NATIONAL COOPERATIVE TRANSIT RESEARCH & DEVELOPMENT PROGRAM

8 Synthesis of Transit Practice

Bus Communication Systems

TRANSPORTATION RESEARCH BOARD
National Research Council

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Administrators, engineers, and many others in the transit industry are faced with a multitude of complex problems that range between local, regional, and national in their prevalence. How they might be solved is open to a variety of approaches; however, it is an established fact that a highly effective approach to problems of widespread commonality is one in which operating agencies join cooperatively to support, both in financial and other participatory respects, systematic research that is well designed, practically oriented, and carried out by highly competent researchers. As problems grow rapidly in number and escalate in complexity, the value of an orderly, high-quality cooperative endeavor likewise escalates.

Recognizing this in light of the many needs of the transit industry at large, the Urban Mass Transportation Administration, U.S. Department of Transportation, got under way in 1980 the National Cooperative Transit Research & Development Program (NCTRP). This is an objective national program that provides a mechanism by which UMTA's principal client groups across the nation can join cooperatively in an attempt to solve near-term public transportation problems through applied research, development, test, and evaluation. The client groups thereby have a channel through which they can directly influence a portion of UMTA's annual activities in transit technology development and deployment. Although present funding of the NCTRP is entirely from UMTA's Section 6 funds, the planning leading to inception of the Program envisioned that UMTA's client groups would join ultimately in providing additional support, thereby enabling the Program to address a large number of problems each year.

The NCTRP operates by means of agreements between UMTA as the sponsor and (1) the National Research Council as the Primary Technical Contractor (PTC) responsible for administrative and technical services, (2) the American Public Transit Association, responsible for operation of a Technical Steering Group (TSG) comprised of representatives of transit operators, local government officials, State DOT officials, and officials from UMTA's Office of Technical Assistance, and (3) the Urban Consortium for Technology Initiatives/Public Technology, Inc., responsible for providing the local government officials for the Technical Steering Group.

Research Programs for the NCTRP are developed annually by the Technical Steering Group, which identifies key problems, ranks them in order of priority, and establishes programs of projects for UMTA approval. Once approved, they are referred to the National Research Council for acceptance and administration through the Transportation Research Board.

Research projects addressing the problems referred from UMTA are defined by panels of experts established by the Board to provide technical guidance and counsel in the problem areas. The projects are advertised widely for proposals, and qualified agencies are selected on the basis of research plans offering the greatest probabilities of success. The research is carried out by these agencies under contract to the National Research Council, and administration and surveillance of the contract work are the responsibilities of the National Research Council and Board.

The needs for transit research are many, and the National Cooperative Transit Research & Development Program is a mechanism for deriving timely solutions for transportation problems of mutual concern to many responsible groups. In doing so, the Program operates complementary to, rather than as a substitute for or duplicate of, other transit research programs.

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The project that is the subject of this report was a part of the National Cooperative Transit Research & Development Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, or the Urban Mass Transportation Administration, U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to the transit industry. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire transit community, the Urban Mass Transportation Administration of the U.S. Department of Transportation has, through the mechanism of the National Cooperative Transit Research & Development Program, authorized the Transportation Research Board to undertake a series of studies to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on measures found to be successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be useful to administrators, dispatchers, maintenance personnel, and others concerned with bus communications. Information is presented on the types of radio equipment available and the uses of bus communication systems.

Administrators, engineers, and researchers are continually faced with problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to the available methods of solving or alleviating the problem. In an effort to correct this situation, NCTRP Project 60-1, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common transit problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCTRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific problems or sets of closely related problems.

There have been major changes in bus communication systems over the last 20 years. This report of the Transportation Research Board describes the types of systems that are currently available and the uses that can be made of the various features for more efficient bus operation.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of public transportation agencies. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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David K. Witheford, Engineer of Traffic and Operations, of the Transportation Research Board, assisted the Project 60-1 Staff and the Topic Panel.

Information on current practice was provided by many transit agencies. Their cooperation and assistance were most helpful.

BUS COMMUNICATION SYSTEMS

SUMMARY

Two-way radio communications equipment has experienced rapid growth in capabilities and reliability over the last twenty years. The microprocessor has become a permanent fixture in mobile and fixed units, providing not only new features, but also new ways of implementing existing functions such as control of transmission frequencies. New data services have become attractive and feasible as a result of the opening of the 800-MHz band by the FCC in 1976 and the significant cost reductions and reliability improvements in digital electronics.

The heart of a two-way communications system, regardless of its purpose, size, or sophistication, is audio transmission. Four different radio frequency bands (low, high, UHF, and 800 MHz) are defined and controlled by the FCC. In addition to traditional voice communications, functions such as alarm reporting and automatic vehicle location are implemented by tone combinations transmitted in the voice spectrum. Such data communication capabilities within bus communications sytems are increasing and may replace most voice communications in the future because they reduce transmission time and provide more information. Bus, driver, and route/run identifications can be transmitted automatically and more quickly. Alarm conditions such as engine overheating and low oil pressure can be transmitted automatically. Passenger counts and vehicle locations can be determined and transmitted. In addition, data transmitted from the buses and maintenance vehicles can be sent directly to data processing computers within the control center for automatic report generation.

The basic radio and voice equipment consists of mobile units, base stations, and control centers. Relay stations (often called repeaters) are used to expand the geographic range of a system. The radio equipment in new bus communications systems is designed to meet stringent electrical and environmental standards. It is designed to be operated reliably in a bus transit environment where it is subjected to electromagnetic interference, electric supply surges and drops, severe vibration and shock caused by deteriorated streets, temperature extremes generated by exposure to direct sunlight and cold northern winters, and moisture from both condensation and improper bus cleaning procedures. As a result of the success achieved with such designs it is generally agreed that equipment for new data services should be specified to meet the same standards.

Suppliers of equipment and services for bus communications systems can be divided into several categories—consultants, prime contractors, manufacturers, and maintenance contractors. Consultants provide a variety of services in acquiring systems. They assess the requirements for a system, perform radio propagation studies of the lcoal transit area, ensure compliance with regulations (FCC, UMTA, state, and local), write specifications, manage the acquisition, provide legal testimony for contested bids, and even broker the sale of the transit agency's old communications equipment.

Consultants do not manufacture equipment or sell either equipment or software. Many larger transit agencies perform some or all of these consultant services themselves. Because of the growing importance of software in bus communications systems, software experience should be considered when selecting a consultant.

Over the last ten years, as systems grew in size and complexity, the prime contractor has come into existence as an entity separate from radio equipment manufacturers. The prime contractor typically bids a system composed of radio equipment, computers purchased from other manufacturers, together with software and additional electronic equipment that the prime contractor has produced itself. However, the distinction between prime contractor and manufacturer is not always clear. Some companies now provide complete systems, assuming the role of both prime contractor and manufacturer. Other companies that have been strictly prime contractors are now acquiring radio manufacturing capabilities.

Ten transit agencies in the continental United States, selected from a group of more than 60 agencies that have or are planning bus communications systems, were contacted. The selection provided a wide distribution of fleet size, geographic location, system age, and system sophistication. These agencies covered service area populations from 150,000 to 7,300,000 people. Their bus fleet sizes are small (99 or fewer), medium (100 to 999), and large (1,000 or more). Some installed bus communications systems as early as 1965 and some currently have requests for proposals pending. Most of these systems were installed in the 1970s. All systems were funded partially under UMTA Section 3, 5, or 9 grants. The capital cost of these systems ranged from $59,000 for a modest, voice-only system to over $7,000,000 (estimated) for a new, large fleet, multi-function system.

The goals set for bus communications were similar regardless of the size and complexity of the system. Improved schedule adherence has been the most frequently sought benefit, and all of the agencies contacted cited an improvement in this area. For small systems, the ability to hold a bus at a transfer point until another bus with transferring passengers aboard could arrive was cited as the second most important benefit. For large systems, second on the list of benefits sought was the reduction of violence and crime against operators and passengers. All agencies identified the ability to report accidents, fires, crimes, and road conditions to other public agencies as a major benefit. Most agencies reported the ability to reroute vehicles in response to emergencies and vehicle breakdown as a significant benefit.

All systems are composed of mobile units in buses and support vehicles (supervisory, maintenance, or transit police), control equipment at fixed locations for bus and maintenance dispatch, and transmitters/receivers located at transmission sites. Larger systems had up to 10 transmission sites, some interconnected with microwave links. The more recently installed systems incorporate a number of additional data functions such as automatic identification of transmissions from mobile units; emergency alarms, either operator initiated or equipment initiated, such as engine overheating; and automatic vehicle location. Most systems operate in one of three frequency bands—high (140 170 MHz), UHF (450 470 MHz), or 800 MHz (806 821 and 851 866 MHz). Some systems that have been expanded operate in more than one band.

System maintenance is usually performed under warranty by the manufacturer (via an authorized local agent) during the first year of operation. After the first year, maintenance is provided in a variety of ways: by the manufacturer, by local communication companies, by communication departments within large agencies, and often by municipal communications departments that serve several different public agencies, such as fire, police, and transit. Contracted maintenance, either through the manufacturer or local companies, is usually provided under one-year renewable maintenance contracts that include regular weekly (or monthly) preventive maintenance, two-day service on mobile units removed from vehicles by agency staff, and immediate (one to two hour) emergency service for central receivers and transmitters.

Initial training is provided by either the manufacturer or the agency's consultant. Most often operators are trained on the job or receive a half-hour to one-hour briefing. Some classroom training is used, usually for dispatchers and maintenance personnel.

In the future, bus communication systems are expected to use more data transmissions and fewer voice transmissions. Most new systems will use the 800-MHz band out of necessity because the UHF band, which is preferred for its greater range, will become increasingly crowded in urban areas. The more basic data services (such as automatic identification of buses, drivers, and routes) and automatic transmission of alarms (such as engine overheating, low oil pressure, and low air pressure) are expected to become commonplace. More sophisticated functions such as automatic vehicle location (AVL) will remain relatively expensive because of the labor-intensive cost of installing and maintaining signposts. Larger transit systems will install AVL systems to improve schedule performance and will gradually install passenger counter systems over the next ten years. Newer technologies, such as cellular radio and satellite communications, will have little impact over the next five years. In time, some of the more popular related data services such as alarm monitoring will be integrated into the radio itself. The number of prime contractors who are not traditional mobile radio manufacturers will probably increase through joint ventures or mergers.

CHAPTER ONE

INTRODUCTION

Transit agencies have experienced difficulty in specifying, purchasing, and deploying bus communications equipment and services. Information concerning these systems is fragmented but the underlying technology is evolving rapidly. This technology is spurred by rapid advances in electronics, particularly the imbedding of microprocessors in most radio equipment. The familiar voice-only systems are giving way to combined voice and data systems and will in time become primarily data communication systems. Some specific problems faced by the agencies are:

- systems are purchased infrequently,
- the cost is high, usually requiring federal or state assistance,
- communications experience is lacking at most agencies,
- the number of experienced consultants and manufacturers is small,
- the preferred frequency spectrum below 800 MHz is crowded.

The purpose of this synthesis is twofold: to gather in one place a summary of current and proposed practice and to provide references to literature, existing bus communications systems, and suppliers of equipment and services that can be used for further study. Information for this synthesis was obtained from a literature search; from numerous telephone calls to transit agencies, consultants, prime contractors, and radio equipment manufacturers; and from a review of product brochures.

In Chapter 2, communications equipment and functions that are available today are discussed. During the discussion common terms that are used in later chapters are defined. The results of discussions with 10 transit agencies that either have or are acquiring bus communications systems are presented in Chapter 3. These systems range from single-channel voice-only systems for 30 buses to multichannel, multifunction systems that combine voice and data communications serving more than 2,500 buses. A brief discussion of future developments is presented in Chapter 4.

The Appendixes contain a bibliography of bus communications and related literature, a partial list of transit agencies that have or are acquiring bus communications, and a list of suppliers. The bibliography (Appendix A) was compiled from several automated databases and is divided into six categories:

- Bus Communications,
- General—Policy, Status, and Trends,
- Cellular Communications Systems,
- Digital Data and Mobile Communications,
- Automatic Vehicle Monitoring, and
- Technical Articles on Mobile Communications.

Appendix B contains a list of more than 50 transit agencies obtained from a search of capital grant applications for radio equipment and from discussions with suppliers. The list of suppliers (Appendix C) is divided into two categories; consultants, and prime contractors and radio equipment manufacturers.

For those transit agencies that have acquired them, bus communications systems have become a vital part of their operation. Comments from some agencies indicate that it would be nearly impossible to revert to operations with a communications system. Each conversation with a transit agency or supplier usually generated a new lead to more information. This synthesis concentrated on systems in the United States, but it is apparent that a study of bus communications systems in Canada would yield significant information. The Canadian government has a strong support commitment to mass transit, as do most provincial and city governments. For example, the systems in Hull, Quebec, and Thunderbay, Ontario are purchasing sophisticated bus communications systems that incorporate telephone information, automatic vehicle location, and report generation.

An area for further study is that of litigation relative to procurements. Several transit agencies indicated that their acquisitions were delayed by challenges through the UMTA appeals process for more than a year after bids were received and that considerable time and money were spent rewriting specifications to accommodate the results of these appeals.

CHAPTER TWO

AVAILABLE COMMUNICATIONS EQUIPMENT AND FUNCTIONS

Two-way radio communications equipment has experienced a growth in features and reliability over the last 20 years similar to that of most electronic equipment. The microprocessor has become a permanent fixture within mobile and fixed units; providing not only new features, but also new ways of implementing existing functions such as the control of transmission frequencies. New data services have become attractive and feasible for the most part both because of the opening of the 800-MHz band by the FCC in 1976 and because of the significant reduction in the cost and the improvement in reliability of digital electronics (mainly microprocessors and solid-state memory). Because of these new services, the need for comprehensive software specifications has increased.

BASIC COMPONENTS

The heart of a two-way communications system (regardless of its purpose, size, or sophistication) is audio transmission. Basic radio and voice equipment consists of mobile radio units, control centers, and base stations as shown in Figure 1. Relay stations[1] are used to expand the geographic range of a system. Some systems also provide direct connection to the public telephone system. Data communication features, such as alarm reporting and automatic vehicle location, are implemented by tone combinations in the voice spectrum that are transmitted in the same way as voice messages.

Transit agencies use four different radio frequency bands defined and controlled by the FCC for two-way mobile communications:

Name	Allocation
Low	30–50 MHz
High	150–170 MHz
UHF	450–470 MHz and 470–512 MHz[a]
800 MHz	806–821 & 851–866 MHz

[a]The 470-512-MHz band is limited to the top 11 metropolitan areas, and is completely allocated in most of these areas.

Very few transit systems use the low band. Older communication systems are typically designed for the high band. Most new systems use the UHF and 800-MHz bands. Most transit agencies have preferred the UHF band when it is available because it is less congested than the high band, has greater range than the 800-MHz band, and is less affected by obstructions, such as buildings, than the 800-MHz band. Some of the high-band systems have been expanded and now operate in both high and UHF bands. As a result of more manufacturers entering the 800-MHz field, the equipment has improved, and the preference for UHF over 800 MHz has declined.

Mobile Radio Units

The most recognizable element of a bus communications system is the mobile radio that is installed in each bus and in most supervisor and maintenance vehicles. A mobile radio consists of a microphone, speaker, control head, receiver/transmitter, and an antenna as shown in Figure 2. The speaker, control head, and receiver/transmitter may be housed in the same enclosure. The control head, when separate, contains indicators, controls, and a connection for the microphone. A separate control head is smaller than a combined unit and requires less space near the driver. Controls range from a simple push-to-talk switch to interfaces for alarm switches and external data equipment, such as automatic vehicle monitoring. Digital circuitry for control functions, such as private-line squelch (discussed later), is also contained within the control head. In large communication systems with extensive data features, the control head may be designed and manufactured by a prime contractor while the receiver/transmitter is purchased under subcontract from a traditional mobile radio manufacturer.

Control Centers

The control center is the hub of the communications network. It provides the interface between the bus dispatchers and the bus drivers and between the maintenance dispatcher and the maintenance vehicles. Communications functions performed at the center include:

- the routing of received signals to one or more speakers and the broadcasting of signals over one or more transmitter channels,
- the logging of all or some incoming and outgoing messages, and
- the patching of mobile units into the telephone system.

[1]Some manufacturers refer to relay stations as repeater stations in their specification literature. The term "relay" is preferred by the FCC and is used in license applications. Except when referring to the commercial name designated by a manufacturer this synthesis will use the term relay.

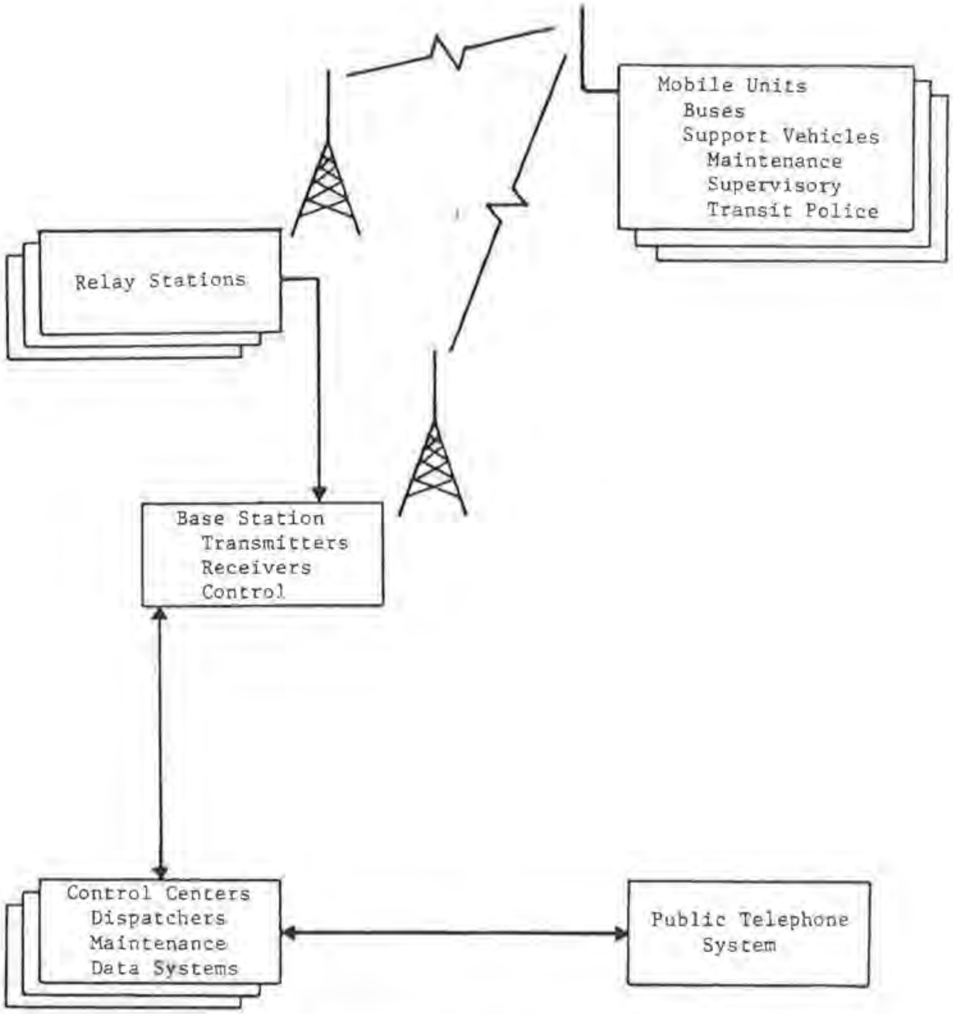

Figure 1 Two-way mobile communications system.

The center also contains equipment that monitors the quality, accuracy, and stability of the transmitter and receivers and provides the means to adjust these factors. In larger, more sophisticated systems, the control center may include extensive data processing facilities for computing schedules and transmitting schedule data to mobile units and for graphically displaying vehicle location (*1*).

A logging tape recorder records all or selected messages automatically on audio tape. A date/time code can be recorded with each message for later identification. Later the tapes can be scanned to find specific date/time codes. The audio tapes for each day are stored for a particular time period before reuse. The recordings are normally used to review emergency situations, such as when a bus is involved in an accident.

A radio-telephone interconnect connects a mobile two-way radio to the public telephone system. The equipment is located either at a base station or a control center. It scans receiver channels for telephone tone signals, verifies that a particular mobile unit is allowed to make calls, and then passes the call to the telephone system. Conversely, it will route calls from the telephone system to a particular mobile unit. The equipment is normally found in larger systems and is restricted to maintenance and supervisory functions. The radio-telephone interconnect eliminates the need to provide radio equipment at all locations that a maintenance supervisor may need to contact. Large transit agencies should consider a complete integration of telephone and radio message handling in new systems because the volume of calls handled by dispatchers (maintenance or operations) are roughly the same.

A large bus communications system may have more than one control center. For instance, bus dispatching and maintenance vehicle dispatching may be done from different locations. When more than one control center is used, FCC regulations require that one must be designated as a master with the ability to preempt the others.

Base and Relay Stations

A base station contains power amplifiers, transmitters, receivers, and control equipment. The station may be controlled by operators (such as dispatchers) through a control center located at the station, or may be controlled remotely over dedicated telephone lines or by radio links connected to a control center.

Base stations are located at transmitter sites. A transmitter site may contain one or more antennas and one or more base stations. The base stations, antennas, buildings, and land may be owned by the transit agency, shared with other organizations, or owned by other organizations. A transmitter site is usually chosen for its superior radio transmission characteristics (e.g., the highest point in the immediate service area).

The purpose of the relay station is to receive the relatively weak signals from mobile units located beyond the reception area of the base station and to relay those signals to the base station. A relay station receives on one frequency and either automatically retransmits on another or sends the audio signal over dedicated telephone lines. When a bus communications system has one or more relay stations, the base station will also contain equipment known as a receiver voting unit that selects the best received signal and passes it to the control center.

SYSTEM EXPANSION METHODS

A brief explanation of private-line squelch, trunked radio, and synthesized radio is presented in the following sections. Bus communications are typically short and occur randomly and infrequently. Therefore, many mobile units can share the small number of radio channels allocated to a transit agency. A method of channel management is required when several units are served by a single channel. Two channel-management methods used are private-line squelch and trunked radio. Private-line squelch is older and usually is found in one or two channel systems. Trunked radio is newer and is cost-effective for large systems (300 or more units) with three or more channels. One of the developments that made trunked radio economically possible was the development of low-cost multichannel radios using synthesized frequency generation.

Private-Line Squelch and Digital Private-Line Squelch

Private-line squelch is a technique that allows a number of mobile radio units to share the same frequency and allows a transmission to be addressed to a specific unit or group of units. All units receive all transmissions, but the transmission will be squelched (the earphones or loud speaker will be switched off) unless it contains a specific subaudible tone assigned to the particular unit. One of 30 tones between 67 and 192 Hz can be assigned to a particular unit. These are called "subaudible" because their amplitude is such that they cannot be heard under normal working conditions.

Digital private-line squelch provides the same nonconflicting frequency sharing as the private line feature, but increases the number of individual squelch controls beyond the 30 available with private line. The increase is obtained by impressing a digital code on the subaudible squelch control tone and assigning unique digital codes to each mobile radio unit or groups of units.

Trunked Radio Systems

A trunked two-way radio system is similar to the familiar switched telephone network. It efficiently uses the limited number of radio channels available to a transit agency by temporarily assigning any available channel to a pair (or group) of users on demand and then releasing it when the call is complete. Such a system is feasible and efficient when the number of users is large and the duration of calls is short.

Trunking should be considered when the number of channels desired by a transit agency is three or more. Trunking became feasible because of two unrelated developments. First, the FCC opened the 800-MHz frequency band to land mobile use; second, microcomputer controlled synthesized radio reduced the cost of multichannel, digitally controlled mobile radios.

Thro (*2*) presents a good description of land mobile trunked systems. The report, "900 MHz Trunked Communications System Functional Requirements Development" (*3*), is being incorporated as a requirement in some requests-for-proposals for new trunked bus communications systems. This latter document was prepared by the Associated Public-Safety Communications Officers, Inc. (APCO) for fire and police communications systems. The 900 MHz in the title is misleading, but it was the name applied to the newly opened frequency band in 1976. The band covered by the document (as is acknowledged in the document) is now known as the 800-MHz band, specifically 806–870 MHz. The following presents a brief description of trunked system implementations summarized from these two documents.

There are two methods currently used to implement trunked two-way radio systems. The first method uses a dedicated channel for switching control, whereas the second superimposes control data on each channel as subaudible tones.

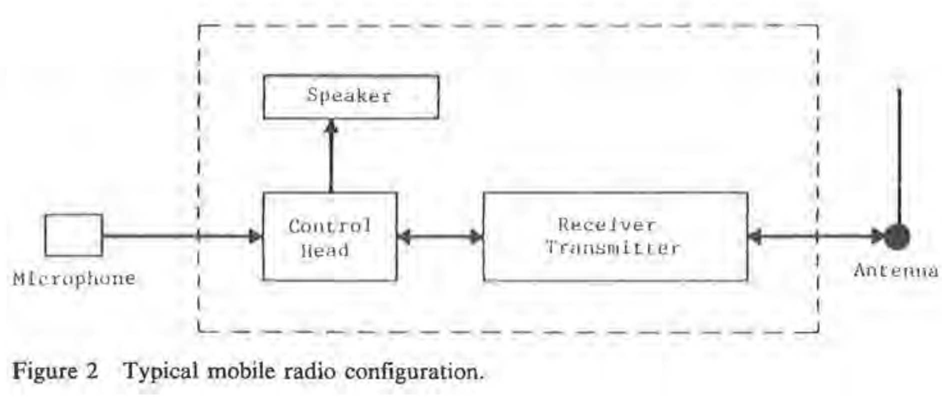

Figure 2 Typical mobile radio configuration.

In the first method, each mobile unit monitors the control channel for its unique identification code, its subfleet code, or a general broadcast code. Upon receipt, the unit switches to the channel specified by the control channel and remains there until message termination. To initiate a call, the caller requests use of a channel by transmitting request and identification codes on the control channel and awaiting acknowledgment from a central controller.

The request will be retransmitted if the acknowledgment is not received within a specified time. Failure of an acknowledgment could be due to temporary transmission failures (dead zones) or simultaneous requests by separate callers. When the acknowledgment is received, it will indicate either the channel to use or it will indicate that the request is pending. A request may queue if no channel is available or if the intended receiver is busy.

In the second method, each mobile unit continuously scans all channels for its unique identification code, its subfleet code, or a general broadcast code. If the code is received the unit stops on that particular channel and remains there until message termination. To initiate a call, the unit scans for an unused channel and then transmits a request and identification code to the controller. An acknowledgment procedure similar to the first method is then used to establish communications. This method is sometimes referred to as psuedo-trunking.

Synthesized Radio

The frequencies used for transmission and reception in older mobile radio systems were controlled by the electromechanical vibration of small crystals mounted in plug-in modules. Until recently, multifrequency (multichannel) systems required a separate crystal for each frequency. To change or add to the frequencies used in a system required the replacement or addition of crystals in all units. The new synthesized systems use voltage controlled oscillators (VCO) for each channel; these are controlled by a microcomputer. Now the frequencies of a multichannel system are defined by data stored in the microcomputer program rather than by the presence of individual crystals. These data are easily changed by temporarily connecting an external programming device to each mobile unit requiring a change.

DATA COMMUNICATION EXTENSIONS

Data communication is used increasingly in bus communications systems and will, in the future, significantly reduce voice communication transmission time. Data communications reduce transmission time or provide more information or both. Bus, driver, and route/run identifications can be transmitted automatically and more quickly. Alarm conditions, such as engine overheating and low oil pressure, can be transmitted automatically. Passenger counts and vehicle locations can be determined and transmitted. Data collected by electronic fareboxes can be transmitted. Data transmitted from the buses and maintenance vehicles can be sent directly to data processing computers within the control center for automatic report generation.

Automatic Identification

Mobile radios can be purchased with encoding circuitry that automatically transmits some combination of radio, bus, driver, route, and run numbers. Comparable decoding equipment at the control center interprets the received identification codes and sends them to numeric displays and to data processing computers for processing.

The simplest encoder transmits a unique digital code that identifies the radio each time the transmitter switch is activated by the driver. An emergency switch is usually included that sends the code repeatedly once it is pressed. The digital code is transmitted as a series of audio tones. At the control center, codes from different mobile units can be queued until they can be acknowledged by the dispatcher. The codes may also be printed. This encoding method allows more efficient use of a frequency channel. To initiate a call, the driver pushes a button, waits for an acknowledgment (usually a light on the control head) from the dispatcher at the control center, and then proceeds to talk. The acknowledgment may also be an indication to hold until the dispatcher is available. The effect of this encoding is to limit on-the-air time to message content only, eliminating the typical "this is unit xxx to base . . . this is base, go ahead" voice establishment of contact. An example of this type of encoding system is the GE-STAR, which uses a quarter second tone at 1600 kHz to transmit the identification code.

Alarms

Alarms, such as engine overheating, low oil pressure, low air pressure or farebox tampering, can be automatically transmitted to the control center. Additional circuitry in the control head is required that operates in a manner similar to the digital encoding of identifications with the exception that the transmission is activated by the alarm event rather than by the driver.

Automatic Vehicle Location

With additional equipment, a mobile radio can automatically transmit the location of a vehicle, to varying degrees of accuracy. This accuracy depends on the number and location of electronic sign-posts installed throughout the service area. Additional onboard equipment includes a separate radio (with a separate antenna) that listens for a continuously transmitted identification signal from the signposts. In some systems, the on-board equipment continuously sends an interrogation signal that will trigger an identification response from a signpost. Location information can be transmitted when the signpost is encountered or it can be saved until the control center requests it. Some systems also save odometer readings taken when the last signpost was encountered and transmit them along with current readings on request to provide a more accurate indication of current vehicle location. Dispatchers can compare vehicle location versus scheduled location or the comparison can be done by a computer at the control center and only exceptions reported to the dispatcher.

Passenger Counting

Over the last ten years a number of electronic passenger counters have been developed and tested (*4,5*). Currently installed counters use either infrared-beam-breaking detectors or pressure-sensitive mats located at the bus door. Passenger counts are calculated using complex algorithms and stored for later transmission from the bus. Transmission is accomplished in a variety of ways including short-range radio, optical signals, direct electrical connection within the maintenance garage at the end of each day, or over the mobile radio system on request by the control center. This last transmission method uses a digital code composed of tones similar to those used for identification, alarms, and vehicle location.

Electronic Farebox

Most electronic fareboxes available today collect and store data about cash (coin and bills) transactions and other types of non-cash transactions such as pass use. These fareboxes can maintain counts by coin types and by type of fare category. The latter data are usually obtained by a signal from the driver. In the future, magnetically encoded passes, similar to credit cards, inserted into farecard readers attached to the farebox may become widely used. As a result, it would be possible to collect a significant amount of ridership data, retrieve the data stored in these fareboxes, and transmit it using the digital transmission capabilities of a bus communications system.

Report Generation

Data processing computers located at the control center can be connected to the bus communications system and extract the identification, alarm, location, and passenger-count information discussed in previous sections. The system can generate preformatted reports or ad hoc reports under operator control. As an example, reports generated by one system (*6*) include: schedule deviation, performance (trip, lay-over, and run times), ridership, road call (correlated with alarms), mobile activity, alarm activity, and dispatcher activity.

Three transit agencies that have report generation combined with their bus communications system are Rhode Island Public Transit Authority, Southern California Rapid Transit District, and VIA Metropolitan Transit.

RELIABILITY

New land mobile radio equipment has been designed to meet stringent electrical and environmental standards. Most equipment meets both MIL-STD-810C (*7*) and EIA 152B (*8*) standards. Some equipment also meets the U.S. Forest Service standard (*9*) for rough terrain equipment. The equipment is designed with heavy cast enclosures, large convection cooled heat transfer surfaces, solid state components, no hand soldering, and a minimum of connectors. Equipment that meets these standards will operate reliably in a bus transit environment where equipment is subjected to severe vibration and shock caused by deteriorated streets, the high and low temperatures generated by exposure to direct sunlight and cold winters, and to moisture from condensation and improper bus cleaning procedures.

CHAPTER THREE

DESCRIPTION OF TEN BUS COMMUNICATION SYSTEMS

In the course of this study, many transit agencies were considered as potential candidates for interviews. These are listed in Appendix B together with their addresses, telephone numbers, and fleet size. The list was compiled from a search of UMTA capital grants for radio equipment and from conversations with consultants, prime contractors, and radio equipment manufacturers. The goal in selecting 10 agencies for interviews was to provide a wide distribution of fleet size, geographic location, system age, and system sophistication. The 10 agencies selected are given in Table 1.

Each agency was asked to respond to a set of 24 questions that covered funding, benefits, specifications, configuration, installation, training, and maintenance. Most agencies were contacted by telephone. Tidewater Regional Transit requested and completed a written questionnaire. The Merrimack Valley Regional Transit Authority was interviewed both in person and by telephone.

The most difficult information to obtain was that for system cost and configuration. For some agencies, cost information was not available. Configuration information was often obtained by calling companies that did the system maintenance. The result is that the descriptions of the bus communication systems used by these agencies contain a varying level of detail as to the amount and type of equipment in the system configuration.

CAPITAL AREA TRANSPORTATION AUTHORITY

The authority operates a fleet of 75 buses, 2 supervisor vehicles, 3 maintenance vehicles, and 8 special buses equipped with two-way radio. It serves the Lansing, Michigan area population of 229,000 people. The bus communications system consists of equipment acquired by separate purchases from two different vendors. Motorola equipment was purchased before 1975. General Electric equipment was purchased in 1975 with aid from an UMTA grant. The decision to purchase was made by the board of directors and the requirements were defined by the staff. The authority is satisfied with the system, and indicated that it would not modify its requirements if it were purchasing the system today.

The directors expected improvements in scheduling and the ability to hold buses for transferring passengers. These benefits have been achieved, plus drivers have been able to report accidents, fires, activity at a crime scene, lost children, and a lost senior citizen. The authority participates in a local civil defense plan where the radio-equipped bus fleet is assigned a role for evacuation.

The older Motorola system consists of eight MOCOM 70 units installed on eight special buses. The newer General Electric system is a two-channel (expandable to four) UHF system with private-line squelch consisting of:

80 GE MASTR II mobile radios,

2 model 539B251 master controllers located at two control centers (manager office and dispatch),

1 model DC55RBS base station (100 watt av.) located on the roof of the control center, and

2 GE PE65 handheld portables.

The reception is acceptable but is somewhat weather dependent. In some instances, transmissions from other cities using the same frequency can be heard.

The General Electric system was installed and is maintained by General Electric's regional distributor, Snip and Anderson, located in Grand Rapids, Michigan. Preventive maintenance is performed every two weeks. Emergency service is available within 24 hours. System testing was performed by Snip and Anderson after installation and was observed by authority personnel.

Training for the drivers was provided in a bus and lasted for less than 30 minutes.

DALLAS TRANSIT SYSTEM

This transit system has a fleet of 560 buses, 38 supervisor vehicles, and 22 maintenance vehicles equipped with two-way radios. It serves a population of 938,250 in the Dallas, Texas area. In 1984 a new system was purchased to replace the two-way radio system that had been installed in 1965. The new system is a combined voice and data system the provides automatic bus and driver identification, automatic transmission of alarms (driver emergency, engine overheating, low oil pressure, low air pressure, and low generator voltage), and automatic vehicle location (AVL).

The AVL subsystem was scheduled to be installed during a second phase of the procurement beginning in early 1985. Approximately 100 signposts will be mounted on signal light poles throughout the area. The AVL subsystem will incorporate odometer sensing to determine location between signposts.

Overall system requirements were defined jointly by the transit system and its communications consultant, Terence J. Collins Associates Inc. The major goal that was sought was better reception. This goal has reportedly been achieved.

The older system used two high-band radio channels that were shared with other public agencies. The new communications system is a Motorola 2500 Transit Dispatch System, which operates in the 800-MHz band. The system consists of:

TABLE 1

AGENCIES INTERVIEWED FOR THIS SYNTHESIS[a]

Agency	Bus Fleet	Population
Southern California Rapid Transit District	2,940	7,000,000
New Jersey Transit Bus Operations	2,250	7,300,000
Mass Transit Administration of Maryland	915	2,000,000
Dallas Transit System	560	938,250
Tidewater Regional Transit (Virginia)	169	800,000
Capital Area Transportation Authority (Michigan)	83	229,000
Kanawha Valley Regional Transportation Authority (West Virginia)	66	250,000
Winston-Salem Transit Authority (North Carolina)	64	150,000
Utica Transit Authority (New York)	40	155,000
Merrimack Valley Regional Transit Authority (Massachusetts)	30	199,000

[a]Listed by fleet size.

560 METROCOM II four-channel mobile radios (for the buses),

60 SYNTOR X mobile radios (for the supervisor and maintenance vehicles),

1 base station,

3 relay stations, and

1 control center with 4 dispatcher consoles, a logging tape recorder, and a radio-telephone interconnect.

The system was installed by Motorola and will be maintained by them during the warranty period of one year. After the warranty period, the City of Dallas Communications Center and the Dallas Transit System will share the maintenance responsibility. Motorola provided on-the-job training for the drivers, and classroom training for the dispatchers. Dallas Transit System staff and Motorola jointly provided on-the-job training for the maintenance staff.

Dallas expects to add 50 more radio-equipped buses by the end of 1984 and to increase its radio-equipped fleet to 1,000 buses within three years. Most, if not all, equipment for these expansions will be purchased from Motorola.

KANAWHA VALLEY REGIONAL TRANSPORTATION AUTHORITY

The authority has 66 buses, 3 supervisor vehicles, 1 maintenance car, and 2 maintenance trucks equipped with two-way radios and serves the Charleston, West Virginia area population of 250,000. The decision to purchase a bus communications system was made by the Board of Members on advice from the staff in December 1976. Funding for the $110,000 system was obtained from an UMTA Section 3 grant (80 percent) and from Kanawha County (20 percent). The system was purchased from General Electric and installed in 1978.

The authority expected to benefit from the ability to hold buses for transferring passengers and to provide immediate communications in the event of an emergency on a bus. These benefits have been achieved, plus the drivers can and do report accidents, fires, bad road conditions, breakdowns, and now and then a sick passenger. The authority participates in an areawide emergency preparedness plan and the bus communications system is central to this role. The authority is generally satisfied with the system but would add a logging tape recorder if the system were purchased today.

The General Electric system operates in the high band and consists of:

75 MASTR II HB mobile radios (66 in buses, 3 in supervisor vehicles, 3 in maintenance vehicles, and 3 spares),

1 MASTR II HB base station,

2 MASTR II HB relay stations,

1 control center for dispatchers (MASTR II Controller 549A1S1 SP),

1 control center for maintenance (MASTR II Controller 549A1S1 SP), and

3 handheld portables (5 watt).

The system was installed and is maintained by General Electric's regional dealer, Communication Services of South Charleston, West Virginia. During the first year of operation, maintenance was covered under warranty.

On-the-job training was provided by Communications Services for both drivers and dispatchers.

MASS TRANSIT ADMINISTRATION OF MARYLAND (MTA)

The MTA serves the Baltimore, Maryland area (population 2,000,000) with 915 radio-equipped buses. The decision to acquire the bus communications system was made in 1970. The system was purchased from Motorola and was installed in 1973.

The prime benefit desired (especially by the drivers) was the reduction in vandalism and muggings. This benefit has been achieved for the most part, plus schedule adherence has improved. Another transmitter site and an AVL system were cited as desirable in the future.

The system operates over eight channels in the UHF band and provides both voice and data service. Four channels are used for buses and the other four are used for supervisors, maintenance, and transit police. Efficient channel use is aided by a digital private-line feature. Data services include automatic bus identification and a driver-actuated emergency alarm. The system consists of:

915 MOCOM 70 mobile radios on the buses plus additional radios on supervisor, maintenance, and transit police vehicles;

2 base stations located at two transmitter sites that are 10 miles apart on the World Trade Building and on Mt. Wilson; and

1 control center with 4 dispatcher consoles.

The radio reception is good, although there is some fading in parts of the service area that are more than 13 miles from the transmitter sites.

The system was installed by Motorola. Motorola provided training for the dispatchers and supervisors. The MTA provides maintenance for the system.

MERRIMACK VALLEY REGIONAL TRANSIT AUTHORITY (MVRTA)

MVRTA serves 199,000 people in 6 northeastern Massachusetts municipalities (Andover, Groveland, Haverhill, Lawrence, Methuen, and North Andover) with 30 radio-equipped buses. The decision to acquire a system was made in 1981. The system was purchased from Motorola for $59,000 in 1982 with aid from an UMTA grant (80 percent) and from the Commonwealth of Massachusetts (10 percent). MVRTA defined the system requirements and wrote specifications using UMTA's "Appendix to Technical Specifications of Bus Mobile Radios and Related Fixed Equipment," 1975 (updated 1979) (*10*) as a guide.

MVRTA hoped to improve schedule adherence, speed road calls, and accommodate transferring passengers by holding buses at a transfer point when necessary. These benefits have been achieved, along with several others. During severe winter storms when many employers and schools close early, MVRTA has been able to reschedule the fleet to provide almost demand-responsive service. After a freight train derailed, MVRTA dispatched buses to carry railroad passengers around the derailment scene. Buses were dispatched to a hotel fire in downtown Haverhill to assist with the evacuation of senior citizens. Drivers report accidents, bad road conditions, downed power lines, and water main breaks. Dispatchers have requested ambulances for sick passengers and have spoken directly (via radio) to unruly passengers resulting in an improvement in their behavior.

The system operates over a single channel in the UHF band and uses a two-tone private-line squelch. The system consists of:

38 MITREX FM two-way mobile radios (30 in buses, 1 in a supervisor vehicle, 2 in maintenance vehicles, and 5 spares),
4 MT500 two-way FM portable radios,
1 MICOR base station and relay, and
2 remote dispatch consoles.

The reception is acceptable, but there are reportedly some dead zones. An additional channel would be added if the system were to be purchased today.

The system was installed and is maintained by the local Motorola distributor, Interstate Communications, Inc., located in Dracut, Massachusetts. The distributor provided training for one dispatcher, who then trained the drivers and other dispatcher.

NEW JERSEY TRANSIT BUS OPERATIONS, INC.

New Jersey Transit Bus Operations, Inc. (NJ Bus Transit) provides bus service for a population of 7,300,000 in New Jersey with a fleet of 2,250 buses. A statewide voice and data bus communications system has been planned and bids are expected in early 1985. Installation is scheduled to be completed in 1986. The plan includes independent bus operators with a combined fleet of approximately 600 buses. The decision to acquire the system was made in 1981. Funds for the system have been allocated from UMTA Section 3, 5, and 9 grants and from the state of New Jersey.

Requirements were defined by the management and staff. The services of a consultant, Sachs-Freeman Associates, were obtained to develop specifications, manage the installation, and verify the testing. The final specifications included, by reference, functional requirements for trunked radio systems in the 800-MHz band that were developed by the Associated Public-Safety Communications Officers (APCO).

Several benefits are expected from the system. Improvements in schedule adherence are expected to reduce the cost of operations by using fewer buses. The cost of dispatching will be reduced by centralizing operations in two control centers located in Maplewood and Camden. Passenger and operator safety should improve by deterring violence and by providing immediate communications in the event of an accident. An improvement in the dispatching of maintenance vehicles is also expected.

The system will provide automatic identification of the bus and driver, trip start and end indication, a message capability, and expansion capability for automatic vehicle location. The identification number of the driver will be downloaded from the control center and the driver will verify its accuracy by pressing a button on the control head. The driver will indicate the start and end of a trip by pressing buttons on the control head. Messages entered at data terminals will be transmitted to other terminals within the system. Terminals will be located at the control centers and 18 garages initially. The message subsystem was specified so that it can be expanded to include data terminals in supervisor and maintenance vehicles.

The FCC has licensed 22 channel pairs in the 800-MHz band for a trunked mobile radio system. The system will provide communications directed to specific vehicles, and to groups of vehicles (subfleets). The subfleet provision will be used by the independent carriers for dispatching. The type and number of components expected to comprise the system are listed below. The exact type and number will vary somewhat depending on which supplier is awarded the contract.

2700 mobile radios for buses, supervisor, and maintenance vehicles (this figure includes a proportion of independent carriers),
21 data terminals,
150 portable radios,
150 pagers,
8–10 transmitter sites,
2 control centers (located in Maplewood and Camden), and
1 AVL subsystem option (located near 18 garages and at the end of bus lines).

The system will be installed and tested by the prime contractor under supervision of NJ Bus Transit and its consultant. Training will be provided both on the job and in classrooms by the prime contractor and by the NJ Bus Transit training department. The prime contractor will provide maintenance for one year after system acceptance under warranty and must offer a three-year maintenance agreement.

SOUTHERN CALIFORNIA RAPID TRANSIT DISTRICT (SCRTD)

SCRTD provides bus service for a population of 7,000,000 in the Los Angeles, California area with a fleet of 2,940 buses. The decision to acquire a bus communications system was made in the early 1970s. Two hundred buses were equipped with mobile radios in 1972 and later another 274 buses were equipped. In 1978, another 1,600 vehicles (buses and support) were equipped and plans were made to acquire and equip another 1,400 vehicles. The $10 million estimated cost of the system that will result is mostly funded by UMTA Section 3 grants.

The requirements and initial specifications were defined by the Los Angeles County Communications Department. Specifications for the current expansion of the system were developed by SCRTD with technical assistance from a consultant, NES, Inc. of Knoxville, Tennessee. This expansion was needed because of congestion in the UHF band and because of limited computer capacity in the current system.

SCRTD expected an improvement in driver and passenger safety and more effective fleet control. These benefits are reportedly being achieved; plus drivers report accidents, fires, and traffic blockages.

The system at the end of 1986 will operate over three frequency bands and provide both voice and data communications. Features expected in the system are: report generation and transfer (similar to electronic mail), AVL (210 buses are now equipped as part of a demonstration), passenger counters, and schedule adherence software. Components of the existing system are:

2800 General Electric MASTR II 10-channel UHF-band mobile radios,
200 RCA 1000 10-channel UHF-band mobile radios,
200 RCA 700 4-channel UHF-band mobile radios,
5 Motorola SYNTOR X high-band mobile radios,
40 Motorola SYNTOR X low-band mobile radios,
200 RCA 1-channel fleet phones (UHF band),
100 portable radios,
18 General Electric MASTR II UHF-band base stations,
6 Motorola MITREX high-band base stations,
3 General Electric MASTR II low-band base stations, and
7 transmitter sites on mountain tops (2 are shared with other public agencies).

SCRTD provided training for their drivers, dispatchers and maintenance staff using materials supplied by the several vendors listed above. SCRTD also provides maintenance for the bus communications system.

TIDEWATER REGIONAL TRANSIT (TRT)

TRT serves the Norfolk, Virginia area population of 800,000 with a fleet of 169 radio-equipped buses. The general manager made the decision to purchase a mobile radio system in 1973 with aid from an UMTA Section 3 grant. Requirements were defined by the general manager and assistant general manager. Specifications were developed by a consultant. The system was purchased from Motorola at a cost of $500,000, which included installation, training, and warranty (120 days labor and one year parts).

TRT expected to improve communications with the drivers, decrease response time in the event of an emergency, and reduce passenger delay time when a bus breaks down. These benefits have been achieved.

The system operates in the UHF band and provides voice and alarm transmission (low oil pressure and engine overheating). If the system were purchased today, the alarm transmission would be deleted from the specifications. The system consists of:

169 MOCOM 70 mobile radios and
1 base station.

The system can be expanded by purchasing more units from Motorola. TRT is not satisfied with the UHF band.

The system was installed and is maintained by Motorola through Commercial Radio Service Corporation of Norfolk. Preventive maintenance is performed weekly and 24-hour emergency service is available as part of a $15,000 per year maintenance contract. Training was provided by Motorola and by TRT staff both on the job and in a classroom.

UTICA TRANSIT AUTHORITY

The authority serves the Utica, New York area population of 155,000 people with 40 radio-equipped buses. The requirements were defined by the general manager. The purchase was made from Motorola with the aid of an UMTA Section 5 grant using a previously negotiated statewide contract. The purchase price was $1,318 per mobile radio. The New York Department of Transportation provided technical assistance in developing the specifications for the system.

The system has reduced response time to bus breakdowns and has improved service for transferring passengers by allowing buses to be held at transfer points when necessary. The drivers report road hazards, accidents, and fires and they communicate directly with each other. The authority is part of a civil defense plan and would use the bus communications system in that role.

The system operates in the UHF band and has the private-line squelch feature. The components of the system are:

47 MAXAR 80 FM two-way mobile radio units (40 in buses, 3 in company cars, 3 in mobile vans, and 1 spare), and
1 base/relay station on Bell Hill.

The reception in the UHF band covers an area of 20 miles radius and is deemed satisfactory.

The system was installed and tested by Motorola through Midstate Communications Electronics Inc. of Oriskany, New York. Maintenance was provided by Motorola through Midstate under warranty for the first year and was then extended by maintenance agreement for another two years. Maintenance is now provided jointly by the authority and by Midstate. The authority removes defective radios and sends them to Midstate for repair. Classes were provided by Motorola for training and written instructions were given to all drivers.

WINSTON-SALEM TRANSIT AUTHORITY

The authority serves the Winston-Salem area (population 150,000) with 64 radio-equipped buses. The General Manager and the Board of Directors decided before 1977 to acquire a bus communications system with the aid of an UMTA Section 6 grant. The requirements were defined by the general manager.

The authority expected to and did achieve an improvment in scheduling. The drivers report items left on buses, accidents, fires, break-ins, and road conditions. The authority is part of a civil preparedness plan and can divert the fleet via radio to meet emergency situations.

The system operates on two-channel pairs in the UHF band and provides automatic bus identification. The system consists of:

69 MASTR II mobile radios [64 in buses and 5 in service vehicles (without automatic identification feature)]

1 MASTR II base station,

1 control center with 3 consoles:

- Dispatching
- Maintenance
- Special dispatching vans for elderly, handicapped, and schools.

The base station is located on top of a bank building in downtown Winston-Salem, ten blocks from the authority. The control center is located at the authority and is linked to the base station by telephone lines. Reception is satisfactory but is sometimes weather dependent.

The system was installed and tested in 1978 by General Electric through Risenweaver Communications, Inc. located in Winston-Salem. Risenweaver has provided maintenance since installation—under warranty for the first year and now under a maintenance contract. Depending on the severity of the problem, maintenance will be provided within 1 to 24 hours. Training was provided on the job by Risenweaver.

CHAPTER FOUR

A BRIEF LOOK INTO THE FUTURE

In the future, bus communications systems will use more data and fewer voice transmissions. Some of the voice transmissions from the control center to the mobile units will be predefined and synthesized. Most new systems will use the 800-MHz band out of necessity rather than preference. The UHF band, which is preferred for its greater range, will become increasingly crowded in urban areas. The simpler data services (such as automatic identification of buses, drivers, and routes) and automatic transmissions of alarms (such as engine overheating, low oil pressure, and low air pressure) will become commonplace. Devices to monitor other on-board equipment, such as air conditioners, will become available. Automatic vehicle location (AVL) systems will remain relatively expensive because the cost of installing and maintaining signposts, which is labor intensive, will not decrease significantly. Larger transit systems, however, will install AVL systems to improve schedule performance. Passenger counters will be installed in larger transit systems slowly over the next 10 years.

Newer technologies, such as cellular radio and satellite communications, will have little impact over the next five years. Once commercial cellular radio becomes established, small transit agencies without bus communications systems may find it attractive because they can obtain the use of a radio system when exclusive allocation of a radio channel is no longer available. They will also be able to avoid initial capital costs by leasing the equipment (*11*). However, the cost per call (currently around 40 cents) and slow connect time (ten seconds or more) will have to be reduced. Currently no supplier (consultant, prime contractor, or radio manufacturer) is predicting that cellular communications will have a role in bus communication systems. Vehicle location via satellite is technically feasible, but is unlikely to become cost-effective for the foreseeable future.

Vehicle location via the LORAN-C radio navigation system is technically feasible and in the future may also become cost-effective as equipment prices fall. This system has been used primarily by the Department of Defense, which is planning to switch to satellite systems by 1997. Nonmilitary use of LORAN-C is growing and will probably sustain the LORAN-C system beyond the year 2000.

The number of prime contractors who are not traditional mobile radio manufacturers is expected to increase. The new data services will require more data processing software and specialized digital circuitry often customized to a particular transit agency. In time, some of the more popular related data services, such as alarm monitoring, will be incorporated into the radio itself. This integration has already started with automatic bus identification.

To benefit most from large multifunction bus communication systems, transit agencies will have to rethink and redesign their operations procedures. Significant improvements in schedule adherence can be achieved with a resulting reduction in costs, but not by using existing procedures. SCRTD is currently reviewing its procedures and other large agencies are expected to do the same. In time, benefits obtained from more sophisticated scheduling monitoring software will become available to small transit systems.

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APPENDIX A

SELECTED BIBLIOGRAPHY

Several automated databases plus reference material at MITRE were searched for bus communications literature. As expected, the initial search directed specifically to bus communications systems yielded only a few references. Because the mobile communications equipment used by buses is also suitable for other mobile communications applications, the search was widened. This wider search added references concerning mobile communications, cellular communications systems, and automatic vehicle monitoring, and various technical articles describing advanced work. All of these additional areas either have an impact on bus communications, such as automatic vehicle location, or may have an impact in the future, such as the cellular radio systems that are now becoming commercially available.

The automated databases searched were:

TRIS (Transportation Research Information Service)—Regulations, legislation, energy, environment, safety, design, construction and maintenance topics in air, highway, rail, maritime, and mass transport.

INSPEC—Topics from Physics Abstracts, Electrical and Electronic Abstracts, and Computer and Control Abstracts.

FEDRIP (Federal Research in Progress)—Topics in physical sciences, engineering, and life sciences.

COMPENDEX—Engineering and technology topics abstracts from the Engineering Index (Monthly Annual).

Ei ENGINEERING MEETINGS—Index of published proceedings of engineering and technical conferences, symposia, meetings, and colloquia.

All of the bus communications references, and selected references in other related areas, are listed below under six categories:

- Bus Communications
- General—Policy, Status, and Trends
- Cellular Communications Systems
- Digital Data and Mobile Communications

- Automatic Vehicle Monitoring
- Technical Articles on Mobile Communications

All cited references are available in English.

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APPENDIX B

TRANSIT AGENCIES WITH BUS COMMUNICATIONS SYSTEMS

No single source exists that lists all transit agencies that use radio communications for their bus fleets. The list presented in this Appendix was compiled from a search of UMTA grant applications, from interviews with suppliers, and from a literature search. A computerized listing of all Section 5, 9, and 9A grant applications from fiscal year 1983 until April 1984 was searched for references to radio, communications, or control. This search yielded a few agencies that were either applying for completely new systems or for additional equipment for older systems. The most productive sources were the consultants, prime contractors, and manufacturers.

The resulting list does not represent all transit agencies that have bus communications systems. However, it represents agencies that vary in geographic location, fleet size, and communications equipment. The addresses, telephone numbers, and fleet sizes presented in the list were obtained primarily from the APTA 1985 Membership Directory (*12*).

Albuquerque Transit System
601 Yale Boulevard, S.E.
Albuquerque, NM 87106
(505) 766-7970 Buses 107

Birmingham-Jefferson County Transit Authority
P.O. Box 10212
Birmingham, AL 35202
(205) 322-7701 Buses 164

Calgary Transit
P.O. Box 2100
Calgary, Alberta
Canada T2P 2M5
(403) 277-9800 Buses 732

Capital Area Transportation Authority
4615 Tranter Avenue
Lansing, MI 48910
(517) 394-1100 Buses 83

Capital District Transportation Authority
110 Watervliet Avenue
Albany, NY 12206
(518) 482-1125 Buses 240

Central Arkansas Transit
800 Wallace Building
105 Main Street
Little Rock, AR 72201
(501) 372-3300 Buses 72

Central New York Regional Transportation Authority
One Centro Center
200 Cortland Avenue
Drawer 820
Syracuse, NY 13205
(315) 471-2100 Buses 192

Central Ohio Transit Authority
1600 McKinley Avenue

Columbus, OH 43222
(614) 275-5800 Buses 323

Centre Area Transportation Authority
330 Osmond Street
State College, PA 16801
(814) 238-0625 Buses 20

Chicago Transit Authority
Merchandise Mart Plaza
P.O. Box 3555
Chicago, IL 60654
(312) 664-7200 Buses 2,300

Connecticut Transit
53 Vernon Street
Hartford, CT 06106
(203) 522-8101 Buses 451

CTCRO
111 Geanproulx
Hull, Quebec
Canada J8Z 1T4
(819) 770-3242 Buses 145

Dallas Transit System
101 North Peak Street
Dallas, TX 75226
(214) 828-6700 Buses 560

Duluth Transit Authority
2402 West Michigan Street
Duluth, MN 55806
(218) 722-4426 Buses 95

Gary Public Transportation Corporation
237 West 22nd Avenue
Gary, IN 46407
(219) 885-6911 Buses 112

Golden Empire Transit District
P.O. Box 2870
Bakersfield, CA 93303
(805) 324-9874 Buses 54

Greater Peoria Mass Transit District
2105 N.E. Jefferson Avenue
Peoria, IL 61603
(309) 676-4040 Buses 57

Greater Richmond Transit Company
101 South Davis Avenue
P.O. Box 27323
Richmond, VA 23261
(804) 358-3871 Buses 208

Indianapolis Public Transportation Corporation
1000 West Washington Street
P.O. Box 2383
Indianapolis, IN 46206
(317) 635-2100 Buses 249

Jacksonville Transportation Authority
100 North Myrtle Avenue
P.O. Drawer O
Jacksonville, FL 32203
(904) 633-2643 Buses 215

Kanawha Valley Regional Transportation Authority
P.O. Box 1188
1550 Fourth Avenue
Charleston, WV 25324
(304) 343-3840 Buses 66

Kansas City Area Transportation Authority
1350 East 17th Street
Kansas City, MO 64108
(816) 346-0200 Buses 310

Long Beach Transit
1300 Gardenia Avenue
P.O. Box 731
Long Beach, CA 90801
(213) 591-8753 Buses 198

Mass Transit Administration of Maryland
One Market Center
300 West Lexington Street
Baltimore, MD 21201
(301) 659-3449 Buses 915

Memphis Area Transit Authority
P.O. Box 122
Memphis, TN 38101
(901) 278-7880 Buses 311

Merrimack Valley Regional Transit Authority
200 Merrimack Street, Suite 401
Haverhill, MA 01830
(617) 373-1184 Buses 30

Metropolitan Atlanta Rapid Transit Authority
2200 Peachtree Summit
401 West Peachtree Street, N.E.
Atlanta, GA 30365
(404) 586-5000 Buses 755

Metropolitan Transit Authority
P.O. Box 100270
Nashville, TN 37210
(615) 242-1622 Buses 125

Metropolitan Transit Authority of Harris County
500 Jefferson
P.O. Box 61429
Houston, TX 77208
(713) 739-4000 Buses 743

Metropolitan Transit Commission
560 6th Avenue North
Minneapolis, MN 55411
(612) 349-7400 Buses 1,126

Milwaukee County Transit System
907 North 10th Street, Room 305
Milwaukee, WI 53233
(414) 278-4835 Buses 600

Municipality of Metropolitan Seattle
821 Second Avenue, Exchange Building
Seattle, WA 98104
(206) 447-6666 Buses 1,300

New Jersey Transit Bus Operations, Inc.
180 Boyden Avenue
Maplewood, NJ 07040
(201) 761-8300 Buses 2,250

Niagara Frontier Transportation Authority
P.O. Box 5008
181 Ellicott Street
Buffalo, NY 14203
(716) 855-7300 Buses 473

Orange County Transit District
P.O. Box 3005
Garden Grove, CA 92642
(714) 971-6200 Buses 673

Ottawa-Carleton Regional Transit Commission
1500 St. Laurent Boulevard
Ottawa, Ontario
Canada K1G 0Z8
(613) 741-6440 Buses 780

Phoenix Transit System
P.O. Box 4275
Phoenix, AZ 85030
(602) 262-7867 Buses 303

Public Transit Administration—City of El Paso
700 A San Francisco Street
El Paso, TX 79901
(915) 533-1220 Buses 155

Regional Transportation Commission
2050 Villanova Drive
P.O. Box 30002
Reno, NV 89520
(702) 323-2800 Buses 37

Regional Transportation District
1600 Blake Street
Denver, CO 80202
(303) 628-9000 Buses 716

Rhode Island Public Transit Authority
265 Melrose Street
Providence, RI 02907
(401) 781-9450 Buses 267

Rochester-Genesee Regional Transportation Authority
1372 E. Main Street
P.O. Box 90629
Beechwood Station
Rochester, NY 14609
(716) 288-6050 Buses 235

Sacramento Regional Transit District
P.O. Box 2110
Sacramento, CA 95810
(916) 321-2800 Buses 204

San Diego Transit Corporation
P.O. Box 2511
San Diego, CA 92112
(619) 238-0100 Buses 280

Santa Clara County Transportation Agency
1555 Berger Drive
San Jose, CA 95112
(408) 299-2884 Buses 654

Santa Monica Municipal Bus Lines
1660 Seventh Street
Santa Monica, CA 90401
(213) 451-5445 Buses 136

Southeastern Pennsylvania Transportation Authority
130 South 9th Street
The Edison Building
Philadelphia, PA 19107
(217) 574-7300 Buses 1,524

Southern California Rapid Transit District
425 South Main Street
Los Angeles, CA 90013
(213) 972-6000 Buses 2,940

Southwest Ohio Regional Transit Authority
1108 Tri-State Building
432 Walnut Street
Cincinnati, OH 45202
(513) 651-3020 Buses 438

Spokane Transit Authority
First Interstate Bank Building
Suite 330
North 9 Post Street
Spokane, WA 99201
(509) 458-2570 Buses 102

Sun Tran
4220 South Park Avenue
Tucson, AZ 85714
(602) 623-4301 Buses 159

Thunder Bay Transit
574 Fort William Road
Thunder Bay, Ontario
Canada P7B 2Z8
(807) 625-2188 Buses 2,555

Tidewater Regional Transit
P.O. Box 2096

Norfolk, VA 23501
(804) 627-9291 Buses 169

Topeka Metropolitan Transit Authority
201 North Kansas Avenue
Topeka, KS 66603
(913) 233-2011 Buses 35

Tri-County Metropolitan Transportation District of Oregon
4012 S.E. 17th Avenue
Portland, OR 97202
(503) 238-4915 Buses 720

Utica Transit Authority
Leland and Wurz Avenue
Utica, NY 13502
(315) 797-1121 Buses 40

Valley Transit
801 Whitman Avenue
Appleton, WI 54914
(414) 735-6101 Buses 38

VIA Metropolitan Transit
P.O. Box 12489
800 West Myrtle Street
San Antonio, TX 78212
(512) 227-5371 Buses 476

Waco Transit System
P.O. Box 2145
Waco, TX 76703
(817) 753-0113 Buses 18

Washington Metropolitan Area Transit Authority
600 Fifth Street N.W.
Washington, DC 20001
(202) 637-1234 Buses 1,651

Westchester County Transit System
112 East Post Road, 1st Floor
White Plains, NY 10601
(914) 285-5600 Buses 321

Wichita Metropolitan Transit Authority
1825 South McLean Boulevard
Wichita, KS 67213
(316) 265-1450 Buses 74

Winston-Salem Transit Authority
1060 North Trade Street
P.O. Box 2738
Winston-Salem, NC 27102
(919) 727-2000 Buses 64

APPENDIX C

SUPPLIERS OF EQUIPMENT AND SERVICES

Suppliers of equipment and services for bus communications systems can be divided into four categories—consultants, prime contractors, radio manufacturers, and maintenance contractors. The following three sections discuss briefly the services and products provided by the first three supplier categories, and list those most active in bus communications systems. The lists were compiled from telephone interviews with suppliers, in which each was asked to list other known suppliers (including direct competitors), and from the discussions with 10 transit agencies presented in Chapter 3. As time permitted, suppliers were contacted directly. These lists were compiled in early 1985 and are undoubtedly incomplete; they are not meant to be an endorsement of particular suppliers. The lists are provided for general information for transit agencies considering the acquisition of a bus communications system and for other researchers. All UMTA-supported procurements (virtually all bus communications systems procurements) require open competitive bids to ensure that all eligible suppliers are informed and given the opportunity to respond to pending procurements.

Maintenance is provided by the service divisions of the radio manufacturers, by local communications companies that may or may not be affiliated with a radio manufacturer, and often by the transit agency or a sister public agency. No listing of maintenance contractors is provided because maintenance arrangements usually are unique to each transit agency. In the description of 10 specific transit agency systems in Chapter 3, maintenance contractors are recognized where applicable.

CONSULTANTS

Consultants provide a variety of services in acquiring bus communications systems. They do not manufacture equipment or sell either equipment or software. They assess the requirements for a system, perform radio propagation studies of the local transit area, assure compliance to regulations (FCC, UMTA, state, and local), write specifications, manage the acquisition, provide legal testimony for contested bids, and even

TABLE C-1

BUS COMMUNICATIONS CONSULTANTS

Consultant	Services Provided: Requirements	Design	Specifications	Implementation	Monitor Testing	Project Management	Other
NES, Inc. Knoxville, Tennessee	●	●	●	●	●	●	
Niacad, Ltd. Nepean (Ottawa), Ontario	●	●	●	●	●		
Omnicomm Tallahassee, Florida	●	●	●	●	●	●	a
Sachs-Freeman Associates Bowie, Maryland	●		●		●		b
Terence J. Collins Associates, Inc. Schaumburg, Illinois			●		●	●	c

[a]Site surveys and site selection, needs assessment, propagation and radio interference study.

[b]Proposal evaluation, broker sale of old equipment, state and local regulations, testimony for litigation.

[c]Needs assessment, UMTA requirements, propagation study (use USGS tape of terrain).

TABLE C-2

PRIME CONTRACTORS AND MANUFACTURERS OF MOBILE RADIO EQUIPMENT

Type of Supplier	Name of Supplier	Location
Prime Contractors	AVM Transit Systems	Fort Worth, Texas
	Fischback & Moore, Inc.	New York, New York
	General Electric Company, Mobile Communications Division	Lynchburg, Virginia
	General Railway Signal	Rochester, New York
	Motorola Communications and Electronics, Inc.	Schaumburg, Illinois
	Wismer and Becker Contracting Engineers	Sacramento, California
Manufacturers	Aerotron, Inc.	Scottsdale, New York
	Astronet, Inc.	Lake Mary, Florida
	E. F. Johnson, Inc.	Waseca, Minnesota
	General Electric Company, Mobile Communications Division	Lynchburg, Virginia
	Harris Corporation, RF Communications Division	Rochester, New York
	Kokusai Electric Company, Ltd.	El Segundo, California
	Midland Land Mobile Radio	Kansas City, Kansas
	Motorola Communications and Electronics, Inc.	Schaumburg, Illinois
	TACTEL Systems	Carnegie, Pennsylvania

broker the sale of the transit agency's old communications equipment. Many larger transit agencies perform some or all of these services themselves. Consultants known to be active in bus communications systems are listed in Table C-1.

PRIME CONTRACTORS AND MANUFACTURERS

The prime contractor has come into existence as a separate entity from radio-equipment manufacturers over the last 10 years as systems grew in size and complexity. The prime contractor typically bids a system composed of (a) radio equipment and computers purchased from manufacturers and (b) software and additional electronic equipment that the prime contractor itself has produced. However, the distinction between prime contractor and manufacturer is not always clear. Some companies now provide complete systems, assuming the role of both prime contractor and manufacturer. Some companies that have been exclusively prime contractors are now acquiring radio manufacturing capability through joint ventures or mergers.

The names and addresses of prime contractors and manufacturers encountered during this study are given in Table C-2.