CARGO SECURITY FIELD TEST

FINAL REPORT

Volume I: Executive Summary

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THE AEROSPACE CORPORATION

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ABSTRACT

A Cargo Security System, designed to reduce the incidence of theft in the pickup and delivery segment of the trucking industry, has been developed and tested. It is comprised of a multi-user vehicle location and status reporting system with provisions for real-time warning of alarm or alert conditions at each vehicle en-route or parked in the freight depot and provides an audit trail of all vehicle movements and transactions. A technical description of the system is presented and the findings of system checkout testing and recommendations for system improvements are documented.

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SUMMARY

The Cargo Security Field Test Program conducted for the Law Enforcement Assistance Administration had as its objective the evaluation of a cargo security system in terms of its impact on cargo theft and the operational utilization of cargo vehicles.

Earlier phases of the overall Cargo Security program had identified the magnitude and distribution of cargo losses within the trucking industry, had established that the pickup and delivery segment of the industry suffered the preponderance of losses, and, with the cooperation and participation of cognizant security officers, had determined that continuous surveillance of vehicle location and status would provide the most cost-effective method of countering theft. A pilot test program was instituted to assess system feasibility and to identify the requirements for an operational system. This program was completed in 1976 and established the system operational requirements for the Field Test Program.

The Field Test Program was designed to evaluate system performance with a total of 40 pickup and delivery trucks operating within a 400-square-mile area of the Los Angeles basin. The program consisted of two phases: (1) the design, development, deployment and checkout of an improved cargo security system, and (2) the evaluation of its impact on cargo operations. To assess the feasibility of sharing common system elements between multiple users, a primary cost consideration in a fully operational system, the 40 vehicle units were equally divided between two independent trucking operations.

The design of the system incorporated the necessary improvements identified during the pilot test program, and was comprised of an automatic vehicle location subsystem deploying signals from commercial broadcast stations and a limited number of proximity units, a vehicle sensor and processing subsystem, a communications subsystem, a data processing subsystem, and display subsystem, all linked by a common communications subsystem.

The overall system was deployed in the Los Angeles test area, and its capability to provide real-time reporting of vehicle location and status and an audit trail of vehicle movements was demonstrated during the system checkout phase of the program.

A non-technical problem, namely the unavailability of a clear mobile radio channel in the test area, precluded completion of system acceptance testing and the initiation of the formal field evaluation, (the checkout phase had been conducted using a radio channel for which an experimental license was obtained; however, during final checkout, it was found that operation on the channel caused interference with regularly licensed users in Southern California,) and the program was terminated by LEAA.

From a technical viewpoint, the state-of-the-art of vehicle monitoring was materially advanced by the successful development and demonstration of the system. Implementation of the system provided an active demonstration of the multi-user, wide-area-coverage capacity of the AVM system and the capability for determining vehicle location using commercial AM broadcast transmissions. The development and subsequent operation of a dedicated, common, mobile radio digital communication link for multiple users was proven viable and to be operationally acceptable from an end-users standpoint. Further, the design and implementation of a sophisticated, combined data-base-driven and event-driven data processing system which operated in a distributed processing environment was completed.

The technical accomplishments and the findings of the system design, development, deployment and checkout phase may be summarized as follows:

- o Vehicle Location System
  - oo A wide-area coverage Automatic Vehicle Location (AVL) system was developed which operated over a 400-square-mile area (an area greater than the sum of the areas covered by all previously developed AVL systems).
  - oo A very accurate, repeatable, and economical AM Phase signal tracking sensor/receiver was developed.
  - oo A differential navigation system combining two location technologies was developed.
  - oo Certain aspects of the external environment resulted in location errors beyond the specified limits and additive augmentation should be incorporated if the system is to realize its full potential in accurately determining vehicle location in an urban environment.
- o Sensor System
  - oo The use of combinatorial logic for detected sensor information in the vehicle demonstrated that false alarms could be minimized while maintaining a full capability of detecting significant events.
  - oo The low-cost, off-the-shelf sensors used in the sys-require that reasonableness criteria logic be in-

corporated to preclude the possibility of generating false data.

- oo The environment of the installed sensors is hostile.
- oo The operational value of the cargo compartment intrusion sensor is questionable.

o Communications System

- oo A single channel, multi-user, digital, mobile radio communication system was developed and successfully implemented.
- oo The system operated on a truly non-interference basis with the normal trucking operation.
- oo A dedicated clear channel is needed for successful system operation. Additional preventive measures and protection are required to combat deliberate disablement of the communications antenna.
- oo Communication coverage in the trucking company yard is unique to each installation, and special measures may be required to provide reliable operation at those specific locations.

o Base Station/Dispatch Station System

- oo An event-driven dispatch display system which operates five devices over a single telephone line communications link was developed.
- oo A simple, comprehensive, user-oriented, interactive dispatch display and recording/printout system was developed.
- oo A transaction history and vehicle recent history re-

cording algorithm and recall procedure was developed to provide security personnel with a log of vehicle activity.

oo A street data base algorithm, digitizing method, real-time nearest intersection look-up algorithm and vehicle in-route/out-of-route algorithm was developed to provide alphanumeric display of vehicle location and route status to the nearest of over 30,000 intersections and 40 truck routes in the 400-square-mile area.

As a consequence of these findings, and the limited operational experience gained on the program, the following recommendations are made:

- o The AM Phase-Lock vehicle location system should be augmented using a microprocessor and odometer sensors to eliminate location inaccuracy due to excessive localized grid warpage resulting from environmental factors.
- o The sensor and communications system should be upgraded to account for the hostile environment, and the operational utility of certain sensors should be re-evaluated.
- o A dedicated clear channel is mandatory for the common communications link.
- o The dispatcher station should be upgraded from a human factors standpoint.
- o The system should be capable of automatic recovery from a power failure.
- o Planning for future installations should include consideration of vehicle conditions from an electrical stand-

point for evaluation of communications coverage at individual freight yards, and installation and operational implications resulting from the trend towards the use of semitrailers for pickup and delivery operations.

- The utility of the system when trucks are in the freight yard should be re-evaluated by potential users.
- Because of the special relationship between drivers and dispatchers, consideration should be given to routing all theft-related data to the security personnel, with only location and driver initiated alarm data being presented to the dispatcher.

CHAPTER 1. INTRODUCTION

Cargo theft is recognized as a major problem resulting in a multi-billion-dollar drain on the national economy. In 1973, the Aerospace Corporation, under contract to the Law Enforcement Assistance Administration, U. S. Department of Justice, initiated a Cargo Security Program aimed at reducing the incidence of cargo theft in the trucking industry. A survey and assessment of the problem identified the magnitude and distribution of theft losses and established that the pickup and delivery segment of the industry was the principal victim of the cargo thief. With the cooperation of industry security personnel, various means of combatting cargo theft were evaluated, and the concept of real-time surveillance of vehicle location and status was developed (Figure 1). Economic studies of the industry led to the establishment of cost limits for such a surveillance system.

Preliminary feasibility studies led to a pilot test program to evaluate the concept in an operational environment. This program, which was completed in 1976, established concept feasibility and identified certain areas of improvement required for an operational system. A formal field test program to evaluate the operational utility of the system was initiated in 1977. An improved system was designed and deployed in the Los Angeles area, but the non-availability of a clear radio communications channel precluded completion of system acceptance and formal field evaluation.

The purpose of this Final Report is to document the functional and technical characteristics of the system, to describe the technical accomplishments achieved during its development and deployment,

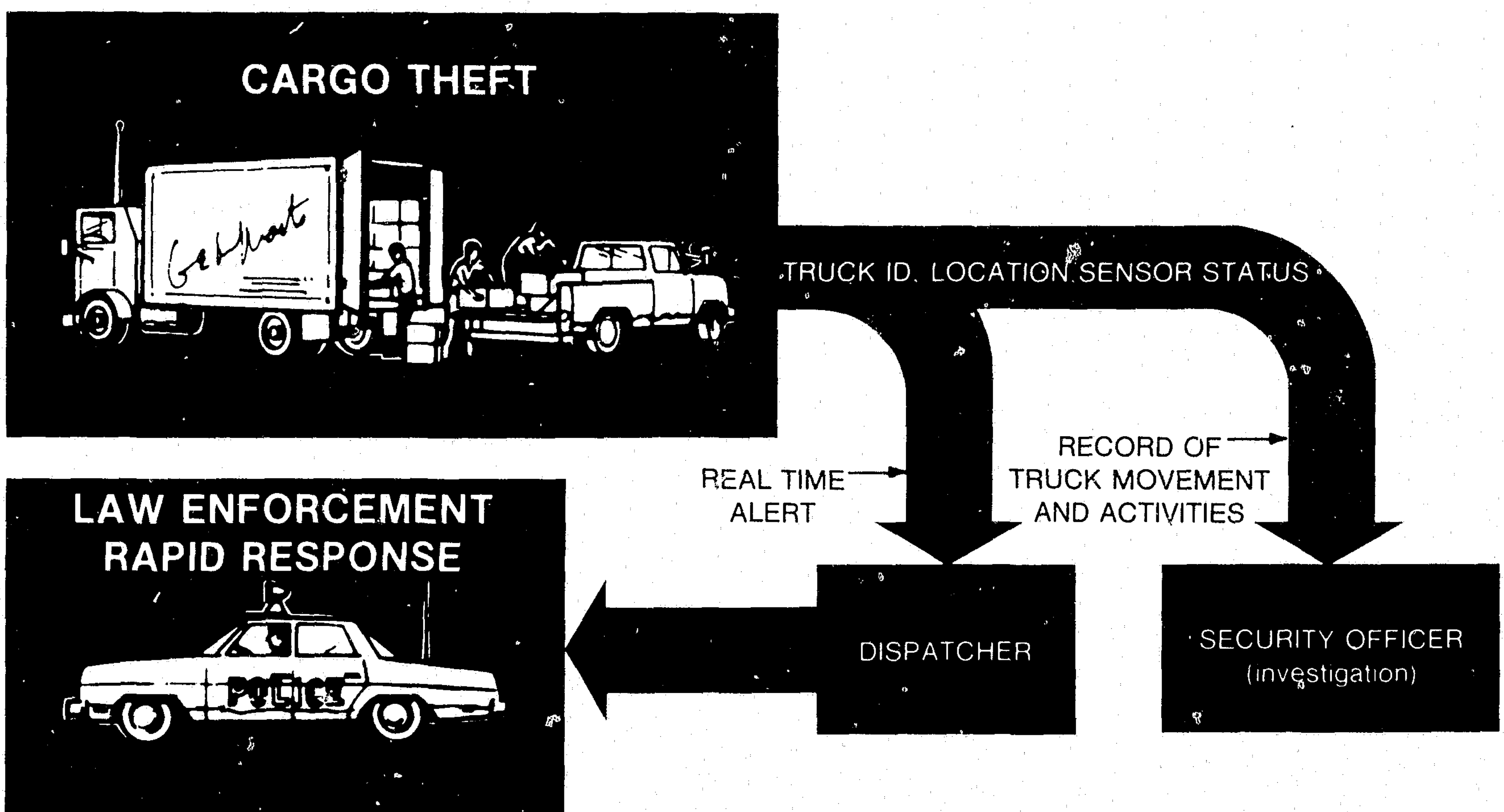


FIG. 1 CARGO SECURITY SYSTEM CONCEPT

and to present the major findings and recommendations resulting from the field test program.

The Final Report is organized in three volumes. This volume provides an overall summary of the program and its findings, and is presented in four chapters:

- o Chapter 1 describes the program background.
- o Chapter 2 summarizes the operation of the system.
- o Chapter 3 reviews the design, development, deployment and test activities.
- o Chapter 4 presents the program findings and recommendations.

Volume II contains a comprehensive description of the overall system, each subsystem, the system installation and deployment, and the system testing performed. Volume III is comprised of detailed technical data on the hardware and software elements of the system and selected items of test data.

CHAPTER 2. SYSTEM OPERATION

The Cargo Security System provides for the following: (1) real-time surveillance of vehicle location and status, (2) display of incipient theft situations and individual vehicle status to the appropriate fleet dispatcher, and (3) data recording of individual vehicle histories for use by security personnel.

The system is comprised of five major elements:

- o A location support element which provides a controlled electromagnetic grid to support location determination.
- o A vehicle element which senses, processes and outputs data from the location support equipment and the vehicle status sensors.
- o A base station element which provides overall system control and processes data from the vehicles and the dispatch station equipment.
- o A dispatch station element which provides for the display and printout of vehicle data.
- o A communications element which provides the data transmission paths between all system elements.

The system is illustrated in Figure 2 and has two modes of operation which are enabled automatically or by dispatcher selection.

Normal Mode. During normal business operations, i.e., when the trucks are engaged in the loading and delivery of cargo. In this mode, the dispatcher is provided with the following display data and hardcopy outputs.

- o A system status display (Route Status) depicted in Fig. 3 which describes the location and status of all trucks and

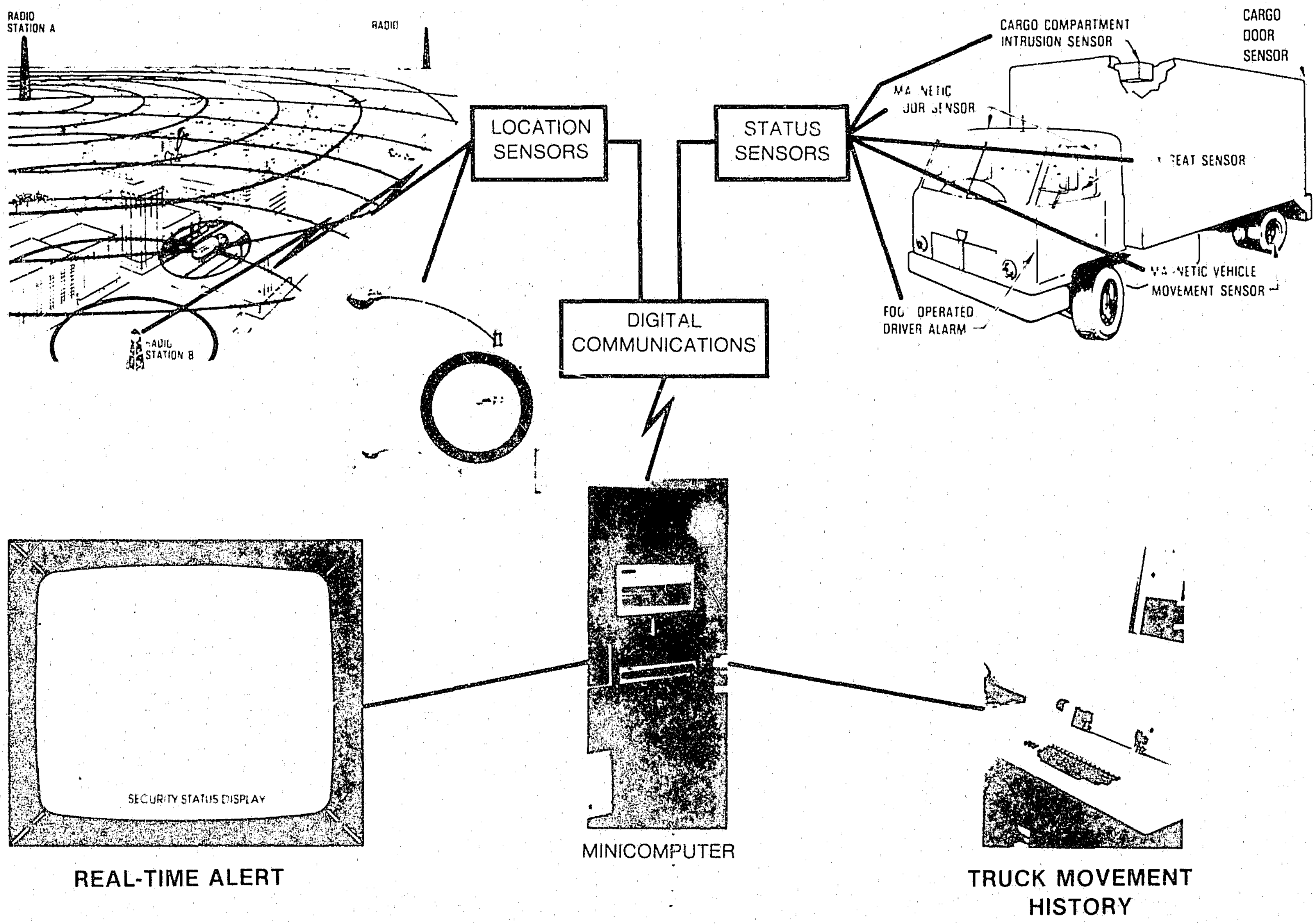


FIG. 2 CARGO SECURITY SYSTEM

an indication of alarm or potential theft situations is the primary system display. Vehicle location and status data on the display is updated whenever significant location changes occur or when a predetermined sequence of sensor actuations is detected. Data transmissions are normally initiated by the vehicle upon occurrence of any of the above events. However, a supplemental base-station-initiated interrogation to verify communications and vehicle system integrity also provides location and status change data.

- A specific vehicle status display (Security Status) provides the dispatcher with detailed sensor status information as well as location information. Supplementary data (e.g., license plate number, truck identifier, appropriate law enforcement jurisdiction, etc.) is displayed to assist the dispatcher in responding to an abnormal situation. Figure 4 illustrates the Security Status display format.
- A printed copy of display information provides the dispatcher with all the significant data relative to an alert or alarm condition, including sensor status, vehicle location and time of occurrence. This information also serves as a permanent record of fleet operations.

After Hours Mode

Outside normal business hours, a vehicle is loaded and parked either within its freight yard or another known location. The after hours mode of the system provides for the real-time detection of attempts to steal or to enter the vehicle with alarm data presented on a separate display located in the security guard area. (Figure 5)

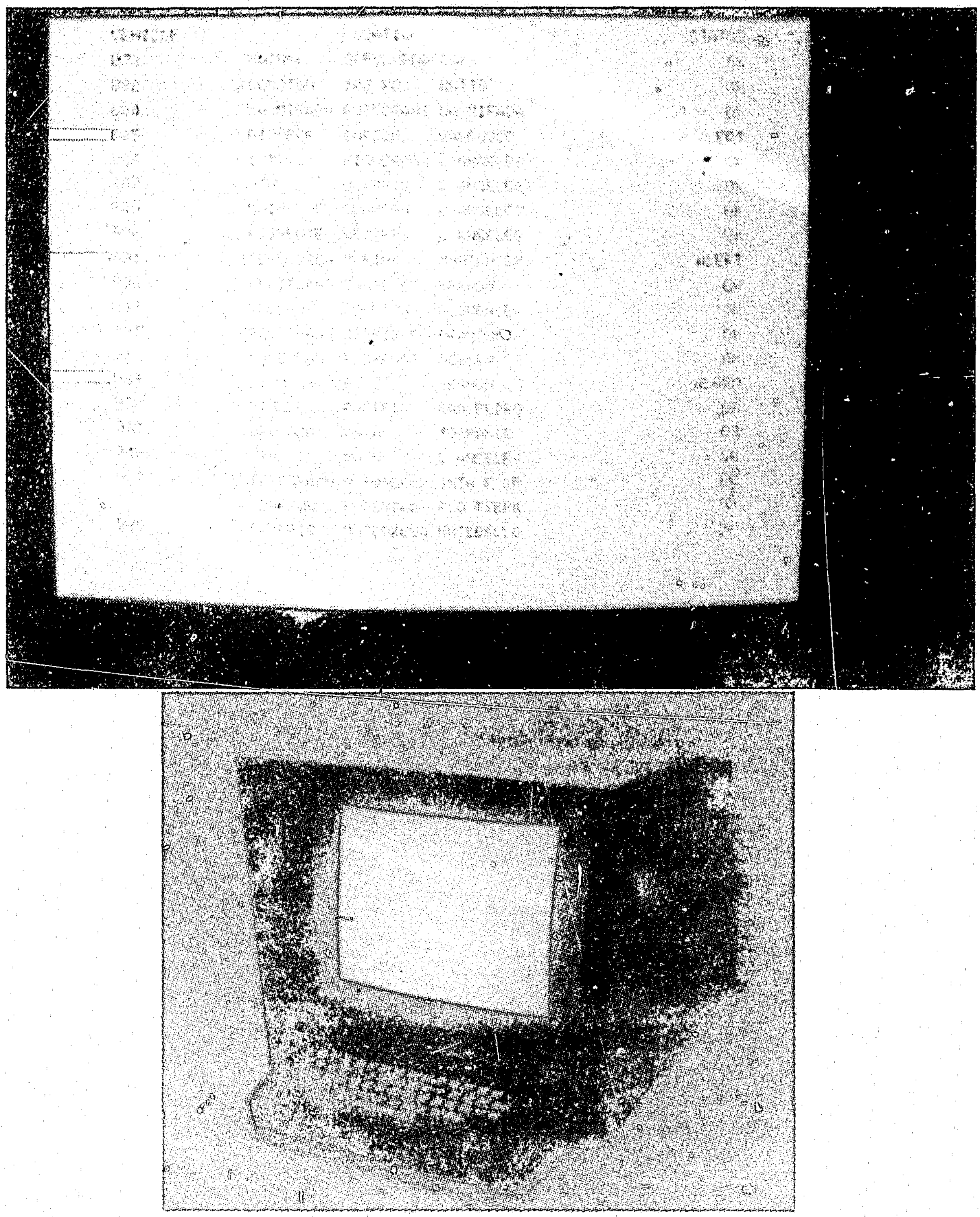


FIG. 3 DISPATCHER'S CRT, ROUTE STATUS MODE

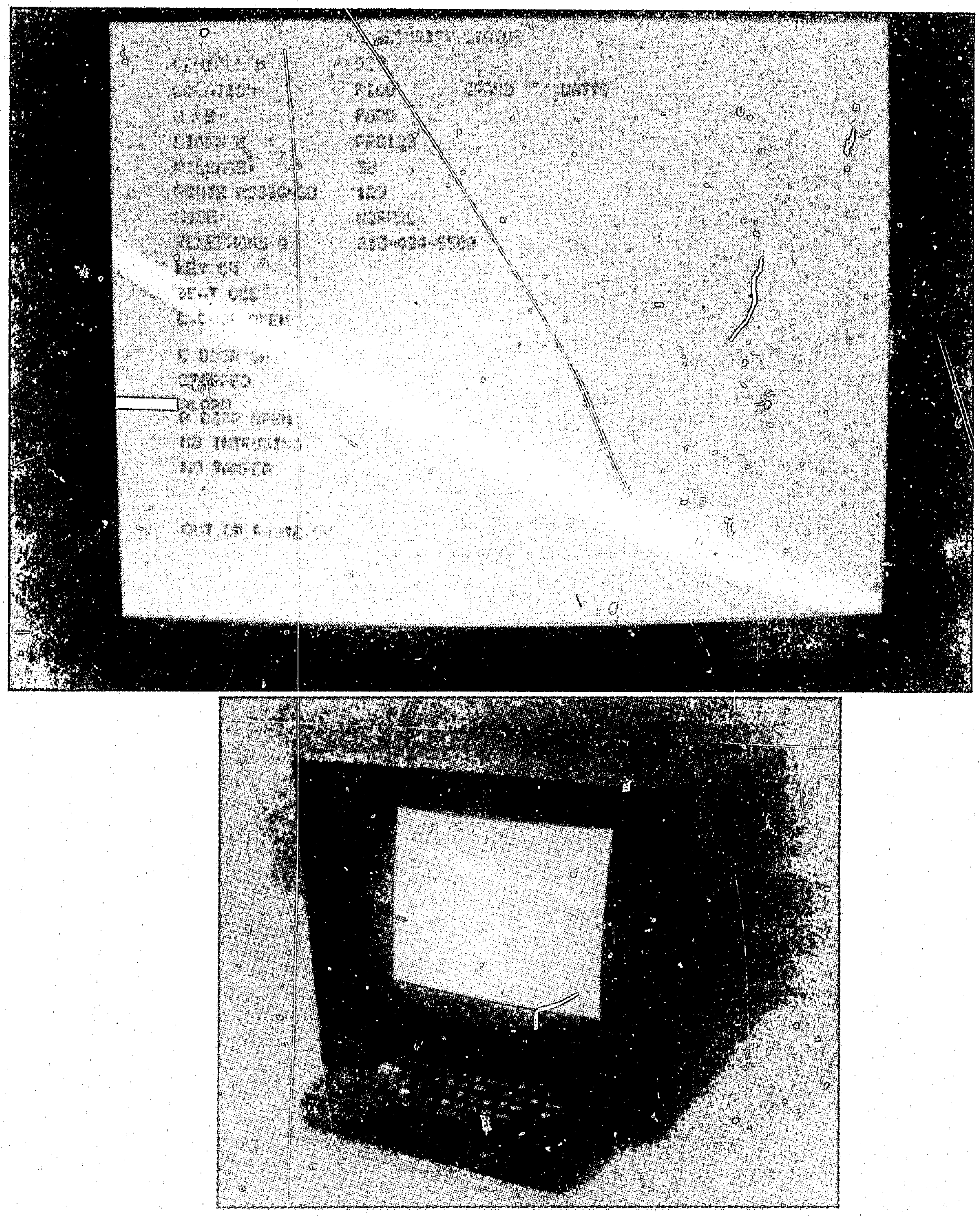


FIG. 4 DISPATCHER'S CRT, SECURITY STATUS MODE

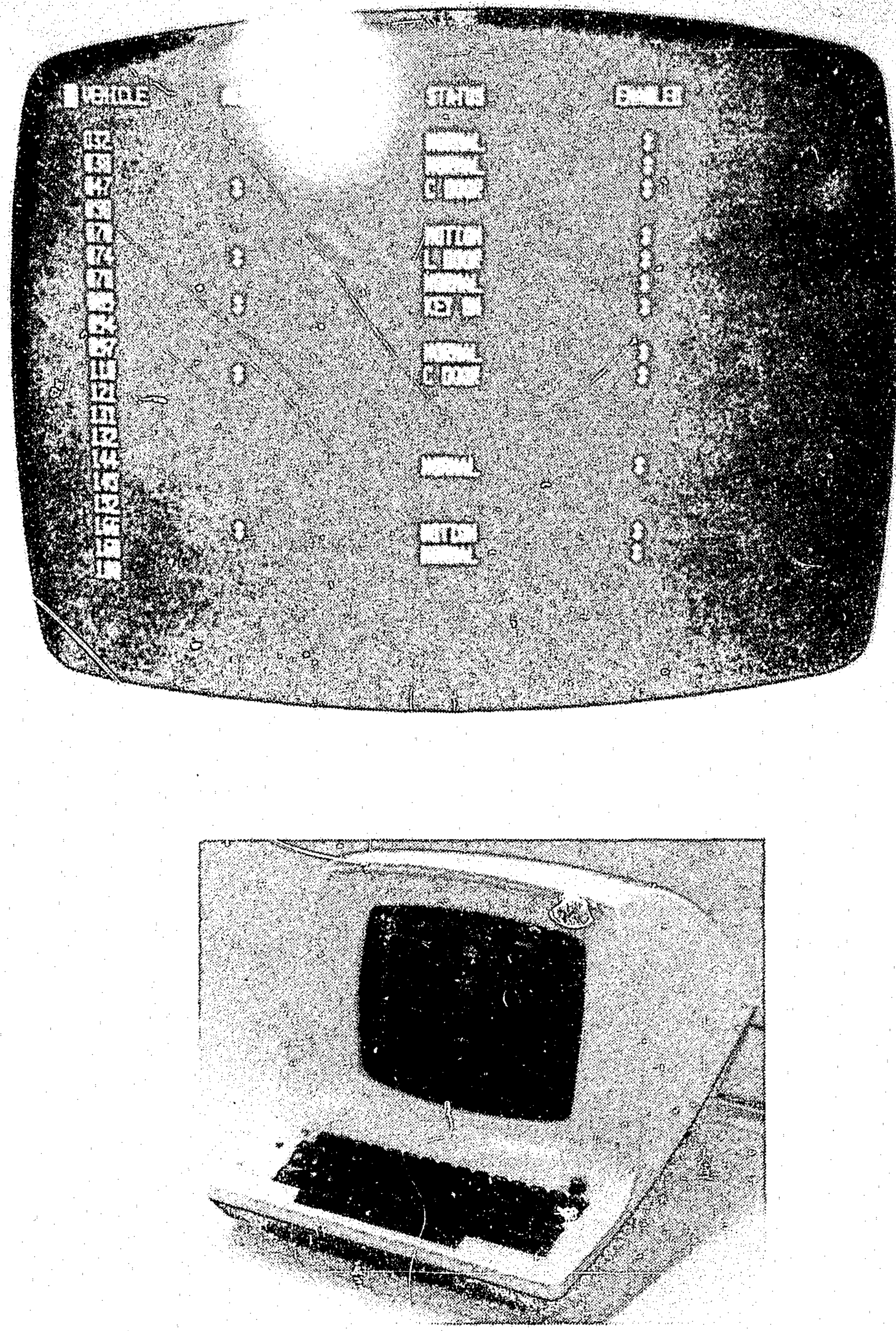


FIG. 5 REMOTE ALARM CRT DISPLAY

In both operational modes, the system records events occurring at each vehicle, and provides a capability for the retrieval of up to three days of individual vehicle histories. The vehicle history data includes delivery and non-delivery stops, route entry/exit, a mileage summary, and all detected alert and alarm conditions.

The system elements and their interfaces are depicted in Figure 6.

A dedicated digital communications link, common to two trucking companies, between vehicles and base station is employed to provide an economical operation and to isolate the cargo security system from trucking personnel and normal dispatching transactions. The base station data processor partitions the data from individual vehicles and dispatch stations to insure that privacy of operational data is maintained.

A controlled electromagnetic environment comprised of phase stabilized commercial broadcast transmissions and low-power proximity units is employed as the primary source of vehicle location data. Three local broadcast stations, with a suitable spatial distribution, are phase synchronized and proximity units installed on utility poles at approximately two-mile intervals throughout the operational area to provide location data. It should be emphasized that the functional operation of the Cargo Security System is not dependent on a specific location technology. However, the location technology implemented must provide suitable performance characteristics and be low enough in cost to warrant its operational deployment over a very wide area (400 square miles minimum).

Within each vehicle unit, separate receivers are employed for detection of broadcast signals and proximity unit transmissions.

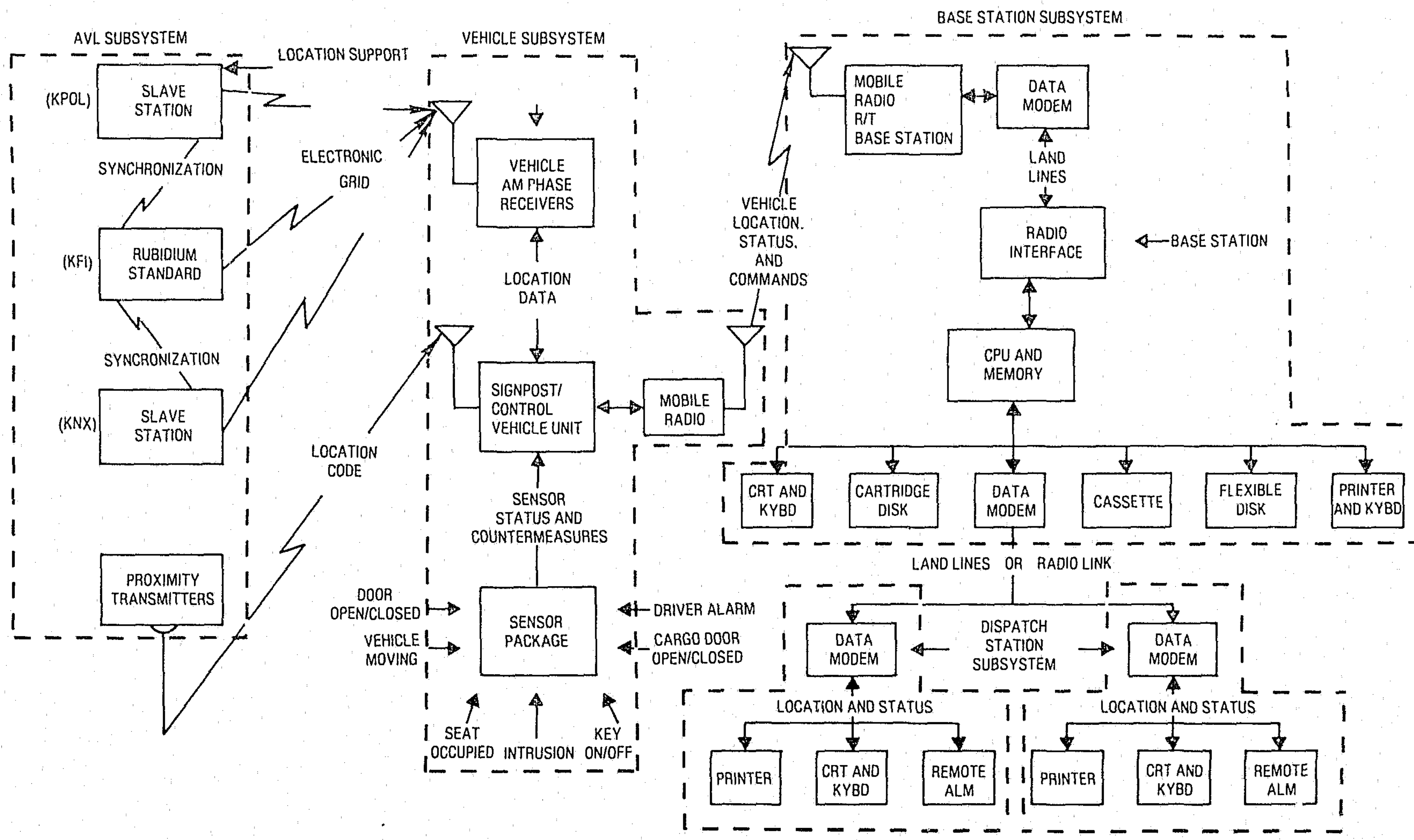


FIG. 6 CARGO SECURITY SYSTEM-FIELD TEST CONFIGURATION

The broadcast receivers, which are described in more detail in later sections of this report, process the received signals to generate phase comparison data unique to the specific location of the vehicle. Similarly, when the vehicle enters an area covered by a proximity unit, the coded address of that unit (unique to a specific installation site) is detected and processed. Both sets of location-related data are routed to the vehicle's control unit for subsequent transmission to the base station.

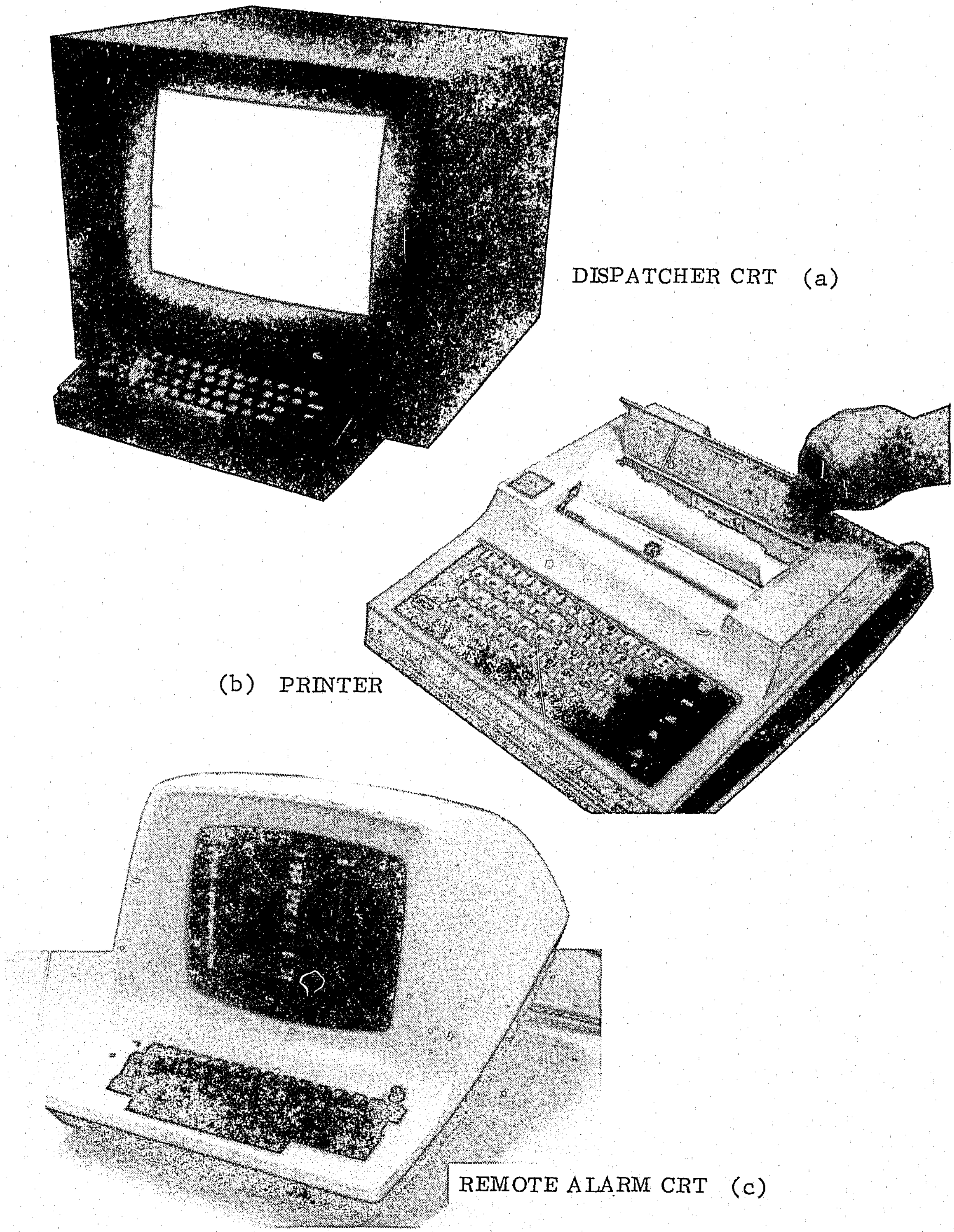
Also contained within each vehicle subsystem is a group of sensors for detection of door openings, intrusion, vehicle motion, driver alarm, ignition key operation, seat occupancy, and any attempts to disable the system by severing sensor wiring or gaining access to the vehicle unit electronics. The sensor data is routed to an on-board processor which provides data filtering by means of a programmable combinatorial logic operation, such that only predetermined sensor combinations actuation sequences are recognized by the system and transmitted to the central processor.

The vehicle control unit interfaces with the mobile communications equipment and data transmissions to the base station are initiated by the vehicle unit upon occurrence of specified events (predetermined sensor actuations, receipt of a proximity unit signal, predefined change in broadcast signal phase changes, etc.), or in response to an interrogation from the base station. The communications interface section of the control unit handles communications protocol, error detection, channel contention, and transmission control.

A dedicated radio communications system shared by all vehicles in the system provides for independent digital data transmission between vehicles and the central base station. Vehicle transmissions are comprised of location related and filtered sensor data. The transmissions are initiated by the occurrence of a specified "event" at a vehicle or in response to a base station interrogation. Transmissions from the base station to individual vehicles include acknowledgement of vehicle data transmissions, interrogations to verify vehicle integrity, modification of the combinatorial logic patterns in the vehicle sensor processor, and reset of vehicle location registers. The radio communications subsystem is comprised of commercial land-mobile radio equipment operating on a dedicated UHF channel.

The base station subsystem includes the communications interface with the vehicles, provides for processing of location and filtered sensor data, is used to generate data bases describing the geographic location and status of each vehicle, partitions the data on a fleet basis, provides the interfaces with the dispatch subsystems located at the individual trucking company locations, and maintains the overall timing and control of the system. Associated peripheral devices provide for system control, program and data storage and recording of system transactions.

Each trucking company is equipped with a dispatch subsystem for the display and printout of associated vehicle data. Communication between each dispatch subsystem and the base station subsystem is by means of dedicated land lines provided by the local telephone company. Each display subsystem can access and display/printout the associated vehicle location and status data. The primary display employed for normal operations (overall status or individual vehicle status) presents color-keyed data for use by the dispatcher. (Figure 7a). Data selection is accomplished via an alphanumeric



DISPATCHER CRT (a)

(b) PRINTER

REMOTE ALARM CRT (c)

FIG. 7 DISPATCH STATION EQUIPMENT

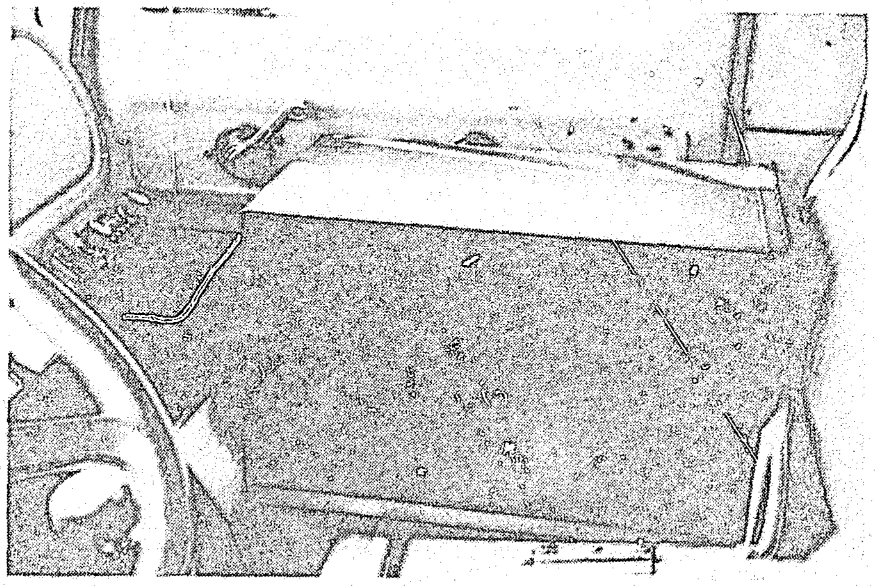
keyboard. In the after-hours mode of operation, sensor data is presented on a dedicated display (Figure 7b) installed in the security guard area. A printer is installed for the purpose of logging events or for the recall of individual truck histories.

The overall system is designed for continuous operation by non-technical personnel and to be totally transparent to routine trucking operations.

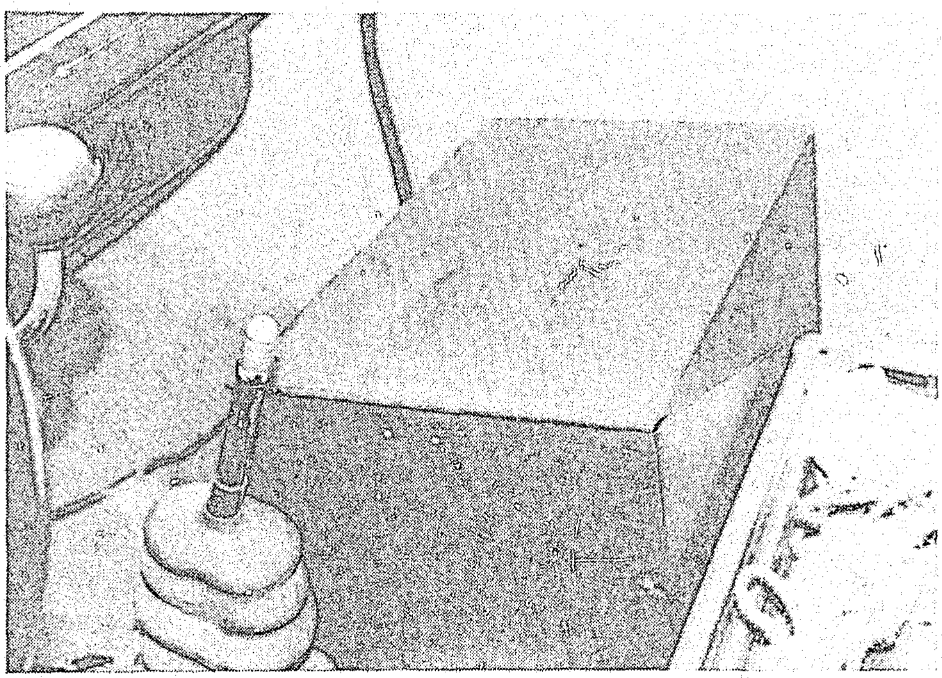
Physically, the vehicle subsystem electronics and communications units are packaged in a single enclosure (Figure 8) to which the sensors, location receiver antenna, communications antenna, and vehicle power are connected. The base station is a modular package comprised of a base station transceiver rack, communications antenna, a computer/interface rack, and the associated peripheral units. The dispatch station consists of the main display (Figure 7) to which the printer and the guard display are connected.

The principal performance requirements established for the Field Test System were as follows:

- Coverage Area - 400 Square Miles
- System Capacity - 256 Vehicles
- Location Accuracy - 600 Feet at 95th Percentile
- Location Designation - Nearest Street Intersection
- Communications - A sufficient carrier level shall be provided over 90% of the area, 95% of the time to enable system performance to be achieved for at least 95% of the time.
- False Reports - False report rate of less than one per vehicle year
- Missed Reports - Missed report rate of less than on major



(a) GI TRUCKING



(b) TRANSCON

FIG. 8 VEHICLE EQUIPMENT ENCLOSURE

alarm status report to the base station per vehicle year, and less than 20% missed responses to base station requests.

- Environment
  - Shock - 20 g
  - Vibration - location dependent, up to 2.3 g
  - Temperature - location dependent, from -40°F to 185°F
- System Reliability - 94% availability total system and 98% for each major unit during scheduled operating time.
- Alarm Conditions - (See Table 1)
- Alert Conditions - (See Table 1)

TABLE 1 CAUSES OF ALERT/ALARM CONDITIONS

INDICATION	CONDITION
R ALERT: (YELLOW)	ROUTE ENTRY YARD EXIT YARD ENTRY OUT OF ROUTE OUT OF ALLOCATED BOUNDARY UNAUTHORIZED STOP TWO TRUCKS AT SAME LOCATION, STOPPED
ALERT: (PURPLE)	KEY OFF, MOTION SEAT EMPTY, MOTION RIGHT DOOR OPEN, MOTION RIGHT DOOR OPEN, SEAT OCCUPIED LEFT DOOR OPEN, RIGHT DOOR OPEN RIGHT DOOR OPEN, KEY ON SEAT EMPTY, KEY ON LEFT DOOR OPEN, KEY ON CARGO DOOR OPEN, MOVING CARGO DOOR OPEN, SEAT OCCUPIED CARGO DOOR OPEN, LEFT DOOR OPEN CARGO DOOR OPEN, KEY ON MILEAGE SUMMARY
ALARM: (RED)	COUNTERMEASURES STOPPED, OUT OF ROUTE, CARGO DOOR OPEN DRIVER ALARM

CHAPTER 3. SYSTEM DEVELOPMENT, DEPLOYMENT AND TEST

A. General

The Cargo Security System for the field test program was developed under Subcontract W-67852 issued to Gould Information Identification, Incorporated by the Aerospace Corporation on 27 January 1977. The primary tasks to be conducted under this subcontract were:

- design, development and fabrication of the Cargo Security System in accordance with the technical specifications
- installation and checkout of the system within a designated test area
- system deinstallation
- preparation of a Final Report
- dispatcher training
- maintenance of the system for a 12-month evaluation period

The first two tasks were successfully completed. The systems operation manual was published, liaison plans formulated, and arrangements for dispatcher training completed pending successful completion of acceptance testing. System acceptance testing (successful completion of which would have enabled the field evaluation phase of the program to proceed) was initiated. At that time, an unresolvable situation, that of communications interference by the Cargo Security System with other users became apparent. Alternative methods of resolving this situation were identified and the cost/schedule impacts evaluated. As a consequence of the LEAA decision to terminate the program, the close-out tasks (System Installation and the preparation of the Final Report) were completed.

B. System Development

The design and development of the system was based on the findings of preceding cargo security programs, contractor recommendation and internal Aerospace Corporation studies. These findings had identified the following needs:

- a radio communications link immune to driver interference and transparent to normal trucking operations
- an improved human interface with the dispatcher, particularly in the methods of presenting alarm and/or alert data, plus the capability to retrieve vehicle activity data for support of security investigations
- an improved AM phase receiver with more phase tracking sensitivity
- improved protection against the hostile environment encountered by truck equipment.

The system design included the following salient technical features:

1. Communications. In keeping with the overall philosophy of creating a multi-user system in order to minimize costs to the individual trucker and thereby encourage the widespread use of the Cargo Security System by industry, the basic design was predicated on the use of a common radio communications link (CCL) and a common base station for system control and data processing. Individual truck data would be routed from the common base station to the appropriate user via dedicated common-carrier land lines.

Extensive testing in the Los Angeles basin established the technical feasibility of the CCL concept and demonstrated its capability to provide the required coverage and data throughput. Based on these findings, the CCL concept was incorporated into the system design.

Standard land-mobile communications equipment (Motorola T1600BM-265 watts ERP base; Motorola MOCOM 10-16 watts ERP mobile) was selected for the CCL, and experimental license (No.7301-ER-PL-76) for simplex operation at 457.7 MHz were issued by the Federal Communications Commission for use in the field test program.

Digital transmissions were made at a rate of 1500 bits/second, with a 32-bit message format for uplink (vehicles to base) and a 16-bit format for downlink (base to vehicles). Data error detection/rejection techniques (modified Manchester code) were employed.

Data transfers between base station and individual dispatch stations were made via C2 conditioned land lines using Bell 202F modems. The lines were operated at 1200 bits/second, and checksum techniques were used for error detection/rejection.

To minimize data traffic and thereby insure adequate system capacity, the design of the cargo security system employed distributed processing, with processing elements located within each vehicle, the base station, and each dispatch station (Figure 9). Control program loading for the individual vehicle and dispatch station processor units was accomplished by the base station via the radio and land-line communications links.

2. Vehicle Location. Predecessor programs had established that commercial AM broadcast transmissions could provide economical wide-area vehicle location data when phase synchronization equipment was added to the exciter stages of the AM transmitters. Concept feasibility and pilot tests had found that the hyperbolic grid re-

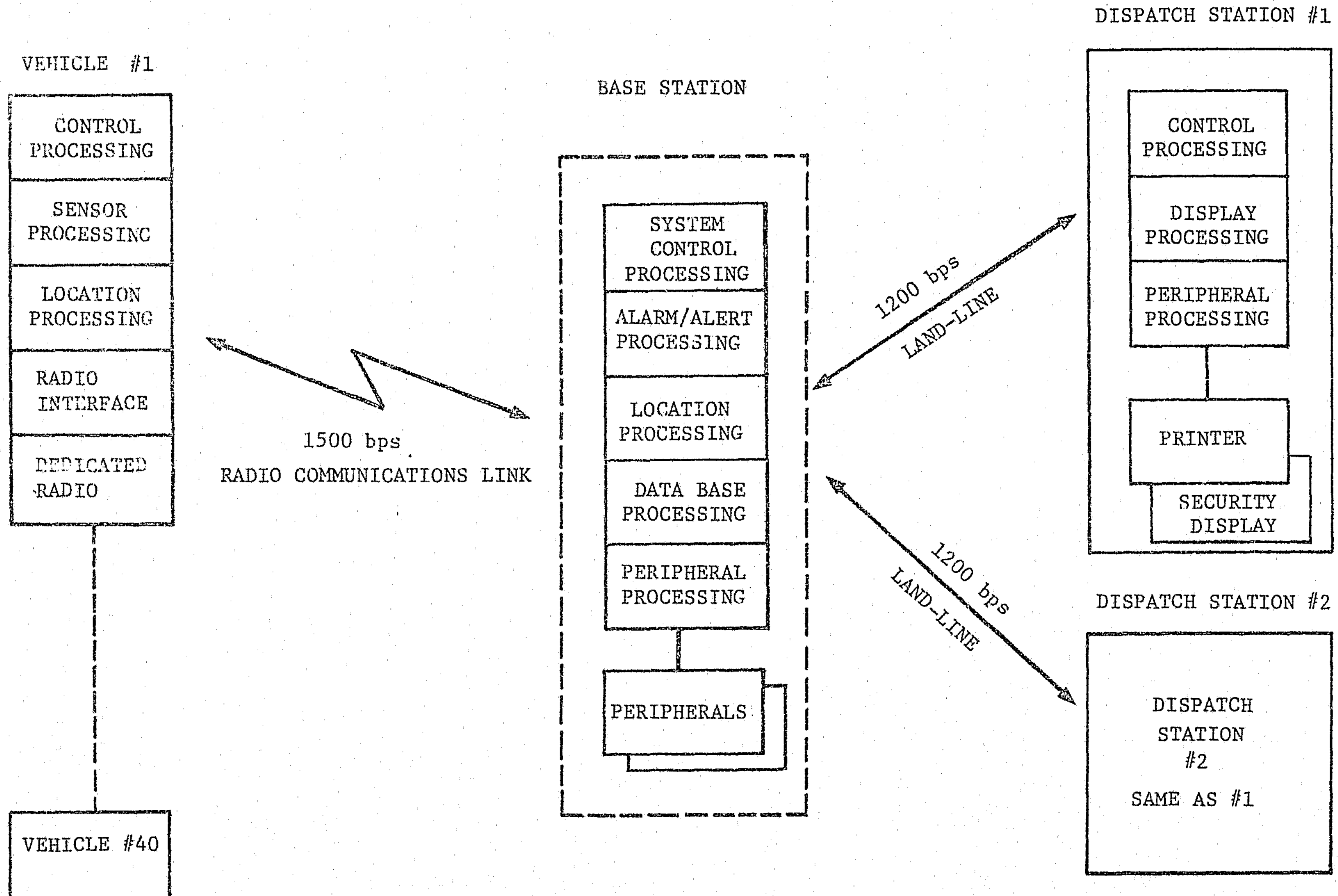


FIG. 9 DISTRIBUTED DATA PROCESSING

sulting from the use of three phase-locked broadcast transmitters was highly stable, and capable of providing very accurate location data.

The earlier testing had also shown that large man-made objects, such as bridges, overhead transmission lines and tall buildings, could induce grid warpages in their immediate vicinity, and further, that signal fades, nulls and carrier overmodulation could induce location offsets.

These findings, coupled with the fact that the continuous-wave nature of the broadcast transmissions provided only a relative (as opposed to an absolute) location, led to the conclusion that a hybrid system comprised of the AM broadcast grid and proximity units should be employed for the Field Test Program.

A new AM Phase-Lock receiver was developed to detect and phase track the RF fields generated by the synchronized AM broadcast transmissions. The receiver used one of the three synchronized frequencies as a master and converted the received master signal (using crystal control) to 5.12 MHz. This master control frequency was used as input to a frequency synthesizer to provide the appropriate local oscillator signals by which the three input channels were superhetrodyned to a common 455 KHz IF. These intermediate frequencies were then linearly mixed to 5 KHz where relative phase between the channels was computed, with the reference 5.12 MHz signal being used as a counter. This design approach provided the advantage of distributing gain across the different frequencies so that no parasitic feedback was induced. The sensitivity of the resultant receiver design was on the order of .1 microvolts. Additionally, phase-lock control circuits were incorporated to eliminate the effects of low signal to noise and over-modulation of the carrier frequency.

An extensive AM phase-lock measurement program was conducted with this new receiver with the following findings;

- o for the areas tested, the measured hyperbolic grid matched the theoretical grid within the close tolerances.
- o the grid was stable under a variety of weather and diurnal conditions
- o carrier over-modulation could induce phase noise equivalent to some 70 feet linear error
- o the receiver would track through phase warps

Based on these test findings, the location system design employed a conventional algorithm for the conversion of phase measurement data to geographic coordinates for each vehicle.

For the conversion of coordinate data to the street intersection data specified for the display formats, a street data base and segment look-up algorithm was developed to select the nearest intersection out of the possible 30,000 intersections within the test area.

The location subsystem incorporated proximity units for reset purposes. A location processing system in the base station provided location updates in AM phase coordinates when the vehicle transmitted the code indicating that it had passed one of these units. Receipt of this message type also initiated a transmission from the base station to the vehicle for the purposes of resetting the phase counters in the vehicle processing unit.

The overall location subsystem then employed differential navigation using the AM broadcast signals for location between widely dispersed proximity units, using distributed processing between each vehicle and the base station.

3. Vehicle Status Reporting. To meet the requirements for minimizing false status data, to improve the dispatcher interface, and to reduce data transmission requirements, an extensive redesign of the vehicle status reporting subsystem was undertaken.

Sensors installed in each vehicle were:

- Cargo door
- Cargo compartment
- Cab doors
- Driver seat
- Ignition key
- Driver alarm switch
- Vehicle movement
- Tamper detectors

The requirements for alarm/alert processing (see Figure 10) included stand-alone sensor reporting (e.g. driver alarm), combinatorial sensor reporting, and combinatorial sensor/location reporting. Further, the requirements for minimizing false reports required a capability to disable a faulty sensor at any vehicle.

These requirements were met by a distributed processing approach. A processor was provided within each vehicle unit to process sensor data prior to transmission to the base station. This processor employed a random access memory (RAM) to perform the required data filtering. The contents of this RAM could be loaded and/or modified by a data transmission from the base station.

After a predefined sequence of sensor events was detected by the vehicle processor, a data transmission was initiated to the base station. (The base station could, however, poll a vehicle to ascertain its sensor status at any time). The sensor data received at the base station was then further filtered and combined with the relevant location data to determine whether the dispatch subsystem should be notified of a vehicle status change.

ALARM INDICATIONS (3)

- DRIVER ALARM
- SYSTEM TAMPERING
- STOPPED + OUT OF ROUTE + CARGO DOOR OPEN

ALERT (Category II) (14)

- STOPS AT UNAUTHORIZED LOCATIONS
- TWO TRUCKS STOPPED AT SAME LOCATION
- SEAT EMPTY PLUS KEY ON
- MOTION PLUS { KEY OFF OR SEAT EMPTY OR RIGHT DOOR OPEN OR CARGO DOOR OPEN
- CARGO DOOR OPEN PLUS { SEAT OCCUPIED OR KEY ON
- RIGHT DOOR OPEN PLUS { SEAT OCCUPIED OR KEY ON
- LEFT DOOR OPEN PLUS { RIGHT DOOR OPEN OR CARGO DOOR OPEN OR KEY ON

ALERT (Category I) (1)

- OUT OF ROUTE

FIG.10 ALARM AND ALERT CONDITIONS

The vehicle processor also provided sensor processing logic alterations required when the vehicle entered a new operating mode (i.e., normal to after-hours and vice-versa). In the after-hours mode, the vehicle processor enabled automatic transmission when any sensor was activated. (Note: The cargo compartment intrusion sensor was activated only when the system was in the after-hours mode of operation).

To simplify the dispatcher interface and to conserve channel space on the land-line communications links, alert/alarm events detected by the distributed processing subsystem were presented to the dispatcher in the form of color-coded bars on the primary display (Figure 11) for presentation of overall fleet status. For individual vehicle status diaplay, only status changes and the accompanying color code commands were routed from the base station to the dispatcher displays.

4. Dispatch Station. The dispatch station provided access to all related vehicle data bases in the base station and employed an intelligent terminal to present vehicle data to the dispatcher, to interface the dispatch station and the base station via land-lines, and to control the local printer and security guard display.

The primary terminal incorporated a microprocessor and local memorv to provide the control and interface functions. This microprocessor system formed part of a distributed processing network designed to minimize the number of leased lines, modems and interface complexity between the dispatch and base stations.

Exchange of information with the base station computer was performed continously by sending small packets of updated information and commands, over the leased lines, to the microprocessor in the

Security Status	Situation Indicated	Color of Bar
OK	Normal	None
PENDING	Truck in yard, but not being monitored by Remote Alarm	Green
ENABLED	Truck is Remote Alarm Mode, but computer has had no contact from truck in over an hour, possible loss of battery power.	None
R ALERT	Potential security problem indicated by truck's location or route	Yellow
ALERT	Potential security problem on the truck	Purple
ALARM	High probability of security problem on truck	Red

FIG. 11 POSSIBLE STATUS INDICATIONS ON DISPLAYS

terminal. The microprocessor, which continously monitored the line for such data, packed the incoming commands and data into files. Upon receipt of a dispatcher command or a base station computer generated command to change the display, the microprocessor retrieved the information from its files and displayed the data on the screen. In case of an alarm update, the microprocessor also enabled an audible signal, upon base station command, to call attention to the changed status condition. Selected information was also routed to the other peripherals, remote alarm CRT and printer, via another I/O port, upon command from the base station computer.

5. Base Station. The central base station was designed for overall system control and was the hub of the distributed processing operation. It was comprised of a base radio transceiver, a minicomputer, communications interfaces, and data processing peripherals.

Architecturally, the base station was organized as an event and/or data-base-driven asynchronous control system operating in real-time with 56 separate devices, 54 of which were remotely located.

The computer processing was performed under the control of a real-time executive, and employed program overlay techniques to identify, process, control, time-tag and record the more than 37 different message types associated with the remote devices, and to provide on-line recording of all system transactions.

6. Vehicle Unit Packaging. A basic requirement of the field test system was that it be immune to driver interference. To meet this requirement, the design of the vehicle unit provided for the total enclosure of all electronic components, and for the detection (via the sensor system) of any attempts to gain access to these components. The three electronic subunits (AM receiver, data controller

and communications transceiver) and the external wiring terminations were totally enclosed by an external cover.

C. System Deployment

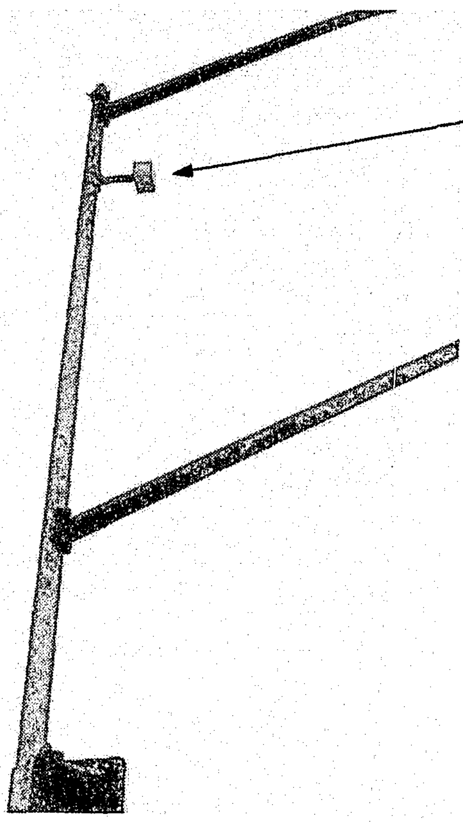
Program planning conducted by the Aerospace Corporation had identified a 397-square-mile area comprised of a total of 40 overlapping pickup and delivery zones of two Los Angeles trucking companies, Transcon Lines of Sante Fe Springs and GI Trucking of La Mirada.

Preliminary analyses established that 256 proximity units, spaced at approximately 2-mile intervals, were required to meet location accuracy requirements. Following the issuance of installation permits by the responsible municipal authorities, these proximity units were installed on utility poles (Figure 13a). Special proximity unit installations for the detection of freight yard entry and exit were installed on the approaches to each trucking company headquarters (Figure 13b).

The AM phase-lock equipment employed for the predecessor program, a rubidium standard in radio station KFI, and slave receiver/exciter units in KPOL and KNX, was recalibrated and checked for phase stability.

The base station equipment was installed in the United California Bank Building in central Los Angeles. This site, with an antenna elevation of 950 feet above sea level, had earlier been selected to provide the required communications coverage for the test area.

Commercial land-lines and modems were leased from the local telephone company for the communications links between the base station in the UCB building and the dispatch stations at the truck-



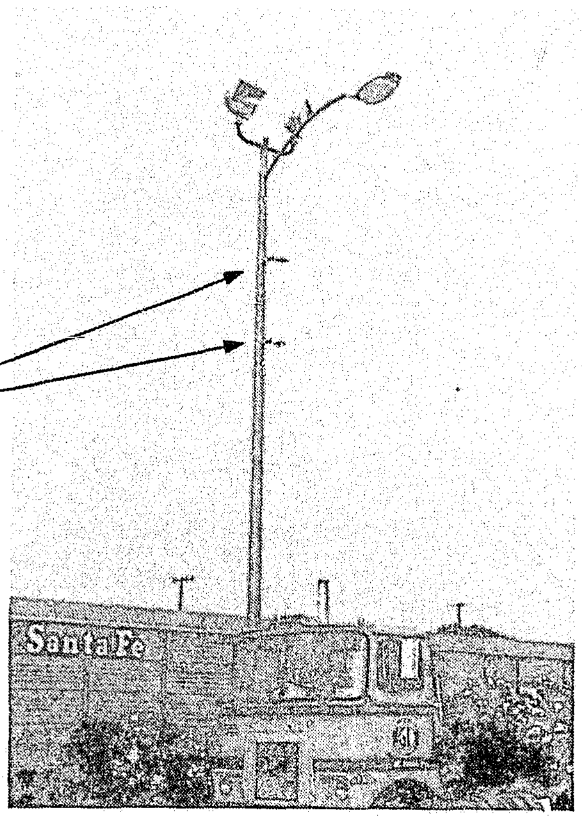


FIG. 12 PROXIMITY TRANSMITTER UNIT INSTALLATION

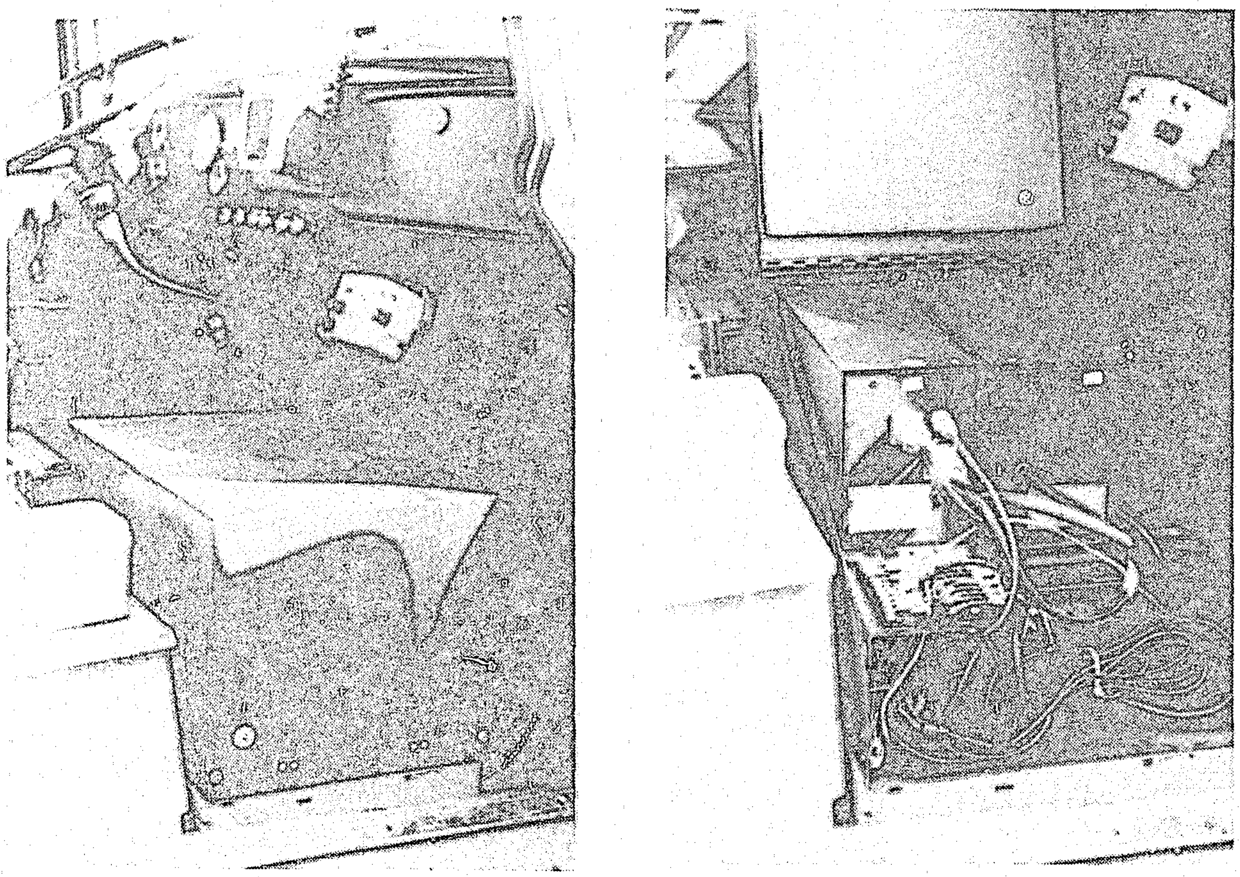
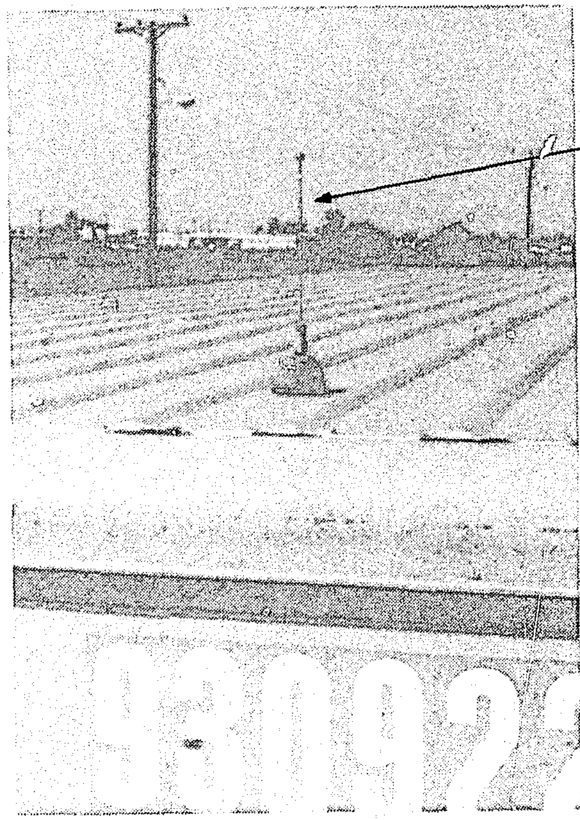


FIG.13 VEHICLE EQUIPMENT INSTALLATION



UHF MOCOM 70 RADIO
ANTENNAS MOUNTED ON
ROOF OF CARGO
COMPARTMENT

COMBINED AM PHASE
AND SIGNPOST ANTENNA
INSTALLATION ON TOP
OF CAB

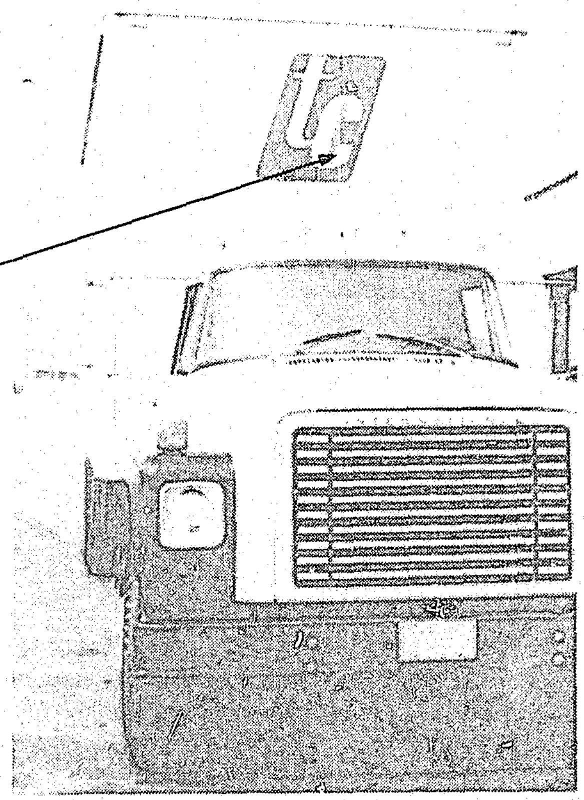


FIG.14 ANTENNA INSTALLATION

ing headquarters in Santa Fe Springs and La Mirada.

Vehicle unit installations were accomplished on a phased basis during periods that the trucks were not operational (evening, weekend, and routine maintenance periods). The vehicle unit enclosure was mounted on the right-hand floor of the cab (Figure 13). The combined AM and proximity unit antenna was installed on the cab roof (Figure 14); the UHF antenna for the dedicated communications link was mounted on the cargo compartment (Figure 14). Sensor wiring was routed to minimize the possibility of deliberate or accidental damage.

D. System Checkout Tests

In parallel with the installation of the vehicle equipment, a series of checkout tests were initiated using a test vehicle to identify technical and operational problems in the test area environment, and to enable corrective measures to be undertaken prior to completion of installation.

The test vehicle was equipped with a standard complement of vehicle equipment, a switch box to simulate sensor actuations, and a set of special purpose testers designed to display various system operating parameters for diagnostic purposes. For the base station system, a standard operational software program was modified to enable detailed examination of critical operating parameters and data. The dispatch station primary displays were located at the base station to facilitate system checkout.

During the checkout phase, numerous technical and operational problems unique to the operational environment were identified and corrected. The following summarizes the principal equipment and operational problems which were <u>identified</u> and <u>corrected</u> during the system checkout phase in Los Angeles:

PROBLEM	SOLUTION
Voltage variations observed during engine cranking	Modify vechicle equipment and system to operate acceptably with transient battery voltage variations over the range of 0 volts DC to + 30 volts DC
Signpost location errors due to digitizing	Re-digitize all signpost locations and modify signpost data base locations to reduce location errors due to digitizing to less than 50 feet.
Dispatch station microprocessor-to-host computer system I/O contention	Modify the vendor supplied software, Develop micro-processor software and host computer software to incorporate time delays and various I/O queues to support program load and program execution in real-time
Street Intersection Estimator Convergence	Mofify system software to condition street segments by increasing segment length and the number of candidate segments to assure intersection existance and estimator convergence on intersection
Real-time Processing of AM Phase Data	Add hardware multiply/divide and high-speed memory to increase program execution speed.
AM Phase Receiver/Vehicle Data Controller Integration	Modify vehicle equipment to insure that phase lane count changes are transferred to the host computer and modify system software and I/O architecture to be tolerant of AM Phase data errors
Sensor chatter in trucking Company Vehicles	Modify vehicle equipment and system software logic to incorporate sensor dependent time delays and additional validity tests before declaration of sensor status changes.

The test vehicle and test software was employed for the initial system acceptance testing (reviewed below). In preparation for the final acceptance test, 35 vehicles were successfully operating in the test area, when complaints of communications interference were received from San Diego Rapid Transit District. Tests and analyses established and the mobile units as the interference sources, and a decision was made to halt further testing until a solution to the interference problem could be identified.

At the time of system shutdown, some operational problems remained, the solutions for which had been identified but not implemented. These problems included:

- Vehicle electromagnetic noise interference with signpost receiver.
- Freight yard communication coverage problem in specific areas at GI Trucking.
- Vehicle location inaccuracy due to multipath (in certain areas).

The system checkout tests included the following:

1. Route and Display Tests. The aggregate of tests involved determination of the adequacy of the nearest intersection algorithm. The results verified that the nearest intersection algorithm using both actual and pseudo intersection data bases satisfied the closest intersection criteria. As part of these tests the out-of-route, prohibited stop and out-of-test area algorithms were evaluated to insure that each of these criteria were met. These tests were satisfactorily performed and demonstrated the functional capability of the system.

2. Remote Alarm Tests. The remote alarm mode (after-hours mode) of operation is declared by the vehicle automatically or under dispatch station/base station control. The testing involved the automatic mode changing by vehicles, as well as under operator control. These tests were satisfactorily performed, thus demonstrating three modes of operation. Further, testing of the submodes of operation including the sensor enable/disable functions as well as periodic activation by individual vehicles was also demonstrated.

3. Dispatch Station Operation. These general tests involved the ability of the system to select and operate the two types of displays required at the dispatch station: Route Status and Security Status. The Route Status display presented the aggregate of all the vehicles assigned to the particular dispatch station whereas the Security Status display presented only those functions of a specific vehicle assigned to that dispatch station. The Route Status display provided only location and status whereas the Security Status display provided details concerning the location,

sensor status, route status and vehicle details as well as the responsible police jurisdiction. these tests verified satisfactory system performance.

4. Individual Sensor Tests. Sensor testing was performed on the vehicles as well as the test vehicles in both the remote alarm mode and normal mode of operation. In the normal mode, testing was accomplished with the in-vehicle RAM loaded and not loaded to determine the success of the RAM load as well as the operation of the combinatorial logic. Tests were performed to determine if the combinatorial logic could be successfully masked by the base station processor. Additional tests were performed to insure that the dispatch station alerts and alarms appropriately reflected the correct status of all the vehicles.

5. System Operation. Preliminary testing of the overall system operation was in process when it was determined that unacceptable interference with the San Diego Rapid Transit Authority communication system existed. At that time there were 35 vehicles and both dispatch stations in operation. During this test, the equipment for both dispatch stations was placed at the base station to facilitate system operational test and evaluation. The testing which was in process included a number of general tests, alert and alarm logic tests, remote alarm tests, data logging and dispatch logging and dispatch restart tests.

E. System Acceptance Testing

The system acceptance tests, the satisfactory completion of which would have inaugurated the formal evaluation of operational performance, was divided into three phases: location and communications, equipment inspection and system operations.

1. Location and Communication. An extensive test of the

vehicle location system and the communications system was conducted throughout the 400-square-mile area designated for operation of the system. Location testing of a sample of 200 and later 50 test points located within the area was performed to identify the location system characteristics and, in part, determine the location accuracy of this system. To accomplish these tests, the communication subsystem was operated to determine if the event logic of the system performed acceptably and to assess the differential navigation characteristics of the system.

a. 200/50 Point Location Testing. Initially, 200 randomly located and widely separated test points were selected to test the location accuracy of the system. These 200 points were further refined to a specific route which was intended to represent normal traffic as well as identify the tracking and differential navigation qualities of the system. Because of the time required to acquire data at each test point, a subset of 50 points was subsequently selected for acceptance testing.

Althought the system had demonstrated an acceptable level of location accuracy in many non-hostile, urban areas during the system checkout testing, the selected test route encompassed many sources of signal distortion and some geographic areas which had not previously been tested. As a consequence, the overall system accuracy achieved during this limited-sample test did not meet system specifications. The principal sources of error, all due to multi path and blockage, identified as a consequence of test data evaluation were as follows:

- freeway overpasses
- high voltage lines
- downtown canyons

b. Communication Coverage. The overall communication coverage testing comprised the initial coverage evaluation, and subsequent testing with the reduced transmitter power output made necessary to reduce interference with San Diego and used during the location system evaluation, included a series of tests with personnel at the base station transmitter/receiver, vehicles, and the San Diego Rapid Transit District, and finally a number of vehicles enabled and operating throughout the 400-square-mile area as well as outside the area. The results of these tests were as follows:

- With the initial system configuration, better than 98% throughput was established throughout the area.
- With a 50% decrease in power out of the base station transmitter unit, very little degradation resulted, only the outer extremities of the test area, south of Long Beach and behind the hill in San Pedro showed any significant effect.
- With a 94% reduction in base station transmitter power, significant degradation resulted. The reduced performance imposed severe limitations on the operational qualities of the system.

2. Equipment Inspection. The composite system installation was inspected to verify that all elements of the system had been properly installed and were in working order. During this inspection, sample testing of vehicle installations at both trucking companies were completed. Installation had been completed on all 40 vehicles; however, one had been removed at Transcon at their request. Further, two of the installations at Transcon (semi-tractor trailers) were incomplete in that the trailers originally configured

to handle the intrusion sensor and cargo door sensors were not present. The remainder of the vehicles were properly installed. The high dollar value intrusion sensors were not installed at the time of this test to reduce the probability of malicious mischief.

3. System Operation. Formal testing of system operation could not be accomplished because of interference with the San Diego Transit operations.

CHAPTER IV. FINDINGS AND RECOMMENDATIONS

Although the Cargo Security Field Test Program was terminated prior to its completion, its development, deployment and checkout demonstrated that a multi-user automatic vehicle monitoring system is technically feasible and can be operated in a severe urban environment by non-technical personnel.

From the technical viewpoint, the development of the system represented a significant advancement in the state-of-the-art of vehicle monitoring, particularly in its concepts of a distributed processing network interconnected by relatively slow speed communications links, and the sharing of a mobile radio communications channel by multiple users.

At the time testing was halted, one major problem that of location accuracy in the vicinity of large man-made structures, and three minor technical and operational problems remained to be implemented in the system, the recommendations for their resolution are presented herein.

The key findings were as follows:

<u>Vehicle Location</u>

- The use of AM broadcast station signals for vehicle location can provide very wide area coverage at minimum cost.
- The AM signal tracking receiver developed for the program provides accurate, reliable and repeatable phase comparison data throughout a wide range of signal environments.
- In most areas (i.e., those devoid of large man-made structures and high-power electrical distribution wires)

the measured hyperbolic grid resulting from the three AM broadcast transmissions is identical to the theoretical predictions.

- Large man-made structures and high-power distribution wires can introduce major phase warps and location offsets.
- Vehicle electrical noise can interfere with proximity signal reception.

Sensors

- The employment of a reprogrammable processor on each vehicle is very effective in minimizing false sensor reports and in filtering out unwanted data.
- The physical environment in which the sensors are installed and operated makes them susceptible to accidental or malicious damage.
- The cost-effectiveness of the cargo compartment intrusion sensor is questionable in light of the fact that it is only activated in the after-hours mode of system operation.

Communications

- The use of a single communications channel shared by multiple users is practical and will allow considerable economies to be made in future AVL systems.
- A dedicated channel allocation is required for successful system operation.
- The vehicle communications antenna installation is vulnerable to accidental or malicious damage.
- Communications coverage at certain locations within the freight yards may be poor or marginal due to such factors

as metal overhangs shielding the antennas at the freight docks, direct signal blockage by freight handling equipment, etc.

Dispatch Station

- The microprocessor based dispatch system enables interactive operation of the five local devices and the base station over a single commercial land-line communications link.
- The use of a microprocessor and its memory minimizes the data traffic on the land-line and thus permits the use of a standard low-speed circuit.
- Restart procedures following recovery from a local power failure or a system-induced momentary failure are complicated and cumbersome.
- The complexity of the primary display keyboard layout makes its use difficult for the non-technical dispatch personnel.
- The reliability of the primary terminal is marginal.

Base Station

- The architectural design of the base station as event and data base driven interactive system serving 56 individual devices is very effective in servicing the variations in demand loads associated with the trucking operations.
- The modular organization of the system data bases segregates system and locale data, and consequently enables the operational software to be general purpose in nature.
- Conversion of geographic coordinates (x-y) to street intersection data imposes the heaviest load on the computer

resources.

- System restart after local power failure or other intermittent system failure is cumbersome and requires technical skills which might not be available in an operational system.

Operational

- Certain system conditions result in an excessive number of transmissions from parked vehicles with the consequence that the truck batteries may be depleted. The primary causes of these conditions are a loss of AM station synchronization (causing an apparent rapid vehicle movement), and poor communications coverage in some areas of the freight yards.
- In view of their unique relationship with the truck drivers, dispatch personnel are reluctant to assume the role of security monitors for en-route vehicles.
- Vehicle maintenance is almost non-existent in some cases with the consequence that vehicle electric noise may be severe enough to interfere with system operation, and that the battery condition may be such that the relatively insignificant loads imposed by system operation can result in vehicle disablement following a short period with the engine off.
- There is an industry trend towards the use of semi-trailers for pickup and delivery operations with the result that cargo compartment protection sensor connections with the vehicle units will require re-design.

As a consequence of these findings, the following recommendations are made:

Vehicle Location

The AM phase-lock system should incorporate an independent means of verifying apparent location shifts caused by multi-path warpage. Preliminary analyses of phase warp data suggest that the use of the existing vehicle movement (odometer) data and the addition of a turn indicator would provide such an independent data source. To provide the additional processing resources needed for this verification process, and to further reduce communications link and traffic and base station loading, a microprocessor should be incorporated in each vehicle unit. The use of proximity units for location reset purposes should be limited for economic reasons.

The acquisition of access permits, as required to accommodate installation and maintenance of proximity units, and coordination with affected agency or companies should be initiated as soon as practical following program go-ahead. Provisions for the use of a special purpose vehicle to support installation and maintenance of proximity units is required.

Sensors

A reassessment should be made as to the utility and cost-effectiveness of all sensors, and of the value to the industry of the after-hours mode of operation. Sensor selection, installation and cabling should take into account their vulnerability to damage, and the increasing trend towards semi-trailer operations in the pickup and delivery service. Consideration should also be given to the use of the on-board microprocessor for data filtering purposes.

Communications

Design of the commercial antenna and cabling should provide for protection against accidental or malicious damage (such as an encapsulated, low-profile antenna) and take into consideration the possible use of semi-trailer configurations in future installations. Use of an on-board microprocessor for communications control should be explored.

In planning for the installation of cargo security system, the availability of a clear channel should be established. Further, the planning task should allow for an investigation of the communications coverage characteristics at the potential user's facilities.

Dispatch Station

The selection and implementation of the primary display should include consideration of unit reliability and the efficiency of its executive software. The design of a special purpose keyboard suitable for use by non-technical personnel is highly desirable. Provisions should be made for an automatic restart following a power or other system failure.

Base Station

The system should provide for an automatic restart following a power or other system failure.

System design tradeoffs should be made in alternative methods of defining specific street intersections for display purposes.

Operational

Installation planning should provide for the correction of vehicle electrical noise problems and the possible installation of new vehicle batteries.

Design modifications should be incorporated to limit the number of transmissions made by a vehicle when in an engine-off condition.

Consideration should be given to the incorporation of an independent power source, chargeable by the vehicle electrical system, to insure system operations during vehicle power trasients and to provide an orderly shut-down in case of vehicle battery failure.

The dispatchers' display should be restricted to vehicle location, driver alarm and appropriate law enforcement data; all security related alarm and alert data should be routed to a separate security officer's display and printer.