bureau	"Juvenile"	"Juv."
Headquarters Units	"Headquarters"	"HQ"
Crime Prevention Unit	"CP"	"C.P."
Tactical Unit	"Tac"	"Tac."
Headquarters Company (Patrol Division)	"Patrol"	"Patrol"
Central Warrant Bureau	"Warrant"	"W"

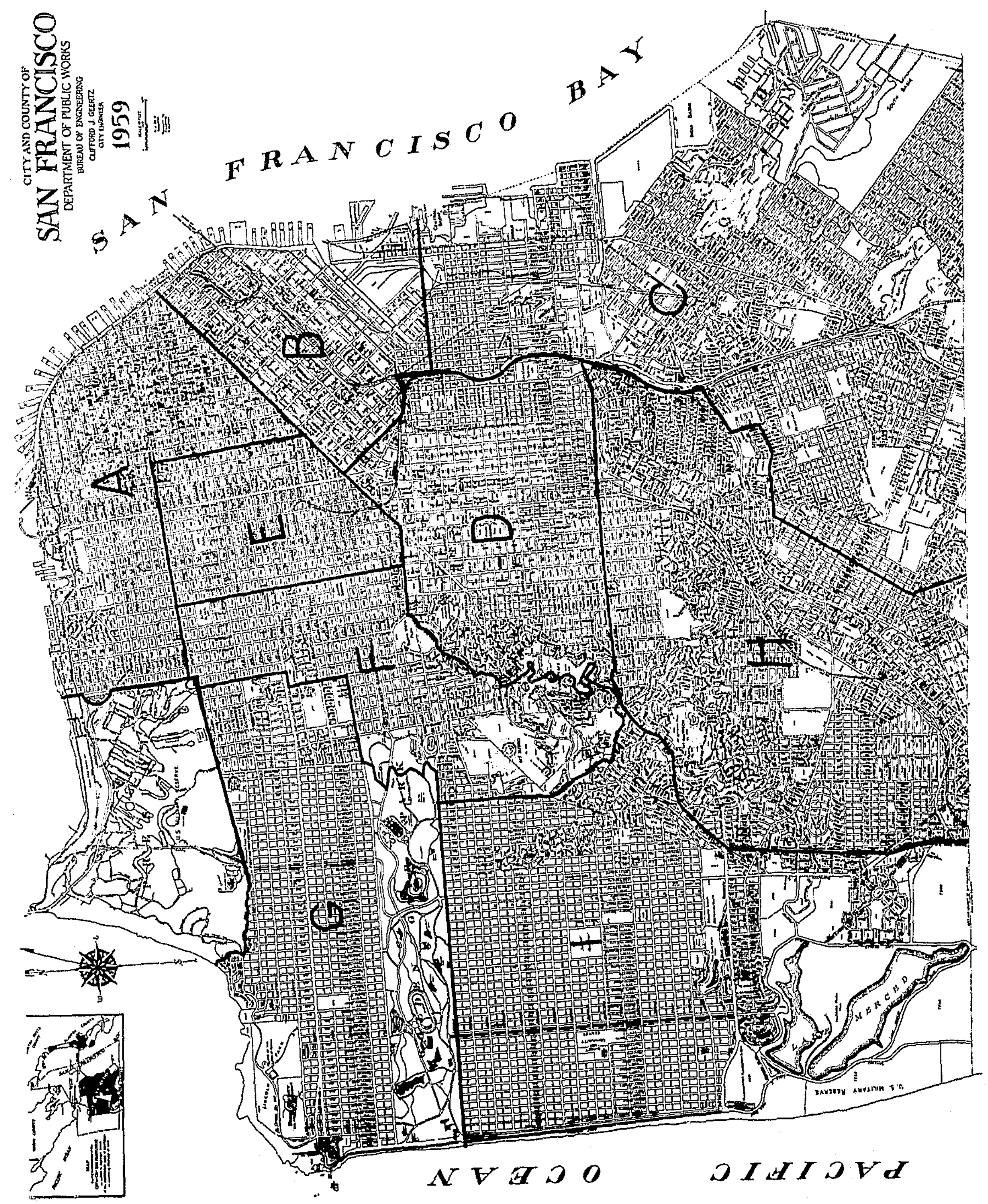

Figure 4-1. Geographic Area Coverage of San Francisco Police Districts

4.0 (Continued)

Figure 4-1 shows the geographic area covered by each station.

Patrol vehicles assigned to the stations are designated by the station prefix and a number to identify the unit. Thus, "Southern One" is "B1" written. In general, a Southern sergeant car is "B10", a Southern wagon is "B12", and a Southern "three-wheeler" is "B301", or "B302". Similar designations apply to other station cars.

Communications personnel perform a multitude of tasks including, but not limited to:

1. Answering telephone complaints from citizens.
2. Answering telephone calls from other departmental units; e.g., district stations.
3. Making telephone calls to support field personnel when radio requests require it.
4. Dispatching field units in response to telephone complaints.
5. Time stamping of complaint/dispatch slips associated with citizen complaints.
6. Time stamping and status board control associated with field unit activity.
7. Performing want/warrant checks through the PIN/AUTOSTATIS terminal.
8. Monitoring and responding to the alarm board display mounted on communications.
9. Performing identification checks through ID Bureau.

Personnel generally rotate between various stations. That is, a dispatcher may switch to answering the telephone at a complaint station. On some watches this procedure is not followed.

Operationally, it is important to realize that the dispatcher may actually answer the telephone and take a citizen complaint. Each dispatcher station has at least two different sets of phone lines or call directors. While on the telephone, it is difficult for the dispatcher to communicate via the radio channel with the field forces. However, it is sometimes necessary for him to do this — either because the telephone call is associated with field activity or simply to provide good service to the public.

Transmission of written data between complaint stations, dispatcher stations, and the PIN/AUTOSTATIS operator is accomplished via the archaic conveyor belt system found in many departments.

An officer in the field who wishes to run a 10-29 (check for wanted) on a vehicle transmits the license plate number to the dispatcher who writes it on a slip of paper and drops it on the conveyor belt. The conveyor belt transfers the paper to the COMPLAINT/PIN/AUTOSTATIS operator who enters it on an IBM Selectric terminal for accessing remote computer files. Sometimes the operator will be on the telephone which delays the request temporarily. The response from the remote files is printed on the Selectric and the operator transcribes it onto the original paper slip before dropping the slip back on the conveyor belt for transport back to the dispatcher.

4.0 (Continued)

Dispatcher and complaint stations are configured around a conveyor belt (Figure 4-2). Dispatcher stations are located at the left end and complaint stations at the right end. An older inadequate status map (Figure 4-2) is located at one end of the room and a newer status board (Figure 4-3) at the other end. The status board actually partitions the room, telecommunications being on the other side of it. Figure 4-4 is a close-up of two dispatcher positions and shows a bank of knobs that control the color lights on the status map and the color alpha-numerics on the status board.

The next section describes the digicom system as it was operated during the evaluation period.

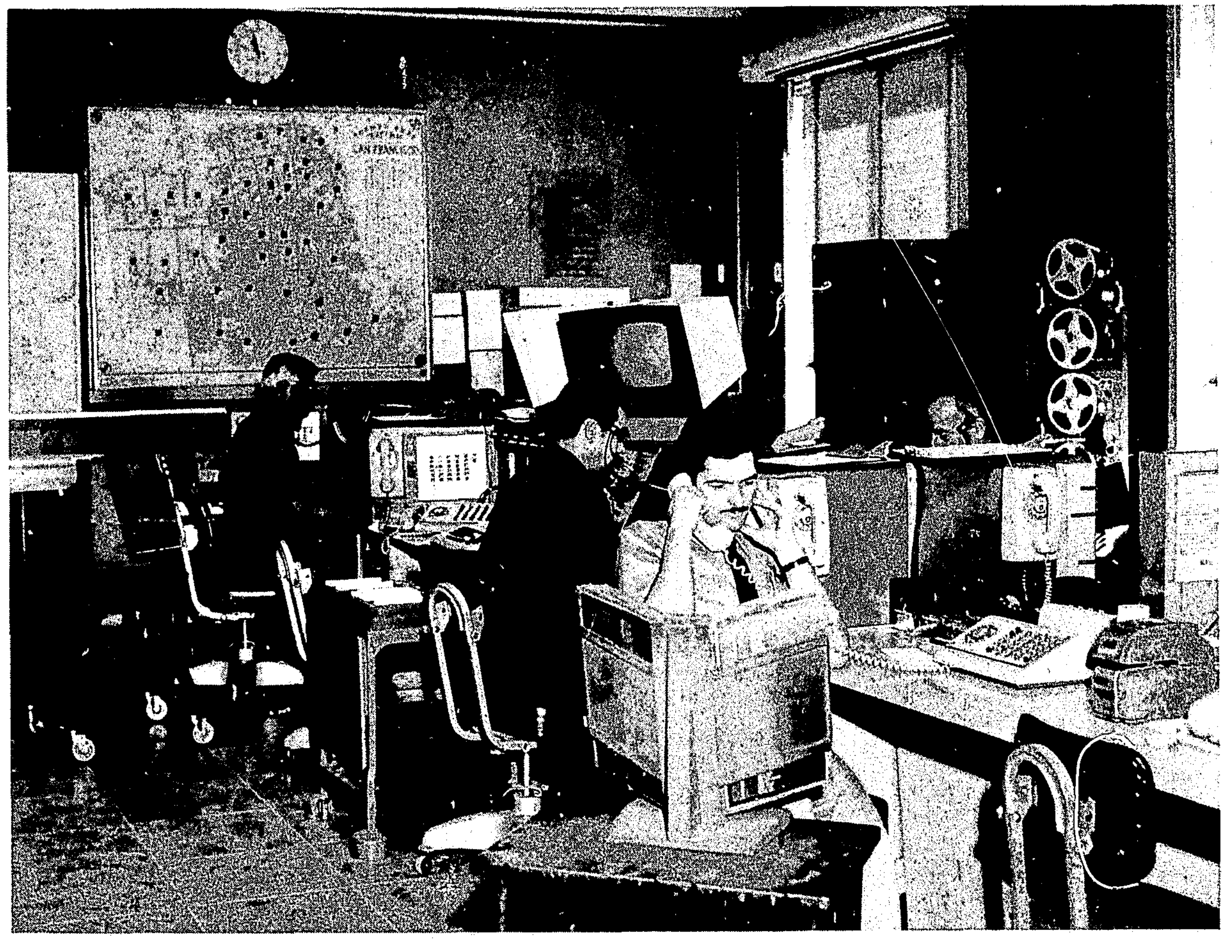

Figure 4-2. San Francisco Police Department's Bureau of Communication

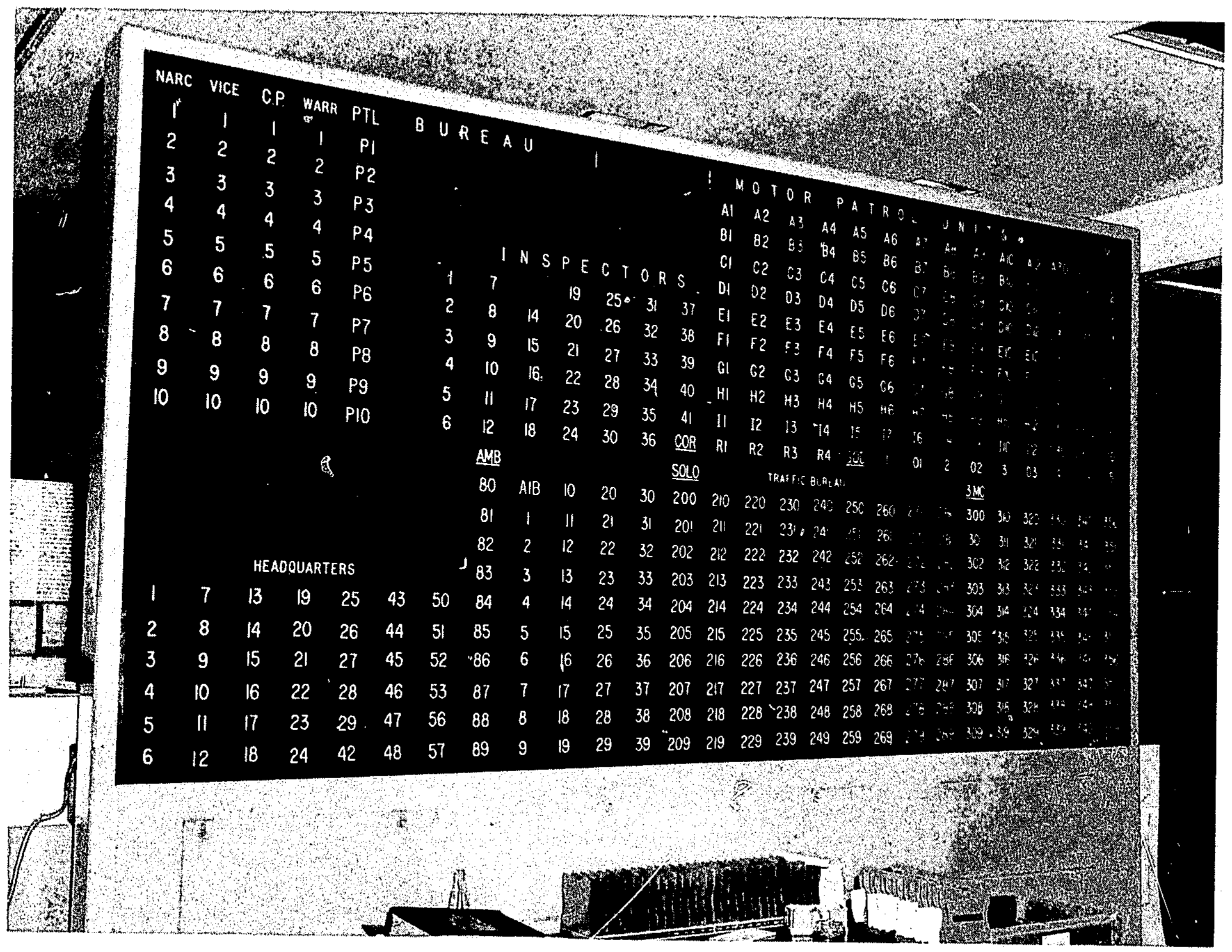

Figure 4-3. San Francisco Police Department Status Board

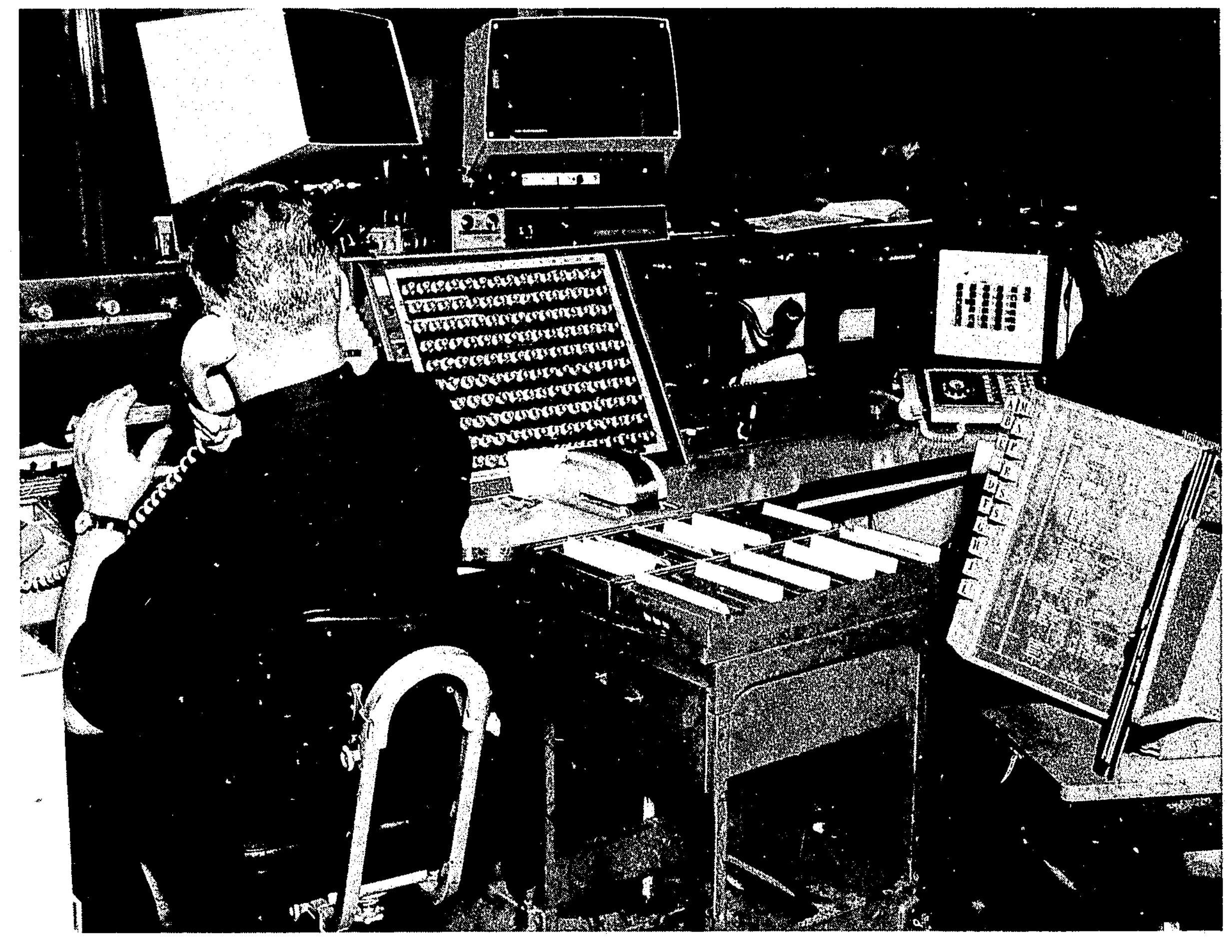

Figure 4-4. Communication Bureau Radio Dispatcher's Operating Positions

5.0 OPERATION OF THE DIGICOM SYSTEM

Figure 5-1 depicts the flow of digital information between the patrol vehicle, central communications, and the remote information files. Briefly, the officer in the field enters a digital message on the digicom unit and transmits it as a tone-coded burst over the voice channel to the base station. At the base station the information is decoded and entered into a computer which transfers and displays the digital information either to the dispatcher or to the PIN/AUTOSTATIS operator. Digital information from the base station is entered into the computer via a keyboard, which outputs it to the encoder for transmission over the voice channel to the patrol units.

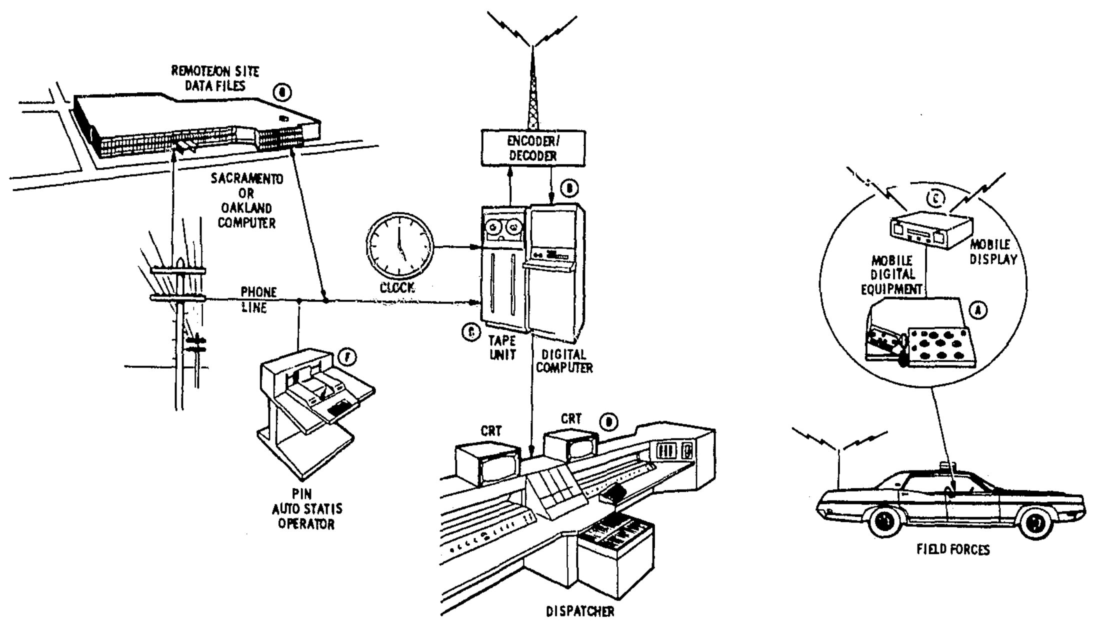

Figure 5-1. San Francisco Police Department Digicom System

5.1 Mobile-To-Base Operation

Essentially, there are two types of digital information that may be transmitted from the mobile units — digital radio codes and digital license plate numbers. For the first type, the officer dials a code selector to the desired position by observing an illuminated readout mounted on the dashboard of the vehicle (Figure 5-2). These prearranged codes are restricted to those used most frequently by the department, such as, in-service (10-8), out-of-service (10-7), message received (10-4), meals (10-7M), and others (Table 5-1). After selecting the appropriate code, the officer depresses the transmit button to transmit the digital message to the base station. Positive acknowledgment is provided because the computer sends a 10-4 (message received) immediately.

Figure 5-2. Digicom Vehicle Installation

5.1 (Continued)

The second type of digital transmission is that of a vehicle license plate number. The SFPD and many other law enforcement agencies have access to computerized banks of information regarding stolen vehicles (10-29s) and registered owner/vehicle description files (10-28s). Presently, these files are accessed via teletype or video terminal and phone lines at the request of field officers. Using digicom, the officer dials in each alpha-numeric of the license plate number by turning one of six dials and observing the appropriate position on the remote display (Figure 5-3). The dials enable a license plate number to be entered while the vehicle is moving as well as when it is stopped. After confirming that the correct license plate number has been entered, the transmit button is depressed. Again the 10-4 acknowledgment assures the sender that his message was received by the base station computer.

An additional capability was provided via software changes after the program had been underway for several months. When a shift changed or another patrol vehicle came on duty, it was necessary for the district station to notify the communications bureau what the new line-up was and what digicom unit was assigned to each vehicle.Typically, these line-ups were late in arriving and

Table 5-1. Digicom Coded Message Capability Mobile to Base

RADIO CODE	MEANING
10-7M	MEALS
10-8	IN SERVICE
10-7	OUT OF SERVICE
10-6	BUSY, IN RADIO CONTACT
CODE 4	NO FURTHER ASSISTANCE
406	OFFICER NEEDS HELP
407	SEND WAGON
408	SEND AMBULANCE
409	SEND TOW
1025	SEND BACKUP UNIT
1011	DESIRE VOICE TRANSMISSION
10-4	MESSAGE RECEIVED
10-96	TIMED LEAVE
LICENSE PLATES	10-29 (CHECK FOR WANTED)
TWO SPARES	?

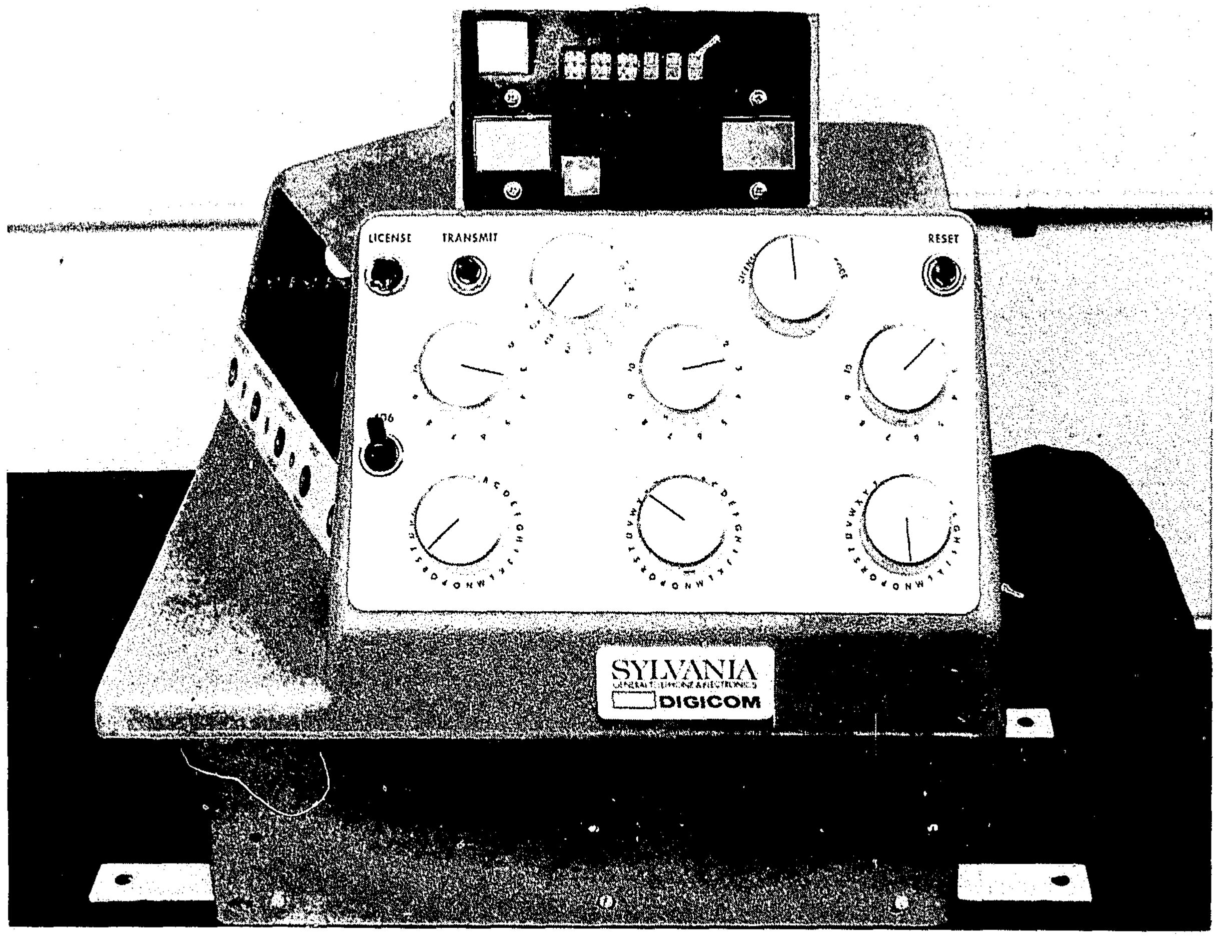

Figure 5-3. Mobile Digicom Units

5.1 (Continued)

sometimes contained errors. Even when a correct line-up was received, the dispatcher had to spend several minutes entering it into the computer memory. Incorrect line-ups meant that a unit would try to transmit that wasn't "on duty" and the dispatcher alerted by the computer would have to determine what unit should be put on duty. The solution to this problem resulted in a powerful new capability in digital communications.

When an officer comes on duty or goes off duty, he uses the license plate mode to inform the computer of the change. For example, when coming on duty he dials a U for UP and his unit designation. A Southern 5 car designated B5 would dial U—B005 on the license plate readout and transmit this to the base station. Similarly, when going off duty (Down) he dials D—B005. If an officer forgets to go off duty, then when a new unit comes on duty with the same digicom unit, the other designation is automatically removed. Two units both attempting to use the same designation are called to the attention of the dispatcher.

5.2 Base Station Operation

The focal point of all activity at the base station is the minicomputer system (Figure 5-4). Starting from the lower right-hand side of the rack, the system consists of an air filter, digital encoder/decoder, computer power supply, Hewlett-Packard 2115A computer, time-of-day digital clock, and CRT controller. The left-hand part of the rack contains a digital tape recorder and control unit.

Digital messages transmitted to the base station are decoded and entered into the minicomputer. The computer checks each message for errors, determines the identification of the field unit sending the message, automatically sends a 10-4 (message received) to the vehicle, and acts as a message-switching network. Messages for the dispatcher are displayed on a video terminal (CRT) (Figure 5-5) and license plate numbers are routed around the dispatcher to the access terminal.

At the dispatcher position, digital status messages (10-6, 10-7, 10-7M, 10-8) are displayed on the CRT adjacent to the vehicle designator. No voice transmissions are required and card minders, buttons, knobs, etc., need not be manipulated by the dispatcher to change the color of light bulbs on a remote status board. The addition of the 10-6 status (in vehicle, busy) means that at a glance, the dispatcher knows whether or not a particular patrol unit can be reached via voice communication. This eliminates time-consuming, channel-crowding transmissions by the dispatcher when he is trying to find an available unit. Two other "status" messages may appear in the status column, 1096 (timed leave) and 406 (officer needs help). Upon leaving the vehicle to investigate a suspicious person or scene, the officer may go 1096. If 5.5 minutes elapse (timed by the computer) without an over-riding status change (10-6, 10-7, 10-7M, 10-8, 406) the line on the CRT corresponding to that vehicle is flashed and an audible alarm is sounded. This feature, in addition to reducing voice transmissions, further reduces the workload on the dispatcher and provides the officer in the field with additional security not otherwise available. Transmission of a 406 is accomplished by flipping a toggle switch and depressing TRANSMIT which causes an alarm to go off and the appropriate light to flash on the CRT.

Although it was not a specific objective of this study to automate any of the dispatcher decision processes, one minor task was semi-automated. The decision on whether or not an officer should take a meal break is handled by the computer if possible. An officer requesting 10-7M receives a 10-4 if no other unit in that district is 10-7M or if those units that are 10-7M have been 10-7M for more than 35 minutes of their alloted 45-minute meal break. If neither criterion is met, the dispatcher is alerted by transferring the message to the "mobile message in" columns on the CRT (Figure 5-6) and the computer sends a 10-23 (standby) to the unit. This capability can be eliminated during critical periods if desired — the mobile unit always receives a "standby."

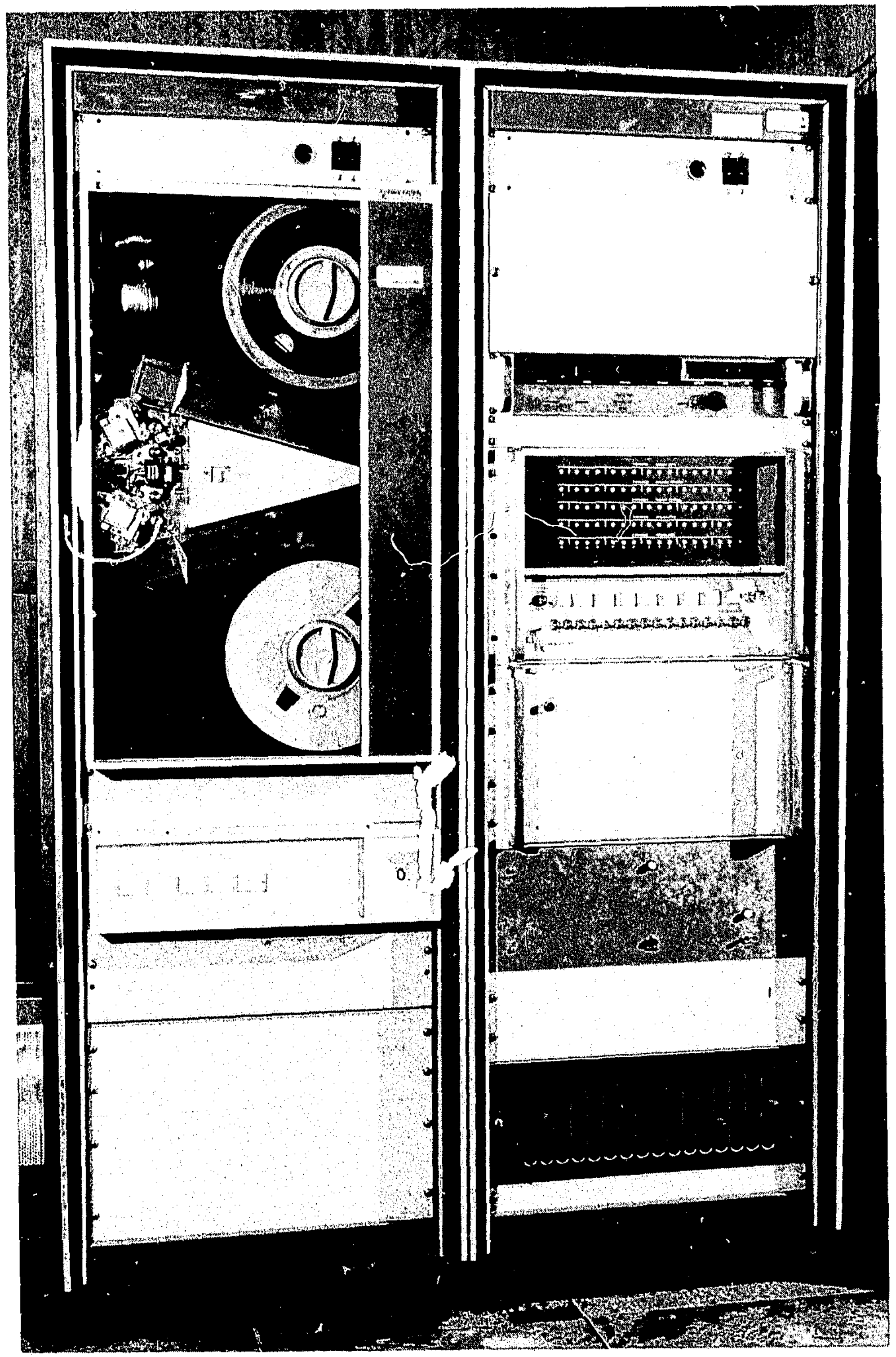

Figure 5-4. Minicomputer System

Figure 5-5. San Francisco Communications Center Showing Digicom Installation

5.2 (Continued)

Digital requests for a tow (409), wagon (407), ambulance (408), and others (Table 5-1) are displayed on the CRT in the "mobile message in" column with the time they were sent. The dispatcher can determine the availability of services and alert them before initiating voice transmissions. If a second digital message (other than status, license plates, or 10-11) is sent before the first one has been acted upon by the dispatcher and removed from the screen, an "M" appears on the CRT in the left-hand margin. The "M" for multiple message alerts the dispatcher to the situation without writing over the existing message.

Complete control of non-emergency voice traffic is provided with the digital 10-11 — desire voice transmission. Any officer wishing to transmit to the base station by voice first sends a 10-11. The computer stacks them in the order they are received and displays the first one ("P") on the CRT in the left-hand margin adjacent to the unit designator. After the dispatcher contacts the unit, he clears the "P" and the computer puts the next one on the screen and so forth. Voice traffic is further reduced and the system is under complete control. Should unauthorized persons attempt to transmit under this condition, they can be easily identified.

CRT UNIT

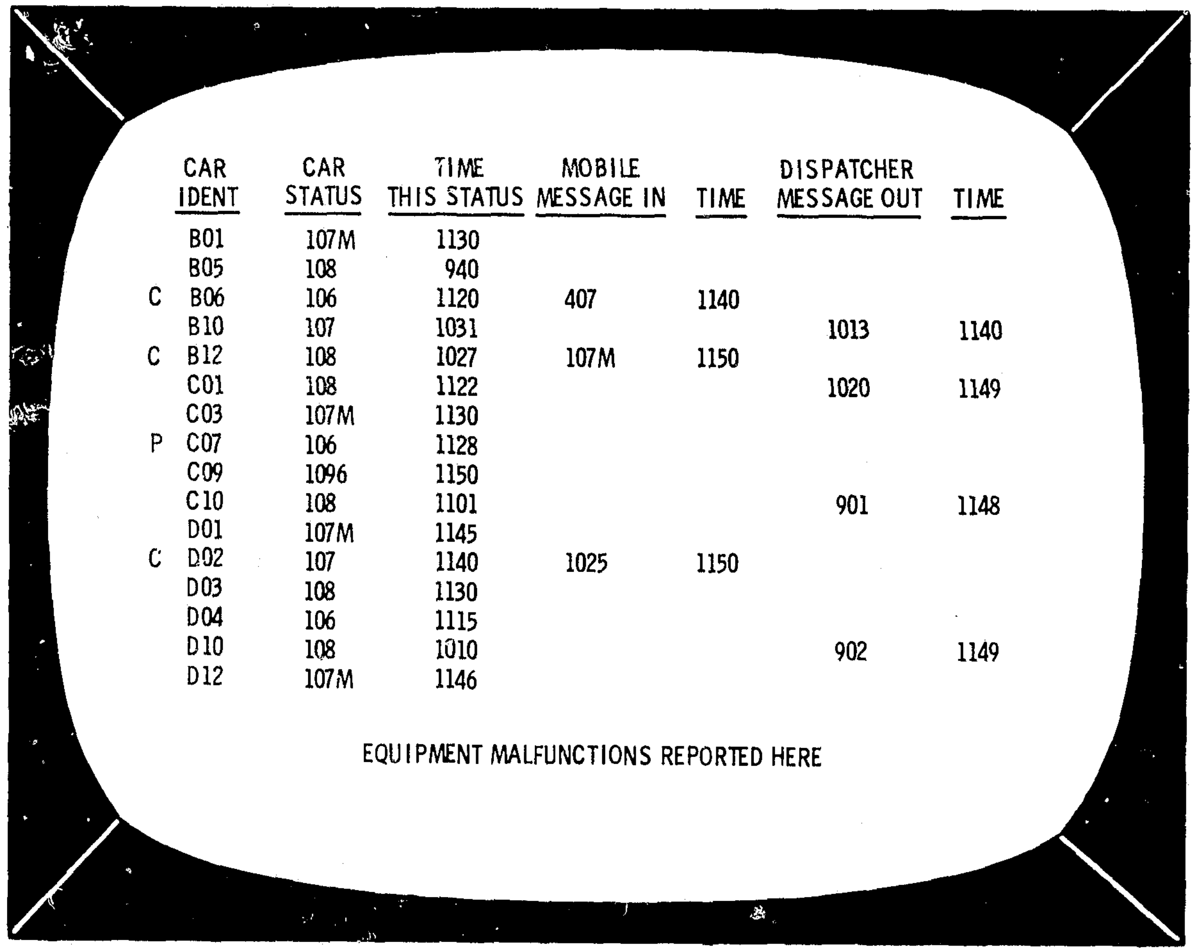

Figure 5-6. Base Station CRT Display

5.2 (Continued)

Although the dispatcher using the digicom system is not directly involved in a license plate check (10-29), it is important for him to be aware of all activity. When a license plate number is received, an "L" appears in the left-hand margin adjacent to the unit designator. The digital response to the check, 10-30 (wanted), 10-32 (clear), appears in the "Dispatcher message out" columns with the time the message was sent out (Figure 5-6). A digital 10-4 (message received) from the officer clears the "dispatcher message out" column, time column, and removes the "L" from the left-hand margin. No action is required by the dispatcher unless the unit fails to acknowledge the response. This would indicate that something may have occurred that requires the dispatcher's attention anyway.

5.3 Base-To-Mobile Operation

In the second mode of operation, the dispatcher can send digitally a number of preset radio codes. Call your station (901), report your location (1020), and others (Table 5-2) are sent via a keyboard located at the dispatcher station. The message is displayed in the patrol vehicle on a

Table 5-2. Digicom Coded Message Capability Base to Mobile

RADIO CODE	MEANING
10-4	MESSAGE RECEIVED
901	CALL YOUR STATION
902	RETURN TO YOUR STATION
410	ASSISTANCE RESPONDING
10-22	CANCEL ASSIGNMENT
10-13	ADVISE CONDITIONS
10-20	REPORT LOCATION
10-30	WANTED
10-31	RECORD
10-32	CLEAR
10-99	SACRAMENTO DOWN
10-23	STANDBY

5.3 (Continued)

readout similar to the one used to display preset codes sent by the officer. Responses to license plate checks, want/warrant checks, gun checks, etc., that do not originate with the dispatcher are displayed on this same readout. Outgoing messages are displayed on the dispatcher CRT in the "dispatcher message out" column until a digital 10-4 (message received) is sent by the appropriate field unit. Receipt of the "10-4" clears the column providing positive acknowledgment without voice communications. Messages may be sent while the officer is away from the vehicle if the radio is on.

5.4 Management Information

The availability of digital information allows the computer to perform functions that can not be done by an already over-burdened dispatcher. In responding to an assigned run, an officer enters his status as 10-6, when he arrives at the scene he enters a digital 10-7 (out-of-service) and when he returns to service goes 10-8. The receipt of a 10-6 initializes a timing subroutine that counts down for 10 minutes and then shows the unit "OVER DUE" on the CRT if a digital 10-7 is not received prior to the expiration of the 10-minute period. The 10-minute period can be varied but was found to be adequate for most assignments in San Francisco. A similar routine times meal breaks (10-7M) and out-of-service (10-7) periods. Failure to enter a digital status before the time limits of 45 minutes and 30 minutes are up results in the unit being shown "OVER DUE" on the CRT.

Proper use of this type of information assures the department that they are providing adequate and efficient response to citizen requests for service. Minimizing out-of-service time also means better overall availability of field forces.

Another important secondary benefit is available with a digital system. Each digital transmission is stored on magnetic tape (Figure 5-4). Analysis of this tape off-line at periodic intervals can provide valuable supervisory information and planning information. Time-consuming coding and keypunching are eliminated and more accurate data is available.

5.4 (Continued)

The temporal distribution of status changes can be reassembled by the computer to provide detailed data on the operation of field forces. Units that are found to be out-of-service for excessive periods of time or taking lengthy meal breaks can be identified. Comparisons of aggregate out-of-service times between districts provides the information needed to realign deployments of field personnel. Travel times are identified with the "10-6" status and can be used together with additional data to reassign field forces within a district if excessive travel times are observed.

6.0 EFFECTIVENESS OF DIGITAL COMMUNICATION FOR LAW ENFORCEMENT

Each of the project goals identified previously is discussed in detail in the following sections. Whenever appropriate, comments are amplified with quotations taken from a tape recording of the radio channel 2 traffic on Friday, 26 September 1969 between 10:00 p.m. and 11:30 p.m. The period picked was felt to be relatively busy but was not singled out for any other reason except that it was prior to the installation of any digital equipment.

6.1 Digital Communication Reduces Channel Congestion

Digital messages sent during project digicom replaced messages previously sent by voice. Because digital messages require less air time than do voice messages, channel congestion is necessarily reduced.

Channel congestion depends on the number of cars, wagons, special squads in the field, time of day, day of week and in particular on the activity that occurred on that day. Two week day periods with a similar number of units in the field do not particularly resemble each other with respect to channel congestion (Figure 6-1). The major reason for this is the type of activity that was prominent during busy periods. Robberies in progress, hot chases, crowd control, etc., tend to cause very heavy radio traffic because of the coordination of field units required.

The impact of digicom in reducing channel congestion was estimated by converting the average time required to make a comparable voice transmission and superimposing it on the graphs. To an extent, this is a conservative estimate because it does not account for repetitions, which generally occur. On Figure 6-1 the upper line shows what the estimated congestion would have been without digicom. Over the 48-hour period (1700—1700) the estimated reduction is 16.8%. This does not allow for the proportion of vehicles that were operating without digicom equipment. Some of the regular patrol vehicles and sergeant cars, all wagons and all motorcycles were not equipped with digital units. In addition, several crime prevention units were operating in the area and they typically use large segments of channel time. Examination of the records showed that 65 to 75% of the vehicles operating during the two-day period were equipped with digicom units. To correct for this situation, we note that the observed utilization level for the 48-hour period was 0.25 and corresponds to 65-75% digicom and 25-35% non-digicom. Had all the operating units been equipped, the observed utilization would have been less than 0.25 but the predicted level would remain nearly the same at 0.3, assuming the estimating method is valid. The simplest correction would be to assume linearity and multiply (100/75) · 16.8% and (100/65) · 16.8% to obtain a corrected estimate of 23 to 26%. The corresponding level of utilization would be expected to be 0.23.

Another way of estimating the reduction in channel congestion involves building a model of the communication channel with and without digital communication. Figure 6-2 illustrates the results of developing such a model. Utilization is the amount of air time used divided by the total available air time. The digitalization level is the percent of voice traffic that is replaced by digital traffic. Thus, if status changes account for 15% of the messages sent but account for less than 10% of the actual air time, the digitalization level would be 10%. Digicom represents a digitalization level of approximately 20% in San Francisco. Departments having more than four possible statuses and running more than two license plate checks per car per shift would have a correspondingly higher digitalization level.

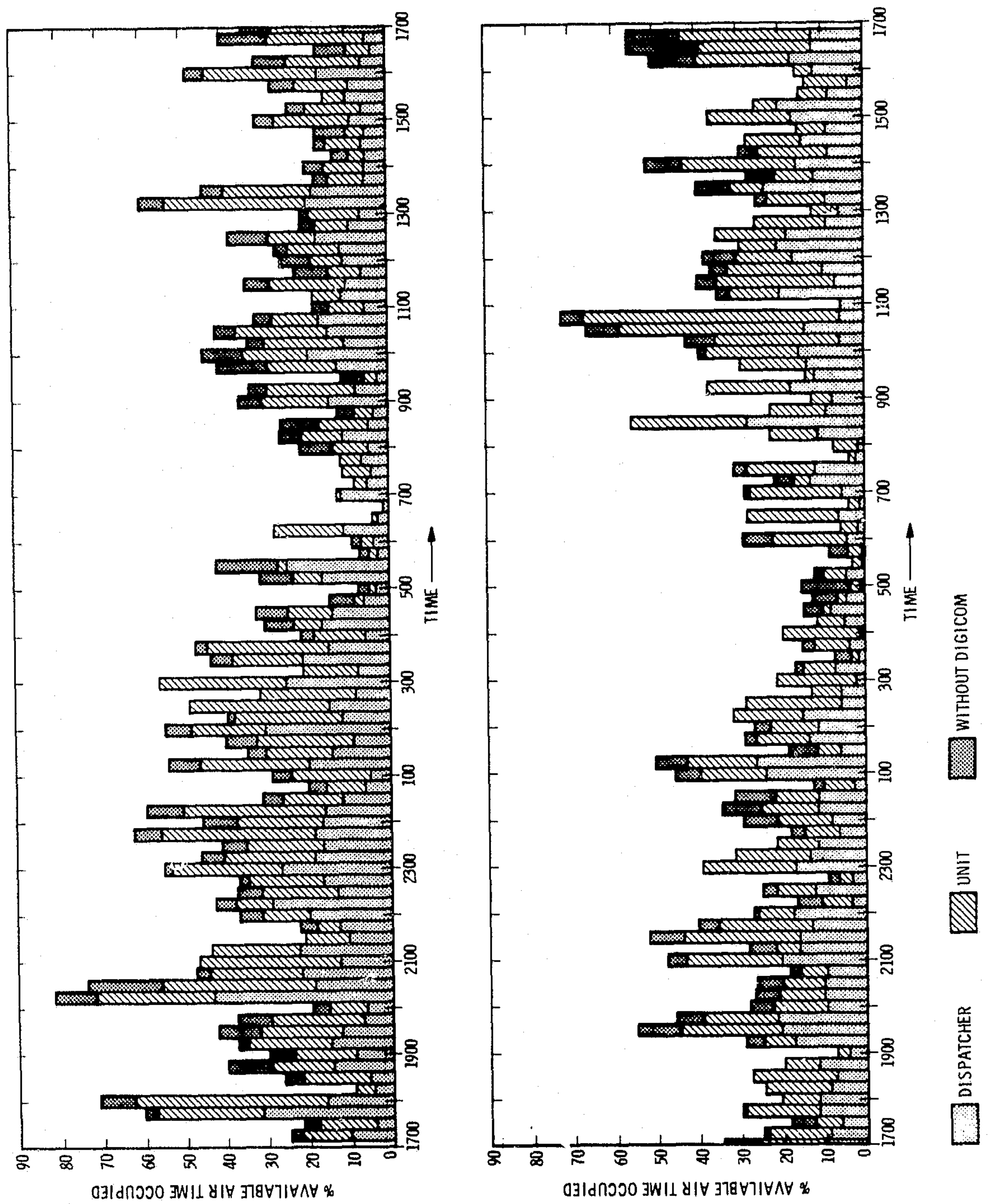

Figure 6-1. Comparison of Channel Congestion for Two 24-hour Periods

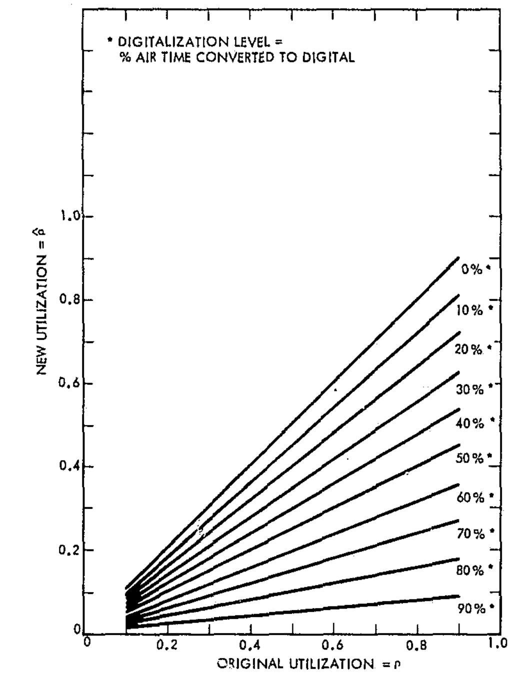

Figure 6-2. Effect of Digitalization Level on Channel Utilization

6.1 (Continued)

Using the figure of 20% digitalization for digicom, we see from Figure 6-2 that a 17-20% reduction in utilization is expected. Higher digitalization levels correspond to increasingly sophisticated equipment. For a more detailed discussion of the model and the results, refer to the next section of this report.

The above figures and estimates do not give an adequate picture of the impact of digital communication on channel congestion. Real time status information available with digicom eliminates message segments other than the status message. Consider the message segments taken from the September 26 tape. H = Headquarters; U = Field Unit.

Time	Source	Message
2221	H:	Potrero Three
	H:	Headquarters to Potrero Three
2225	H:	Potrero Three
	H:	Headquarters to Potrero Three
	U:	No Three Car This Watch
	H:	10-4
	H:	Potrero Two
	H:	Headquarters to Potrero Two

6.1 (Continued)

Time	Source	Message
2226	H:	Potrero Five
	H:	Headquarters to Potrero Five
2227	H:	Potrero Five
	H:	Headquarters to Potrero Five

2236	H:	Potrero Five
		Headquarters to Potrero Five

Each of these messages would not be necessary if the correct status of the units were known by the dispatcher. Unlike the status board with two or three lights for status, digicom permits any number of statuses including on and off duty. The dispatcher always knows whether or not an officer can be reached via radio and always knows what units are on duty!

Message segments not related to status are also sent unnecessarily. For example:

Time	Source	Message
2129	U:	Mission Five
	H:	Mission Five
	U:	Is that tow coming for this 1030 auto?
	H:	Sending it now
	U:	Will you 10-9 please?
	H:	Sending it now
	U:	10-4

2140	U:	Southern Two Headquarters
	H:	Southern Three
	U:	That's Southern Two Headquarters
	U:	Can you ascertain whether or not a tow is responding and if it isn't, could you get us another one please
	H:	10-4
2141	H:	Southern Two Tow on the way
2142		
2143	H:	Southern Two do you copy tow on the way?

6.1 (Continued)

Time	Source	Message
2155	H:	Potrero One 902
	H:	Potrero One 902
	U:	Potrero One 10-4

2221	H:	Southern Two 901
	H:	Southern Two 901

No response heard on the tape.

Using digicom tow requests, wagon requests and ambulance requests are sent digitally. When location is not known by the dispatcher, it is given by voice but the request is still digital. The digital request is displayed on the CRT serving as a visual reminder to the dispatcher. When the service request has been obtained, the dispatcher clears the CRT and sends a digital 410 (requested assistance responding). Again, a number of voice transmissions related to the request are eliminated using digital communications. Similar considerations apply to the 901 (call your station), the 902 (return to your station), and other digital base-to-mobile codes.

6.2 Digital Communication Reduces Dispatcher Workload

The message segments described above were eliminated with digicom. Time the dispatcher formerly spent in responding to these message segments and requests represents a reduction in the work performed by him.

Status changes which required the dispatcher to find the appropriate dispatch slip, time stamp it, and rotate a knob to update the status board/map are almost completely automated. Meal changes and on-view investigations still require that the dispatcher write down the location, but the remaining functions are automated.

Occasionally, the radio will be off when a digital message (901, 902, etc.) is sent to a unit. Eventually, the dispatcher would become aware of this because the message would remain on the CRT for lack of a 10-4. A minor modification to the present system would enable the computer to send the message again if a status change is received but no 10-4 acknowledgment has been sent from the mobile. The dispatcher would no longer have to re-send the digital message which would further reduce his workload.

The most significant workload reduction for the dispatcher is associated with the digital 1029 license plate check. Digicom eliminates the voice traffic associated with the request and response and eliminates writing the request down. Again, a segment from the voice tape amplifies this point:

Time	Source	Message
2148	U:	Southern Three to Headquarters
	H:	Southern Three go ahead
	U:	License Victor Ocean Eight Six Five Nine Copy?

6.2 (Continued)

Time	Source	Message
	H:	Coming in too weak. Can't hear you. Try it again.
	U:	License Victor Ocean 8659
	H:	What state
	U:	California plates
	H:	10-4
2149	U:	Southern Three to Headquarters
	H:	Southern Three
	U:	Ah, there is a correction on that license plate, it is Victor Ocean Harry 659
	H:	10-4

2151	H:	Negative Southern Three
	U:	Southern Three 10-4

This is not an isolated example peculiar to San Francisco. San Jose has similar problems, as examples from the December 1968 tape illustrates.

Time	Source	Message
1922	U:	San Jose 1 15B 10-8 a 10-29 Adam Xray Zebra Five Three Zero
	H:	That number is
	U:	10-9
	H:	The numbers only
	U:	Five Three Zero
	H:	10-1

1926	H:	B15B Adam Xray Zebra Five Thirty Clear
	U:	B15B Check

	U:	San Jose 1 B21 clear on my 10-29?
	H:	Stand by B21
	H:	B21 David George Lincoln 183 Clear

6.2 (Continued)

Time	Source	Message
2347	U:	San Jose 1 19A a 10-29 Charles William John Zero One Two
	H:	B-9 you have to say again you were covered. I have 2800 block but I don't know the street
	U:	San Jose 1 19A
	H:	19A
	U:	10-29 Charles William John Zero One Two
	H:	19 vehicle is clear
2348	U:	B 19A 10-29 on Charles William George Zero One Two
	H:	Ah 19A for the third time that vehicle is clear
	U:	19A 10-4, sorry.

In addition to eliminating all voice traffic and writing associated with these 10-29s, digicom reduces the possibility of transmitting an incorrect license plate number. An officer making a 10-29 observes the license plate number visually before transmitting it and is unlikely to miss the obvious error, such as VO, 8659, because most California plates are three alpha characters followed by three numerics or vice-versa. Repetitions are unnecessary and the return response need not be repeated.

6.3 Digital Communication Offers Added Personal Security

San Francisco uses a 10-96 radio code which allows an officer to leave his vehicle to investigate a suspicious situation with added security. If the officer is not heard from in five minutes, a cover unit is dispatched. The load on the dispatcher has prohibited the use of the 10-96 except during very special situations. Digicom permits the 10-96 to be used whenever an officer feels it would be desirable. If a status change is not received before 5.5 minutes is up, the dispatcher is alerted by flashing the appropriate line on the CRT and sounding an audible alarm.

During the digicom project, the 10-96 was seldom used. A meeting with field personnel revealed why this was the case. First, a number of men complained that the five-minute period was too long or too short. Second, one of the men who had used the 10-96 indicated that it was treated as a 406 (officer needs help emergency) by the dispatcher. This was embarrassing to him because he simply had not had time to return to his vehicle and send a new status. There was also some evidence that going 10-96 was considered "sissy" by the men.

Modifications to the equipment would permit a variable time to be entered on the 10-96 from the vehicle. A strict understanding of the meaning of 10-96 would eliminate the 406 response problem. Used properly, the digital 10-96 offers added personal security, especially when one-man patrol cars are used extensively.

A digital 406 was also provided with digicom but its only use came as a result of an accident caused by someone unfamiliar with the equipment. However, 93 percent of the men surveyed did not want the digital 406 eliminated and most were impressed with the way it worked.

6.3 (Continued)

The greatest improvement in personal security is a byproduct of digital 10-29s. Because digital 10-29s do not require large amounts of valuable air time, and do not require a dispatcher's involvement, they can be run on a routine basis. Turn-around time--the time between inquiry and response--is reduced to 20-35 seconds (or less depending on machine location and configuration). Together, these two factors mean every license plate can be checked and a response obtained before the officer leaves the vehicle.

6.4 Digital Communication Increases Efficiency in Command and Control

Examples previously cited under dispatcher workload also impact on command and control. Digital transmission of 901, 902, 1020, etc., improves overall efficiency. Eliminating the routine work of the dispatcher allows him to deal more effectively with voice traffic and dispatchers. Reduced channel congestion improves the efficiency of the field personnel in transmitting information requests and on-view investigation data to the dispatcher. Current status available at the dispatcher position enables him to make correct dispatching assignments. Correct assignments reduce travel time; thus increasing overall availability. Knowledge (available at a glance) of the time a unit changed status means that some calls can be held if they are of low priority and a unit that is close by is expected back in service shortly.

Departments can assign reasonable time periods to each status. When a unit stays in a particular status for a period which exceeds the specified limit, the computer alerts the dispatcher that the unit is "OVERDUE". This is the equivalent of an automatic "safety check" and provides supervisory personnel with the information needed to minimize out-of-service time. During periods of peak activity, it is important to minimize out-of-service time to increase unit availability and maintain good overall responsiveness to requests for service.

6.5 Digital Communication Simplifies the Routine Operations of Radio Car Operators

Status changes which previously required the radio car operator to contact the base station by voice are now accomplished by rotating a dial and pushing a button. Immediate confirmation of the status change is assured because the system is under computer control. This procedure simplifies status changes, especially during peak activity periods where standby time may be large for voice transmisssions.

Mobile requests for tows (409s), wagons (407s) and ambulances (408s) are simplified because, once a request is sent, the officer may leave the vehicle if desired with confidence that his request is visually displayed to the dispatcher and when the assistance is obtained he will receive a digital 410. Repeated call-ups to determine the status of the requested assistance are eliminated.

License plate checks (10-29s) are entered via six rotary dials described previously. The effort required to do this probably exceeds the time required to make a voice transmission. However, errors and repetitions are reduced which tends to simplify the overall operation. The response to the 10-29 on persons and vehicles is digital which eliminates the requirement to stay in radio contact for an unknown period waiting for a response.

San Francisco normally runs about 300 10-29s per day city-wide. During the month of January before installation of digicom, a total of 9579 checks or an average of 309 per day were run. During the month of April, they averaged 374 per day and during May they averaged 372 per day. These figures represent a 20% increase city-wide. Allowing for the fact that digicom only operates on one radio channel and in only 65-75% of the vehicles, this probably represents an increase in 10-29s of nearly 100% on radio channel 2. Obviously, the men in the field consider it much easier to run 10-29s with digicom than without.

6.6 Digital Communication Increases Information Throughout Without Increasing Channel Congestion

One of the more significant characteristics of digital communications is the ability to send greater amounts of information without increasing radio channel congestion. There are 28,800 seconds in an 8-hour shift. A 50 car channel using voice status changes of three seconds duration and making 30 changes per car per shift would use 16% of the available air time. Three hundred cars equipped with digital communication devices for status only would require less than 15% of the available air time.

License plate checks presently average 20 seconds of air time. A fifty car channel averaging four checks per car per shift would use 14% of the available air time. Equipped with digital devices, the same fifty cars could run 80 checks per shift/car for the same 14% of air time.

These simplified calculations ignore the effect of normal voice traffic on channel congestion. Present channel congestion probably prohibits running as many as four 10-29s per car per shift by voice. Digitally, they can easily be run and require less than 1% of the available air time.

6.7 Digital Communication Improves System Responsiveness

A digital system operating under computer control minimizes the turn-around time. During busy periods, this is of particular significance. Consider the following tape segments:

San Francisco Tape

Time	Source	Message
2143'30"	H:	Southern 1
35"	U:	Potrero 1
38"	H:	Potrero 1
43"	U:	Potrero 1 10-8
45"	H:	Potrero 1 10-8

2209'09"	U:	Mission 5 10-8
13"	H:	Mission 5 10-8

San Jose Tape

Time	Source	Message
1916'40"	U:	B11A San Jose 1
50"	U:	B11A San Jose 1
1917'01"	U:	11B San Jose, 11B
33"	-	Traffic from other units
1918'45"	U:	B11A 10-8 (cut off other units)
47"	U:	Miscellaneous traffic
52"	U:	B11A 10-8
1919'00"	H:	11A Check
02"	U:	11B San Jose
10"	-	Miscellaneous traffic on channel

6.6 (Continued)

Time	Source	Message
1920'05"	H:	B3 a welfare check on 11B First & Julian
09"	U:	B3 10-4
11"	-	Miscellaneous traffic
20"	U:	B11B 10-8
22"	H:	11B check
45"	H:	B3 your call 10-22
48"	U:	B3 10-4
1921'00"		

On the San Francisco tape it is taking 4-7 seconds to change status. On the San Jose tape it took B11A over 2 minutes to change status. The B11B unit took almost 4 minutes to change status and a "welfare check" was started in the interim. Under digicom, these changes could have been accomplished in less than 1 second.

Any digital inquiry receives an immediate 10-4 acknowledgment. The computer monitors the voice lines also, and should a voice transmission be initiated simultaneously with a digital transmission, the computer waits for the voice transmission then sends the digital response. This is accomplished so quickly (milliseconds) that even if additional voice transmissions are made immediately (human reaction time), the digital response fits between them.

Digicom reduced the turn-around time on 10-29s from several minutes to less than 35 seconds on the average. Although the limited funding available did not permit a direct connection of the digicom system to the remote computer files (PIN/AUTOSTATIS) in Alameda County and Sacramento, it could be done under a permanent installation. Turn-around time would then be reduced to that realizable on the given machine configuration. Remote files that are accessed via telephone lines and serve agencies state-wide would typically have a 10-30 second turn-around times. On-line files controlled by the police department could produce turn-around times of less than three seconds.

Increased responsiveness means less standby time by the officer in the field. Decreased standby time decreases out-of-service time. Prompt pertinent information supplied to the officer in the field increases overall effectiveness and provides added personal security. Citizens who are detained while an officer waits for the response are likely to complain.

6.8 Digital Communications Supports MIS

Information received in a digital system and written on magnetic tape is valuable in supporting police management information systems (MIS). Typically, police departments do not collect data and/or do not have the resources available to analyze data relating to the service level they provide. The sequential data on status changes can be reassembled on an off-line computer system to monitor response times, out-of-service times, in-service times and general unit availability (Tables 6-2 through 6-6).

As an example of how this information can be used, consider the results of one week's data in San Francisco. The Southern 1-4 cars, Potrero 1-5 cars, and Mission 1-6 cars were grouped to produce the results for Southern (B), Potrero (C), and Mission (D) (Table 6-1) districts. The period covered is 1130 May 26 to 1120 June 2, 1970.

Table 6-1. Status Change Data for 1 Week*

Status	Mean			Standard Deviation			% Total Time		
	B	C	D	B	C	D	B	C	D
10-6	6.9	10.2	8.6	6.8	7.8	7.3	10	16	17
10-7	22.0	25.1	22.4	16.4	16.6	15.8	29	32	34
10-7M	42.0	45.4	46.0	6.0	6.4	5.4	11	15	14
10-8	23.0	16.9	15.9	31.0	32.6	29.8	50	37	35

6.8 (Continued)

The Potrero District, which covers the largest geographical area, has the largest mean time 10-6. In general, 10-6 is associated with travel and this result would be expected because secondary units and cover units would have to travel farther on the average. Southern appears to be a balanced district in that 10% of the total time is spent 10-6, 29% 10-7 (out of service), 11% 10-7M (meals) and 50% 10-8 (in service). It is generally recognized that 50% in-service time is required to maintain good responsiveness in an area. Potrero with 37% availability and Mission with 35% availability spend 16% and 17% of their time 10-6, respectively. These figures indicate that both the Potrero and Mission districts are short on manpower. One additional man assigned to each district for the seven-day period would raise the availability figures to approximately 46% (Potrero) and 40% (Mission). A total of three additional men would have to be assigned to the Mission District to reach an overall 50% availability.

The same data can be examined for each shift and by day of the week to determine exactly where manpower deficiencies exist. Because the data is automatically collected in a computer-compatible form, it is easily examined on a continuous basis to improve manpower utilization and maintain good system responsiveness. Inequities which lead eventually to morale problems can be isolated and corrected.

Data collected city-wide over long periods of time can be used to quantify the need for manpower. Rather than citing a general increase in the crime rate as justification for manpower requests, exact data on manpower utilization can be presented to justify the request. Furthermore, it is simple to calculate exactly the magnitude of the deficiency.

*Figures do not include 10-6 if greater than 30 minutes, 10-7 if greater than 60 minutes, or 10-7M if less than 10 minutes.

Table 6-2. Sample Computer Printout from Digicom System Southern District

**** B 2 (19) MONDAY JUNE 1, 1970 ****

STATUS	TIME	D-TIME	RADIO CODE	RECEIVED	TIME	SENT	TIME
TEN 8	2	11					
TEN 8	13	27					
				VKH 887	14		
						10-32	19
						10-32	20
				ZTU 100	23		
						10-32	24
						10-32	24
						10-32	25
						10-32	25
				SDU 100	26		
						10-32	27
10-07	40	36					
TEN 8	116	19					
				DND 953	123		
						10-32	124
10-06	135	23					
10-06	158	7					
TEN 8	205	38					
				CTS 330	218		
						10-32	221
				UYW 934	222		
						10-32	228
						10-32	229
				CWE 468	229		
						10-32	231
				CXH 513	232		
						10-32	235
				333 AIC	240		
						10-32	241
10-06	243	1					
10-07	244	13					
TEN 8	257	6					
				ONU 636	301		
						10-32	302
10-06	303	2					
TEN 8	305	34					
				070 BOJ	324		
						10-32	328
10-07	339	0					
TEN 8	339	5					
10-06	344	2					
10-07	346	3					
TEN 8	349	58					
				DOE 811	404		
						10-32	407
10-7M	447	2					
						10-23	447
10-7M	449	31					
						10-23	449
				MWD 389	512		
						10-32	512
10-7M	520	0					
						10-23	520
10-06	520	38					
TEN 8	558	31					
				RXV 079	608		

Table 6-3. Sample Computer Printout from Digicom System, Southern District

**** B 3 (8) FRIDAY MAY 29, 1970 ****

STATUS	TIME	D-TIME	RADIO CODE	RECEIVED	TIME	SENT	TIME
CAR UP	0	3					
10-06	3	8					
TEN 8	11	0					
10-06	11	3					
10-07	14	35					
TEN 8	49	28					
				VOS 987	59		
						10-32	100
						10-32	101
TEN 8	117	2					
10-06	119	2					
10-07	121	76					
				UGL 203	206		
						10-32	208
TEN 8	237	2					
TEN 8	239	2					
TEN 8	241	2					
TEN 8	243	6					
10-06	249	142					
TEN 8	511	6					
10-06	517	3					
10-7M	520	45					
						10-23	520
TEN 8	605	115					
				XLU 100	622		
						10-32	624
CAR UP	800	0					
TEN 8	800	0					
10-07	800	107					
TEN 8	947	4					
10-06	951	1					
10-07	952	35					
TEN 8	1027	1					
10-07	1028	19					
10-06	1047	2					
TEN 8	1049	1					
10-06	1050	1					
10-07	1051	48					
TEN 8	1139	1					
10-7M	1140	30					
						10-23	1140
						10-23	1140
TEN 8	1210	15					
10-07	1225	6					
TEN 8	1231	7					
				063 ARD	1231		
						10-32	1232
				WGR 820	1235		
						10-32	1236
TEN 8	1238	16					
				WZK 043	1239		
						10-32	1240
				WRF 571	1244		
						10-32	1249
10-06	1254	5					
10-07	1259	5					
TEN 8	1304	6					
10-07	1310	39					
TEN 8	1349	12					
				CYA 638	1357		
						10-32	1357
				TKX 707	1358		
						10-32	1359
10-06	1401	6					
10-07	1407	35					
TEN 8	1442	2					
10-06	1444	3					
10-07	1447	10					
TEN 8	1457	10					
TEN 8	1507	46					
				485 AJI	1512		
						10-32	1515
						10-32	1515
						10-32	1516
CAR DOWN	1553	973					

Table 6-4. Sample Computer Printout from Digicom System, Potrero District

**** C 5 (20) FRIDAY MAY 29, 1970 ****

STATUS	TIME	D-TIME	RADIO CODE	RECEIVED	TIME	SENT	TIME
CAR UP	712	0					
TEN 8	712	6					
10-07	718	21					
TEN 8	739	1					
10-06	740	9					
				409	748		
						410	748
10-07	749	32					
TEN 8	821	0					
10-07	821	123					
10-06	1024	9					
				XPU 282	1033		
10-07	1033	32					
						10-32	1035
				CWW 419	1036		
						10-30	1041
						410	1043
TEN 8	1105	0					
10-07	1105	25					
TEN 8	1130	1					
10-06	1131	4					
TEN 8	1135	3					
10-7M	1138	48					
						10-23	1138
TEN 8	1226	9					
10-07	1235	23					
TEN 8	1258	0					
10-07	1258	130					
				CXM 626	1304		
						10-32	1306
						10-32	1306
						10-23	1508
CAR DOWN	1508	0					
CAR UP	1508	1					
TEN 8	1509	9					
10-06	1518	3					
TEN 8	1521	12					
				RMH 044	1524		
						10-32	1525
				MNY 900	1528		
						10-32	1529
10-07	1533	36					
TEN 8	1609	1					
10-07	1610	14					
TEN 8	1624	14					
				UHE 100	1630		
						10-32	1631
				RXM 846	1632		
						10-32	1633
10-06	1638	8					
10-07	1646	1					
10-06	1647	6					
10-07	1653	14					
10-07	1707	12					
TEN 8	1719	0					
10-06	1719	20					
10-07	1739	5					
TEN 8	1744	4					
10-07	1748	13					
TEN 8	1801	10					
10-06	1811	12					
10-07	1823	78					
TEN 8	1941	0					
10-06	1941	32					
				BFE 532	1956		
						10-32	1958
						10-32	1958
10-07	2013	12					
				231 BJB	2024		
						10-32	2025
TEN 8	2025	9					
10-07	2034	37					
TEN 8	2111	0					
10-7M	2111	28					
						10-23	2111
						10-23	2112
10-06	2139	23					
10-7M	2202	11					
TEN 8	2213	3					
10-06	2216	22					
CAR DOWN	2238	508					

Table 6-5. Sample Computer Printout from Digicom System, Potrero District

**** C 5 (20) SATURDAY MAY 30, 1970 ****

STATUS	TIME	D-TIME	RADIO CODE	RECEIVED	TIME	SENT	TIME
CAR UP	706	0					
TEN 8	706	13					
10-07	719	18					
TEN 8	737	1					
10-06	738	5					
10-07	743	26					
TEN 8	809	0					
10-06	809	55					
				RTH 445	817		
						10-32	818
						10-32	818
						10-32	819
						10-32	819
				409	820		
						410	820
TEN 8	904	0					
10-06	904	11					
10-07	915	45					
				DMZ 407	917		
						10-30	918
				409	918		
						410	918
TEN 8	1000	0					
10-07	1000	149					
				FDF 336	1022		
						10-32	1025
						10-32	1025
				409	1030		
						410	1031
10-7M	1229	45					
						10-23	1229
TEN 8	1314	0					
10-06	1314	13					
10-07	1327	9					
TEN 8	1336	1					
10-07	1337	18					
TEN 8	1355	0					
10-06	1355	7					
10-07	1402	77					
CAR UP	1519	13					
10-07	1532	22					
TEN 8	1554	16					
10-06	1610	2					
10-07	1612	11					
TEN 8	1623	5					
TEN 8	1628	15					
10-06	1643	2					
TEN 8	1645	24					
10-06	1709	29					
10-06	1738	9					
TEN 8	1747	6					
10-06	1753	7					
10-07	1802	24					
TEN 8	1826	47					
				WQP 163	1837		
						10-23	1838
						10-32	1838
						10-32	1838
10-06	1913	7					
TEN 8	1920	1					
10-07	1921	9					
TEN 8	1930	0					
10-7M	1930	55					
TEN 8	2025	1					
10-06	2026	6					
10-07	2032	9					
10-06	2041	18					
				VXX 785	2042		
						10-32	2046
				BSS 458	2052		
10-06	2059	36					
						10-32	2100
10-07	2135	13					
TEN 8	2148	0					
10-07	2148	3					
10-07	2151	48					
TEN 8	2239	0					
CAR DOWN	2239	530					

Table 6-6. Sample Digicom Printout for a Mission Car

**** D 5 (14) THURSDAY MAY 28, 1970 ****

STATUS	TIME	D-TIME	RADIO CODE	RECEIVED	TIME	SENT	TIME
CAR DOWN	3	0					
CAR UP	3	17					
CAR DOWN	20	0					
CAR UP	20	1					
10-06	21	4					
10-07	25	43					
TEN 8	108	35					
10-06	143	12					
10-07	155	8					
TEN 8	203	51					
10-07	254	143					
TEN 8	517	83					
10-06	640	5					
10-06	645	11					
10-06	656	17					
10-07	713	53					
				VJZ 286	719		
						10-32	720
				407	720		
						10-23	720
				409	721		
						410	721
						10-22	722
10-07	806	70					
TEN 8	916	8					
10-07	924	20					
TEN 8	944	32					
10-07	1016	9					
TEN 8	1025	8					
10-06	1033	5					
10-07	1038	110					
10-07	1228	22					
TEN 8	1250	1					
10-06	1251	17					
10-07	1308	39					
TEN 8	1347	0					
10-7H	1347	48					
						10-23	1347
TEN 8	1435	12					
10-06	1447	67					
10-06	1554	25					
TEN 8	1619	4					
10-06	1623	10					
10-07	1633	114					
TEN 8	1827	2					
10-06	1829	10					
10-07	1839	14					
TEN 8	1853	2					
10-06	1855	15					
TEN 8	1910	1					
10-06	1911	4					
10-07	1915	35					
10-06	1950	2					
TEN 8	1952	15					
10-07	2007	14					
TEN 8	2021	0					
10-7H	2021	43					
						10-23	2021
TEN 8	2107	15					
10-06	2122	65					
10-07	2227	97					

6.9 Field Evaluation Questionnaires

Two questionnaires were distributed to all San Francisco Police Department personnel involved in the digicom project. The summarized results and a brief discussion are presented in this section.

The first questionnaire (Questionnaire 1) was distributed approximately one month after digicom was fully operational. No transmission difficulties were observed in general (71% of the time). Newer modems (modulator/demodulator) that are currently available should increase this to the point where 90-95% would never have any difficulty transmitting. The majority of those responding felt that the equipment saved time, was easier than using voice, and was faster than using voice. Difficulty in reading the displays, especially during high ambient light periods was found to be caused primarily by a deterioration of the plastic lens in the readout. The temperature in the display housing was high enough to melt the lens. A modification was made to the unit to correct the heat problem, a shade for the display was provided, and all the lens were replaced to correct the situation.

The second evaluation form (Questionnaire 2) was distributed at the conclusion of the evaluation period while the equipment was still operating. Overall response to digital communication is very positive. More than 90% feel that digital status messages are useful and feel an additional status would be desirable. Most officers felt they could send status messages between segments of voice traffic. Eighty percent felt that digital messages base-to-mobile were useful and 70% had returned to their vehicle and found a digital message waiting. A clear majority felt digital 10-29s were easier and faster than voice; 85% wanted to be able to send 10-28s. Surprisingly, only about 30% felt it took too long to dial in a license plate number. The sound of the digital messages (crickets) did not bother 80% of the men and 58% don't even notice them anymore. More than half of the personnel could tell the channel was less crowded (52%) and some felt they had to wait longer because of the digital transmissions (a clear conflict because digital replaces voice). Nearly everyone wanted additional digital capability and flexibility. They particularly want to be able to send all possible license plate numbers, names of suspects, and street addresses.

QUESTIONNAIRE 1

SAN FRANCISCO POLICE DEPARTMENT

DIGICOM 100

PHASE I - EVALUATION FORM

Dates of Your Evaluation Period March 22, 1970 thru April 15, 1970

% N.C.	% Yes	% No		
2	71	27	1.	Have you been able to transmit without difficulty from all locations with DIGICOM? If "No" - Please list location and if possible the date and time on the back of this form.
49	17	34	2.	Is this location usually a difficult area for regular radio (voice) transmissions?
			3.	Do you think that being able to send DIGICOM status messages:
10	76	14		- Saves you some time?
11	65	24		- Is easier than using voice?
15	67	18		- Is faster than using voice?
30	20	50		- Is more reliable in an emergency?
45	15	40		- Has no value to you?
5	87	8	4.	Did you spend some time "practicing" the method of sending license checks and coded messages? (setting up the display but not transmitting)
1	66	33	5.	Have you been able to use "10-7" when arriving at the location of all your runs?
6	51	43	6.	Do you think that watching the display while dialing the desired message: - Is safe while driving the car? - Is desirable for police operations?
2	60	38	7.	Are the displays readable under most conditions?
			8.	Please use the back of this form to explain all "no" answers.
			9.	Please give comments and suggestions regarding any problems you have had with DIGICOM.

QUESTIONNAIRE 2

SAN FRANCISCO POLICE DEPARTMENT

DIGICOM I

FINAL EVALUATION FORM

The time and effort of all San Francisco Police Department personnel in contributing to the success of the digital communications evaluation is gratefully acknowledged. Practical results obtainable only through operation have provided information to evaluate the concept. The results will be useful not only to San Francisco but to all law enforcement agencies throughout the United States and Sylvania.

In completing the final evaluation form, please keep in mind the program objectives:

1. Evaluate the effectiveness of digital communications capability for police patrol cars.
2. Determine if digital equipment can reduce radio channel congestion.
3. Alleviate the workload on the dispatcher to provide increased availability for dealing with voice traffic.
4. Decrease the time between message sent and verification, thus decreasing officer standby time.
5. Decrease the response time on 1029s.
6. Increase personal safety by providing automated 1096 timing capability.

Certain equipment limitations, such as transmission difficulties, readout illumination, hot sheet placement, cable connectors, and general reliability could be improved or eliminated through design changes and/or modifications. In filling out the form, assume that the equipment operates as you would like it to operate.

PLEASE CIRCLE ONE. N.C. = NO COMMENT

N.C.	Yes	No		
4%	24%	72%	1.	Member of the Communications Bureau.
30%	30%	40%	2.	Proposition I?
1%	91%	8%	3.	The ability to transmit status from the vehicle digitally is useful in police operations?
2%	67%	31%	4.	Interrogation of unit status by the computer eliminating the need for manual entry would be desirable?

Questionnaire 2 (Continued)

N.C.	Yes	No		
4%	81%	15%	5.	An additional status should be provided for on-view investigations when the officer is unavailable but in radio contact?
5%	41%	54%	6.	The 10-6, 10-7, 10-8 sequence which establishes travel times and out-of-service times should be eliminated?
17%	58%	25%	7.	Data collected on travel times and out-of-service times cannot be used to substantiate the need for additional patrol manpower because it is inaccurate?
3%	61%	36%	8.	It is frequently possible to send digital status messages "in between" segments of voice traffic?
3%	70%	27%	9.	If the 1096 could be set for 5, 10, or 15 minutes, it would be more useful?
8%	58%	34%	10.	When a 1096 expires, a single cover unit should be sent.
8%	28%	64%	11.	When a 1096 expires, it should be treated as if it were an emergency.
2%	5%	93%	12.	The 406 should be eliminated?
2%	53%	45%	13.	If the 406 is available, it should be activated by a single switch?
10%	72%	18%	14.	The 10-4 should be assigned to a separate button to reduce operator time?
9%	61%	30%	15.	The 407, 408, and 409 should always be sent by voice because the dispatcher doesn't know where to send the requested assistance?
27%	30%	43%	16.	The dispatcher does not respond to digital transmissions as quickly as he does to voice transmissions?
4%	43%	53%	17.	The digital CODE 4 and 1025 should be eliminated?
12%	8%	80%	18.	This whole program has been a waste of my time?
24%	38%	38%	19.	The cost of furnishing the Sylvania/digicom system during the evaluation was paid for by the Law Enforcement Assistance Administration?
10%	80%	10%	20.	The digital codes which may be sent by the dispatcher are useful?
70%	10%	20%	21.	Additional "receive" radio codes would be useful? For example, ______________________________ .

Questionnaire 2 (Continued)

N.C.	Yes	No		
23%	70%	7%	22.	I have returned to my vehicle and found a digital message waiting?

You may answer both parts of question 23!

N.C.	Yes	No		
			23.	Digital 1029s are useful because:
6%	72%	22%	a.	It is easier than using voice?
4%	76%	20%	b.	It is faster than using voice?
22%	62%	16%	c.	It does not require human intervention at the base station?
33%	33%	34%	d.	It increases officer security.
				are not useful because:
32%	32%	36%	a.	It takes too long to dial in a license plate?
22%	3%	75%	b.	Stolen cars are not important?
20%	40%	40%	c.	Stolen cars often have "cold" plates?
31%	23%	46%	d.	Other patrol activities are more important than checking license plates.
10%	85%	5%	24.	It would be useful to be able to send digital 1028s (vehicle registration request)?
39%	22%	39%	25.	The license code switch should be eliminated by assigning its functions to the digital radio code selector switch?

Please answer the following general questions without usuing the "no comment" response. If necessary, just answer with the first response that comes to mind.

Yes	No		
52%	48%	26.	Radio channel 2 is less crowded with digicom operating?
30%	70%	27.	I generally have to wait longer to make voice transmissions because there are so many digital transmissions?
20%	80%	28.	The sound of the "crickets" bothers me?
64%	36%	29.	A buzzer or some signal should be supplied so I know when a digital "cricket" is for me?
60%	40%	30.	It is useful to be able to "go on and off duty" using the digicom unit?

Questionnaire 2 (Continued)

Yes	No		
50%	50%	31.	The radio channel is usually busy when I want to use it.
35%	65%	32.	More extensive training should be supplied in the future?
58%	42%	33.	I don't even notice the "crickets" anymore?

Future digital systems and/or devices can provide extensive capability that is not available under DIGICOM I. Please indicate whether the following improvements would be useful.

98%	2%	34.	A direct link from the vehicle to remote computer files, such as PIN and AUTOSTATIS.
87%	13%	35.	The capability to send out-of-state license plates?
96%	4%	36.	The capability to send all California license plates including trucks and motor cycles?
96%	4%	37.	The capability to send vehicle identification numbers?
75%	25%	38.	The capability to send driver license numbers?
94%	6%	39.	The capability to send names of persons or suspects?
87%	13%	40.	The capability to send an address indicating location?
69%	31%	41.	I would not mind using a modified typewriter keyboard to enter digital information.
91%	9%	42.	A small Cathode Ray Tube (CRT) or television screen to display what I have typed would be superior to the present display.
84%	16%	43.	I would like to be able to type in license plate numbers rather than turning knobs or pushing levers.
81%	19%	44.	A digital 1029 should automatically return the vehicle description and VIN number?
75%	25%	45.	Information regarding assigned runs; e.g., location, radio code, names, etc., should be sent digitally and displayed so that I don't have to copy the information down?
60%	40%	46.	Run disposition should be handled digitally wherever possible so that I don't have to spend time filling out forms.
60%	40%	47.	I should be paid overtime for filling out this form?
37%	63%	48.	Would car to car digital communication be useful?
71%	29%	49.	Would hard copy printout of a run assignment be useful?
24%	76%	50.	Does the DIGICOM system hamper your work by placing excessive operational requirements on you.

7.0 MODELING THE EFFECT OF DIGITAL COMMUNICATION DEVICES ON CHANNEL UTILIZATION

This section is devoted to developing and discussing the mathematical model of the communication system. The results, depicted in a variety of different graphs, may be used to predict the effect of digitalization of various types of communications typical of a modern police department. In the following sections, some basic model concepts are introduced. In subsequent sections, variations of the model are developed and computed results presented.

7.1 Model Concepts and Parameters

The basic type of model applicable to our study of police communications is a queueing model. The reasons for this are simple enough. A typical police department has only a few channels, in many cases only one, over which to transmit its messages. Since there are many more vehicles on patrol than there are channels, it is not at all unusual for a patrol vehicle to be forced to wait for another message to be completed before it can transmit. Consequently, we may say that the vehicle is waiting in a queue until the channel is free. Of course, no actual queue forms in a physical sense, but for modeling purposes it is convenient to imagine a queue forming. (As will be discussed later, placing messages in an imaginary queue until the channel is free does not impose a first-come-first-served priority discipline on the queue. Many other types of priority schemes are possible, including the random selection of a message in the queue to use the channel next.)

Even if more than one channel is available to a particular police department, a group of cars is usually assigned to one and only one channel. Though other channels may be free, a car must normally use only the channel to which it is assigned. Consequently, in our model we may restrict our analysis to a single channel and the collection of patrol vehicles and dispatchers assigned to it.

Continuing in our definition of the queueing model, we may think of the channel as a facility providing "service," or a "service stall" in the parlance of operations research. A message begins to receive service when it finds the channel free and begins message transmission. Service is completed when the message transmission is completed. The message service rate μ is the speed at which messages can be processed, measured in number of messages completed per second.

The arrival rate λ denotes the rate at which messages are generated that require transmission. The arrival rate is usually measured in number of messages generated per second. When a message is generated it begins transmission immediately only if the channel is free. Otherwise, it joins the abstract queue to await its turn. Its passage through the queue may be governed by any of several priority schemes, the appropriate one being selected in advance.

One may calculate several variables that describe, quantitatively, how efficiently messages pass through the system; that is, through the queue and the communications channel. One such variable is the utilization ρ defined by $\rho = \lambda/\mu$. As its name suggests, the utilization is simply the fraction of time that the communications channel is busy. Another variable is the number of messages L_q in the queue. Another is the number of messages L in the system (queue plus channel). Note that it is not always true that $L = L_q + 1$. This holds except when $L_q = 0$; then L may be one or zero. Two other variables are the mean waiting time W_q in the queue and the mean waiting time W in the system. More commonly, we speak of W_q as the mean waiting time until message transmission begins and W as the mean waiting time until message transmission is complete. The mathematical formulas for the variables discussed here are derived in the Appendix.

7.1 (Continued)

The queueing model applied here is sometimes called the infinite queue model. This is because there is no limit on the number of messages that can be in the queue. A model of finite queue length would allow only a fixed number of messages to be in the queue at any one time. Any additional messages above that number would be turned away and permanently lost. The finite queue model does not seem to apply to police communications. It might apply to cars seeking service at a gasoline station where only a finite number of cars could line up without exceeding the space limiation and blocking the sidewalk. In this case, additional cars would look elsewhere for gasoline.

Only one additional point of discussion remains regarding the queueing model. In introducing the parameters λ and μ we tacitly assumed that the message arrival rate and the message service rate would be Poisson distributed. This is the case in most communication problems and indeed in most queueing problems. But it was necessary to specifically ascertain the type of arrival distribution and service distribution that applied to police communications. To do this, extensive computer tapes of message traffic were obtained from the San Francisco Police Department. Interarrival times between messages were plotted and found to yield an approximate Poisson distribution with $\lambda = 0.072$. A cumulative probability distribution of message lengths was obtained. It was sufficiently close to the cumulative Poisson distribution with $\mu = 0.222$. If the message arrival rate and service rate seem abnormally high, it is because we are employing the term "message" in an unusual sense. Normally, a message might consist of a few spoken words by the dispatcher, a few words from the mobile unit, and perhaps several seconds of pause followed by more words from the dispatcher. We chose to consider such a conversation as not being a single message, but being several distinct messages. In this way, each message is an uninterrupted segment of air time. This is done because the seconds of delay that elapse between these uninterrupted message segments can be used to transmit a digital message. If the channel were considered to be blocked during the entire conversation, then no digital messages could be sent during the pauses.

The values of $\lambda = 0.072$ messages per second and $\mu = 0.222$ messages per second correspond to peak period communications observed for several days in the San Francisco Police Department. Peak periods were found to occur in the early evening (5:00 p.m. to 8:00 p.m.) and often around midnight. While λ will vary for other channels, the message processing rate μ is probably typical for many departments throughout the United States. The value $\mu = 0.222$ was used in calculations in subsequent sections. However, the Appendix discusses the effect that different values of μ would have on the variables L, L_q, W and W_q.

Many police departments have records indicating what their channel utilization ρ is during peak periods. If not, the dispatcher and supervisors usually have a feeling for the correct utilization values, and an understanding of how they vary over time. However, to aid in the prediction of ρ when new patrol configurations are conceived (possibly by combining channels and using digital equipment) or when historical data about utilization is absent, a method for predicting channel utilization is presented.

Predicting a range for channel utilization, rather than a single figure, during long periods will be our goal. To accomplish this, we will categorize the types of messages and suggest the number that might be sent in each category per car. Then, we will be able to predict ρ as a function of the number of cars assigned to the channel.

Table 7-1 shows how most police communications can be divided into four message categories. Each category has an upper and lower figure for the expected number of messages per car. (Here we are not using "message" in the same sense described earlier when it denoted a short uninterrupted interval of air time. We are using it here to mean the conversation associated with a particular

Table 7-1. Message Categories

Message Type	Messages Per Car Per Hour	Average Duration for Voice Transmission (Seconds)
Status	3 — 7	3
Administration	1/4	5
Run Assignments	1/2 — 1	15
Cover Assignments	1/4 — 1/2	10
On-View Cases	1/4 — 1/2	15
Field Requests	1/4	15

7.1 (Continued)

request. This is because police administrators are more accustomed to thinking in the latter terms, and Table 7-1 will be easier for them to use if it is so formulated. At any rate, the goal is to obtain utilization ρ and the particular concept associated with "message" does not affect ρ. When the latter (conversation) concept is used, the message arrival rate is also the same fraction of what it would otherwise be. Consequently, the utilization is unchanged since $\rho = \lambda/\mu$.

As Table 7-1 shows, experience indicates that run assignments may require on the average between 0.5 and 1.0 messages per car per hour during peak periods. Statistics indicate that the average duration of these messages is approximately 15 seconds. Similar estimates are shown in Table 7-1 for other message categories. Figure 7-1 shows how utilization may vary as the number of cars per channel is increased. As an example, the low estimate of utilization when there are 30 cars per channel is obtained by dividing the total message processing time by the number of seconds available in an hour: $30[(3)(3) + (1/4)(5) + (1/2)(15) + (1/4)(10) + (1/4)(15) + (1/4)(15)]/3600$. Rather than accept the upper and lower bounds given in Table 7-1, many police communicators will wish to make their own estimates of the hourly messages that their cars process by message category. Then their own particular values of ρ can be found for the specific number of cars assigned to the channel.

7.2 Digitalization of Status Messages

Some police departments are interested in taking as a first step the digitalization of status messages only. A great deal can be accomplished doing this alone, particularly if each car transmits perhaps thirty or more status messages per shift. On the other hand, if a high number of cars are operating on a channel, then digitalization of status messages is significant even if only a few status messages are involved.

As an example of some of the results, consider the effect of digitalization on channel utilization. We define channel utilization (or simply utilization) to be that fraction of time that the channel is being used to transmit messages. Suppose 60 cars are assigned to a channel. Let us say that we have determined out utilization in peak periods to be 0.60. This is a very high channel utilization and one that should not be allowed to exist. Suppose we then determine that 30 or more

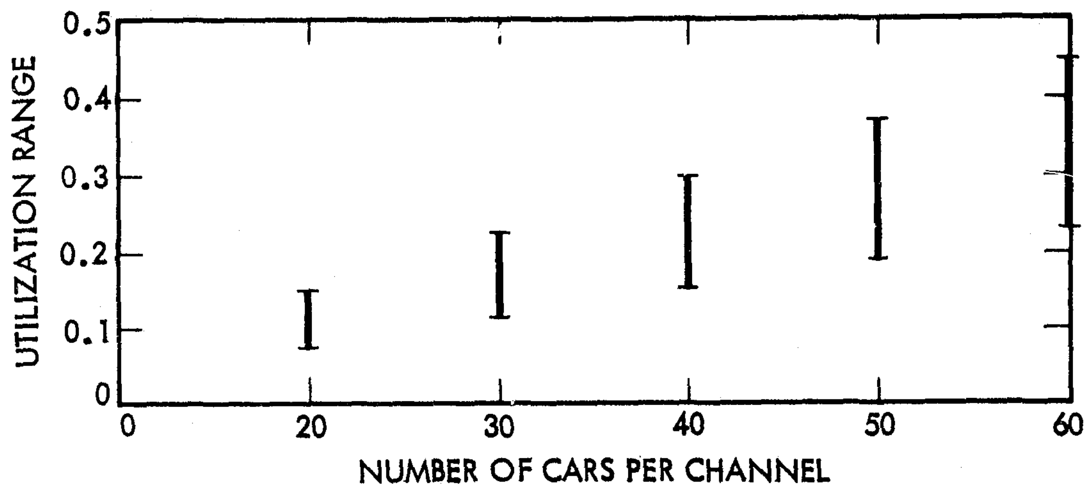

Figure 7-1. Predicted Channel Utilization

7.2 (Continued)

status messages are sent by voice from each car per shift. If we can digitalize an average of 30 status messages per car per shift, the utilization is reduced from an intolerable 0.60 to a manageable 0.47. (See Figure 7-7. A detailed description of the figures will follow.)

Some police departments may feel that few of their status messages are candidates for digitalization — that most must continue to be transmitted by voice. Digitalization can still have a dramatic effect if a large number of cars are assigned to each channel. For example, if 100 cars are assigned to a channel, a utilization of 0.60 is reduced to 0.47 if only 20 status messages are digitalized per car per shift. (See Figure 7-10.) This is a digitalization of only 2.5 status messages per hour per car.

Digitalization of status messages alone has a significant effect on other parameters besides utilization. But before discussing this, let us qualify our exemplary results just stated by discussing the manner in which they were obtained.

The results stated in the opening paragraphs of this section and the results depicted in Figures 7-2 through 7-18 are based on what we shall call the "infinite queue equations." In operations research the infinite queue equations model steady-state queue behavior when all individuals seeking service line up at a single service stall and no limitation is placed on possible queue length. In our context, "individuals seeking service" are simply patrol officers or dispatchers trying to initiate a message. The "service stall" is simply the transmission channel which of course can be used by only one message at a time.

Individuals in the queue may be selected for service according to any priority scheme desired. Two major types of priority schemes may be suggested as typical of what happens in police administration. One is the first-come-first-served policy. The bulk of the citizen complaints are non-emergency, or at least they are non-emergency in the sense that the dispatcher does not give the complaints special precedence over others awaiting his attention. That is, for the most part, he handles the complaints and initiates the corresponding messages to the patrol cars on a first-come-first-served basis. The other type of priority scheme that sometimes applies to police communications is random service. In this situation, police officers in the queue waiting for the channel to become free are selected for service at random, without any regard to the time they have been

7.2 (Continued)

waiting. While messages originating at the base station are usually transmitted by the dispatcher on a first-come-first-served basis, messages originating in the field usually gain access to the channel on a random basis.

Fortunately, the fact that two different priority schemes are operating presents no problem for the infinite queue model. In the Appendix we show that the parameters we will be calculating have the same mean values for either priority scheme. It is true that the variances of the parameters are different for the two types of priorities, but we are only concerned with mean values in this initial study of digitalization.

To obtain numerical results from the queueing model, we must identify the probability distribution describing the frequency of occurrence of messages (the message arrival rate) and the length of time it takes to transmit a message (the message service rate). In most practical situations involving voice messages, both the arrival rate and the service rate obey the Poisson distribution, at least to within a satisfactory approximation. This was found to be the case with the San Francisco data, and the literature on voice communications suggests it is a very reasonable assumption to make for other police departments.

Since the Poisson distribution is characterized with only one parameter, only two inputs are necessary for the queue model: the mean message arrival rate λ and the mean message service rate μ. Although any time units may be used as long as consistency is maintained, we have usually measured λ in terms of messages per second in this report. With λ and μ as inputs, we can quickly compute the channel utilization ρ by the defining equation

$$\rho = \frac{\lambda}{\mu} \qquad (1)$$

In many cases, it is more convenient to take ρ and μ as input and compute λ. Most police administrators probably have a better feeling for their typical channel utilization ρ and for their average message time $1/\mu$ than for the message arrival rate λ.

Taking any two of the three quantities μ, λ, and ρ as input, equations may be employed which permit the calculation of four very useful parameters describing the communications system. One is the average number of messages L in the system. In this context, the system is defined to consist of the service stall (i.e., the communications channel) and the queue (the messages waiting to use the channel). The variable L may be computed by

$$L = \frac{\lambda}{\mu - \lambda} = \frac{\rho}{1 - \rho} \qquad (2)$$

[Equation (2) and the following three equations are derived in the Appendix.]

We will use L_q to denote the average number of messages in the queue itself. This quantity may be calculated according to

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{\rho^2}{1 - \rho} \quad . \qquad (3)$$

The average waiting time W that a message encounters from the time it joins the queue until it has satisfactorily been transmitted is given by

$$W = \frac{1}{\mu - \lambda} \quad . \tag{4}$$

Finally, the average waiting time W_q that a message must undergo from the time it joins the queue until it can begin transmission is given by

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} \quad . \tag{5}$$

To apply the queueing model to the digitalization of status messages, Equations (2) and (5) must be adapted to our purpose. Our desire was to make the results as applicable as possible to many police departments and not be tied only to San Francisco where $\lambda = 0.072$ and $\mu = 0.222$ were measured. However, if we allowed both λ and μ to vary over a range of values, a rather large number of graphs or tables would be required. It seems that $\mu = 0.222$ would probably be a reasonable value for most departments, especially since our "messages" are the separate distinct parts of the overall assignment that is transmitted. However, λ no doubt varies widely from one department to another. Since most police administrators have a better feeling for utilization ρ than for λ, we chose to let ρ be an independent variable in the computations.

Before introducing all of the graphs relating to status messages, a discussion of the equations behind the graphs is in order. Let S be the average number of digitalized status messages that are transmitted by each car per shift, and let T_V be the average time required to transmit a status message when it is sent by voice and T_D be the time required when the message is digitalized. We define $\hat{\rho}$ to be the new utilization after digitalization has been implemented for S status messages, and we define $\hat{\mu}$ to be the new message processing rate, averaged over both the voice and the digitalized messages. If we are given ρ and μ we may calculate λ by $\lambda = \rho\mu$. Assuming that the unit of time is seconds, then the total number of messages transmitted in an eight-hour shift is $(3600)(8)\lambda$. Without digitalization, over an eight-hour shift, the channel is busy a total of $(3600)(8)\rho$ seconds. If there are n cars on the channel, then a total of $n \cdot S \cdot (T_V - T_D)$ seconds are saved over the 8-hour shift. This means $\hat{\mu}$ may be calculated by

$$\hat{\mu} = \frac{3600 \cdot 8 \cdot \lambda}{3600 \cdot 8 \cdot \rho - n \cdot S \cdot (T_V - T_D)} \quad . \tag{6}$$

Then, $\hat{\rho}$ follows from

$$\rho = \lambda / \hat{\mu}$$

Now the mean number in the system L, the mean number in the queue L_q, the mean waiting time before service is completed W, and the mean waiting time before service is begun W_q may be computed from

$$L = \frac{\hat{\rho}}{1 - \hat{\rho}}$$

$$L_q = \hat{\rho} L$$

$$W = \frac{L}{\lambda}$$

$$W_q = W \cdot \hat{\rho} \quad .$$

Figures 7-2 through 7-6 show how the parameters describing the system appear as a function of the original utilization ρ. A value of 30 cars per channel was assumed in this case. This number is typical of many police departments. The number of status messages digitalized was varied from 10 to 40 by increments of 10.

The three parameters $\hat{\rho}$, L_q, and W_q are probably the most interesting of the five. Consequently, they are studied in more detail by varying the number of cars per channel over the values 60, 100, 140, and 300. These results are shown in Figures 7-7 through 7-18. Throughout all of these calculations in this section, it was assumed that $T_V = 3$ seconds and $T_D = 1$ second.

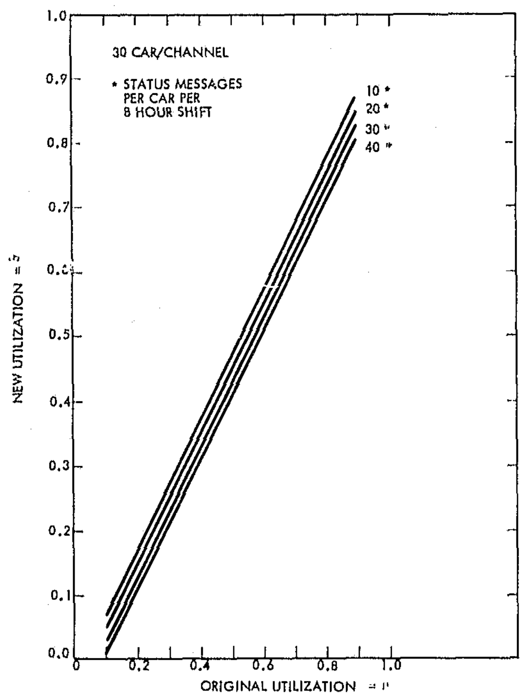

Figure 7-2. New Utilization with Digital Status Messages — 30 Cars/Channel

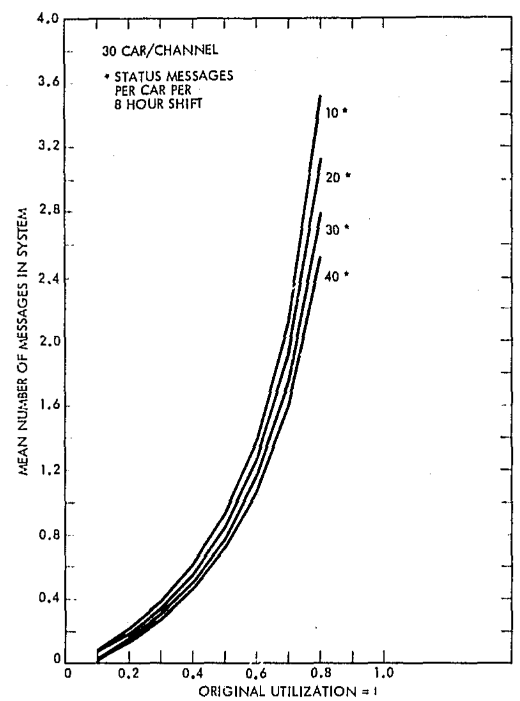

Figure 7-3. Mean Number of Messages in System with Digital Status — 30 Cars/Channel

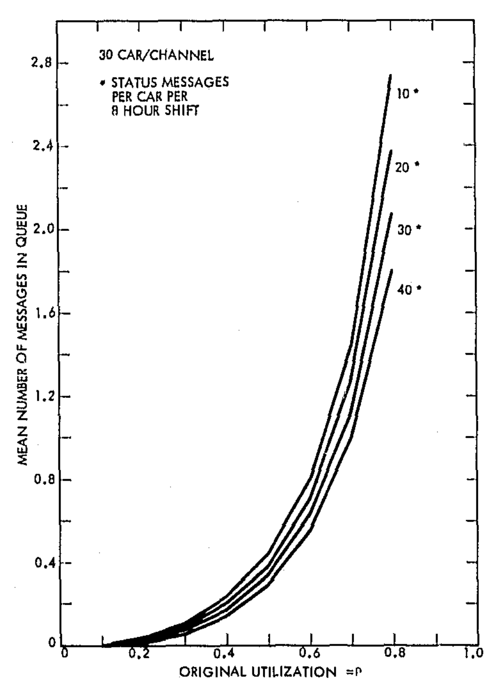

Figure 7-4. Mean Number of Messages in Queue with Digital Status — 30 Cars/Channel

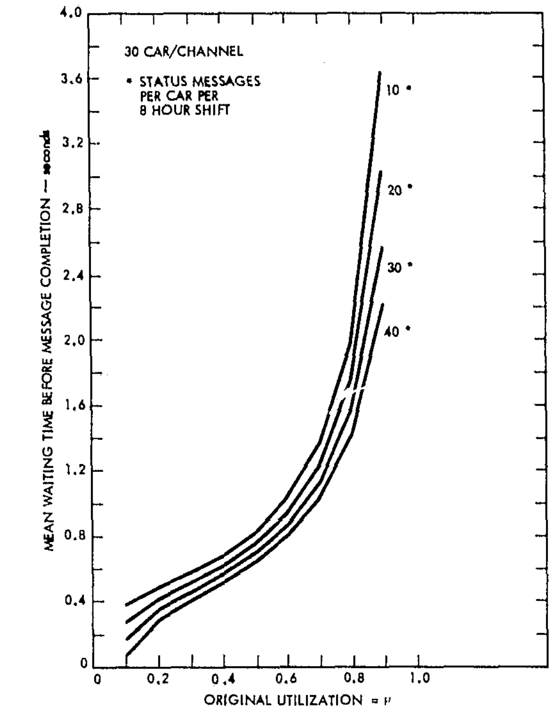

Figure 7-5. Mean Waiting Time Before Message Completion with Digital Status — 30 Cars/Channel

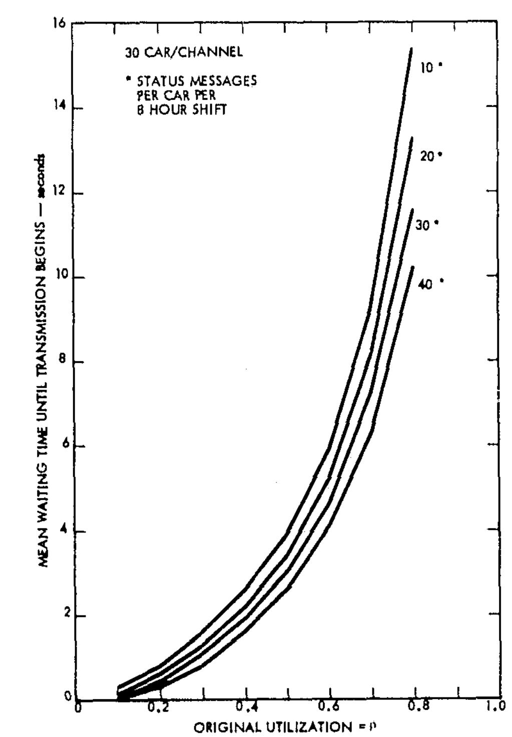

Figure 7-6. Mean Waiting Time Until Transmission Begins with Digital Status — 30 Cars/Channel

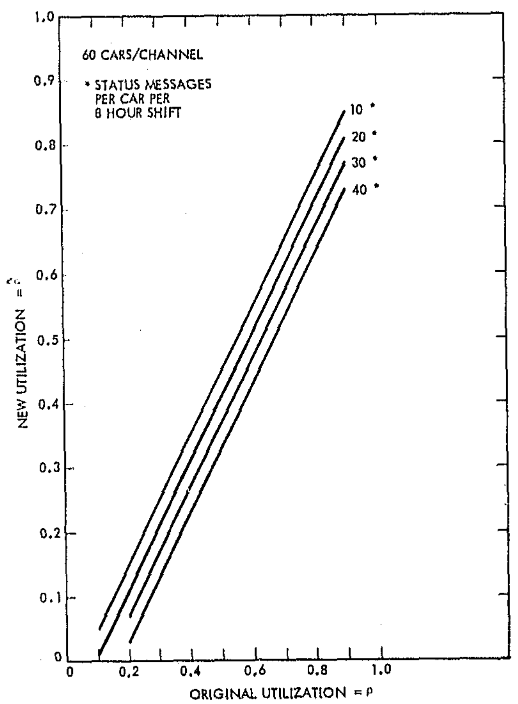

Figure 7-7. New Utilization with Digital Status Messages — 60 Cars/Channel

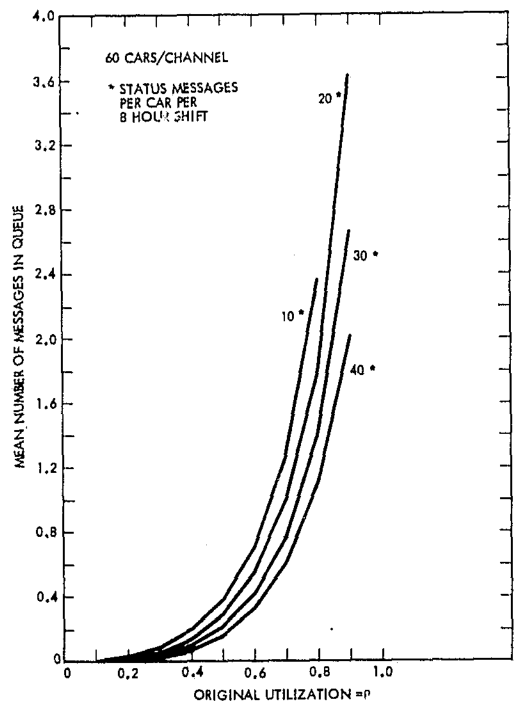

Figure 7-8. Mean Number of Messages in Queue with Digital Status — 60 Cars/Channel

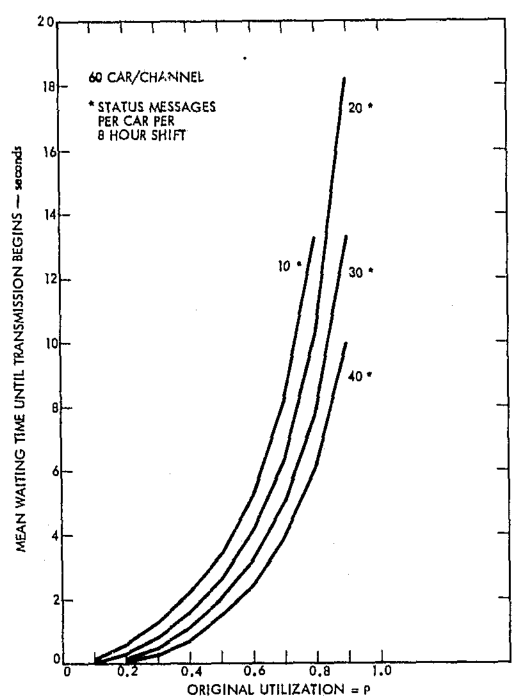

Figure 7-9. Mean Waiting Time Until Transmission Begins with Digital Status — 60 Cars/Channel

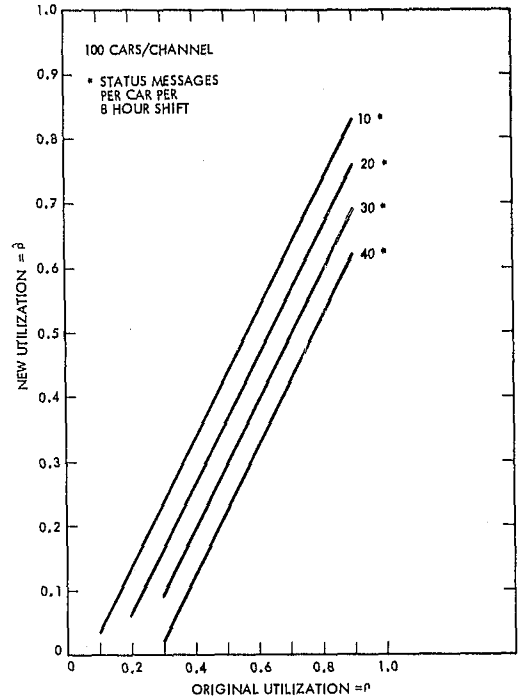

Figure 7-10. New Utilization with Digital Status Messages — 100 Cars/Channel

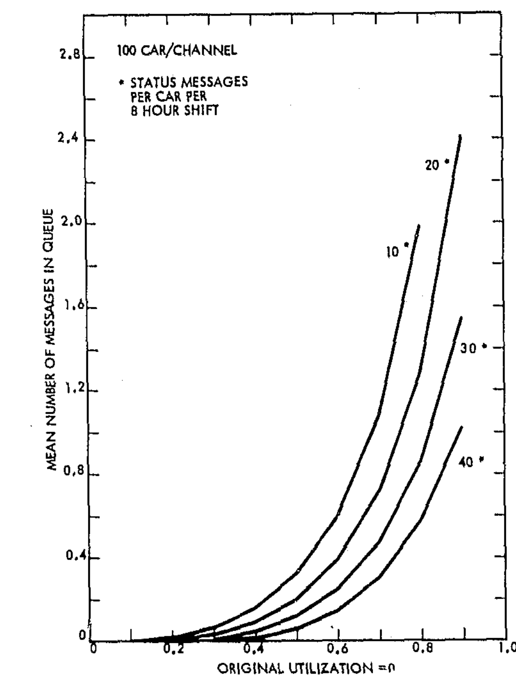

Figure 7-11. Mean Number of Messages in Queue with Digital Status — 100 Cars/Channel

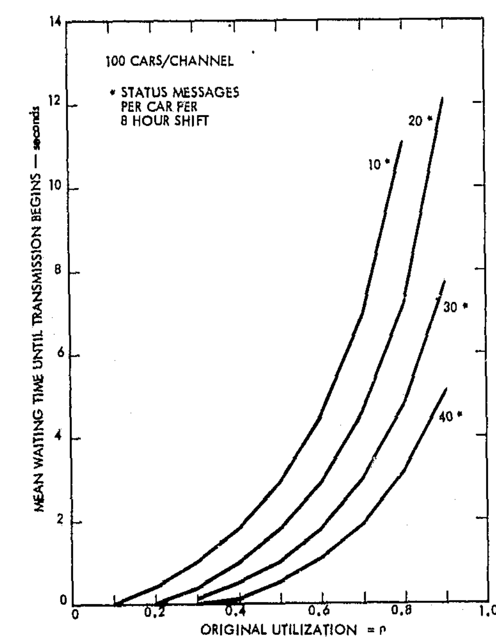

Figure 7-12. Mean Waiting Time Until Transmission Begins with Digital Status — 100 Cars/Channel

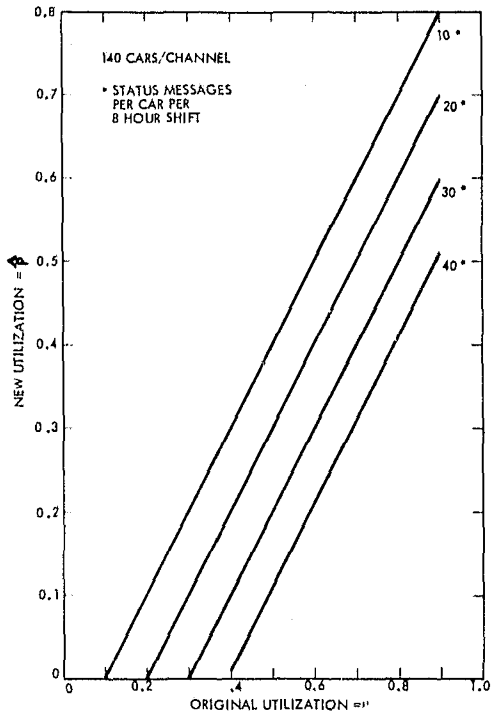

Figure 7-13. New Utilization with Digital Status Messages — 140 Cars/Channel

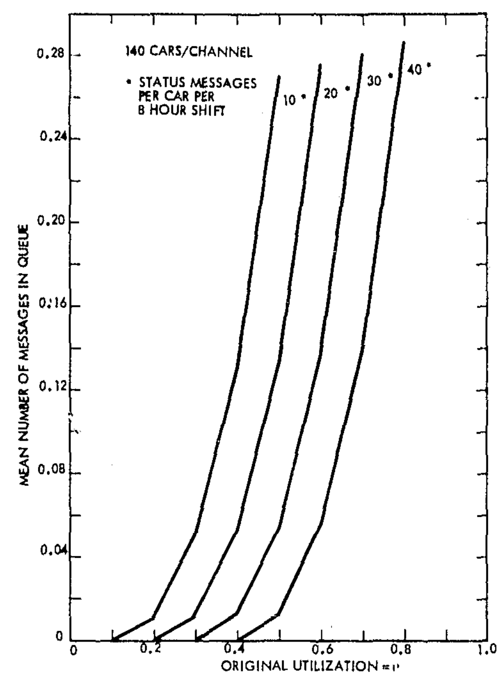

Figure 7-14. Mean Number of Messages in Queue with Digital Status — 140 Cars/Channel

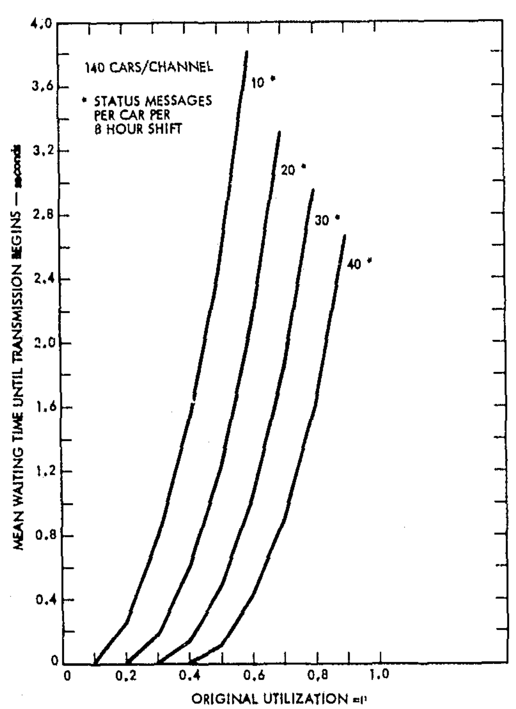

Figure 7-15. Mean Waiting Time Until Transmission Begins with Digital Status — 140 Cars/Channel

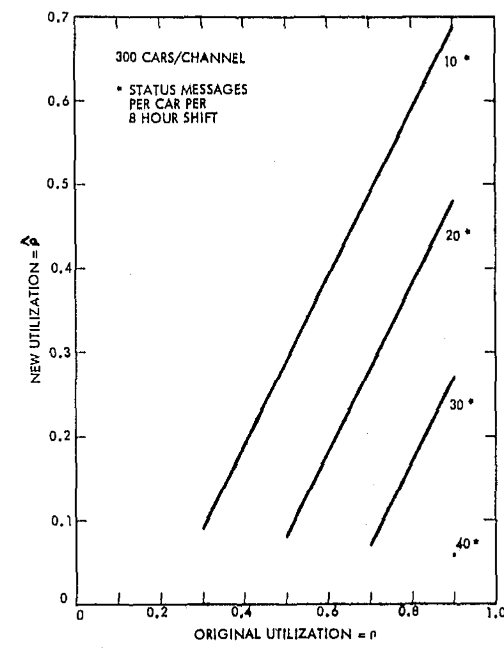

Figure 7-16. New Utilization with Digital Status Messages — 300 Cars/Channel

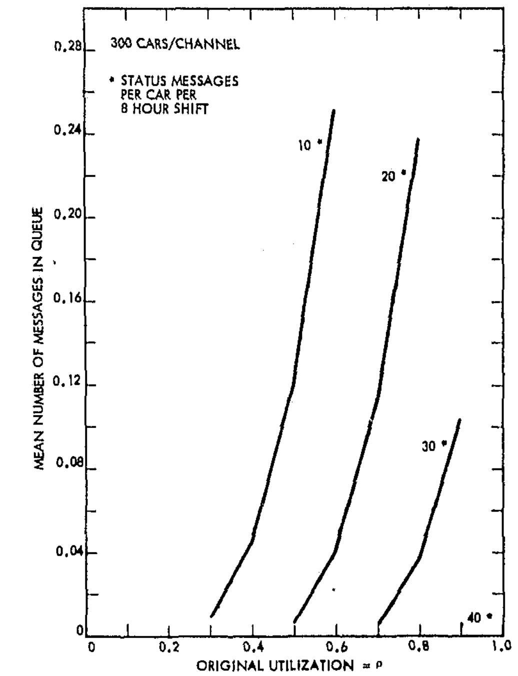

Figure 7-17. Mean Number of Messages in Queue with Digital Status — 300 Cars/Channel

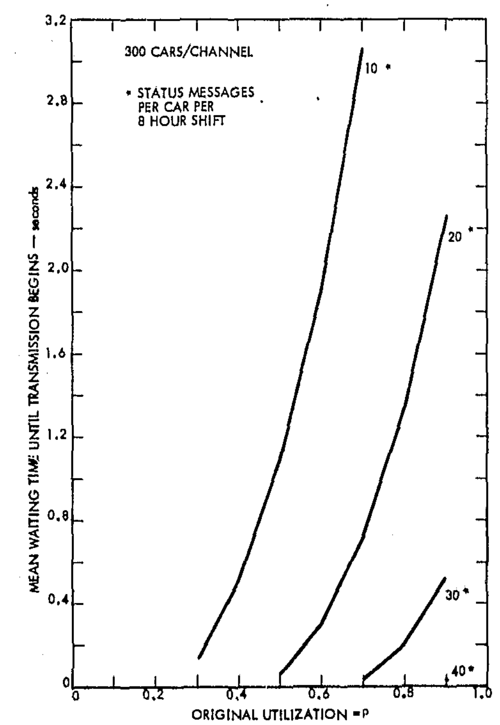

Figure 7-18. Mean Waiting Time Until Transmission Begins with Digital Status — 300 Cars/Channel

7.3 Digitalization of License Checks (10-29s)

To study the effect of the digitalization of license checks, the queue model discussed previously is used. But before using the model, we must derive expressions for the parameters ρ, L, L_q, W, and W_q that are applicable to the digitalization of license checks. In dealing with status messages we assumed that when digicom was installed a certain number of status messages per shift were digitalized. But the average number of messages transmitted per shift did not change. Experience indicates that a different situation holds with respect to license checks. In San Francisco few license checks were run under normal conditions, but the number processed after digicom was installed went up dramatically. In summary, when digitalization is applied to only status messages, the utilization drops sharply and the number of messages being processed is essentially unchanged, but when digitalization is applied to only license checking, the utilization is essentially unchanged but the number of messages processed rises sharply.

Since utilization is essentially unchanged when the additional license checks are digitalized, it follows that $\hat{\rho}$, L, and L_q have approximately the same values they had with no digitalization and no additional license checks. However, since $\hat{\lambda}$ would be larger after implementing digicom, the W and W_q would be smaller; see Equations (11) and (12). This is as expected because the mean waiting time is being lowered by averaging the effect of the very rapidly processed digitalized license checks. However, the waiting times W and W_q associated with voice messages only are approximately the same as they were before the additional digitalized license checks were imposed on the system. On the basis of this discussion, it seems that the best way to assess the effect of digitalization of license checks only is by comparing system performance when the additional checks are performed without digicom and when they are performed with digicom. To be on the conservative side, the performance with digicom will use the waiting times associated with voice message only rather than the smaller waiting times that prevail when the digitalized license checks are averaged in.

To derive the equations that reflect the processing of additional license checks without digicom, we may assume that the original utilization ρ is known and that the average message processing rate μ for voice messages has been established. Then the message arrival rate λ may be calculated from $\lambda = \rho\mu$. Thus, originally a total of $(3600)(8)\lambda$ messages were processed in an eight-hour shift, on the average. If there are n cars on the channel and each processed an additional ℓ license checks per shift, then the total number of messages processed is $(3600)(8)\lambda \cdot \ell$. This means the new arrival rate $\hat{\lambda}$ is given by

$$\hat{\lambda} = \frac{(3600)(8)\lambda + n \cdot \ell}{(3600)(8)} \quad . \tag{6}$$

Before the additional license checks were imposed on the system, an average of $(3600)(8)\rho$ seconds of on-the-air time were required in an eight-hour shift to process all the messages. If the additional license checks would require T_L seconds of air time when processed by voice without digicom, then the total processing time for all messages would average $(3600)(8)\rho + n\ell\, T_L$ seconds per shift. This gives a new message processing rate of

$$\hat{\mu} = \frac{(3600)(8)\lambda + n\ell}{(3600)(8)\rho + n\ell\, T_L} \quad . \tag{7}$$

7.3 (Continued)

Now the new utilization rate for processing additional license checks without digicon is

$$\hat{\rho} = \hat{\lambda}/\hat{\mu} \quad . \tag{8}$$

The other parameters may be calculated from:

$$L = \frac{\hat{\rho}}{1 - \hat{\rho}} \tag{9}$$

$$L_q = \hat{\rho} \cdot L \tag{10}$$

$$W = \frac{L}{\hat{\lambda}} \tag{11}$$

$$W_q = \hat{\rho} \cdot W \quad . \tag{12}$$

For many police departments, thirty cars per channel is a typical figure. Figure 7-19 indicates what would happen when there are thirty cars assigned to a channel and additional license checks are processed. If the original utilization was a very low $\rho = 0.1$, then processing 20 license checks per-car per-shift would create a new utilization at the intolerable level of 0.52. Processing the additional license checks by digicom would maintain the utilization at approximately 0.1, according to the discussion provided above. Twenty license checks per shift seems to be a conservative goal, representing only 2.5 per hour. For Figure 7-19, as well as for all other graphs in this section, a value of $T_L = 20$ seconds was used.

Figure 7-20 shows that the mean number of messages in the system becomes excessive, even for very small ρ's, when 32 license checks per-car per-shift are added to the communication workload without digicom. Figure 7-21 is a similar result with respect to the mean number of messages in the queue. Figures 7-22 and 7-23 show the effect of additional license checks on the mean waiting time before a message can be completed and before it can be initiated. According to Figure 7-23, if the original utilization is only 0.2 and 32 additional checks per shift are imposed, the mean waiting time before a message can begin transmission is a high 73 seconds without digicom but a mere 1.1 seconds using digicom.

Figures 7-19 through 7-23 are valid only when there are 30 cars per channel. Figures 7-24 through 7-26 depict similar results for the parameters ρ, L_q, and W_q when there are only 20 cars per channel. Figures 7-27 through 7-29 show these parameters when there are 40 cars per channel. Finally, Figures 7-30 through 7-32 apply when there are 60 cars per channel.

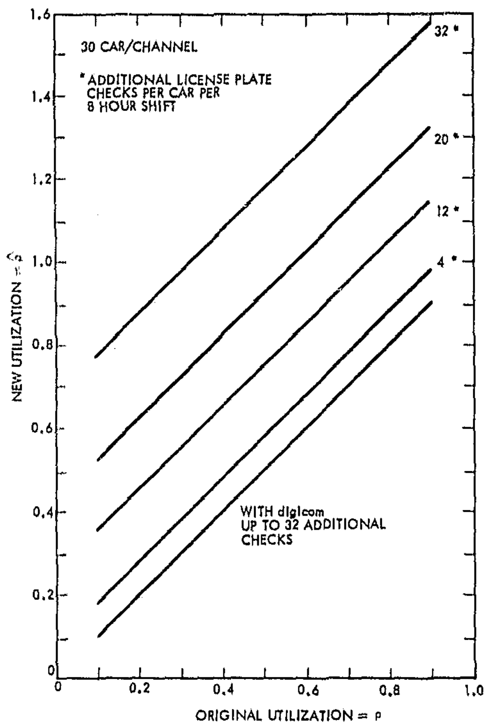

Figure 7-19. New Utilization with Digital Status Messages and Additional Voice License Plate Checks — 30 Cars/Channel

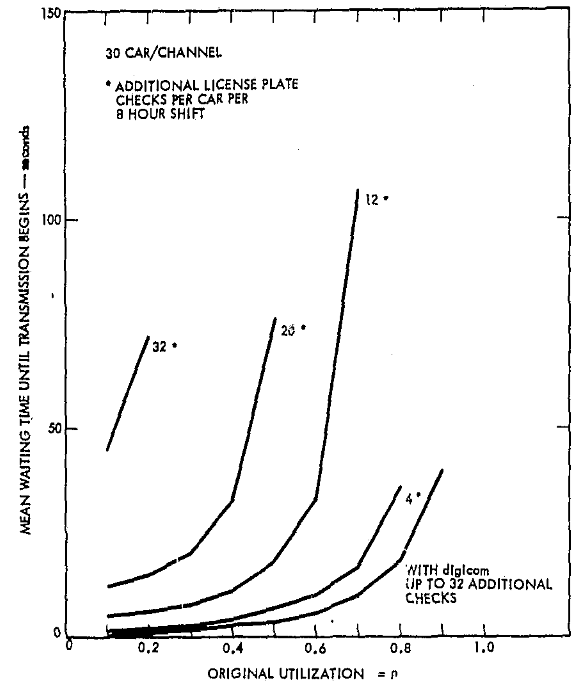

Figure 7-20. Mean Waiting Time Until Transmission Begins with Additional Voice License Checks — 30 Cars/Channel

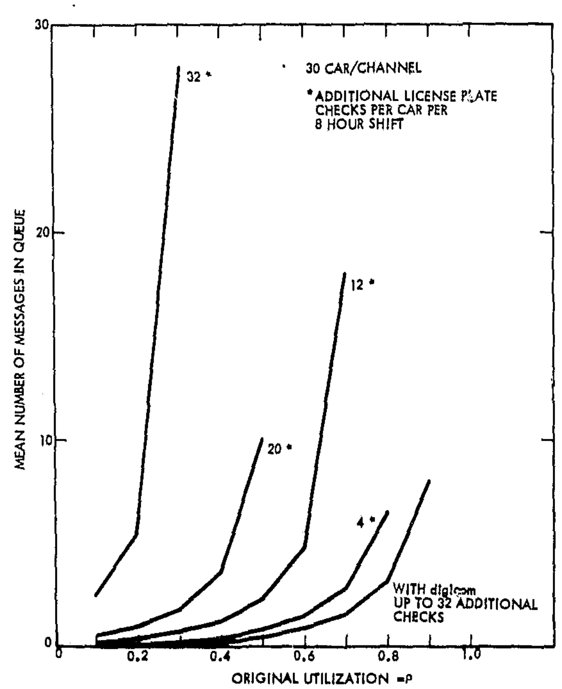

Figure 7-21. Mean Number of Messages in Queue with Additional Voice License Checks — 30 Cars/Channel

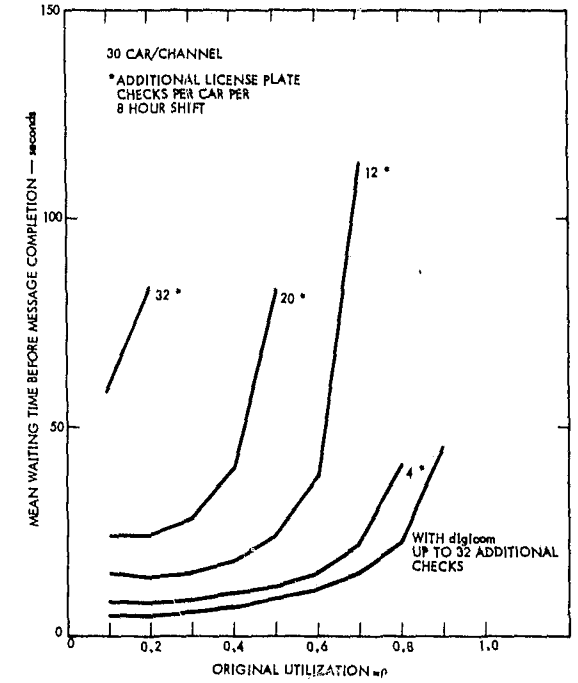

Figure 7-22. Mean Waiting Time Before Message Completion with Additional Voice License Checks — 30 Cars/Channel

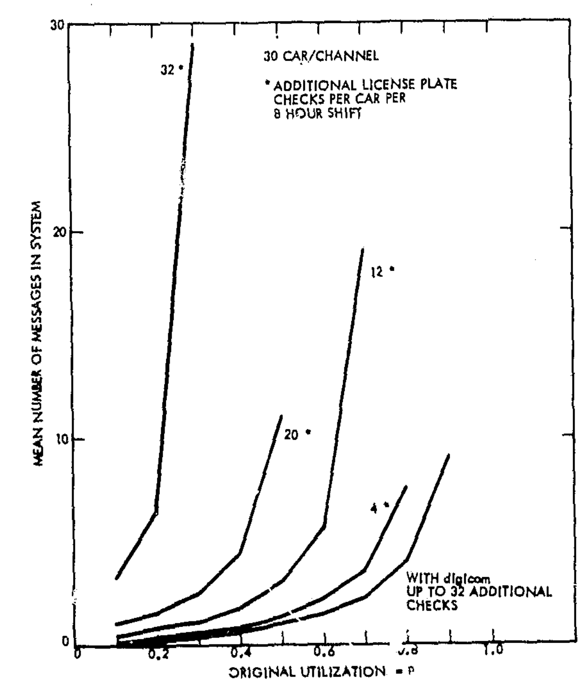

Figure 7-23. Mean Number of Messages in System With Additional Voice License Checks — 30 Cars/Channel

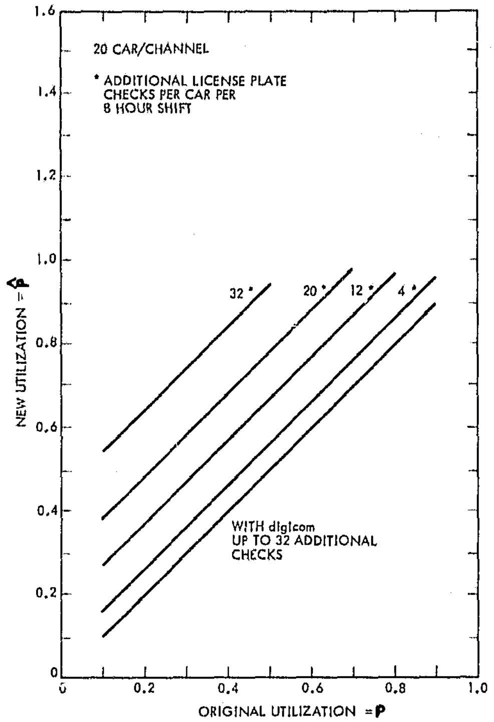

Figure 7-24. New Utilization with Digital Status Messages and Additional Voice License Checks — 20 Cars/Channel

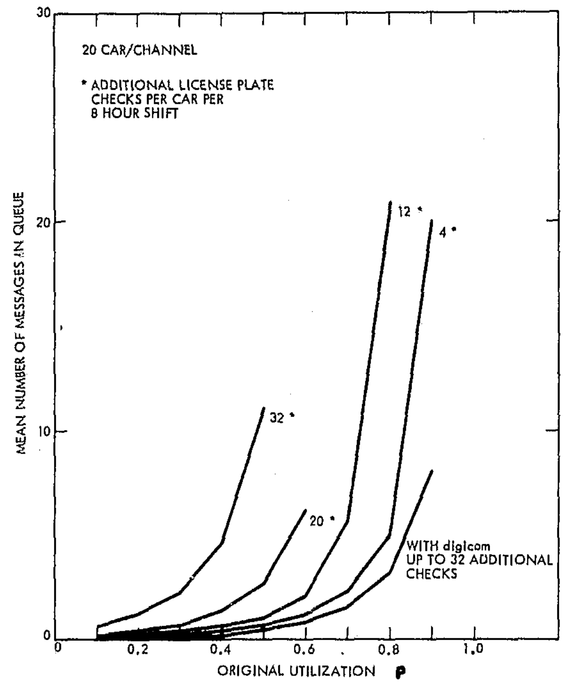

Figure 7-25. Mean Number of Messages in Queue with Additional Voice License Checks — 20 Cars/Channel

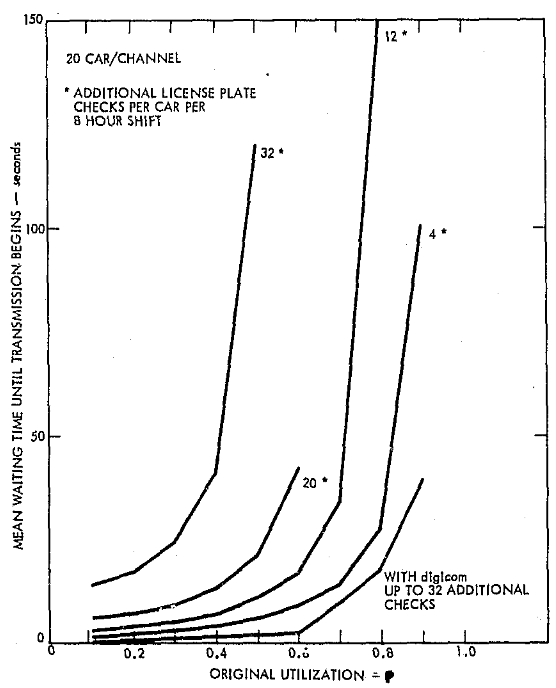

Figure 7-26. Mean Waiting Time Until Transmission Begins with Additional Voice License Checks — 20 Cars/Channel

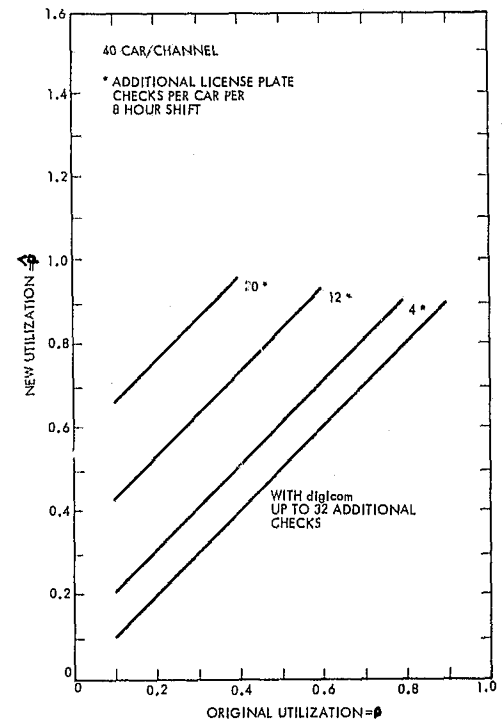

Figure 7-27. New Utilization with Digital Status Messages and Additional Voice License Checks — 40 Cars/Channel

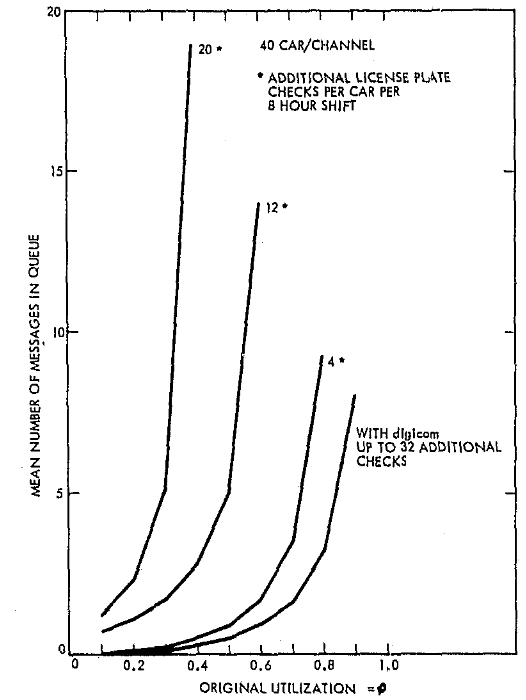

Figure 7-28. Mean Number of Messages in Queue with Additional Voice License Checks — 40 Cars/Channel

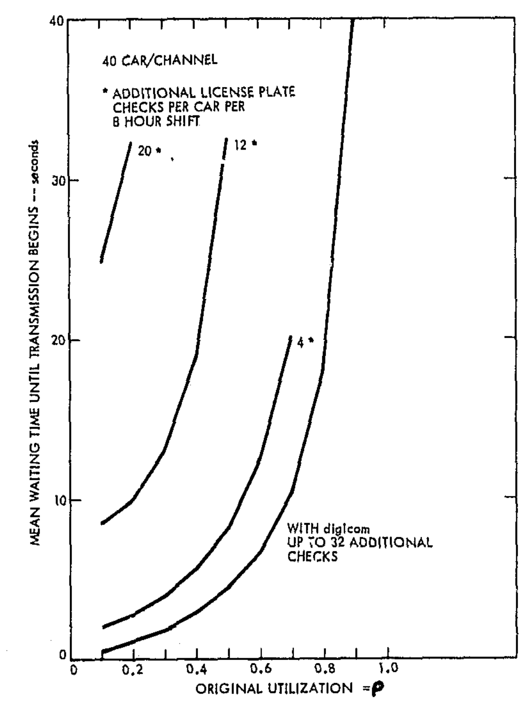

Figure 7-29. Mean Waiting Time Until Transmission Begins with Additional Voice License Checks — 40 Cars/Channel

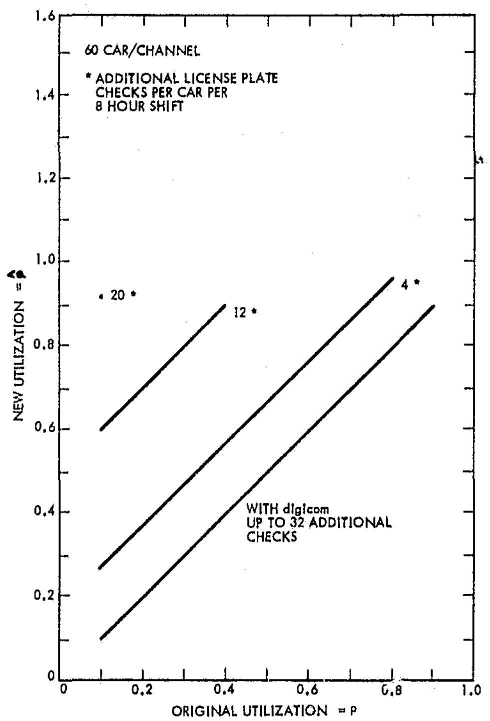

Figure 7-30. New Utilization with Digital Status Messages and Additional Voice License Checks — 60 Cars/Channel

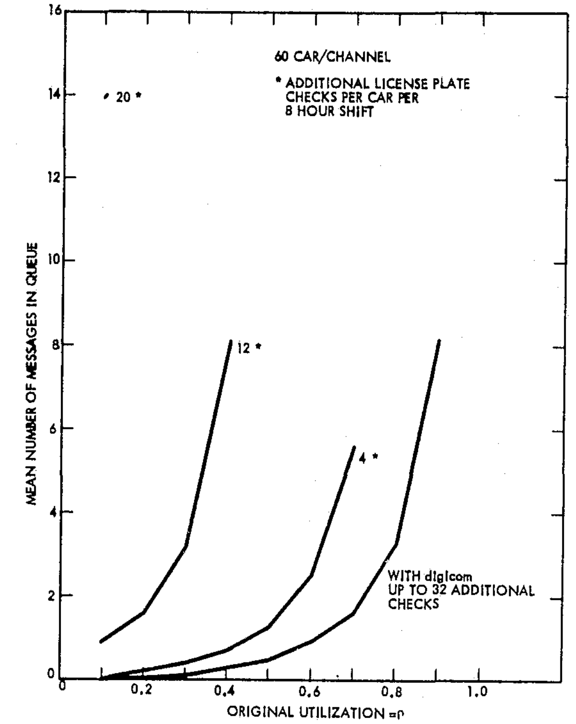

Figure 7-31. Mean Number of Messages in Queue with Additional Voice License Checks — 60 Cars/Channel

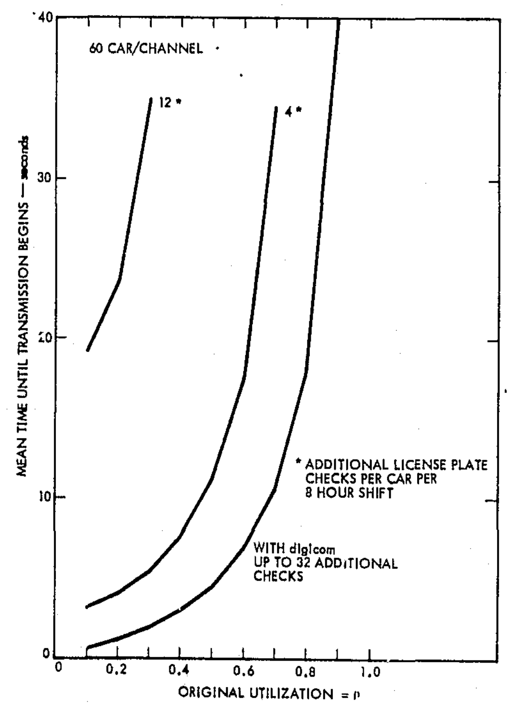

Figure 7-32. Mean Waiting Time Until Transmission Begins with Additional Voice License Checks — 60 Cars/Channel

7.4 Channel Congestion as a Function of Digitalization Level

Some police departments may wish to determine the effect of the digitalization of status messages only. This may be the case with certain departments that operate with a large number of vehicles per channel. Other departments may wish to assess the impact of digital license checks alone before implementing the system. Consequently, the previous sections were devoted to these subjects, but most police departments will wish to digitalize status messages, license checks, and other types of calls as well. Therefore, the purpose of this section will be to evaluate the effect of various overall digitalization levels on the utilization, the number of messages in the queue and in the system, and the mean waiting time in the queue until message completion.

To study the effect of the digitalization level, assume that some fraction D of the total message traffic is digitalized. We are not saying that this fraction is the number of messages that are digitalized, but rather that it represents the fraction of the message traffic load that is digitalized. Therefore, if the original utilization is ρ, then $D\rho$ is the part of the utilization affected. If we assume the digitalized traffic can be transmitted in a negligible amount of time, the new utilization is

$$\hat{\rho} = (1 - D)\rho \quad .$$

Neglecting the transmission time for digitalized messages may not be appropriate in cases where we expect to greatly increase the traffic. For example, processing many additional license checks or processing status messages with an increased number of cars per channel might create so many digitalized messages that their on-the-air time could no longer be neglected. But that represents a situation that could not have existed without digicom because the original utilization ρ would almost certainly have exceeded one, an impossible condition. But in this section we are dealing with utilizations that are already in effect and are therefore considerably less than one even with voice transmission. Consequently, the message traffic is low enough so that the fraction digitalized may be neglected.

With the new utilization $\hat{\rho}$ we may calculate the mean number L in the system and the mean number L_q in the queue according to

$$L = \frac{\hat{\rho}}{1 - \hat{\rho}}$$

$$L_q = \hat{\rho} L \quad .$$

Since we are simply digitalizing existing messages and not generating new ones, our arrival rate λ is unchanged. Therefore, the mean waiting time W until message completion and the mean waiting time W_q until the message is out of the queue and begins transmission are given by

$$W = \frac{L}{\lambda}$$

$$W_q = \hat{\rho} W \quad .$$

7.4 (Continued)

Most police administrators will have their own ideas about what digitalization level can be successfully attained in their department, just as they have their own ideas about what their current utilization level is during peak periods. However, Table 7-1 provides some guidance when needed. Suppose a channel with 28 cars assigned currently has a utilization ρ and it is desired to digitalize the status messages and administrative messages only, of which there are an average of 4.0 and 0.5 messages per hour, respectively. There is little error in assuming that the digitalized messages are processed with a negligible amount of air time, so the new utilization is

$$\hat{\rho} = \frac{3600\rho - 28[4(3) + 0.5(5)]}{3600} \quad .$$

The digitalization level D is

$$D = \frac{\rho - \hat{\rho}}{\rho} \quad .$$

In some cases the digitalization level D is known but the new utilization $\hat{\rho}$ is unknown. Then, Figure 7-33 may be used to read $\hat{\rho}$ directly. Figure 7-34 shows how various levels of digitalization will reduce the mean number of messages in the system and Figure 7-35 shows how the mean number of messages in the queue is reduced. Note that when only 40 percent of the messages are digitalized both variables are reduced to less than half their value at the zero percent level (which represents no digitalization). Figures 7-36 and 7-37 represent similar results for the mean waiting time until message completion and the mean waiting time until transmission begins.

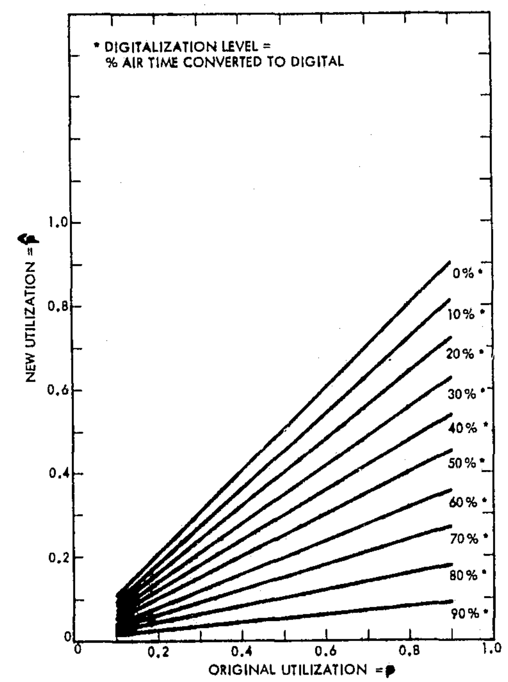

Figure 7-33. Effect of Digitalization Level on Utilization

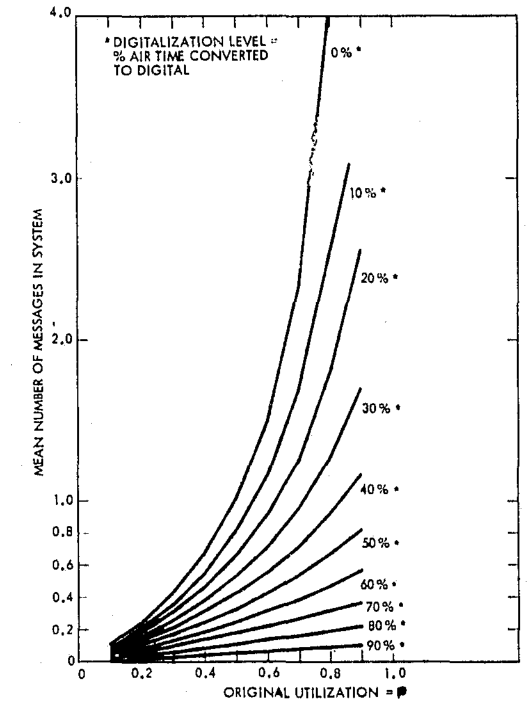

Figure 7-34. Effect of Digitalization Level on Mean Number of Messages in System

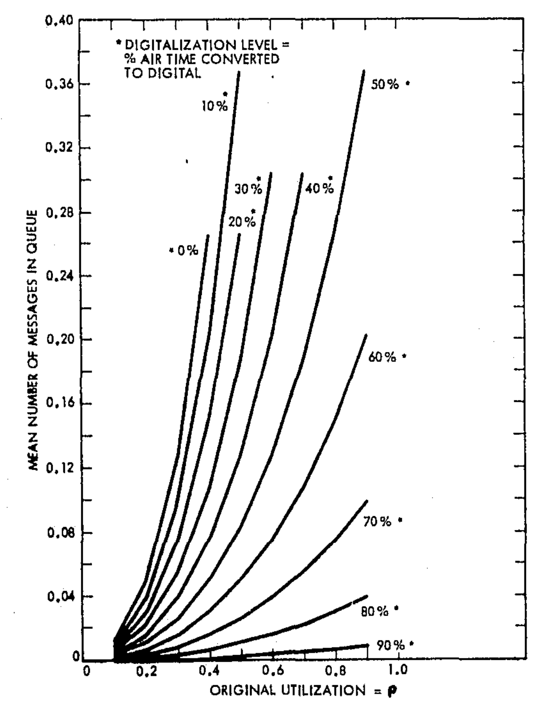

Figure 7-35. Effect of Digitalization Level on Mean Number of Messages in Queue

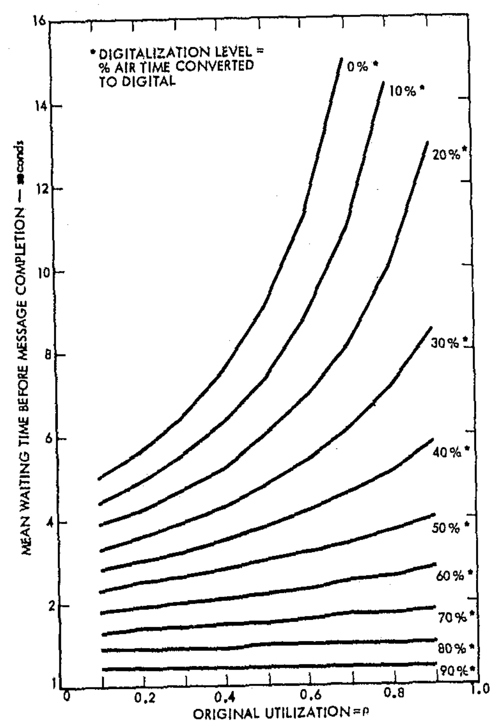

Figure 7-36. Effect of Digitalization Level on Mean Waiting Time Before Message Completion

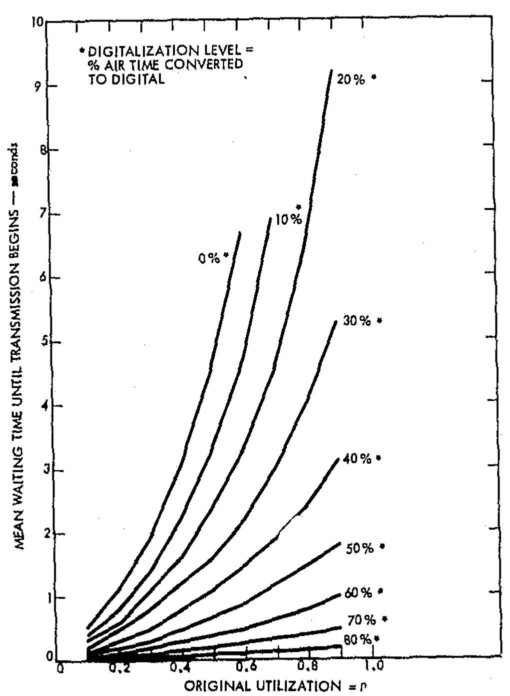

Figure 7-37. Effect of Digitalization Level on Mean Time Until Service Begins

7.5 Cost Considerations for Various Levels of Digitalization

Digitalization of message traffic can occur at various levels and with various configurations of equipment. Table 7-2 shows six levels of equipment that are possible along with the approximate cost and the approximate percentage by which channel utilization would be reduced. At Level I the status messages from the mobile units to the base station are digitalized. Confirmation messages from the base station to the mobile unit are tone-coded but not displayed in the mobile. Level II incorporates all the capability of Level I and in addition it allows for the digital transmission of any four preset codes from the base station to a patrol vehicle. Level III includes the capability of Level II and permits eight additional preset codes to be transmitted digitally from the base station to mobile units. Since four preset codes were possible in Level II, this means that a total of 12 are possible in Level III. Level IV approximates the digicom mobile unit. It has all the capability of Level III and also allows digital transmission of license checks from the patrol units to the base station. Level V is a digicom mobile unit combined with a teleprinter. Level VI is equivalent to the latest available digital device. Each mobile unit contains a 64-character video (CRT) display. Using this system, essentially all police communications can be done digitally except emergency broadcasts. It should be noted that the approximate cost data given in Table 7-2 applies only to the equipment in a mobile unit and not to the facilities at the base station. Base station costs vary with the number of mobile units and the complexity of the base equipment desired. A crude estimate would be in the range of $10,000 to $100,000 to support equipment from Level I to Level VI.

Figure 7-38 is a plot of the percentage reduction of channel utilization as a function of the various digital equipment configurations. Sometimes it is of interest to study the percentage reduction obtained per dollar invested, although in many cases a certain reduction must be obtained regardless of the cost. Figure 7-39 is a plot of the percentage reduction per dollar invested based on the mobile cost estimates. To be conservative, the higher cost estimates of Table 7-2 are used. Figure 7-39 shows that the lower levels of equipment configuration are "efficient" in reducing channel utilization. However, for many departments the magnitude of the reduction is below the acceptable level.

Table 7-2. Levels of Digitalization

Level	Messages Digitalized	Equipment Cost Per Car	Percentage Reduction Of Channel Utilization
I	Mobile-to-Base: status messages Base-to-Mobile: confirmation messages	$300—400	13%
II	Level I plus four preset codes for Base-to-Mobile transmissions	$400—500	15%
III	Level II plus eight additional preset Codes for Base-to-Mobile transmission	$500—600	21%
IV	Level III plus Mobile-to-Base License checks	$1200—1500	26%
V	Level IV plus teleprinter	$1500—2400	59%
VI	Digicom 300	$3000	95%

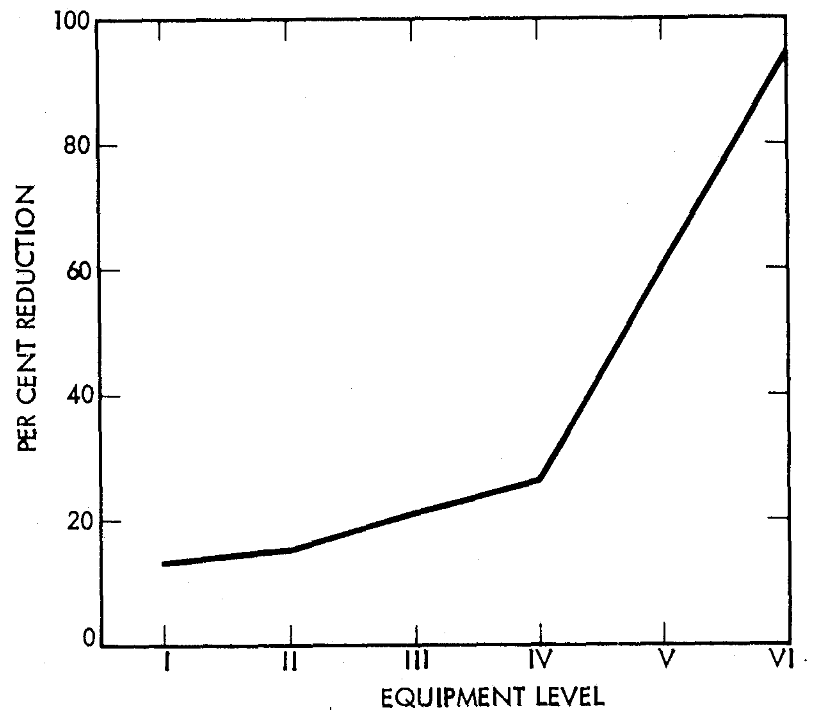

Figure 7-38. Percentage Reduction of Channel Utilization as a Function of Various Digital Equipment Configurations

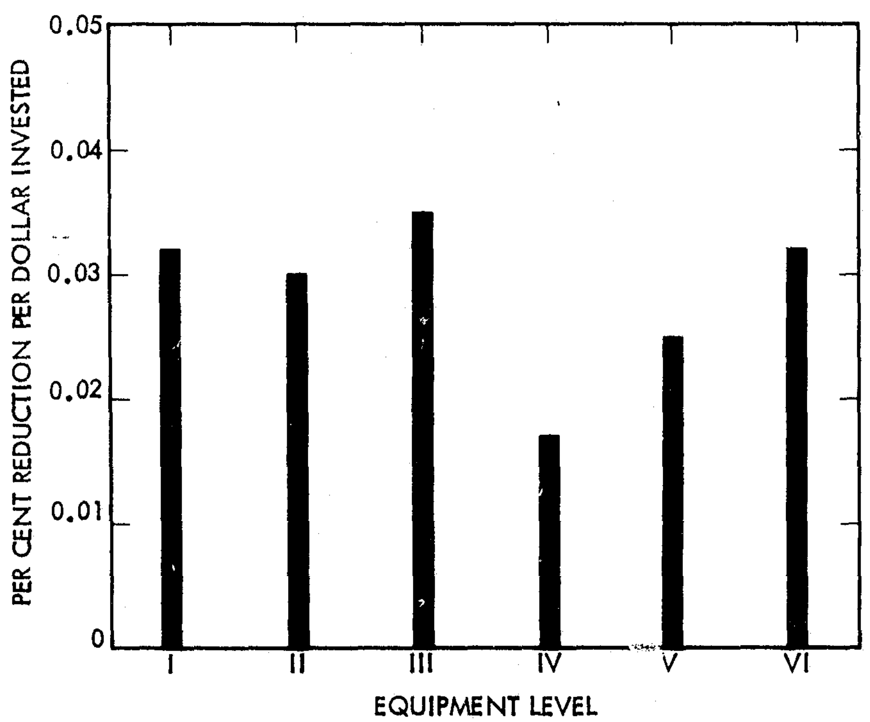

Figure 7-39. Percentage Reduction per Dollar Invested Based on the Mobile Cost Estimates

8.0 CONCLUSIONS AND RECOMMENDATIONS

Project digicom has established that digital communication devices can:

1. Reduce channel congestion to an extent limited primarily by the sophistication of the device.
2. Reduce the workload on the over-burdened dispatcher.
3. Provide additional personal security to field personnel.
4. Increase command and control efficiency.
5. Simplify the routine operations of dispatchers and radio car operators.
6. Increase information throughout without contributing to channel congestion.
7. Improve the responsiveness of the communication system.
8. Provide valuable management information.

Obviously, channel congestion can be reduced by adding more channels and dispatchers as required. Even if such channels are available, equipment costs may easily approach those of the most expensive digital system. More dispatchers tend to reduce the workload on any given dispatcher at least for a short period of time. However, more radio channels and dispatchers do not offer the other improvements available in a digital system.

One of the most important attributes of a digital system (not addressed during this project) is the independence of digital information and the particular radio channel. Unlike voice communication which typically must be addressed to a specific dispatcher and hence is constrained to a single operating frequency, digital information may be transmitted on any channel and then directed to the appropriate dispatcher at the base station. During a period of peak voice activity on one channel, an officer may select an alternate channel and transmit his information.

Digital communication promises to be an innovative addition to the capabilities of law enforcement agencies in dealing with problems inherent in a system that has grown tremendously over the past decade. It is a natural part of the overall command and control systems already implemented in many large cities. Computerization of complaint station functions, dispatcher functions, records, and data bases have as their natural extension computerization of the patrol car.

As a first step in accomplishing this objective, the Law Enforcement Assistance Administration, Public Safety Agencies and industry should work with the Federal Communication Commission in formulating the necessary rule changes to permit operation of two-way digital devices on public safety frequencies.

8.0 (Continued)

In conjunction with the FCC effort, additional investigations should be conducted where a sophisticated digital system has been integrated into an automated command and control system. Digital equipment for such a system could be designed for evaluation of the equipment and system configuration now that the concept has been evaluated and proven to be feasible as well as useful.

A brief discussion of what the next generation digital systems will be like is included in the next section.

9.0 FUTURE DIGITAL COMMUNICATION SYSTEMS

Over the past decade there has been a proliferation of automated local, state, and national information systems. The San Francisco Police Department presently has terminals for accessing: CLETS (California Law Enforcement Telecon System), AUTOSTATIS (Automatic STatewide Auto Theft Inquiry System), PIN (Police Information Network), and their own MIS (Management Information System). CLETS is probably typical of the direction police automated information systems will go in the future. A single CLETS terminal provides access to the California Highway Patrol AUTOSTATIS files on stolen and wanted vehicles and stolen license plates, access to the Department of Motor Vehicles AMIS (Automated Management Information System) files on driver licenses, vehicle registration, and driver/vehicle histories, access to the Department of Justice CII (Criminal Identification and Investigation) files on wanted persons, stolen articles and stolen guns, and automatic referral on negative inquiries to NCIC (National Crime Information Center, FBI). Future systems are expected to be further integrated to provide local, state and national inquiry from a single terminal and automatic referral on negative inquires.

The success of automated information systems in providing police with a tremendously important new capability is not completely untainted. Inquiries from the officer on the street have increased dramatically. Radio channels already overloaded are now taxed unbelievably, and dispatchers in some instances simply can't handle the additional workload. More dispatchers and radio channels are a temporary solution, but a solution not without serious drawbacks. More radio channels and dispatchers mean decentralization of command and control. Many cities are already divided into two to six dispatching zones. When this happens, inter-zonal dispatching decreases or ceases completely except in emergencies. Herein lies the difficulty, optimum utilization of field forces dictates that the closest available unit be used to cover a call or provide fill. Even when a closer car may be able to switch his radio to the proper channel, the dispatcher may select another unit farther away which is assigned to his primary frequency. As the number of dispatchers and frequencies multiply, so does this type of inefficiency. Even if this solution were not inefficient and therefore expensive (poor manpower utilization), the costs of converting to new radios, transmitters, base station equipment, and adding new personnel can be prohibitive. Also, personnel costs continue for the lifetime of the system.

Several alternatives are available to police departments in the form of mobile terminal devices which will function in the squad car. The recently announced Sylvania/digicom 300 (Figure 9-1) is an example of such a device. Digicom 300 provides two-way digital communication between mobile units and the base station. Status as well as other preset codes and up to 64 characters of alpha-numeric information may be sent or received.

To run a license plate check, an officer on the street simply types in a license plate number and a two-letter state designator if necessary and pushes a button indicating what type of information he wants. Taking the California system as an example, he can request a PIN, AUTOSTATIS, or CLETS inquiry or any combination. The digital information is decoded at the base station processor, reformatted, and sent via telephone line to the appropriate remote computer system. The response via telephone line is reformatted (e.g., stolen = 10-30) and sent to the vehicle where it is displayed on the video terminal. Similar considerations apply to drivers license inquiries, suspect names, etc.

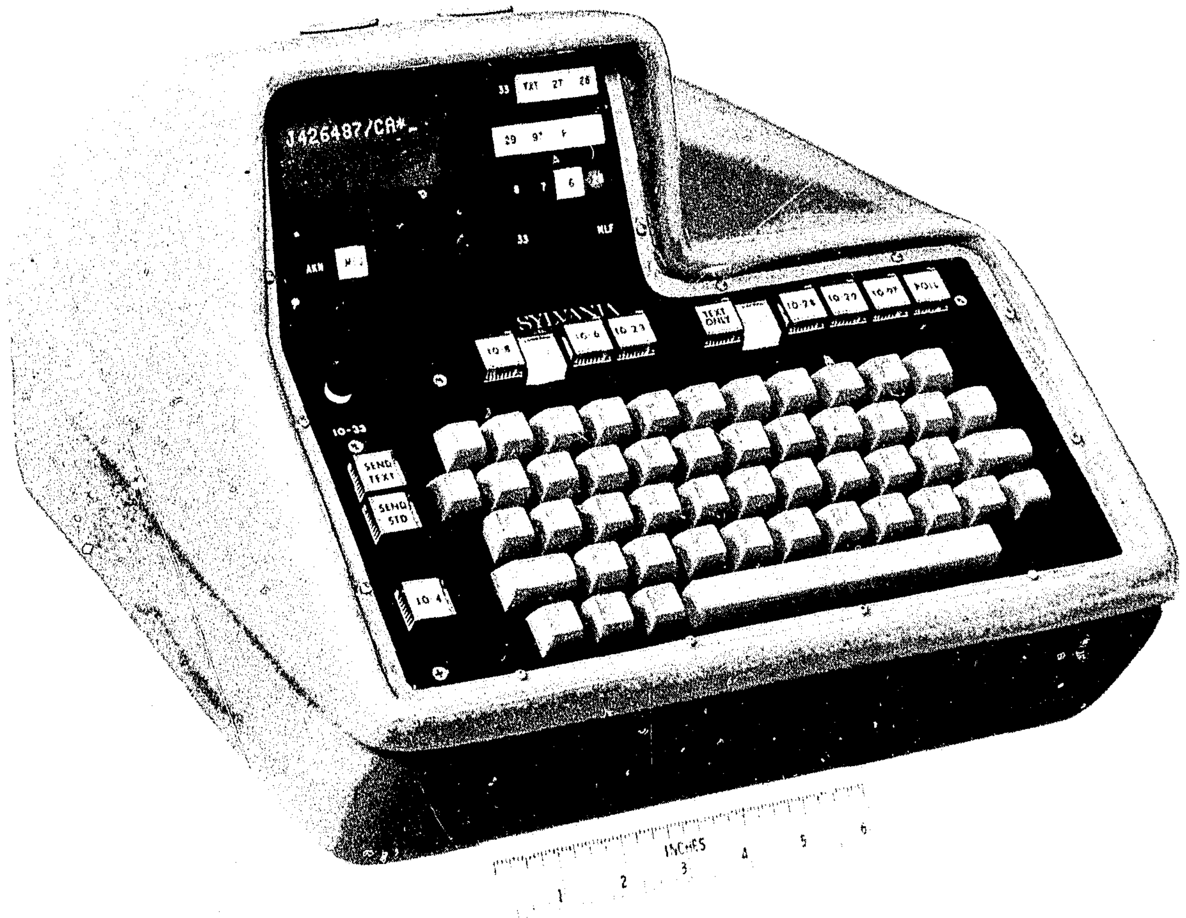

Figure 9-1. Sylvania/digicom 300

9.0 (Continued)

Significantly, this type of system requires very little channel time, 1 to 3 seconds, and does not require the dispatcher's attention at all! The information can be transmitted on any channel available in the squad car. Typically, it is possible to send 10 to 15 times as much information for the same amount of channel time. No additional personnel are required and the already over-burdened dispatcher is relieved. The response to the inquiry is displayed whether or not the officer is in the vehicle.

A natural extension of a digital system involves automating the functions of the dispatchers and complaint clerks. In an automated system, calls to the police are answered by a complaint clerk who enters the incident information into a computer via a keyboard. The computer searches files of street addresses, converts the street address to a reporting area and displays the call location to the appropriate officers to respond and radios the information to them. If the squad car is equipped with a Sylvania/digicom 300 unit the message can be sent digitally.

The responding officer enters his digital status and proceeds to the scene. Arrival at the scene is also relayed digitally and when the call is cleared again a digital status change is sent. In most situations, the disposition of the call can also be handled with the Sylvania/digicom 300 unit.

9.0 (Continued)

At the base station, the computer can be programmed to provide a complete record of each event. Each record would contain the time the call was received by the complaint clerk, the time the unit(s) were dispatched, the time they arrived at the scene, the time they cleared the call, and the disposition of the call. This information can be stored on magnetic tape as a permanent log and written on a teletype to provide immediate access during the day. District stations can also be equipped with a teletype terminal to provide complete information on the runs given to men assigned to their station.

The Sylvania/digicom 300 has an optional printer attachment that can be activated from the base station or the mobile unit. When activated, any information on the mobile CRT is written on the printer. When a "hit" is made on a license plate, suspect, etc. this is a particularly useful capability. Supervisory cars equipped with the printer option can receive each run assignment given to men under their control. Upon demand from the supervisor's digicom 300, the base station computer can supply the status and/or location of his men.

Frequently, the dispatcher acts as a message switching point. Requests for units to call their station or return to their station that originate at the station can be entered into the computer via a Sylvania/digicom 300 or a teletype if they do not have radio transceivers. The computer can relay the message to the unit via the digital system. Requests for a wagon by the field units can be sent to the wagon via the computer without human intervention. The response from the wagon can also be sent back to the squad car. If the wagon is on an assignment the computer can automatically inform the requesting unit. Requests for tows can be transferred to a single point from all units throughout the city. When the tow is responding, a digital message (410) indicating that the requested assistance is responding can be sent. Ambulance requests can be handled in a similar manner.

On-view investigations where an officer simply informs the dispatcher of his location and type of investigation can be handled digitally. Furthermore, the computer can automatically alert the dispatcher if an on-view investigation has taken longer than a specified period of time. The time period can be set by the officer in the car or preset by the department. Car stops where an officer radios a license plate number and location can also be handled digitally. The license plate can be checked through the remote files automatically. Again, the district station can be provided with a record via the teletype link if required.

Vehicle location is another aspect of command and control that is compatible with digital systems. Expensive and complex systems are presently available that can locate a car to within several hundred feet. Less expensive semi-automated systems are also available. An example is the Sylvania/digimap 100 which is compatible with all Sylvania/digicom equipment (Figure 9-2). Digimap is a pressure sensitive map mounted on a grid-matrix board within easy reach of the driver. Pressure applied to any point on the map activates the digicom unit and transmits the location coordinates and map identification number to the base station.

At the base station the information is decoded and displayed on a dynamic situation display or stored for access upon demand. Vehicle location is the final ingredient needed for a completely automated command and control system.

The complaint clerk enters the request for service into the computer. Information regarding the priority, location and type of incident are all that is required for action by the computer. Based on the digital location and status information of the patrolmen, the incident location, the priority

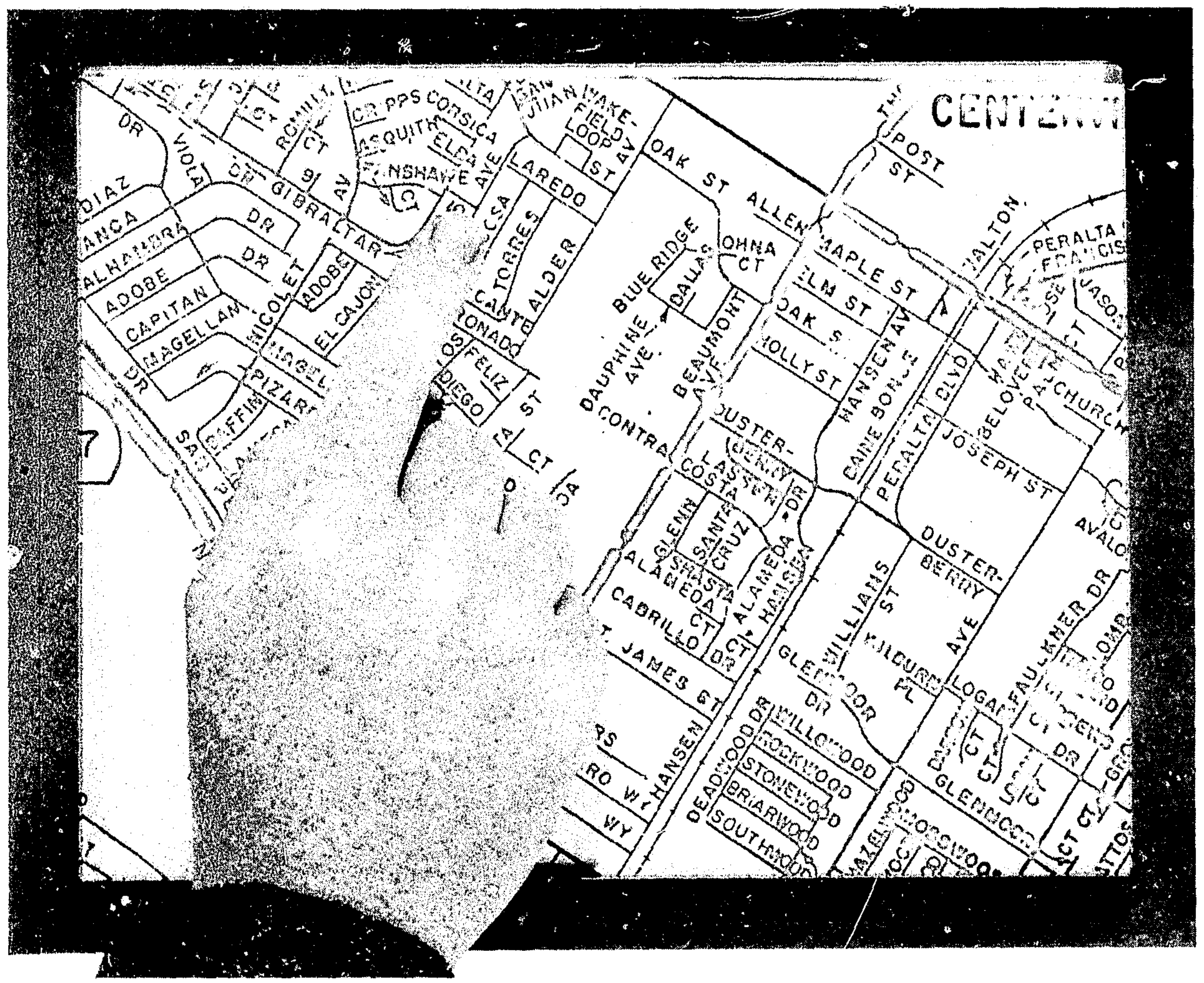

Figure 9-2. Sylvania/digimap 100

9.0 (Continued)

and radio code, the computer selects one or more units to respond. Low priority calls may be held when a unit is close by but out-of-service. Emergency calls will probably be displayed to a dispatch commander for follow-up. Information regarding the call is sent to the vehicle and displayed. Run acknowledgment and the responding status are sent digitally. "No response" situations can be referred to the dispatch commander for action. Arrival at the scene, in-service and disposition are digital. Complete records of all field activity are available on magnetic tape and hard copy. Complete information needed for manpower deployment is available in computer compatible form.

Special crime prevention units equipped with digicom/digimap units can be deployed into areas as desired. The computer system can use them in an emergency and/or display their location and status to the dispatcher. Roving units or floating cards equipped with digicom/digimap can be deployed into areas where particularly heavy demand is anticipated. Again,the computer can automatically utilize them if the situation or policy requires it.

9.0 (Continued)

Significantly, digital systems are not channel dependent. Units operating in an area on a frequency that is different from the responsible dispatchers can still communicate with him digitally. Digital systems are also private systems. It is extremely difficult to "listen in" on a digital system.

Obviously, digital communications will not replace voice communications; however, the capabilities available in a digital system warrant consideration and implementation by law enforcement agencies. The costs of these systems are not excessive when amortized over the lifetime of the equipment and when compared to the alternative of continued poor manpower utilization.

APPENDIX

MATHEMATICAL DERIVATION OF EQUATIONS FOR THE INFINITE QUEUE MODEL

In this section a derivation of the equations relating to the infinite queue model is given and some of the salient features of the model are discussed. The derivation is similar to that given in several books on queueing theory, such as Queues, Inventories, and Maintenance by P.M. Morse.

The model consists of a single service stall (which is the communications channel) before which only one queue is allowed to form. No limitations are placed on the size of the queue, and thus the model is referred to as the infinite queue model. The name may be misleading because no such thing as an infinite queue ever exists. The name is attached because it is impossible to set a finite bound N which the queue length cannot exceed. However, we can make the assertion that as N approaches infinity, the probability that the queue length exceeds N approaches zero.

A finite queue model would be applicable in those situations in which it is impossible, usually for physical reasons, for the queue length to exceed a certain bound. There seems to be no justification for placing any particular bound on the size of the queue that could conceivably form in police communications. Although in any given situation there is a fixed, limited number of patrol units assigned to the channel, there is no such limitation on the need for message traffic. Conceivably, more messages may be pending at any one time than there are cars on the channel.

To derive the equations for the model, we let λ denote the message arrival rate and let μ denote the message service rate. The arrival and service distributions are assumed to be Poisson distributed, which is often a valid approximation in practice. The channel utilization ρ is defined to be $\rho = \lambda/\mu$.

Let P_n be the probability that there are n messages in the system. The system is defined to consist of both the queue and the communications channel. P_n is the steady-state probability; transient formulas will not be derived. Our first goal is to find a general expression for P_n in terms of λ, μ, and ρ.

To derive an expression for P_n we will consider what happens as the system changes from having n messages to having $n + 1$ or $n - 1$ messages. Such changes do not occur continuously, but rather in a discontinuous fashion at discrete moments in time. Moreover, the system cannot proceed from having n messages to suddenly having $n + 2$ messages; it must first pass through the condition of having only $n + 1$ messages. In essence, we are saying that the probability of two messages arriving (or being completed) at the same time is zero.

Although our goal is a derivation for steady-state conditions, we will temporarily introduce the continuous time variable t and the small increment dt. From the Poisson distribution, the probability of a message arriving during the interval (t, t + dt) is λdt. The probability of a message being completed in the same interval is μdt. As dt approaches zero, our discussion of the preceding paragraphs indicates that it is impossible for two messages to arrive or for two messages to be completed in the small interval (t, t + dt). However, the probability that no message either arrives or is completed in this interval is $(1 - \lambda - \mu)$dt. This leads to the equation

$$P_n(t + dt) = \mu dt\, P_{n+1}(t) + \lambda dt\, P_{n-1}(t) + (1 - \lambda - \mu) dt\, P_n(t) \quad . \qquad (1)$$

This equation simply says that the probability there are n messages in the system at time t + dt is equal to

- the probability there were n + 1 messages in the system at time t and a completion occured, plus,
- the probability there were n -1 messages in the system at time t and an arrival occurred, plus,
- the probability there were n messages in the system at t and no messages arrived or were completed in (t, t + dt).

The derivative $dP_n(t)/dt$ is defined by

$$\frac{dP_n(t)}{dt} = \lim_{dt \to 0} \frac{P_n(t + dt) - P_n(t)}{dt}$$

Hence, it is true in the limit that

$$P_n(t + dt) = dP_n(t) + P_n(t) \quad . \qquad (2)$$

Substituting Equation (2) into the left-hand side of Equation (1) and dividing by dt yields

$$\frac{dP_n(t)}{dt} = \mu P_{n+1}(t) + \lambda P_{n-1}(t) - (\lambda + \mu) P_n(t) \quad . \qquad (3)$$

Under steady-state conditions $P_n(t)$ is independent of t. Since it does not change with t, it follows that

$$\frac{dP_n(t)}{dt} = 0 \quad .$$

Dropping the independent variable t which does not affect steady-state conditions, we may write

$$\mu P_{n+1} + \lambda P_{n-1} - (\lambda + \mu) P_n = 0 \qquad n = 1, 2, 3, \ldots \qquad (4)$$

Equation (4) is not valid for $n = 0$ since P_{-1} is not defined. But a similar equation is applicable:

$$\mu P_1 - \lambda P_0 = 0 \quad . \qquad (5)$$

Equation (5) may be rewritten as

$$P_1 = \lambda/\mu\, P_0 = \rho P_0 \quad .$$

Letting n = 1 in Equation (4) we have

$$P_2 = \left(\frac{\lambda + \mu}{\mu}\right) P_1 - \frac{\lambda}{\mu} P_0 = \rho^2 P_0 \quad .$$

Continuing in the same fashion, it follows by induction that for any n

$$P_n = \rho^n P_0 \quad . \quad n = 0, 1, 2, \ldots \tag{6}$$

Since the P_n are probabilities, it must be true that

$$\sum_{n=0}^{\infty} P_n = 1 \quad .$$

Therefore,

$$\sum_{n=0}^{\infty} \rho^n P_0 = P_0 \left(\frac{1}{1-\rho}\right) = 1 \quad . \tag{7}$$

The infinite sum in Equation (7) converges since the utilization ρ must be less than unity if steady-state conditions are to prevail. If ρ were not greater than unity the queue length would grow without bound and steady-state conditions would never be obtained. We may use the results of Equation (7) to rewrite (6) as

$$P_n = \rho^n (1 - \rho) \quad .$$

Having obtained an expression for P_n it is now possible to derive formulas for the mean number L of messages in the system and the mean number L_q of messages in the queue. L is simply the expected value that follows from the equation

$$L = \sum_{n=0}^{\infty} n P_n$$

$$= \sum_{n=0}^{\infty} n\rho^n (1 - \rho)$$

$$= (1 - \rho)\rho \sum_{n=0}^{\infty} n\rho^{n-1}$$

$$= (1 - \rho)\, \rho \cdot \frac{1}{(1-\rho)^2} = \frac{\rho}{1-\rho} = \frac{\lambda}{\mu - \lambda} \quad .$$

Similarly, L_q is obtained from

$$L_q = \sum_{n=1}^{\infty} n P_{n+1}$$

$$= \sum_{n=1}^{\infty} n \rho^{n+1} (1 - \rho)$$

$$= (1 - \rho)\rho^2 \sum_{n=1}^{\infty} n \rho^{n-1}$$

$$= (1 - \rho)\rho^2 \cdot \frac{1}{(1-\rho)^2} = \frac{\rho^2}{1-\rho} = \rho L \quad .$$

Since steady-state conditions prevail the mean queue length L_q must equal the mean waiting time W_q in the queue times the mean arrival rate λ . Therefore,

$$W_q = \frac{L_q}{\lambda} \quad .$$

The mean duration of a message is $1/\mu$. Therefore, the mean waiting time until a message is completed is

$$W = W_q + 1/\mu$$

$$= \frac{L_q}{\lambda} + 1/\mu \quad .$$

After some manipulation, this expression reduces to

$$W = \frac{1}{\mu - \lambda} = \frac{L}{\lambda} \quad .$$

END