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Special Committee on Electronic Research in the Highway Field

(As of December 31, 1967)

Richard C. Hopkins, Chairman
Bureau of Public Roads, Washington, D. C.

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Foreword

One of the most urgent requirements of the next decade is for this nation to effect major improvements in the movement of highway vehicular traffic. The completed mileage of Interstate highways, forging toward the completed system within a few years, has demonstrated the extent to which adequacy of geometric and structural design can alleviate traffic problems. However, the limited-access highway also has served to emphasize some operational problems as well as to create some new ones peculiar to it. For instance, driving at higher speeds has made locating and reading conventional signs more difficult; and, motorists who become stranded on fenced or isolated highways find it difficult to communicate their needs to the appropriate authorities.

The factor which now must receive increased attention is that of communications. An integrated communications system to satisfy the information exchange requirements generated in the planning, construction, maintenance, operation, and use of the highway system is urgently needed.

This RECORD comprises the papers that were presented at a conference session on highway communications during the 47th Annual Meeting. It should be of immediate interest to those who are responsible for decisions on, and implementations of, communications systems associated with highway functioning.

The first paper was prepared to introduce highway administrators to the national telecommunications problem. It stresses the limits of the radio frequency spectrum as a "natural resource" and indicates the need for coordination of the public and private use of radio services. This paper reports on the existing mechanisms for such coordination and the benefits which should develop through their use.

The National Conference on Highway Communication for Service and Safety developed a recognition of the national telecommunications problem within the cooperating agencies. This, and the concerned inquiry into proper solutions in the highway field, are reported in the second paper.

The third paper describes research being undertaken by the Bureau of Public Roads to provide the first-generation framework for future highway communications system development. The completed systems analysis will describe an integrated system and provide a model for evaluating alternative subsystems.

The dissertation on electromagnetic compatibility is presented to provide highway engineers with an insight of the considerations in this area that must be given to forthcoming engineering designs.

An insight of the eventual requirements for communications in evolving automatic traffic control systems is given by an ardent researcher in this field. Counsel is given regarding the need for communications developments to keep pace with control technology.

The discovery and development of new mediums for communications holds promise of alleviating some of the problems posed by the crowded radio frequency spectrum. A research scientist from the Ionospheric Telecommunications Laboratory of the Environmental Science Services Administration discusses his work having such an objective.

To complete the conference review of highway communications, a researcher from industry outlines a state-of-the-art technique by which conservation of available mediums can be effected.

—Richard Hopkins

Contents

The Federal-State Telecommunications Advisory Committee

CHARLES E. LATHEY, Special Assistant to the Director of Telecommunications Management, Executive Office of the President

ON July 20, 1967, the Director of the Office of Emergency Planning established the Federal-State Telecommunications Advisory Committee. The need for such a committee had long been recognized.

The mission assigned to the Federal-State Telecommunications Advisory Committee is to:

- Provide a forum to which mutual federal-state telecommunication matters of interest may be referred for advice and assistance.
- Initiate, aid and assist in the development of policies for adoption by federal and state governments concerning the procurement of communication services and systems by states and local governments.
- Encourage and make recommendations looking toward the improvement of federal-state telecommunication coordination procedures.
- Encourage and make recommendations looking toward the development and improvement of telecommunication resources of state and local governments where there is a mutual federal-state interest with respect to such resources.

The list of members on the committee includes:

- The Director of Telecommunications Management/Special Assistant to the President for Telecommunications in the Executive Office of the President who serves as the committee chairman.
- The Defense Commissioner of the Federal Communications Commission who serves as the committee vice chairman.
- Assistant Secretaries from the Federal Departments of Commerce; Defense; Health, Education and Welfare; Housing and Urban Development; Justice; State; and Transportation.
- Senior representatives from the Federal Advisory Commission on Intergovernmental Relations, Bureau of the Budget, General Services Administration and the Office of Emergency Planning.
- State representatives provided by the Governors of Alaska, California, Illinois, Louisiana, New York, South Dakota, Tennessee, Utah, and Vermont.
- Representatives from the Council of State Governments and the Governors' Conference.

Paper sponsored by Special Committee on Electronic Research in the Highway Field and presented at the 47th Annual Meeting.

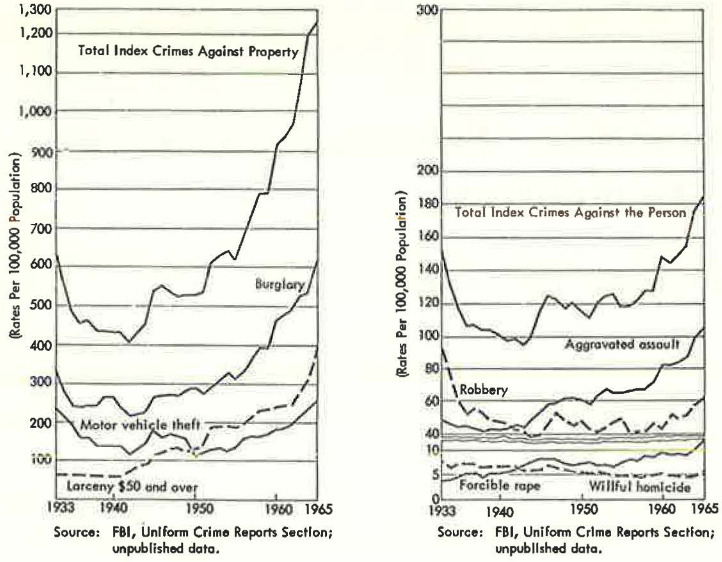

Figure 1. Index Crime Trends, 1933-1965.

THE COMMITTEE'S ENVIRONMENT

The Federal-State Telecommunications Advisory Committee has found an environment characterized by insistent demands for more adequate communications throughout the nation. These demands are quite evident in such areas as law enforcement, education, air and water pollution, health, welfare, transportation, science, poverty, civil rights, public information, research and development, programs analysis and control, national defense, security, and the nation's economic growth.

Law Enforcement Telecommunication Demands

Law enforcement demands for better telecommunications have been widely publicized. Indicative of these demands is the rapidly rising crime rate (Fig. 1)—a rate requiring diversion of more and more of our national wealth for its control.

"The Challenge of Crime in a Free Society"[1] points to the need for better law enforcement telecommunications. The report states that:

- Probably the single greatest technical limitation on the [law enforcement] system's ability to make its decisions wisely and fairly is that the people in the system often are required to decide issues without enough information.
- The scientific and technological revolution that has so radically changed most of American society during the past few decades has had surprisingly little impact upon the criminal justice system . . . more than two hundred thousand scientists and engineers are helping to solve military problems, but only a handful are helping to control the crimes that injure or frighten millions of Americans each year . . . most police could have been equipped 30 or 40 years ago as well as they are today . . . the overwhelming majority of reformatories, jails and prisons are, technologically speaking, a century or more in the past.

[1]A Report by the President's Commission on Law Enforcement and Administration of Justice, February 1967.

"The Challenge of Crime in a Free Society" speaks extensively of the need for better law enforcement and administration of justice telecommunication needs. Overall, the report makes about 200 recommendations—more than 20 are telecommunication recommendations. Among others, the latter recommend public emergency call boxes, a single nationwide number so that the public may call the police, computer-assisted command control systems, automatic car-locator systems, portable recording devices, frequency sharing, changes in frequency requests to the FCC, greater use of multichannel radio trunks, better portable radios, fingerprint identification systems, data information systems for court operations and correctional institutions, alarm systems, immediate response inquiry systems, law enforcement directories, and the application of systems analysis procedures to assure that all requirements are defined and met on an adequate basis within reasonable costs.

When speaking before the International Association of Chiefs of Police on September 14, 1967, the President of the United States praised the work of his Commission on Law Enforcement and Administration of Justice and he lauded the Commission's report. The President then said:

- What America needs is a policy for action against crime in the streets—and for all the people of this country to support that policy.
- Let us act instead of talk about crime.

Health Telecommunication Demands

Like law enforcement, the nation's health telecommunication demands have been widely publicized. For example, on February 28, 1967, President Johnson stated:[2]

- In 1967 . . . the Federal Government is investing more than $440 million in the construction of health facilities, $620 million for health manpower education and training, $1.3 billion in biomedical research, $7.8 million to provide medical care, but each gain, each victory, should focus our attention more sharply on the unfinished business facing this Nation in the field of health—infant mortality is far higher than it should be—handicaps afflicting many children are discovered too late or left untreated—grave deficiencies remain in health care for the poor, the handicapped and the chronically ill—many types of mental illness, retardation, arthritis and heart disease are still largely beyond our control—in some U.S. counties infant mortality rates are 300 percent higher than the national average—seventy percent of automobile accident deaths occur in communities of less than 2500 people where medical facilities are often poorest—though we have good techniques for detecting and curing cervical cancer, eight thousand women die each year for lack of proper care—emergency rooms in U.S. hospitals are seriously overcrowded.
- In 1965, more than 14,000 job-connected deaths and 2 million disabling work injuries caused untold misery and privation to workers, 230 million lost man days of production and billions of dollars in lost income.
- The United States is facing a serious shortage of health manpower. Within the next decade this Nation will need one million more health workers.

The President's message is abundantly clear in stating a need for action. In his message to the Congress, the President said:

- We must . . . develop new ways of assisting doctors to reach more people with good health services.

[2]The President's Message on Education and Health in America to the Congress of the United States, February 28, 1967.

- We need to strengthen our Partnership for Health by encouraging regional, state and local efforts—public and private—to develop comprehensive programs serving all our citizens.

Telecommunications technology can now provide information dissemination on a real-time shared basis. This would permit all professional health personnel to be aware of newly developed surgical and treatment techniques, new drug developments, and access to researched diagnostic information. The technology can materially assist in hospital and patient administration, diet preparation, treatment routines, patient surveillance, and actual treatment. Closed circuit and public television and educational radio can materially improve public and professional health education. The technology to do these things is available now.

Education Telecommunication Demands

In the educational area we see soaring enrollments of students, rising requirements for teachers, higher educational costs per student, new requirements for facilities, increased demands for public and professional education, and note that, next to national defense, education is probably the largest single enterprise in the United States.

On February 28, 1967, the President of the United States in his "Message on Education and Health to the Congress of the United States" said that:

- At least three million adults in America cannot read or write. Another 13 million have less than an eighth grade education . . . this is a national tragedy and an economic loss for which each one of us must pay.
- One child in ten in our country is afflicted with a handicap . . . we must . . . give attention to their special educational needs.
- In 1968 more than 170 thousand new teachers will be needed to replace uncertified teachers, to fill vacancies and to meet rising student enrollments. By 1975, the Nation's schools will need nearly two million more new teachers.

And before the Delegates of the Williamsburg Conference on October 8, 1967, President Johnson stated:

- One lesson of our experience in economic and social development is quite clear: Education is the greatest single bottleneck.
- If the world's financial systems were forced to function with no better facts than these which educational systems live by, a financial panic would swiftly seize all capitals of the world.
- We seem to need more facts. We seem to need to put a program together.
- I can see no reason in the world why modem technology cannot, for example, permit the best professor in the world to teach students all over the world.

"The Catalog of Federal Assistance Programs," June 1967, published by the Office of Economic Opportunity in the Executive Office of the President indicates that:

- Five federal agencies are independently administering 17 different federal assistance programs of "Basic Education for Youth and Adults."
- Eleven federal agencies are independently administering 50 different federal assistance programs on "General Education."
- Nineteen federal agencies are independently administering 128 federal assistance programs on "General Education."
- Fifteen federal agencies are independently administering 74 federal assistance programs on "Vocation and Job Training."

And education in one form or another is involved in many of the other federal assistance programs listed in the catalog. Many of these programs result in telecommunication projects. For example, the University of Wyoming is experimenting with telelecture and telewriting facilities over an extensive system serving many cities and providing instruction to small groups of students in rural areas. In addition, the Department of Health, Education and Welfare has assisted in the development of approximately 180 noncommercial educational television facilities. Throughout, effective coordination procedures should be established among federal agencies for the coordination of such programs involving telecommunications if education is to receive adequate telecommunication support. The present uncoordinated approach tends to proliferate dedicated systems and does not provide for the most economic use of the facilities installed.

Present technology can relieve teachers of most of their administrative duties, extend their geographical area of influence, and improve their teaching content and teaching aids. At the same time, present technology can permit cost reduction and can improve the educational level of public and private students. This, of course, will not just happen. We must begin now to lay out a progressive program and establish effective coordination to assure that telecommunications adequately support national educational goals and objectives and meet the demands which are evident in this field.

Highway Service and Safety Telecommunication Demands

A highway communications gap of sizable and growing proportions exists today in the United States. Although vehicular communications started in 1921 with experimental radio telegraph installations, we have progressed since that time to a point only where the driver must still communicate by horns, lights, and arm and hand signals—means available in Napoleon's era. The driver still must rely almost entirely on his eyes for a thousand details of the roadway and the danger ahead. In fact, vehicular density on the nation's highways results in so much information input to the driver's eyes that the limit of his ability to perceive and react is approaching saturation. This need not be the case. Consider the paradox that during 1966 the most sophisticated communications system in the history of mankind brought to us from the surface of the moon, clear pictures of the lunar surface. Our feats in space only emphasize our lack of progress in achieving adequate highway communication.

Facts demonstrate a need for better highway communication, not only from highway users to law enforcement and service organizations, but also from service organizations and law enforcement organizations to the drivers:

- Ten thousand people are injured daily in traffic accidents and we see a rate of 1,000 fatalities per week along our national highways—53,000 fatalities per year (1966).
- There are more than 41,000 miles in the Interstate Highway Systems. These are limited-access highways with long distances between interchanges. Personnel stopped between interchanges and needing help of many kinds have no means of communication to assist them in receiving service—medical aid, vehicle repair, fuel, and other such needs.
- Road construction costs average between hundreds of thousands of dollars to more than one million dollars for each mile of road developed. Yet, no figures are included for communications planning during highway planning—communications which can materially increase the highway capacity and bring needed services and safety to its users.

At the National Conference on Highway Communication for Service and Safety conducted in Denver, Colorado, during the period August 20-23, 1967, it was agreed that communication is a key to safety and service and a key to increasing the capacity of our highways.

The urgency of the highway traffic problem and the need to increase highway capacity and safety, to reduce congestion, and to facilitate urban and rural travel have given rise to varied attempts to provide solutions. These solutions now lean heavily toward the use of electronic and other types of communication, but on experimental bases only.

The uncoordinated proliferation of various electronic systems, developed at various points in time for various parts of the country and to satisfy special requirements, have resulted in vehicle-driver-highway regulations which differ from state to state and from community to community.

That action is needed was testified to by every member who attended the National Conference in Denver, Colorado. It was a firm belief that communications could materially improve the safety of the highway users. It was also a conclusion of the conference that federal and state governments should begin to develop a national integrated communications system to support highway users.

The highway cost in human life along our highways is greater than it is for all of the military conflicts in which this country has been engaged. The cost in terms of broken lives, pain, and social disorganization cannot be measured, nor can the cost of traffic congestion be estimated in terms of lost productive effort.

The dependency and interdependency of each element of the total highway system on a communication subsystem demands that primary and urgent attention be given to the total highway communication needs. Communications should be designed so that they will meet the information needs of the highway planners, administrators, maintenance, enforcement, and operations personnel, as well as the motoring public, for whom the highway system exists.

This is not a simple undertaking. Involved are many factors:

- Communication needs are different for rural highways than they are for urban highways.
- There are, at the present time, no approved standards to be met by organizations providing communication along the highways.
- Some stretches of Interstate highways have extremely sophisticated communication systems, whereas others have none or have systems which are totally inadequate.
- The communication needs from the motorist to and from the highway administrators and maintenance personnel appear to be by radio means, and this requires frequencies in an already overcrowded land mobile portion of the spectrum.
- Highways being built or being designed for the future have not included communication as one of the planning items.

In the past, the nation has deferred to law enforcement officials for the handling of motorist aid along the highways. This should not be. Law enforcement officials—already in short supply and inadequately supported by communication means—are needed for law enforcement.

Modern technology is available to permit satisfaction of highway communication needs, but this will not just happen without a determined program developed and implemented by federal and state officials. We need now to assess the requirements and to begin to meet them in the most reasonable and realistic manner.

THE OVERALL FEDERAL-STATE SITUATION

On March 18, 1967, before the Conference of Governors, the President of the United States said:

- Individuals may differ about the wisdom of specific social or economic programs. But we are wholly in accord on this: Once we commit public money to enhance the public well-being, to fight poverty, to improve the lot of our cities, we have a fiduciary responsibility. Many of my days are spent in trying to live up to that responsibility—in trying to find more efficient and effective ways to use the public's dollars for the public good. Certainly one of those ways is the constant improvement of relationships between federal and state governments.

- Today the remarkable system of government devised by the genius of the Founding Fathers faces a complex and bewildering world. As it enters the final third of the 20th Century, our Union faces problems of a magnitude undreamed of by the drafters of our Constitution in mass education; hard-core poverty, both urban and rural; urban blight and renewal; modern law enforcement; transportation; and air and water pollution.

- Essentially, these are local problems demanding local solutions. The Federal Government itself cannot teach a child, police a street, rebuild a neighborhood. These are tasks for the communities and states. At the same time, they are problems that few if any states can meet alone. Crime, poverty, polluted air and water do not respect state or county boundaries. A practical, working, Federal-State partnership has been imposed by the very necessity of responding to these problems—because they were too complex for either level of government to meet alone.

- The closer we can work together, the sooner, the better, the more economically the job will be done.

The federal government, in an effort to cope with the problems gnawing at the base of our society, has undertaken a massive program of federal assistance to state and local governments (Fig. 2). Since 1957 alone, federal assistance to state and local governments has increased almost fourfold. That is, from 1957 to 1967 funding assistance has risen from about $4 billion to about $15 billion. Moreover, the rates at which state and local governments are expanding their own funds in support of these federal-state programs are growing rapidly. In fact, in his State of the Union Message in 1967, President Johnson said:

- During the past three years we have returned to state and local governments about $40 billion in Federal aid. This year alone seventy percent of our Federal

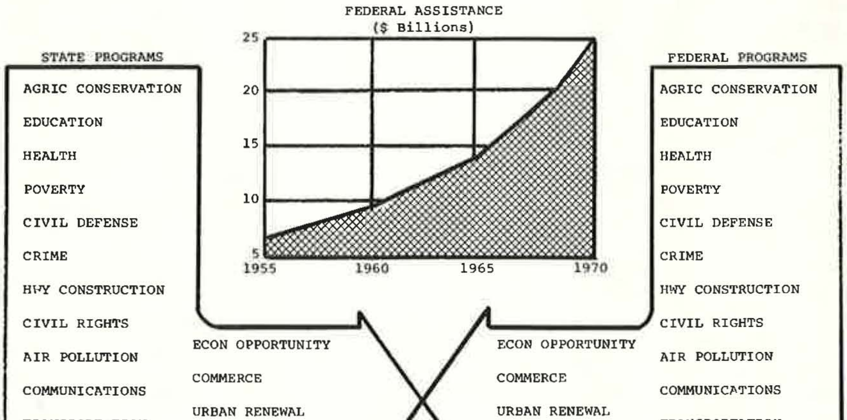

Figure 2. Mutual Programs.

expenditures for domestic social programs will be distributed by state and local governments. With Federal assistance, state and local governments by 1970 will be spending close to $110 billion annually.

The federal assistance effort is tremendous (Fig. 3). Involved are more than 400 federal legislative acts which authorize more than 450 programs of assistance. These programs are being administered by about 35 federal agencies directly to more than 92,000 elements at the state and local levels of government. The legislative, operational, and administrative impact of these programs on state and local governments is yet unknown, therefore, it is difficult to assess the detailed increased communication requirements that exist in support of program objectives and goals. However, studies conducted by the Director of Telecommunications Management and his consultations with about 1200 officials in federal, state, and local governments and industry reveal that:

- About $450 million of the total $15 billion being provided in 1967 by the federal government will be spent by the states for telecommunication facilities and services.
- Less than a handful of states have an appointed director or coordinator of state telecommunications for the coordinated use of program funds dedicated to modern telecommunications or for the coordinated use of other funds appropriated by the states for telecommunications, and for the continued and necessary overall coordination of telecommunication activities within and between the states and between the states and the agencies of the federal government.
- Most states are unaware of their overall telecommunication requirements and unaware of their present investment in, and expenditures required for, telecommunication facilities and services.

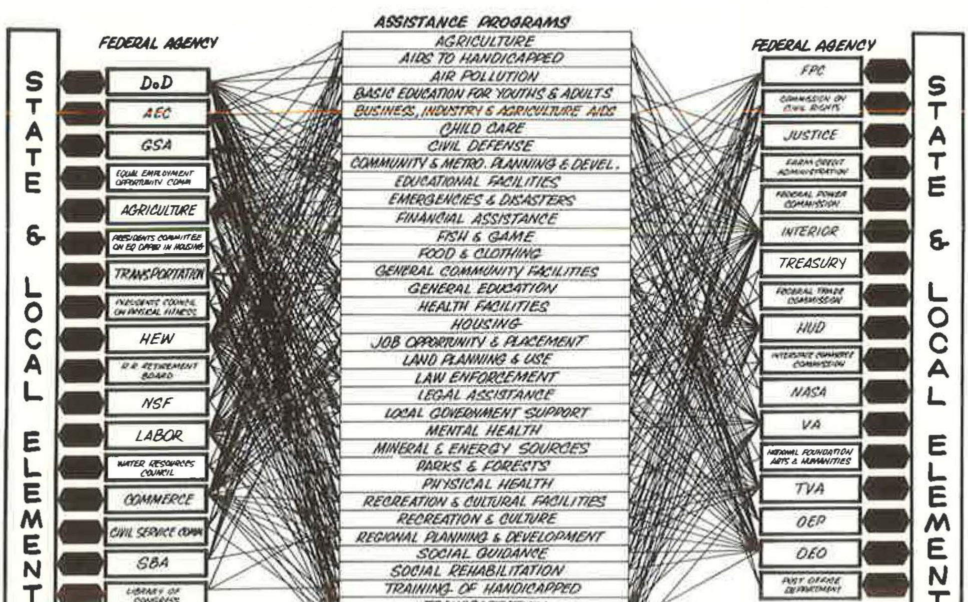

Figure 3. Coordination communication requirements for federal assistance programs.

- Most states are conducting no long-range planning on a continuing basis to assure adequacy of state communications under all conditions—normal and emergency.
- Little federal-state coordination in telecommunication systems development and use is being effected, although federal and state objectives are similar and joint use of facilities and services offers a considerable saving potential.
- Most states possess numerous dedicated telecommunication systems which could be improved operationally and which could be more economical if they were consolidated.
- The federal and state governments have differing and sometimes conflicting telecommunication policies. This is particularly noticeable in policies relating to the procurement of government-owned and government-leased telecommunication facilities and services.

Almost all states are becoming aware of their inadequate telecommunication systems and services, and many are trying to develop adequate statewide telecommunications. They recognize that the collection, analysis, and dissemination of information is vital to modern government operations. They also recognize the need for utilization of technological advances as they occur and appear useful. But the states are in difficult positions. This is evidenced by the foregoing list of inadequacies, but can be more specifically illustrated if we review the conditions found in one state—conditions generally existing in most states.

TELECOMMUNICATIONS AT THE STATE LEVEL

As the population increases (Fig. 4) and the public becomes more mobile, demands for government services change in amount, character, and pattern. To meet these demands, government work forces increase. And, as work forces increase, additional telecommunication services are required to handle the concurrently increasing collection, dissemination, and exchange of information among elements of the increasing work forces.

At the same time, there is a greater need for coordination between state agencies, between states, between states and regional bodies, and between states and the federal

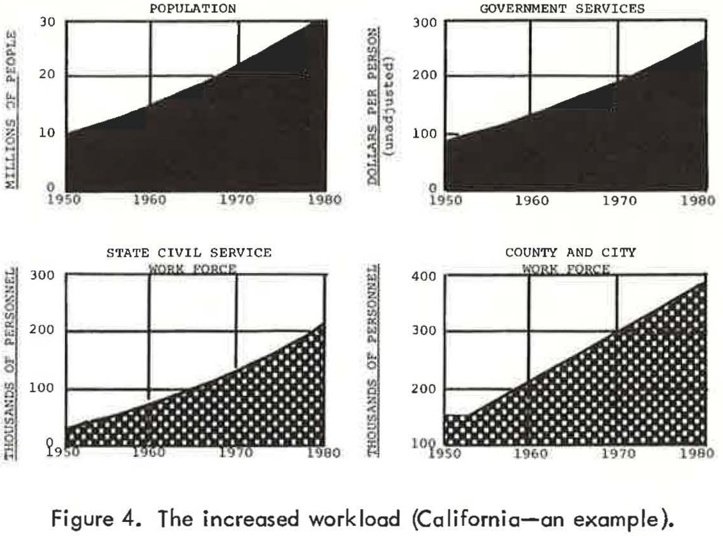

Figure 4. The increased workload (California—an example).

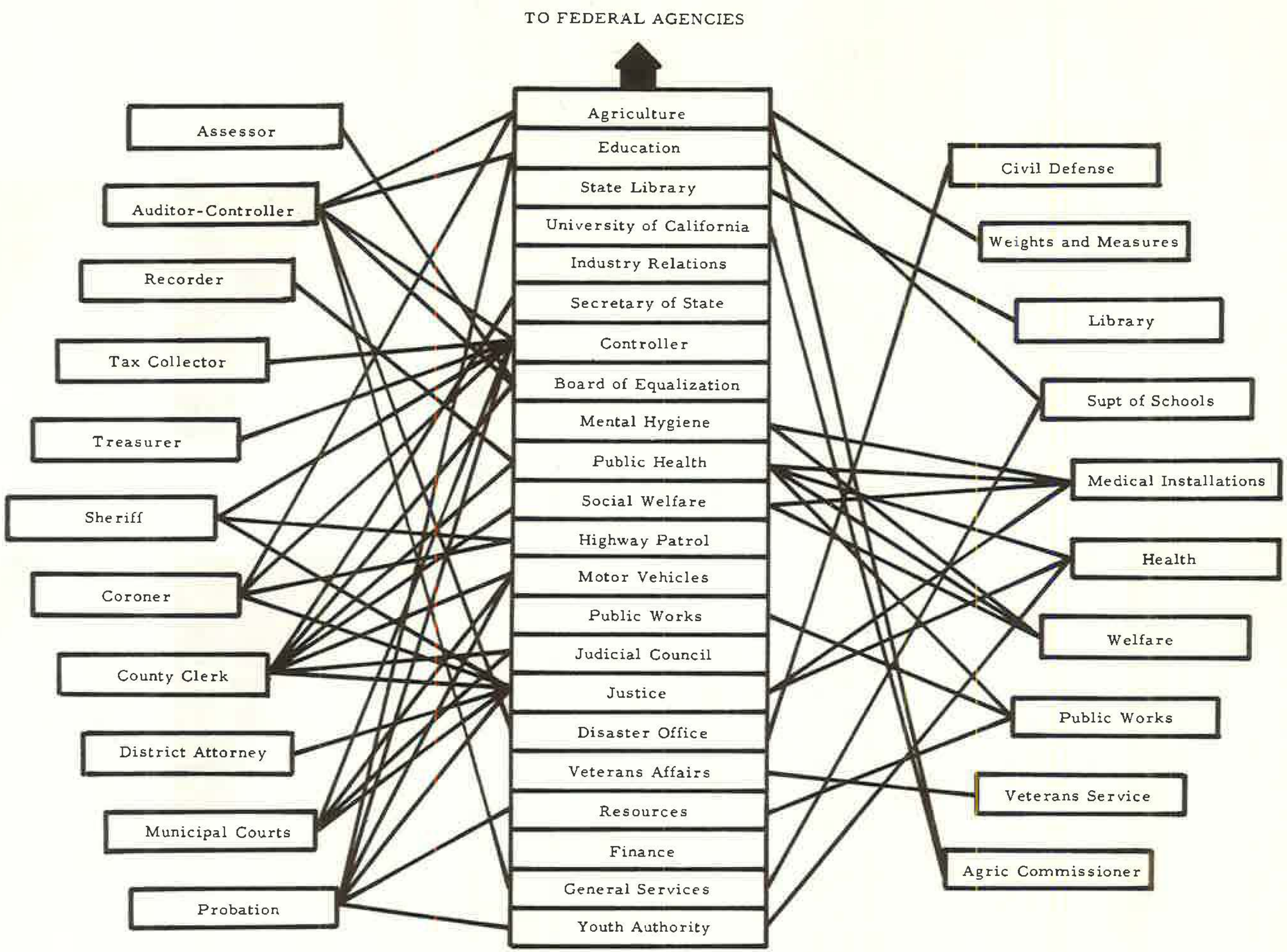

Figure 5. Information flow between federal, state and local governments (California—an example).

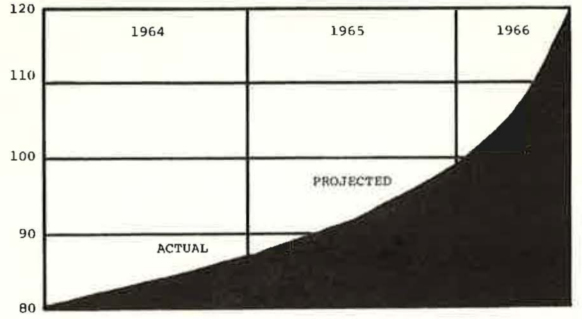

Figure 6. ADP growth trend (California computer acquisitions, 1964-1966, an example).

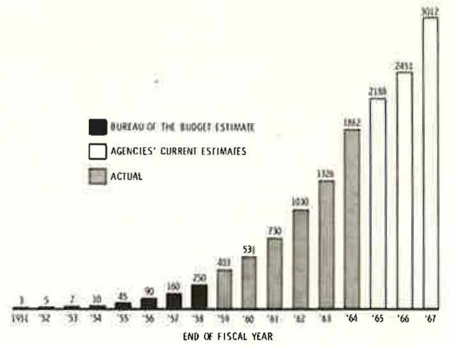

Figure 7. Federal government ADP growth trends.

government. The traffic load and pattern of traffic flow not only stem from coordination and information exchange activities generated by the public and state government elements, but also from coordination and information exchange activities created by mutual federal-state and state-to-state programs and operations. For example, highways, law enforcement, and natural disaster operations are not confined to single municipal, city, town, and state boundaries. Figure 5 shows the lines of telecommunication traffic flow among county government-state government and federal government elements.

In the past, most telecommunication demands were met by voice and rather low-speed record communication means, but, as the information explosion has grown in intensity, we have seen a dramatic rise in computer use and interconnection. Figure 6 shows the actual computer acquisition trend in one state. This is typical for most states. It is not unlike the computer acquisition trend in the federal government (Fig. 7). Between the federal and state computer systems we see the eventual need for interconnection, the need for information comparability, and the sharing of information in areas of mutual interest.

Another characteristic of state communication traffic can be observed by looking at Figure 8, which shows communication requirements percentages in an actual state and

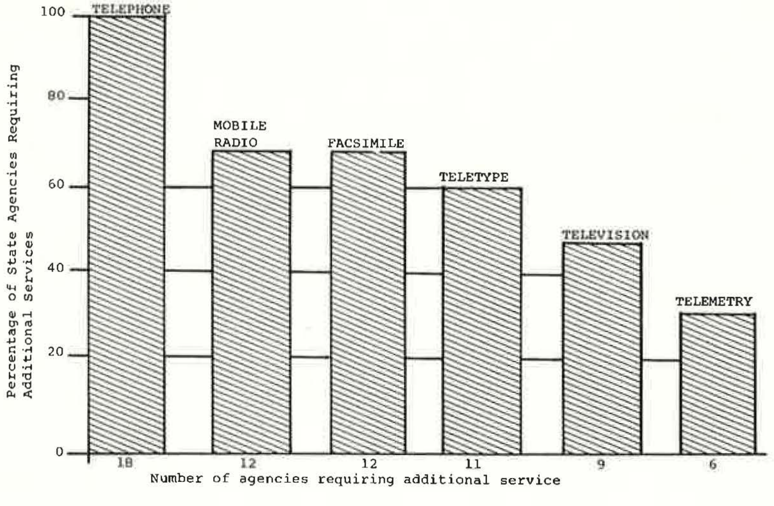

Figure 8. Service requirements of state agencies.

which represents the conditions existing in most states. Of 18 state agencies polled in one state, 100 percent of them indicated a need for more voice communications, 65 percent indicated a need for more mobile radio and facsimile communications, 60 percent indicated a need for more teletype communications, 47 percent indicated a need for more television, and about 30 percent indicated a need for more telemetry facilities.

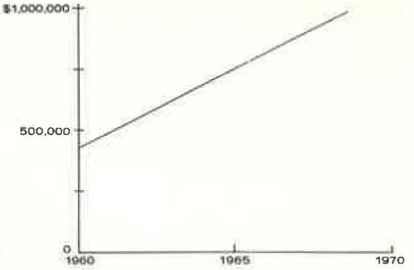

Figure 9. Trend in telecommunications at the state level.

Throughout the states, telecommunication costs are rising just to meet minimal demands. Figure 9 shows the condition existing in one state surveyed—a trend which most states find almost impossible to support without a corresponding increase in telecommunication adequacy. It is this area of costs that is primarily creating an awareness of the need for better state telecommunications planning. With such rising costs, most states find they are supporting inadequate telecommunication systems.

For example, one state's communication systems actual inventory shows that within the state's boundaries there exist at least seven statewide radio relay systems (Fig. 10). These are special purpose systems which are not interconnected with each other. Each system is operated and maintained by an individual group that has no functions involving any of the other systems. The problem of consolidating these systems, which the state is attempting to do, seems to be a simple matter, but the state is faced with serious obstacles. That is, the state needs (as do other states) financial assistance to consolidate and eliminate duplicative facilities and services because the costs are too great for the state to handle this matter on its own. At the same time, the federal government—which provides funds for telecommunications in many of its assistance programs—has not provided legislation or funding assistance to states for the improvement of telecommunications on a statewide all-purpose, day-to-day basis.

To further confuse the picture, we find that federal government policy states that the federal government will rely on private industry for the provision of telecommunication services. However, federal legislation providing assistance to the states is generally written in a manner that provides for the federal government to reimburse the states only for telecommunication expenditures involving capital investments. This means that the federal government must, as a rule, lease telecommunication facilities and services and that state and local governments, to obtain federal assistance, must purchase, own and themselves operate telecommunication facilities and hardware that could be obtained in most instances from commercial sources more economically on a leased basis.

This is an undesirable situation. The interconnection of state-owned and commercial systems brings about divided management over communications—a situation that can result in lowering the quality of service and bring about delays in maintenance. Actually, federal regulations tend to prohibit the interconnection of state- and local government-owned systems with those of the common carriers for these reasons, except during periods of emergency.

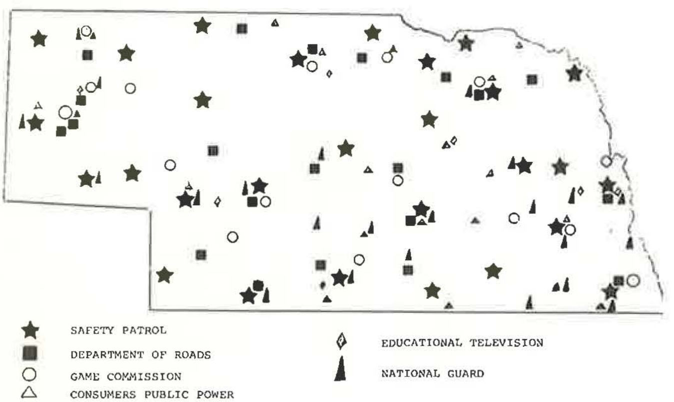

Figure 10. Existing state agency radio installations.

This, then, is a part of the environment with which the Federal-State Telecommunications Advisory Committee must cope in the accomplishment of its mission. Now, let us look at the environment at the national level of government.

TELECOMMUNICATIONS AT THE NATIONAL LEVEL

At the national level of government we find:

- A Director of Telecommunications Management/Special Assistant to the President for Telecommunications in the Executive Office of the President. In addition to many other responsibilities, he is charged with coordination of the telecommunication activities of the executive branch of the government, including those for day-to-day and mobilization operations.
- A National Communications System, being developed by a single manager on an evolutionary basis to meet the requirements of the federal government under all conditions.
- A Federal Communications Commission which has regulatory authority over the nation's communications industry.
- A General Services Administration charged with the procurement of services for the federal government.
- A continuing review by the Director of Telecommunications Management of communications requirements in support of the nation's goals and objectives.

We also note the development of nationwide telecommunication systems by the federal government—telecommunication systems, which, if connected to state systems, can make the nation's telecommunications more responsive to government operations—federal, state, and local. For example:

- The National Communications System, now composed of approximately 47 formerly independent and separately managed systems, offers a means whereby federal and state governments could more clearly coordinate in the accomplishment of their goals.
- The Federal Bureau of Investigation in cooperation with the Federal Department of Justice and the states is developing a National Crime

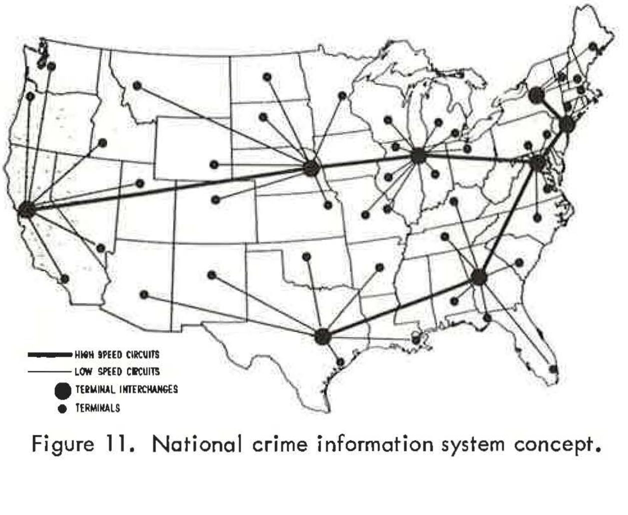

Figure 11. National crime information system concept.

Figure 12. Communities to be connected by the NADWARN teletypewriter network.

Information System (Fig. 11). This system eventually will serve all national law enforcement officials. It is partially in operation and is expected to be greatly improved by the end of 1969.

- The Department of Commerce, through the Environmental Science Services Administration, is developing a Natural Disaster Warning System (NADWARN) (Fig. 12) to serve approximately 2900 communities throughout the United States. Actually, the NADWARN will complement the National Warning System (Fig. 13), which is under the control of the Federal Office of Civil Defense. The NAWAS is a part of the National Communications System.

- The Department of Transportation through the Bureau of Public Roads is beginning to develop a nationwide system of communication in support of the nation's highways. At present, this effort is taking the course of a study to determine highway communication requirements and the development of a methodology which can be used for proposed systems analysis.

For one person to talk to another over a distance beyond the sound of the human voice, communication engineering standards and procedures must be compatible over the entire communication path being used. By the same token, the nation's telecommunications serve all people and meet a variety of requirements in the collection, analysis, dissemination, and exchange of information. Therefore, total systems planning is needed as is effective coordination between governments—federal, state, and local—

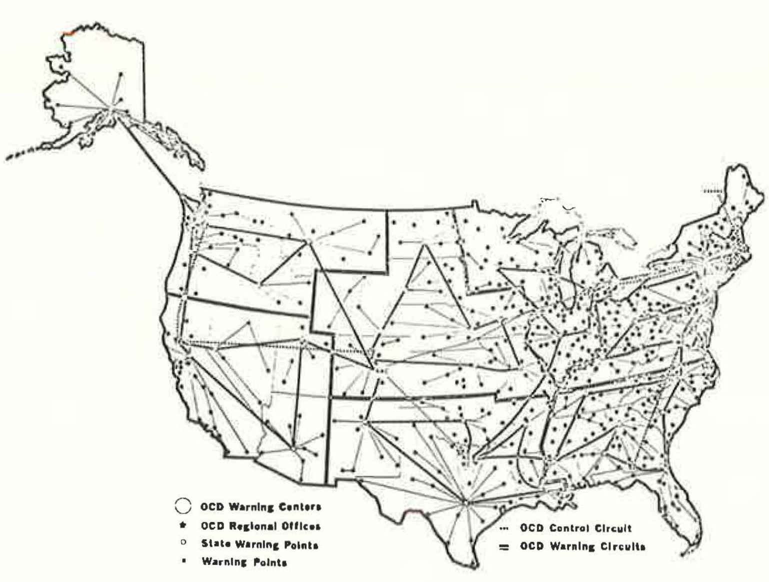

Figure 13. National Warning System, Office of Civil Defense.

and industry telecommunication officials. In addition, telecommunications policy must be developed and adhered to in a coordinated manner by telecommunication planners and managers.

THE FEDERAL-STATE TELECOMMUNICATIONS ADVISORY COMMITTEE ROLE

The Director of Telecommunications Management believes that the Federal-State Telecommunications Advisory Committee based on the past experiences of the federal government in telecommunications planning and management, can materially assist the states in their development of adequate communications. That is, the committee can serve in the capacity of developing and recommending to the states:

- A methodology for systems planning which can be used on a continuing basis—a methodology which takes into account state consolidation of existing systems and the evolutionary development of adequate telecommunications to support modern government operations.
- Management structures that the states could adopt to assure the adequate coordination of telecommunication activities and the development of adequate state telecommunications.
- Telecommunication procurement policies that can assure the states of communications adequacy at reasonableness of costs.
- Steps that can be taken by the states, or jointly by the federal and state governments, in the overcoming of telecommunications problems—administrative, legislative, operational, and financial.
- Procedures for federal-state coordination on a continuing basis.

The committee has met several times and certain members have accepted initial areas of investigation. These include the following:

- How can states develop adequate management structures for the coordination—federal, state, and local government—of telecommunication activities?
- How can states develop statewide all-purpose telecommunication systems in lieu of the many separate independent systems that now exist in almost all states? That is, what methodology can they use?
- How can states consolidate telecommunication funds provided through federal assistance programs so that cost savings and adequate communications may be provided?
- To what degree should federal and state telecommunication systems be permitted to interconnect?
- What are the federal, state, and industry responsibilities in the development of adequate nationwide telecommunications?

The foregoing are only indicative of the mutual federal-state areas of concern which the committee will be addressing in the future. The accomplishment of such studies will not be easy because the existing environment, as described in the foregoing, offers many obstacles to the solution of the problems facing the committee. Much could be accomplished in a relatively quick time period if the states should undertake measures to:

- Establish adequate statewide telecommunication management structures.

- Conduct statewide telecommunication planning on a total systems basis so that all requirements can be considered in systems development.
- Conduct long-range planning on a continuing basis.

SUMMARY

The Federal-State Telecommunications Advisory Committee has been established to form a basis for a federal-state partnership in the planning and development of adequate telecommunications to meet the needs of modern government—federal, state, and local. Its membership consists of high-level federal and state government representatives.

Under the chairmanship of the Director of Telecommunications Management in the Executive Office of the President, the committee serves as a forum to which mutual federal-state telecommunication matters of interest may be referred for advice and assistance.

Matters being considered by the committee are complex—complex because of the financial, operational, administrative, and legislative factors imposing constraints on the development of adequate federal and state telecommunications. In addition, management structures appear inadequate, there is a lack of telecommunications coordination between the various levels of government, total systems planning exists in only a few states, and most existing telecommunication systems are inadequate to meet the needs of modern government operations—federal, state, and local.

At the same time, we are experiencing rapid advances in telecommunications technology—advances which could materially contribute to the meeting of communication requirements in all functional areas. We see great advances in computer-communication networks, in communication satellite systems, and other means.

We look forward to the prospect of telecommunication centers in the home and office; to the transaction of business from our homes and offices by videophone; to new means of public and formal education through communications; and to improved communications in support of highway service and safety, law enforcement, health, welfare, civil defense, science, and other activities.

We see rapidly increasing demands for telecommunications, and note the savings which may be made by adequate coordination and planning. And we see increased emphasis being placed on the importance of telecommunications to the conduct of government operations. This emphasis has been dramatized recently by the President's appointment of a special task force on communication policy and the establishment of the Federal-State Telecommunications Advisory Committee within the Executive Office of the President.

The emphasis and the federal and state governments' willingness to join together to resolve telecommunications problems and difficulties and to establish procedures for effective coordination and planning are major telecommunication milestones in assuring the future adequacy of telecommunications in support of modern government operations—federal, state, and local.

A Report on the National Conference on Highway Communication for Service and Safety

BERNARD H. FLOOD, Communications Engineer, Arizona Highway Patrol

•THE 3-day National Conference on Highway Communication for Service and Safety sponsored by the American Association of State Highway Officials, the Automotive Safety Foundation, and the International Association of Chiefs of Police convened at the Continental Denver Hotel, Denver, Colorado, on August 21, 1967. Cooperating agencies were the Department of Transportation; the International Bridge, Tunnel and Turnpike Association, Inc.; the National Association of Counties; the National League of Cities; the National Aeronautics and Space Administration; and the Public Health Service.

The Steering Committee for the Conference was composed of A. E. Johnson, Executive Director, AASHO; D. Grant Mickle, Vice-President, ASF; and Quinn Tamm, Executive Director, IACP. John C. Kohl, Executive Secretary, Division of Engineering, National Research Council, National Academy of Sciences, was Chairman of the Conference.

A broad cross section of government, highway users, service organizations, manufacturers, and technical specialists was represented by the 126 attendees of the Conference. The official purpose of the Conference was stated as follows:

> To explore the need for—and characteristics of—an advanced communication system to provide for the safety, security, and service of the highway user. This Conference is to exchange information between official agencies, manufacturers, user groups, and other interested parties, to help official agencies determine general performance criteria for such a communication system.

The importance of the derivation of definitive results from the Conference was stressed by Federal Highway Administrator Lowell K. Bridwell in the opening session. Mr. Bridwell also expressed his opinion that the United States is presently on the threshold of the next major highway technological advance.

A definition of the problem and its magnitude, from the point of view of cognizant highway user agencies, police traffic services and highway official organizations, was undertaken. Emissaries from representative groups in each of these categories attempted to delineate the parameters and focus the issues of the situation.

Following this, detailed presentations pertaining to individual existing and proposed motorist assistance programs were outlined. In addition to such suggested innovations as expanded police patrol, the reporting of disabled vehicles by cooperative motorists, and increased helicopter and television surveillance, many somewhat unique, complete motorist assistance communications systems were detailed by their sponsors and advocates. Some of the more notable of these programs are reviewed in the following.

HELP (Highway Emergency Locating Program) provides for the outfitting of automobiles with 5-watt, 27 MHz Citizens Band transceivers. This would enable emergency calls for highway assistance to be placed by the average motorist. Highway authorities,

Paper sponsored by Committee on Electronic Research in the Highway Field and presented at the 47th Annual Meeting.

garages, towing and ambulance services, in addition to 24-hour-a-day CB teams, would monitor motorist transmissions and arrange for the necessary assistance.

REACT (Radio Emergency Associated Citizen's Teams), the predecessor of HELP, consists of volunteer CB channel monitoring by organized round-the-clock CB teams.

CRW (Community Radio Watch) is designed to enlist the aid of all land mobile radio users to cooperate with local authorities by alerting police and other responsible agencies when crimes, accidents, and fires are detected.

A method of strategically located telephone call boxes, directly connected via landline to central dispatch points, is finding both experimental and practical use in some parts of the country. Similarly, radio call boxes can afford emergency communications. Frequency shift keying tones (70 MHz) are coded to convey "police," "ambulance," or "wrecker" information via repeaters to a central dispatch point. Call boxes are in use that can also provide 150 MHz voice transmissions.

The DAIR (Driver Aid, Information and Routing) system utilizes 27 MHz CB frequencies. It requires an AIC (Aid and Information Center), MRS's (Message Relaying Stations), magnetic triggering traps placed in the road, roadside transmitters at properly spaced locations, and interconnecting cable laid between the MRS's and the AIC. The automobile driver, who must acquire a DAIR console for his vehicle, dials a selected service. Coded tones are conveyed from the vehicle via the mobile CB transmitter to the nearest MRS, thence via cable to the AIC for acknowledgment by a dispatcher. For information, the motorist dials "0" and is instructed by the dispatcher to change to another CB frequency for two-way communications.

RRA (Radio Road Alert) is a method of communicating with the motorist by the activation of prerecorded messages carried in the equipped vehicle. Coded messages from low-power, 27 MHz roadside transmitters trigger a memory storage in the vehicle and cause recorded announcements to be made through the automobile entertainment radio.

A system called "Multicom" utilizes induction radio techniques. Roadside cables installed within the highway right-of-way are used to establish localized communication zones at strategic points along highways. Verbal traffic information or routing instructions are received by the vehicle's broadcast receiver or by special low-frequency receivers.

Ancillary programs not necessarily requiring direct contact with the moving automobile were described. In this connection such conveniences as changeable visual signs and information services, as well as emergency necessities (fire, police, medical and mechanical assistance), were mentioned.

Conference participants deliberated on the technical and economic merits and disadvantages of many of these projects during open floor discussions and during later "workshop" sessions. Objections to the widespread use of CB frequencies were based on the certainty that frequency congestion and interference would follow. The propagation characteristics and troublesome "skip" associated with 27 MHz were discussed. It was pointed out that the utilization of roadside call boxes would require that the stranded driver abandon his vehicle, thus creating a hazard to other motorists, and become a pedestrian on the highway at great personal risk. Induction systems and low-frequency broadcasts would permit only one-way communication and would, hence, be of limited value to a motorist attempting to summon assistance. The complexities of operation and the expense associated with sophisticated programmed routing and magnetic triggering trap systems were cited as extreme disadvantages. Ideas with respect to the desired capabilities of a suitable communications system were advanced by highway user group and automotive fleet operator representatives.

During a "Technical Considerations" session, pertinent topics such as radio spectrum usage and radio systems, telephone and other wire systems, and the day-to-day operation and administration of possible highway communications systems were touched upon. Presentations in these areas were made by federal and state officials as well as commercial executives.

The presentation of formal Conference papers was brought to a close by two timely submittals stressing the "systems approach" to the ultimate design of a highway communications network. The applicability of the aerospace industries method of approaching similar complex situations was emphasized. Major research projects, presently in progress under the cognizance of the Bureau of Public Roads, were described.

At this juncture the Conference members were divided into representative groups. Four "Performance Criteria Workshops"—Highway Officials, Police Officials, Road Users, and Service Organizations—were set up. Each group attempted to reach agreement as to just what the requisites for a potential highway communications system should be.

The results of the efforts of each individual workshop were summarized and discussed. Unanimity of opinion was evident on one key item—the recommended formation of a permanent working group or committee to follow through on the myriad of vital issues brought forth during the Conference.

The end of the Highway Communication Conference was marked by the presentation of the Conference Report by E. M. Johnson, President of AASHO. Major conclusions and opinions agreed on during the Conference were set forth in the Report. Some of these significant items follow.

There has been no concerted demand by the public for a highway communications system; however, the motorist's need for travel information, assistance, and advance hazard warnings should be anticipated. Concrete steps should be taken before action is forced by public pressure.

Although communications systems presently used in the operation of highways are antiquated when compared to today's air travel and railroad communication systems, a direct parallel cannot be drawn. One major factor contributing to the difference in requirements between highway travel and other transportation media is that highway operations are subject to thousands of different political jurisdictions. Coordination is vital.

Simplicity, uniformity, reliability, minimum operating and maintenance cost, and public approval of a communications system are essential. The potential communication system should be compatible with the vehicle, the highway, the environment, jurisdictions involved, and the growth that will take place.

The communications system should provide for communication among proper authorities, services, and highway users without undue interference. The design of the system should preclude the dissemination of information to those not properly concerned. The ability to determine the exact services needed, and to reassure the caller, makes two-way voice communication desirable.

Should the radiation of RF energy be necessary in connection with a selected system, the necessity for availability of frequency allocations may become a serious problem.

Improved and more rapid medical service, increased police patrols, and concerted efforts to educate drivers (thus eliminating the need for many minor mechanical assistance needs) are desirable regardless of the ultimate highway communications system to be utilized.

The results of the Conference on Highway Communications for Service and Safety were very adequately described by the closing remarks of Mr. Johnson in the Conference Report.

> The exploration of the past three days has apparently given each person in attendance some awareness of problems and needs he had not previously had. It seems rather obvious that industry can provide the necessary hardware and technology when a determination has been made as to the detailed requirements of a communication system to meet the safety and service needs of the traveling public. The two cosponsoring public agencies intend to use the information gathered at this conference to draft performance and operational criteria for a highway communication system which it is hoped will be substantially uniform throughout the country. Undoubtedly the selection of the system type and its installation will be controlled by the availability of funds.

A Systems Analysis of Highway Communications

WILLIAM W. WOLMAN, Chief, Traffic Systems Division, Bureau of Public Roads

•THROUGHOUT the evolution of highway transportation, one-way communication from the highway to the driver has developed from landmarks and guide posts to route numbers and information signs, and from semaphore control devices to traffic-actuated signal systems. But communication from the highway to the vehicle (roughened pavement, traffic bumps, curbs, etc.) is rudimentary, and communication from the driver to the highway or from the driver to the control subsystem is nonexistent.

Furthermore, official communications within the needs of the highway system (engineering, operations, enforcement, research, etc.) have grown in a random fashion to supply particular demands for service. Compatibility among such communications installations is usually accidental because each design satisfies the requirements of a special purpose group. Police and maintenance networks are probably the most extensive systems developed to date. However, attempts to make use of these networks in emergency situations are usually unsuccessful because of the lack of interconnections and the capacity of their intended traffic.

State agencies other than police and maintenance have developed their own, and often parallel, systems. In the interest of overall economy, the entire communications needs for a state must be considered before establishing the final system for highways. Indeed, the other agencies should have communications systems analyses undertaken so that a truly compatible statewide system can be established.

Currently, operational highway communications are amazingly good, considering that total requirements never have been defined and that no attempt has been made to design a complete system specifically for highway needs. In fact, the growth of operating communications has much in common with the way the highway system itself has evolved. However, the costliness of maintaining several separate communication systems should be sufficient basis for designing an integrated system. Other considerations are improved service, radio frequency spectrum conservation, additional service, disaster networks, etc.

Based on this background, the Office of Research and Development of the Bureau of Public Roads developed a prospectus for "A Systems Analysis of Highway Communications," and on May 22, 1967, entered into a contract with Communications and Systems, Inc. of Paramus, New Jersey, to perform the study. The report of the analysis is to be in a form suitable for use by the Bureau of Public Roads and all other agencies responsible for decisions regarding highway communications systems.

This analysis of communication requirements is, in fact, a systems analysis of information requirements arising from highway planning, highway construction, highway operation, highway maintenance, and highway use. The word "communications" as used here denotes more than the communication means by which information is transferred. Within this connotation, all of the informational needs that arise from highway functions are included.

Therefore, the purpose of this research is to structure an integrated system concept tailored to the information requirements associated with all highway functions. The objective of this analysis is to develop a logical design concept that interrelates the parameters of a highway communications system. This logical design concept, or

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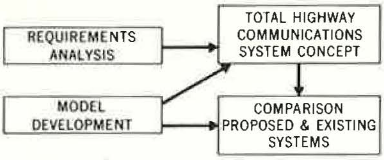

Figure 1. Research approach.

model, is for use in evaluating forthcoming engineering designs for proposed subsystems. Also, the logical design concept will assist responsible agencies in evaluating their requirements in terms of system compatibility, enhanced service, frequency spectrum conservation, and other factors.

An important point, which should be made at this time, is the distinction between a highway system and a highway communications system. This is because the highway communications system, which is the subject of these comments, is so closely interrelated with the functions of the highway system itself.

A highway system may be defined in terms of its function, that is, to provide a safe and efficient means for transportation of people and goods. The criteria for such a system would include such factors as maximum safety and minimum congestion.

A highway communications system, on the other hand, functions to provide a reliable and effective means for the transmission of needed information to support the highway system. Criteria for a highway communications system would include such things as reliability and timeliness.

Also, there is a major consideration, which will affect the implementation of the results of this systems analysis, that should be kept in mind. In the usual process of a systems analysis, the analysis provides those requirements which must be filled. Various concepts are developed as a means of filling these requirements and one or more concepts are selected. Performance requirements are developed, engineering specifications are developed, and finally some organization delivers to an agency a system meeting the requirements developed from the systems analysis.

In the case of the analysis of highway communications that is being performed for the Bureau of Public Roads, it is important to remember that no one agency will ever engineer a total highway communications system for the entire United States. Rather, upwards of 30,000 autonomous agencies will determine the subsystems that will be integrated ultimately to comprise a total communications system for the entire United States. Moreover, the system to be implemented will be developed in increments over time and distance and over changes within the autonomous agencies.

The research approach being used by the contractor in the performance of this systems analysis is organized under two major tasks (Fig. 1). One major task is the requirements analysis, the other is the model development. From the requirements analysis, and with input from the model development task, a total highway communications system concept will be developed. With the model in hand, a comparison will be made between the proposed subsystem (in the total highway system concept) and existing subsystems that can be described on the basis of the analysis of current requirements.

Primary subtasks are, of course, identified within each major task. Within the requirements analysis task there is an analysis of current operations being performed by reference to literature and an examination of ongoing functions within certain departments and agencies of the states. Also, an analysis of projected operations is being performed from literature reference and examinations of current research projects and experimental projects that can be assumed to generate communication requirements associated with highway operation over the next 5-year period. From the results of these two subtasks, the analysis of current operations and the analysis of projected operations, parameters associated with highway communications system requirements will be defined.

Within the model development task, the development of the model structure itself is currently under way. This work will be followed by an analysis of the sensitivity of the model and a period of model test and evaluation.

The investigation of current operations involves the analysis of ongoing state highway department operation which can be abstracted from an investigation within certain states, from current projects, from conferences and symposia, and from special studies and reports. It is importantly involving the analysis of ongoing functions obtained by operations research groups which have taken information from selected state highway

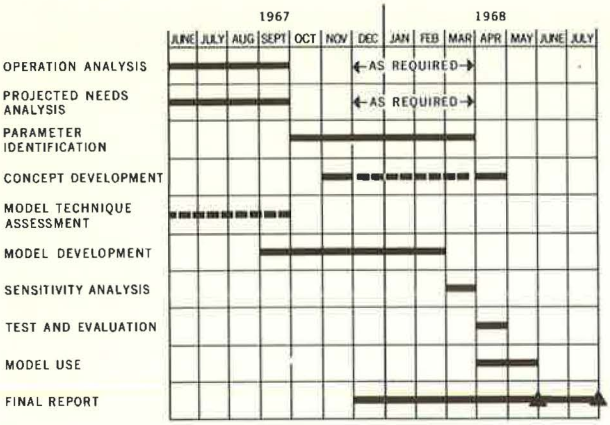

Figure 2. Task schedule.

departments. Also, the informational requirements of other groups interfacing with state highway functions will receive consideration. Such groups are enforcement agencies, motor vehicle departments, regional agencies and authorities, local and municipal governments, and civil defense planners.

The analysis of projected operations involves the study of future operations that can be projected from an examination of advanced experimental projects, from conferences and symposia, and from special studies and reports. Some of these ongoing projects include: stranded motorist detection, area traffic surveillance, route guidance, passing aid, merging control, urban traffic control, and flow sensing and surveillance.

A discussion of the first-phase effort within a particular state highway department will describe best one portion of this research. In the assessment of an ongoing operation, the organization of the state highway functions are examined. These functions then are defined in terms of an analysis of the activities that make up these functions.

Seven states were selected for an ongoing operations analysis: New York, New Jersey, Georgia, Texas, California, Nebraska, and Ohio. These states were selected on geographical representation, on representativeness of certain types of state highway organizational structure, and on the basis of various communication subsystem activities that were of particular interest to the project for providing a specific project data input. A pilot study first was completed in New York and New Jersey and analyzed before undertaking the formal inventory effort. The procedures were refined and the visits for specified lengths of time for sampling of informational requirements were made to all of the states.

The task schedule indicates the way the major tasks and primary subtasks fit into the overall program (Fig. 2). The operations analysis and the analysis of projected needs have been under way from the beginning of the project. They were completed at the end of October 1967 and will be resumed later on an iterative basis. These tasks are concurrent and interdependent. The results are now being subjected to an intensive analysis that will continue through March.

At the end of November, a set of parameters were indentified on the basis of the information collected through October, and an initial requirements matrix was drawn. These identified parameters have provided the basis for the development of an initial concept for a communications system, for some hypothetical state, to fill the needs developed from the progressing analysis.

Under the model development task, model technique was ongoing from the early days of the research effort. It continued on a part-time basis until the model development task was inaugurated. From November 1967

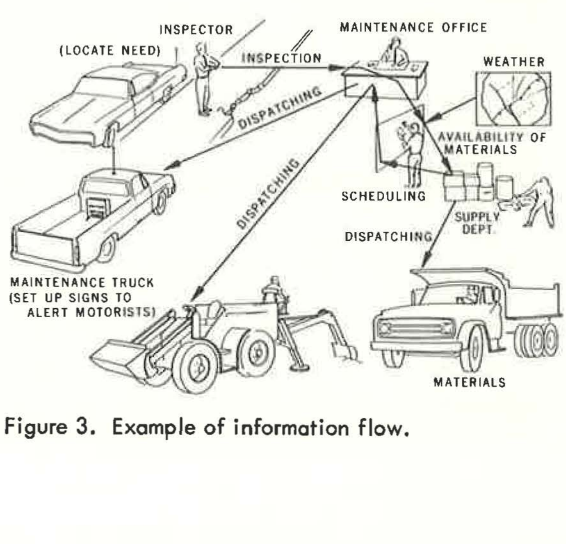

Figure 3. Example of information flow.

MAINTENANCE ACTIVITIES

1.0 UPKEEP HIGHWAY

1.1 NON-SCHEDULED

1.1.1 CONDITION DETECTION

1.1.2 NEED EVALUATION

1.1.3 ACTION

1.1.3.1 WARN VEHICLES

1.1.3.2 SET DETOUR

1.1.3.3 CONDUCT REPAIR

1.1.4 REPORT

1.1.4.1 ADVISORY

Figure 4. Example of information categories.

through February 1968, an intensive model development activity will be in process. During the first two months, similar to certain other tasks, an initial model was developed. The work will continue and final development of the model is anticipated at the end of February. During March, a formal sensitivity analysis for this model will be performed. The model will be tested during April and the model itself will be used in April and May to compare the proposed concept with current systems.

Preparation of the final report will begin in December and will continue to first-draft delivery on May 31. After an evaluation by the Bureau of Public Roads, a final report will be delivered by July 31.

The operations research teams made their entries into the several states with general guidance of the activity that was to be anticipated. The analysis began by looking at the organization of the state highway functions. Charts from the "Traffic Engineering Handbook" and state sources provided knowledge of typical organizations. The specific functions—maintenance, for example—were then located within the proper department and the operating flows of information were followed throughout their courses. The same approach was also made in sampled county and municipal governments.

The information which was obtained from actual ongoing operations that were taking place within specific functions at the time of the operations research visit may be described by an example. Such is suggested by the informational flow for some maintenance functions (Fig. 3). For instance, an inspector has located the need of highway repair. There is then an information transfer from this inspection point to the maintenance office. This need is then sent to scheduling. Scheduling then gathers information from weather service, the availability of materials, etc. With this input, information from scheduling goes back to the maintenance office. Then materials are dispatched from the supply department, the maintenance office dispatches repair equipment, the proper detour or warning signs are put in place, and the highway repair is made.

Information obtained on the maintenance activity (and all other activities investigated) will be organized by orders of categories (Fig. 4). For example, within the maintenance function, we can assumed one category of activity called "Upkeep of Highway" and this may be denoted by "1.0." Under upkeep of highway, we can anticipate "Non-scheduled" and "Scheduled" maintenance. Under non-scheduled maintenance, which may be designated "1.1," certain activities and subactivities are identified by additional numerical indicators. The analysis was interested in the characteristics of the information transfer associated with each of these categories of activities. Following the completion of the operations research, the numerical indicators become the factors that were manipulated for analyses.

An information characteristics matrix provides a way in which data may be organized and structured in a meaningful manner (Fig. 5). For an example, by this tech-

X_{ij} LINE	ACTIVITY	VOLUME 1.	TOLERANCE DELAY 2.	GRADE OF SERVICE 3.	AVERAGE MESSAGE LENGTH 4.	ERROR RATE/SN 5.	DIGITAL OR ANALOG NEED 6.	ETC
1	51.1.3	DIST R_1	CHART 23	.99	EXP DIST 130 WORDS	10^{-5}	DIGITAL	
2	51.1.4	DIST R_3	30 SEC	.999	VAR DIST 1 WORD	10^{-8}	DIGITAL	
3	51.1.5	DIST A_3	3 MIN	.99	5 MIN	38 dba	ANALOG	
4	51.2.1	DIST R_1	CHART 24	.99	EXP DIST 150 WORDS	10^{-5}	DIGITAL	
5	51.2.2	DIST A_4	10 MIN	.99	3 MIN	38 dba	ANALOG	
ETC	ETC	ETC	ETC	ETC	ETC	ETC	ETC	

TYPE MESSAGE	TOLERABLE DELAY
EMERGENCY	1 to 30 SECONDS
PRIORITY	< 1 MINUTE
ROUTINE	< 15 MINUTES
ADMINISTRATIVE	< 24 HOURS

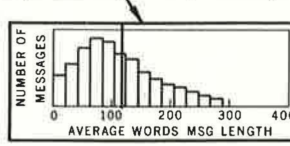

Figure 5. Example of characteristics matrix.

nique the parameters volume, tolerance delay, grade of service, average message length, error rate, whether digital or analog, can be directly associated with the numerical indicators which refer to the functions and activities previously mentioned. Entering such a matrix, it may be found that "Chart 23" applied to the Tolerance Delay for subactivity 51.3.3. Chart 23 may then contain the information that the tolerable delay associated with this kind of information for this particular subactivity is categorized in terms of requirements listed as "Emergency," "Priority," "Routine," or "Administrative." Measures of such delays may be 30 seconds, 1 minute, 15 minutes, and 24 hours, respectively. The parameters of Average Message Length for the same activity may show that the average length is 130 words with an exponential distribution as shown on another chart.

This has been a broad description of the study that is being performed for the Bureau of Public Roads for use by all agencies responsible for decisions as to communication systems associated with highway functions. This paper has described what needs to be done, why it is being done, how it is being done, and where and when some of the effort will take place.

This systems analysis will provide a first-generation framework for future system development. It will reduce the probability of overlooking certain requirements; it will identify constraints; it will reduce foreseeable problems; and it will produce better decision criteria for selection of communications.

Electromagnetic Compatibility—A Necessity for Highway Communications

STANLEY I. COHN, Director, Systems Sciences Research Division, IIT Research Institute, Annapolis, Maryland

•WITH the growth of the highway systems in the United States and the potential of an ever-expanding use of the highway system, the need to communicate between various points on the highway and between the vehicle and the highway system becomes an important requirement. An obvious answer to the problem and particularly to communications concerning vehicles must involve the use of the radio spectrum. The highway system is not the only user, or potential user, of the spectrum which is undergoing these growth pains. Many other users of the spectrum are also vieing for increased use of this natural resource. This paper attempts to show what consideration must be given to electromagnetic compatibility (EMC) in designing highway communication systems. By not considering these factors in the early design, it is conceivable that a system could be designed which could be inoperable in the real world.

NATURE OF THE PROBLEM

The ever-increasing use of the highway system implies a need for increased communications to and from vehicles both for purposes of providing information and for control of vehicular traffic. The design of a system for one of these functions may differ greatly from that of another because of the types of information involved. Potential electromagnetic compatibility problems, which can exist between these systems and also other systems that use electromagnetic energy in the environment, also greatly influence the design and operation of the system.

There are numerous factors that must be taken into account in EMC techniques. They range from design of components to design of equipment and systems to considerations of frequency allocation and frequency assignment, and also involve economics of the use of the radio spectrum, the nature of the environment in which the equipment is intended to operate, and the technical characteristics of the equipment under design and other equipment in the environment. As one can see from this list, EMC involves not only the systems under design but must also take into account characteristics of other systems and must consider a number of nontechnical factors.

EMC AND SYSTEM DESIGN

To best see the approach required to insure EMC, let us examine the path taken from the requirement for an electronic equipment through the various steps to its use in the field. By doing this, one can begin to see the picture forming that a small change in a very early stage can produce radically different results in later stages and conversely, when equipment is operated differently from what was intended, how undesirable results are often obtained.

The first step in the process is that of determining a requirement for a system or equipment. At first glance, it is difficult to see how EMC thinking can occur at this early stage. The requirement is usually for some device to perform a specific function and, in our case, by means of electromagnetic energy. Since the device uses

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electromagnetic energy, we must be cognizant of the fact that it could be a potential compatibility problem. Certainly, one must consider which band is best suited to perform this function, but he must also consider what competition exists in these bands for other uses of the spectrum. Here is where the first concept of systems work must be exercised; namely, trade-offs. We are, of course, aware of examples of trade-offs—for instance, the weight and volume vs performance—but sometimes in the early conceptual stage we forget that performance is a function of the electromagnetic environment in which the equipment is to operate. Sometimes we may be better off choosing a band which does not give the theoretically optimum performance for the intended use but does, in fact, result in better overall performance when competing in the electromagnetic environment with other equipment doing other jobs.

Tied hand in hand with this early requirement phase is the allocations process. First we should define what we mean by allocations as contrasted to assignment. There are really two types of allocation which must be considered. First, the genererally accepted definition of allocation—the allocation of frequency bands to perform particular functions—and, second, the allocation of equipments to operate in appropriate bands. The allocation job is the responsibility of frequency management personnel. When performing this function, the frequency manager must obviously consider EMC. When doing an equipment allocation, he must review the proposed use to be sure that it meets the legal requirements set up by international treaties and national rules. He must also consider whether the proposal makes sense when it is considered with the other equipment already operating in that band or when it is considered with equipment that is not yet operating in the future. Again, the trade-off concept must be exercised.

In his other allocation job, the frequency manager is responsible for providing appropriate space in the spectrum for the various services which it can provide. In exercising this function of subdividing the spectrum and allocating it to various services, he cannot neglect EMC. Providing a band to perform a particular function that is sub-harmonically related to, for instance, a service using high-powered equipment that would interfere does not really provide spectrum space at all. By contrast, frequency assignment is the process of authorizing a discrete frequency to a specific operational user.

The next step in the process involves writing the specifications for the equipment. Here, many times, the importance of the EMC portions of the specifications is forgotten because the individual concerned with writing the specification relegates this to a very low level. Many times he will grab off the shelf some already "canned" interference specifications which may or may not apply to his situation or equipment. By doing this, he is not really giving his equipment or other equipment a fair shake in the spectrum-usage game. What should really be done in this phase is a consideration of the environment in which the equipment is operated and the generation of realistic specifications that apply to this situation. Sometimes, it may be necessary to push the state-of-the-art to achieve these specifications and other times, they may be impossible to meet. In the latter case, if the specification cannot be met, at least the causes and the amount of disturbance to the spectrum will be known.

In many cases, the developmental phase of equipment is the next step of the process. Here again the development engineer should not ignore spectrum conservation principles. If he finds that a particular portion of the specification cannot be met, he should not ask for a waiver for the overall specification but should explain his particular problem and why that portion of the specification is unattainable. He should also indicate what levels can be met. With this information, it should also be possible to determine what the effect of this change will be and the importance of it to the overall spectrum.

The next step in the cycle of a spectrum-using equipment is the design phase. Here the equipment is taken from a bread board model and turned into a final prototype. Many times compromises are needed for the sake of production expediency. The design engineer should be fully aware of good EMC practices and be equally sure that the changes which he makes do not cause adverse conditons in spectrum usage. To do this, he must have an awareness of how the equipment is to be used and of the other equipment that exist with it in the field. In following the equipment through the production phase, he must continually be assured that good practices are being followed.

Now our equipment is coming off the production line in quantity; but, we must be sure that it does, in fact, meet the finally agreed upon specifications. This requires good measurement techniques and good test equipment. We, in the EMC field, have long been aware that there are problems with test equipment. Good measurements are not only important at this stage but in prior stages of the cycle.

We finally are ready to put our piece of equipment in the field. It has gone through all the previous stages of the cycle and now must be assigned an operating frequency. Here we have an important step from an EMC standpoint. It is very easy to look at a list and make quick judgment and assign a frequency, but by doing this are we really playing fair with our spectrum system? Many times, to avoid controversy, assignments are given on a noninterfering basis. Is this because we do not have the spectrum space available or because we have not taken time to assign that frequency properly with respect to the rest of the "occupiers" of the spectrum? Frequency assignment should be engineered considering as many factors of spectrum occupancy as possible and should include present and future use of the spectrum. By taking the easy route now, we may be making it infinitely more difficult to squeeze assignments into the spectrum at a future time when the secondary user's priority becomes high.

We are now ready to operate our equipment. Will it work? Certainly it will work if all of the steps have been followed and the right decisions have been made. But the user is also part of the spectrum-utilization cycle. He cannot make arbitrary changes without interrupting spectrum balance. There are many examples of this that can be cited; in some cases he may not feel the effects, although others certainly will.

Suppose we now look at some of our present problems in spectrum crowding to see how bad the situation is and will be in the future. In his report on "Frequency Management within the Executive Branch of the Government," October 9, 1966, the Director of Telecommunications Management shows many examples and reasons for the crowded condition of the spectrum. Some of the statistics projected in this report are (a) FCC licensed safety and special services radio transmitters are growing at a rate of 20.3 percent per year, (b) broadcasting revenues are growing at 12.3 percent per year, (c) world telephones are growing at a rate of 7 percent per year, (d) the sales of electronic goods are growing at a rate of 11 percent per year, (e) the gross national product is growing at a rate of 5.2 percent per year, and (f) the population is growing at a rate of 1.5 percent per year.

From this it can be seen that the uses of radio and the radio spectrum are growing at a much faster rate than our economy. This increased demand on our spectrum resources cannot help but get us into even more difficult problems unless action is taken immediately. Certainly, everyone has a part to play in spectrum utilization. I am not sure that we are fully aware of that part, and I am positive that only a very few know how their part ties in with the others that affect the overall spectrum usage picture.

By looking at the foregoing statistics, we see that EMC begins to take on an additional dimension; namely, that of economics. Economic considerations are a very important part of the quest for better spectrum utilization. The rather large view of the economics of spectrum utilization is sometimes missed. Examples of this are the impact of a service or new use of radio energy on the economy, the cost of changing allocation, and capital investment in equipment manufacture.

Sociological factors also play an important part in the spectrum utilization picture. The ability to communicate information to large masses of people can obviously change their social patterns and, conversely, the sociological needs of people influence the services that can be provided by the spectrum. Political and legal implication influence the use of the spectrum as well. International treaties, national legislation, and regulations concerning the spectrum are all important considerations.

EMC IN HIGHWAY COMMUNICATIONS

The aforementioned considerations apply to any electronic system that uses the spectrum. The purpose of the rest of this presentation is to illustrate, by example, some of the EMC factors that have to be considered in the design of highway communications systems.

Suppose one looks at the present emergency highway communication system, which uses radio, on the Washington Beltway. There are radio call boxes placed on both sides of this highway. These are periodically spaced around the Beltway. The system involves pushing one of several buttons, depending on which type of emergency is involved, and a coded signal is transmitted to a central headquarters and then the appropriate emergency vehicle is dispatched. I do not have data on the frequency of use of this system but I imagine that the time occupied in transmitting the information from the emergency call boxes is a very insignificant fraction of the total time, probably in the order of minutes per day. In order to insure that interference-free messages arrive at the central headquarters, this system must operate on a clear devoted channel. It is, therefore, using the frequency spectrum in a somewhat inefficient manner. If my assumption is correct, the time occupancy of the channel in actual transmission is quite small but the channel must be available for use at any time. The question then arises: Is availability a use?

Since the use of the radio spectrum is obtained without charge, the utilization of the radio energy to accomplish this mission has probably turned out to be the least costly means. In fact, the spectrum does have value and its use in transmission of energy and being available to transmit energy should be measured in some economic terms. The fact that no other user can occupy the channel means that the incumbent user must bear the complete cost of this channel. If one were to charge for the use of the spectrum, an economic analysis would show that a radio system from these fixed locations around the Beltway might be very costly. A system using land-lines for this function might probably turn out to be considerably less expensive. However, the above is at the moment merely speculation, since there are not means of measuring the economic value of spectrum usage. In the future, it appears that some means of establishing this value will be found. As spectrum crowding becomes severe, some value critieria will, of necessity, have to be established. When this happens, the systems that can utilize alternate means without great economic burden will be required to change their mode of operation.

This first example serves to illustrate the economic factors that must be considered in systems design. Although this is an existing system, it is quite possible that it may set the pattern for future systems, and serious examination of the above factors must be given before we crowd ourselves out of the spectrum.

Another example that would tend to illustrate the effects of man-made noise on the systems design will be given next. Consideration is being given to an inductively coupled highway communications systems between vehicles and a base station or stations. Such a system would be low-powered and in a sense be very conservative on our spectrum resources. The main undesirable feature of this type of communication is its susceptibility to the ignition noise generated by a vehicle. This ignition noise problem has been pretty well conquered in the land mobile services by the use of the resistive ignition wire or resistor spark plugs in the vehicle containing the mobile equipment. Occasionally, interference is experienced when unsuppressed vehicles are close by, but the probability of this happening for any length of time is quite small and the service is generally satisfactory.

In the situation where inductive coupling between the vehicle and communication system is used, the ignition noise problem takes on a different complexion. Since all vehicles are always close to the antenna (requirement of the system), ignition noise from all vehicles will be additive and the resulting noise might well be considerably higher than the signal. Conquering this problem will require all vehicles to be suppressed to a great degree, and the resulting cost might be too large a burden for the public to bear. This mitigating noise factor must be balanced in the design of this type of highway communications systems.

In this example, we have seen that the characteristics of the vehicle become a very important factor in the design of the communication systems. Although the use of the spectrum by such a system might generally be reduced, the noise problem would be the controlling factor. An alternate approach, which might serve as an example, might be the use of present land-mobile type equipment to perform this highway-to-vehicle communication function. Here one really gets into spectrum crowding.

The use of the land-mobile band to perform the highway communication function has several major problems from an EMC standpoint. As noted earlier, the growth of the FCC Licensed Safety and Special Services Radio Transmitters has been approximately 20.3 percent per year. This is mainly in the land-mobile services. In addition to this, the other land-mobile users are experiencing a similar growth. The number of users has been steadily increasing in the past few years. More business and industrial users find that this method of communication is a great aid in their business. In urban areas, the spectrum squeeze is particularly noticeable.

In a number of the larger cities the conditions are such that there is no additional spectrum space available within the allocations to accommodate these services. Because of shared usage of channels, some of the users have actually resorted to other means of communications. A number of other potential users have decided not to join an already crowded situation. If more spectrum space were available for land-mobile service, there would no doubt be a very great demand in urban areas. Although the urban area problem is more severe, increased use of the land-mobile type service for highway communications must compete with many, many users.

In addition to direct spectrum growth due to greater demand for service, intermodulation problems become quite severe. This then is another problem in the EMC field that would result from putting this service into the crowded portion of the spectrum.

CONCLUSIONS

In this paper I have attempted to review the EMC field and show the factors which must be considered in systems design. The examples given were meant to illustrate how the EMC problem enters into highway communications.

My purpose in presenting this paper has been to acquaint you with the necessity of including electromagnetic compatibility considerations in your efforts. This is most important and should be given your full attention when you are considering new systems in the highway communications field.

Communication Requirements in the Methodology of Automatic Control of Highway Traffic

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•THE transportation system of the United States is the largest system in the world. Transportation is an activity that accounts for about one-fifth of the economic effort of the nation, an activity with a monetary value of approximately $170 billion per year. Intercity freight and passenger movement involves more than a trillion ton-miles and a trillion passenger-miles, respectively (1). Undoubtedly the transportation system is responsible to a great extent for the high state of economic and technical development of this country.

However, in many aspects the system is not functioning well. The provisions for the movement of small packages of goods and for short- and medium-haul passenger transport, for example, are quite poor in many respects. Many countries, much less affluent and with lesser transport facilities, have better and cheaper services in many transport functions.

The highway segment of the transportation system in the United States is no exception to the general situation. It is the most highly developed system in the world and has provided mobility, land access, and individual choice of mode to a degree beyond comparison. The system contains more than 3. 5 million miles of roads and streets, and the number of vehicles is almost 100 million (2). More than half of the population is licensed to drive, and the vehicles are driven an average of about 10, 000 miles per year for an annual total of almost a trillion vehicle-miles (Fig. 1).

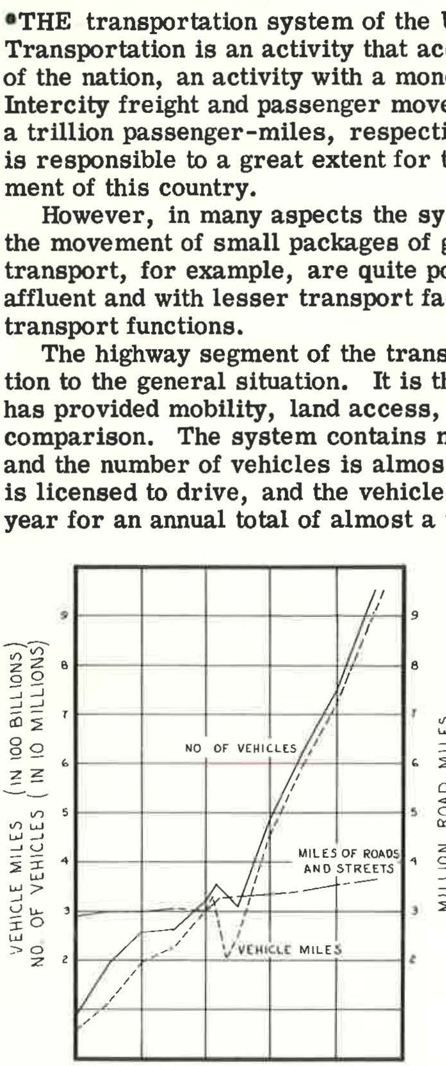

Figure 1. Highways, vehicles, and travel in the United States.

Much of this travel is confined to a small portion of the highway network. Consequently, serious congestion and delay are commonplace, as are the consequent frustrations and costs. Traffic continues to grow at about 5 percent per year and seems insatiable, although large allotments of public funds, land, and other resources are appropriated to accommodate increased travel.

TRAFFIC ACCIDENTS

The safety situation is more serious than the functional deficiencies. Motor-vehicle operation produced more than 13 million accidents in 1966, with 53, 000 persons killed, almost 2 million injured, and $10 billion in costs (3). The accident situation has been worsening in recent years. From 1936 through 1961 the annual death toll remained at about 38, 000 per year, with fewer during World War II. In 1962 the toll jumped above 40, 000 for the first time and then it grew

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TABLE 1

MOTOR VEHICLE DEATHS AND DEATH RATES

Year	No. of Deaths	Mileage Rate*	Population Rate**
1961	38,091	5.2	20.8
1962	40,804	5.3	22.0
1963	43,564	5.4	23.1
1964	47,700	5.6	24.9
1965	49,163	5.5	25.4
1966	53,000	5.7	27.1

*Deaths per 100 million vehicle-miles.
**Deaths per 100,000 population.

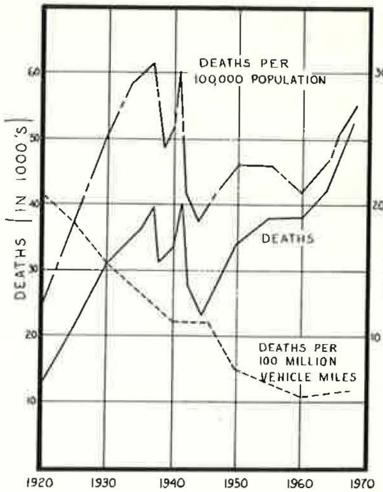

Figure 2. Traffic deaths and death rates.

steadily through 1966, increasing about 40 percent in 5 years (Table 1 and Fig. 2).

Of equal significance are the corresponding changes in fatality rates. The number of fatalities per 100 million vehicle-miles rose from 5.2 in 1961 to 5.7 in 1966, an increase of 10 percent. The population rate increased 30 percent in the same 5-year period.

Even before 1962 it could be said that (a) motor-vehicle accidents are the third leading cause of death in the United States; (b) more American lives have been lost in motor-vehicle accidents than in all of the wars in which the United States has engaged; (c) more children die as a result of motor-vehicle accidents than from any other cause; (d) half of the victims are in the prime of life, between 15 and 44 years of age; and (e) from the social and economic viewpoint, motor-vehicle accidents could be considered the most serious cause of death and injury in the United States. Air pollution resulting from vehicle operation is becoming a serious health problem, and motor-vehicle noise is contributing to hearing loss and ear injuries.

AUTOMATIC CONTROL OF TRAFFIC

Many authorities now agree that a reasonable degree of safety and efficiency will come to highway transportation only with the development of an integrated system involving a large measure of automatic control (4, 5). From the viewpoint of safety, many feel that the driver is doing about as much as can be expected of him and that the system involves operations that are too complex, too fast, too dangerous, and too monotonous to be controlled without extensive use of automatic devices.

Support for this proposition comes from the other principal modes of transport of persons—air and rail. These media have been made safer only by taking away from the operator more and more of the operation of the vehicle and the decision-making. Ross (5) says, "In an ideal (automobile-like) system, control of the vehicle would be relinquished."

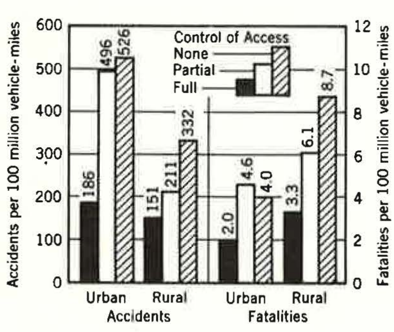

Figure 3. Effect of control of access on accidents and fatalities.

Results achieved on existing highways through full control of access also illustrate the safety value of automatic control (Fig. 3). It is to be noted that partial control of access is not effective and that full control of access requires elimination of grade crossings and usually implies a freeway facility. The freeway automatically separates opposing traffic, automatically eliminates cross traffic, and automatically restricts access to a few locations especially planned to receive and discharge traffic.

Increased Efficiency

Automatic control of traffic would also increase the efficiency of the system. Safe headways between vehicles could be shortened because of the reduction in reaction time, with a corresponding increase in capacity (Fig. 4). Headways could be further reduced if controls eliminated skid, dive, and brake fade. A competent control system would permit full use of all lanes on a multiple-lane highway during heavy directional flows. Median strips and their barriers could be eliminated and the overall roadway narrowed. The maximum capacity of two-lane roads could be developed by providing for passing maneuvers whenever safe, rather than depending on the driver's judgment and on sight conditions.

There would be many other benefits. Travel times would be reduced and rides would be smoother and more pleasant. The mental, nervous, and physical condition of the driver should be greatly improved. He would not need to steer a car continuously, without respite. He would be relieved of practically all the tension-producing incidents, which occur as often as every few seconds in dense traffic and can add up to several hundred in a day's driving. There is little question that an effective control system will cost a lot of money, but many proponents of automatic control claim that the increased efficiency will save enough on new construction to pay for the system.

THE TECHNOLOGY OF CONTROL

The sense of proposals for traffic control systems can best be understood, perhaps, by an illustration of one approach to the problem. A highway could be arranged like a railroad with the lanes of the highway separated from each other as are railroad tracks. Devices corresponding to switches, turnouts, crossovers, etc., could be designed to provide for access, egress, and movements from lane to lane. Some equivalent of the railroad's traffic control and compliance enforcement system—the block system, centralized traffic control, complete automatic control—could be applied and presumably would yield equivalent safety.

Such an arrangement would be cumbersome and inefficient, and much better systems can be designed using more modern and sophisticated equipment, but the use of a rail or its equivalent may be feasible.

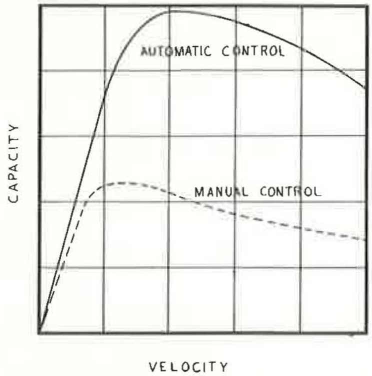

Figure 4. Capacity with manual control and with automatic control.

Guidance and Spacing

A guidance system is required. For a number of years approximately 30 percent of motor-vehicle accident deaths have resulted from single-car accidents, most of them involving a car running off the road without having been involved in a collision in the roadway, and most frequently on relatively level, tangent sections of highway under good roadway and climatic conditions. A spacing system is required also to prevent a vehicle from being involved in a collision on the roadway.

Many devices and systems for guidance and spacing have been proposed or developed. Some prototypes have been demonstrated, and some components are being used in real traffic control. Much published material on these subjects has appeared in recent years (4, 5, 6, 7, 8). Most of the manufacturers in the automobile, electronics, communications and control industries have devoted some effort to research in automatic control of traffic.

Devices for guidance include one using a wire or cable in the center of the lane sensed by magnetic pickups on the vehicle, one involving two wires and a different detection system, a dual radar beam device, colored stripes followed by photoelectric cells, radioactive isotopes detected by scintillation counters, and a mine-detector type of apparatus. A mechanical guidance system may be required to cope satisfactorily with unusual forces (such as those involved in skidding) encountered in some vehicular, climatic, roadway, and traffic conditions. A rail, a groove or some similar device could be employed, and some existing applications of these could be adapted to highways. For example, the subways of Paris and Montreal use vehicles that ride on rubber tires but that also have flanged wheels and rails for safety and for some guidance functions. Horizontal guide wheels bearing against rails outside the vehicle body or against a guide rail in the center of the lane have been used. Another arrangement is the rail-road vehicle which operates on rubber tires on road or track but which is guided by flanged wheels when on the railroad. The latter system is in development for use in buses in the New York metropolitan area.

For the most part, lateral spacing will be accomplished satisfactorily by the proper arrangement of guidance elements. Longitudinal spacing is primarily concerned in the simplest applications with maintenance of safe headways in unidirectional flow. Suggested devices include detector coils in the roadway coupled to roadside detector units that transmit signals to the vehicles, radar-type devices that continuously measure the distance to the preceding vehicle, and block system arrangements somewhat similar to those used in rail transportation. Some of the systems recently developed for use in mass transit, such as the San Francisco Bay Area Rapid Transit system, might merit adaptation to highway traffic control.

At this time there is little need for concern over duplication of effort in developing different devices to perform somewhat the same function. Experience with control systems for other modes of transportation indicates that more than one safeguard is needed for any situation, and it is best if these are based on different but compatible means.

THE METHODOLOGY OF CONTROL

The technology of automatic control of highway traffic is entirely feasible. Much of it has been feasible for years; at the Arden House Conference in 1958 it was agreed that "Means for performing many functions . . . are technically achievable. Besides the word of authorities working on the problem, this is confirmed by the phenomenal progress in the development of electronic systems in aircraft, guided missiles and automation" (4). What is lacking is the methodology, i.e., the specification of what is to be accomplished by the control system. To quote again from the conference report, "Electronic scientists alone cannot provide solutions. The greatest need for progress today is a clear-cut definition of the various traffic and safety problems to be solved."

Such definitions, or methodology, must be supplied by highway engineers. The first requirement is to agree on a set of goals and adopt a policy. To that end the following principles are suggested as fundamental rules for an automatic control system for highway traffic:

1. The vehicle should move efficiently on the highway from entrance to exit.
2. The vehicle must hold properly to an arranged path.
3. The vehicle must not collide with a person, another vehicle, an animal or other object.

The second and third principles should cover all types of accidents on the highway.

Subsidiary conditions must be developed and established. For example, the system must "fail safe" and must possess a very high degree of reliability, and it is suggested that any required changes in the vehicle should not materially impair its mobility when off the controlled highway. To illustrate the extent of the need of methodology, Figure 4 was left dimensionless, because there has been no agreement on the safe headway requirements under manual control, let alone automatic control.

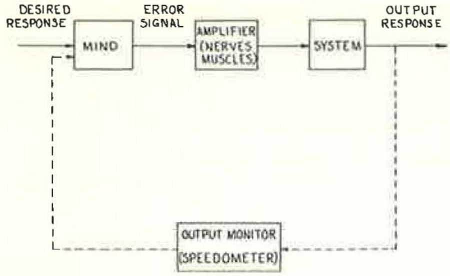

Figure 5. Speed control, manual.

Communication Requirements

The communications required in control systems for highway traffic will depend on the type of control technology, the degree of control to be exercised, and the order of the control system. If, for example, the guidance system employs a mechanical linkage of the vehicles to a fixed path such as a rail or a groove, the control system and the associated communications required to maintain the vehicle in the proper path will be vastly different from that employing a radio-wave type of connection between the vehicle and the road.

Maintenance of proper speed will be common to most systems and can serve as an illustration. In the ordinary operation of a vehicle the driver performs most of the control tasks, and he performs them on the basis of his desires and information coming to him through his senses—principally vision, but also including hearing, touch, balance, etc. The ordinary contemporary vehicle furnishes one additional control element, a feedback communicated to the driver by a speedometer [Fig. 5, adapted from Pitman (9)]. With this information the driver can control his speed to meet desired or required conditions by operation of accelerator or brakes and in so doing he allows for changes in grade, roadway, and traffic conditions.

Under automatic control the speed control mechanism becomes much more complex, as shown in Figure 6 (10). Here, with the inputs coming from the driver's desire, from the control system, and from external disturbances, many pickups and feedback loops are required to produce the required gain in the system. There is no doubt, however, that it can be accomplished. Automatic speed control devices satisfactorily responding to driver input are common on many of today's vehicles, and a system such as that shown in Figure 6 has been demonstrated in a field test installation.

It can be seen that, under manual operation, most of the communications are concerned with messages originating outside of the control system and transmitted to the driver. With automatic control, much of this is inside the system and consists of transmitting messages or signals from one element of the system to another element of the system. There is no need, and in fact it is undesirable or impossible, to transmit all the data to the driver also.

The function of the driver primarily will be to monitor the operation to assure its proper functioning, and he will need the right to override the control system in the event of a malfunction. In this respect his task, and the role of the communications

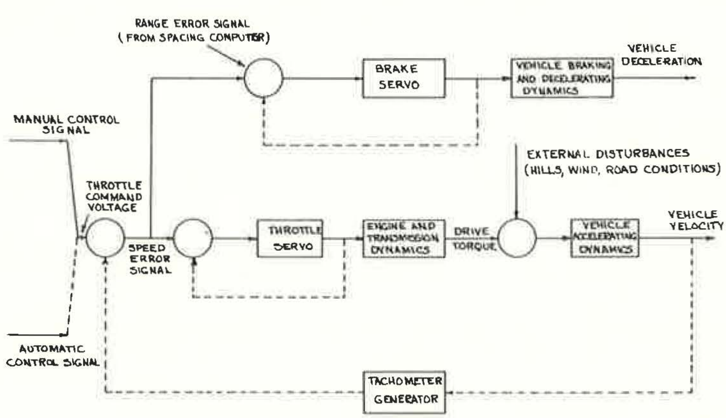

Figure 6. Speed control, automatic.

system, can be likened to that of the airplane pilot and the air traffic control system in the operation of aircraft under instrument flight rules. The motor-vehicle operator will need sufficient information transmitted to him to assure him that the vehicle and control system are performing properly and meeting input requirements, to inform him of his position in the system both fundamentally and with respect to nearby vehicles, and to advise him, in advance, of any changes of position or speed that are going to be effected by the control system. Much of this can be accomplished with visual displays and oral messages inside the vehicle in addition to some external display messages. In all likelihood the driver will need a means of direct communication, such as a radio receiver and possibly a transmitter.

Communications Technology

Techniques, devices, and systems are available or feasible for all the communications requirements of automatic control of highway traffic. This was apparent at the time of the Arden House Conference and has been substantiated and reinforced in the intervening years.

The National Conference on Highway Communication, held in August 1967 at Denver, was not specifically concerned with automatic control, but the following comments, taken from the conference report of E. M. Johnson, President, AASHO, are pertinent (11).

> The story of transportation has been related to the story of communication. There has been an evolution from blazes on trees and piles of stone to the familiar highway signs and signals of today. Now the environment has changed, volumes and speeds of traffic have increased and drivers have to negotiate a complicated highway and street system. A driver is required to make many split-second decisions based on judgments of factors over which he has control and factors over which he does not have any control. The information on which decisions are based is practically all obtained by visual observations of the driver.
>
> It was stated that the communication systems presently used in the operation of highways are outmoded whereas air travel communication systems are greatly advanced and the railroads use centralized traffic control and freight car location communication systems. . . .
>
> The exploration of the past three days has apparently given each person in attendance some awareness of problems and needs he had not previously had. It seems rather obvious that industry can provide the necessary hardware and technology when a determination has been made as to the detailed requirements of a communication system to meet the safety and service needs of the traveling public.

NEED OF RESEARCH

The urgent need in the field of automatic control and communications is immediate creation of an all-out, intensive research and development effort. Although general requirements extend to the consideration of radically new and exotic means of transportation, there is a critical need to deal with a combination of wheeled vehicle, roadway, and driver not differing substantially from the present components.

The work will be costly and it will be difficult, but it can be done. It can be started immediately, because funds in terms of tens of millions of dollars could be made available from federal and state funds appropriated for research and for highway safety. Additional millions should be available from public health funds. Certainly sufficient talented manpower and sufficient material resources are available.

There is no need to delay research work while awaiting results of efforts to improve the investigation of accidents and the preparation and analysis of accident reports. From the standpoint of accident prevention through traffic control, the basic actions of the vehicle during the accident event are well enough known to provide a foundation for the development of preventive measures. In the great majority of accidents the basic actions are two—either the vehicle collides with another vehicle, a person, or an object within the roadway, or the vehicle leaves the roadway and collides with an obstacle.

SUMMARY AND CONCLUSIONS

The highway transportation system of the United States is the largest and most highly developed system in the world. Yet it is not functioning well. Serious congestion and delay are commonplace and the casualties resulting from motor-vehicle accidents constitute a continuing catastrophe. Fatalities rose from 38,000 to 53,000 in the five-year period from 1962-66, an increase of 40 percent. Fatality rates, both on a mileage basis and on a population basis, increased alarmingly during the same period. The motor-vehicle accident problem is one of the most serious problems in the United States.

There is a hope and a prospect that in the distant future relief and improvement will come through the development of new and exotic forms of transportation. However, there is an immediate need to deal with the present highway situation and in terms of a combination of wheeled vehicle, road, and driver not differing substantially from present components.

Many authorities now agree that an acceptable degree of safety and efficiency will be achieved in highway transportation only with the development of an integrated system involving automatic control to the most feasible extent. The logic of this position is based on the performance of air and rail transportation systems and on the beneficial experience with freeways and other highways where a considerable degree of control is exercised. The critical need is a great research and development program committed to produce such a system.

Research work can begin immediately, because existing knowledge of the accident event is sufficient to provide for the specification of most end results required of the control system. Fundamental principles of those specifications, or the methodology, suggested are: (a) the vehicle should move efficiently in the system; (b) the vehicle must hold properly to an arranged path; and (c) the vehicle must not collide with a person, another vehicle, an animal or other object. In addition, the system must be highly reliable, must "fail safe," and must meet many other criteria.

All of the required technology of control and communication is available or feasible. Certainly sufficient talented manpower and sufficient material resources are available. The work will be costly, but funds should be available from research, safety, and public health appropriations—federal, state, and local. It is anticipated that the costs of research and development and of the implementation of the developed system will be repaid by the gains in efficiency of the system in addition to the reduction in accident experience.

It is likely that the eventual system will differ from today's arrangement in many respects, but competent research can be trusted to produce a satisfactory solution that will meet objectives. For if research can develop and launch a space vehicle, control it in flight thousands of miles from earth, and land it on the moon within a few seconds of its planned arrival time, then research can find a way to safety.

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Use of Surface Waves in Communication With High Speed Vehicles

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The problem of communicating with and controlling vehicles moving in a one-dimensional frame is becoming more important in view of the increasing demands for fast and convenient transportation means. The future will undoubtedly reveal some form of continuous communication link between moving vehicles (automobiles, as well as mass transport vehicles) and a central control or communication station. Recent concern has been with the possibility of providing a suitable communication link without requiring additional space in the electromagnetic spectrum.

This paper discusses the use of surface waves in communicating with moving vehicles. The results of research being conducted indicate that, although there are still some unanswered questions, the surface wave line shows considerable promise as a potentially useful communication link.

•THE PROBLEM of maintaining a continuous communication link with a moving vehicle is one of pressing importance, not only in the area of mass transport but also in the highway field. Since highways are essentially one-dimensional, the techniques that apply to tracked vehicles may also be applied to the highways of the future. In this regard, one might envision a limited-access superhighway where a car is under the control of the driver only until he clears the entrance ramp. He then signals central control that he wants to "lock on" to the automatic control device, and he is free to read, watch TV, or do paper work. The operation of the vehicle would be completely controlled by a central computer which would maintain the necessary headway, a safe speed, and be alert to impending dangers. The driver thus gives up the right to pass other vehicles or otherwise dictate his own vehicle's performance. Since a person normally uses a private vehicle rather than a mass transport vehicle for reasons of personal convenience, it is quite logical to assume that the driver is willing to relegate the responsibility for vehicle performance to the central control facility. The mechanics of driving the vehicle are not attractive but are necessary if one is to enjoy this personal convenience.

If completely automatic control of private vehicles on the major highways can be achieved, then we are in position to combine the best of the mass transport concept with the convenience and comfort of private transportation. The traveler then need not be concerned with the problem of dealing with traffic and avoiding dangerous situations. In short, the driver can give his attention to matters that are his specialty. Thus, millions of man-hours of effort can be gained by executives and other high-level workers for whom transit time is otherwise lost.

The concept of continuous automatic control of tracked vehicles is more apparent and much more immediate. Even the most conservative highway engineers admit that, in some localities, the convenience of individual vehicles for interurban travel is taxing our economy unduly and an alternative must be found. If travel by mass media can be

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made attractive, the highway congestion problem can be significantly relieved. In this regard, the mass transport concept is being pursued vigorously by the Office of High Speed Ground Transportation of the U. S. Department of Transportation. Research is being sponsored by that office, which is addressed to the problem of meeting the transportation demands of the metropolitan areas. Interurban travel of the future must be largely by mass transport media. To be attractive, however, mass transport media must be clean, efficient, and fast, and must provide the traveler with certain conveniences which he, in fact, has a right to expect.

Of considerable importance in the mass transport medium of the future is a completely automatic control system. This will require a communication link that could also provide certain passenger conveniences such as television and telephone.

The cybernetics of a completely automatic system clearly would designate the central control unit (the computer) as the brain and the communication link as the nervous system. Thus, the brain can function properly only if the nervous system provides a continuous link with the functioning members of the overall system. The link becomes even more important under adverse environmental conditions when the human senses become less functional. In that case the driver indeed should rely on a "nervous system" and a "brain" not limited by environmental conditions.

THE SURFACE WAVE LINE

At the ESSA Research Laboratories, attention is being given to the communications link as it applies specifically to the mass transportation problem. The work is sponsored by the Office of High Speed Ground Transportation and is directed toward the development of a system that is predominantly a guided wave system with a negligibly small component of radiation. This would permit the use of a band of frequencies even though that band is assigned for another use.

The idea of guided waves for use with mass transport vehicles is not new. The British and the Japanese have both considered this concept and have conducted considerable experimental research. An excellent article which describes the position of the British Railways in this regard is given in a recent article by Barlow (1). The British Railways have, in fact, long recognized the need for uninterrupted coupling between the moving vehicle and a central communication facility. They have considered various schemes that would meet the demands of the transportation system (1, 2, 3). The Japanese likewise have concerned themselves with various communications schemes for use on the New Tokaido Line (4). This high speed line between Tokyo and Osaka provides passenger trains running at up to 150 mph. The communication schemes considered in Japan included both guided and leaky waves (5, 6, 7). In the latter, arrangement is made for radiation along the length of a waveguide by virtue of slots which can be adjusted to control the amount of radiation and the pattern.

Figure 1 depicts the nature of the problem and defined tasks; the major items that the Department of Transportation would like to provide are pointed out. It would be highly desirable if we could provide a sufficient bandwidth to satisfy the demands of convenience as well as safety for the interurban traveler. For example, the TV and telephone are conveniences the traveler has a right to expect. The safety aspects include providing key pieces of information to the central control unit—headway, speed, location, and obstacle detection, as a minimum. Ideally, this should be accomplished without requiring space in the already overcrowded electromagnetic spectrum (8).

The nature of the problem is clearly such that one must seek a compromise at the very outset. A good transmission line is, by definition, a poor antenna, and an antenna is a poor transmission line. The nature of a transmission line is such that it provides the guiding mechanism so that energy does not leave the structure. On the other hand, an antenna is a device that encourages energy to become detached; i. e., it is an impedance-matching device that matches the transmitter impedance to free space impedance in an efficient manner, and energy is thus encouraged to radiate from the structure. The problem of communicating with a moving vehicle brings out the basic difference between these two distinct concepts. On the one hand, a transmission line is desired in order that additional space in the electromagnetic spectrum is not required. An efficient device is also desirable in order to reduce the attenuation along the guiding

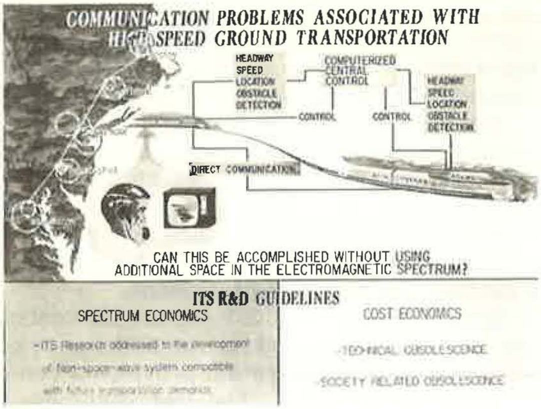


Figure 1. Pictorial representation of communication problems associated with high speed ground transportation.

structure. At the same time, a communication link with the moving vehicle must be maintained without turning to the concepts embraced in the definition of an antenna. Hence, we are led at once to a wired-wireless system (as it is sometimes called)—wired in the sense that there is a main guiding line and wireless in the sense that there is no wired connection to the moving vehicle.

The research being conducted indicates that a surface wave line may economically and adequately serve the needs of the high speed mass transportation program. It can be an efficient device, having low loss, and yet the energy can be coupled off at random points at almost any desired level of coupling.

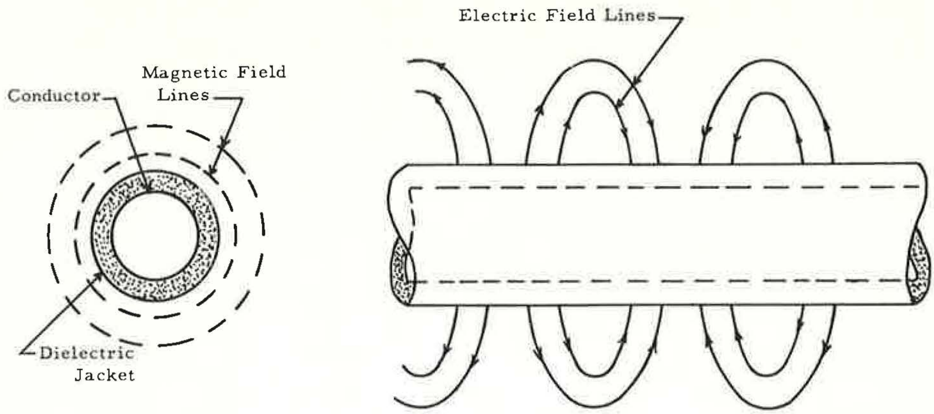
For our purposes, we define a surface wave simply as the wave propagating along the inductive interface between two media without radiation. It is distinguished from the leaky wave by the fact that there is not a continuous radiation of energy but, rather, the wave is bound to the surface by virtue of the boundary conditions. Radiation takes place only at curvatures, nonuniformities, and discontinuities. In this sense, radiation is taken to mean energy converted from the surface wave field to some other form. Because the interface between the two different media acts to bind the wave and guide it, the wave is sometimes called a trapped wave.

The chief characteristic of a surface wave is that its phase velocity is less than that of free space. This means that, in general, the field decays exponentially away from the structure (Fig. 2 shows how this comes about for the G-line, which will be discussed further). Power flow is parallel to the guiding structure except for the power flow into the structure due to the losses. There is a definite relationship between the decay away from the guiding surface and the phase velocity along the guiding surface. As the phase velocity decreases, the field concentration increases, i. e., the decay coefficient increases.

The surface wave structure that appears to be the most promising for purposes of communicating with a moving vehicle is that usually referred to as the G-line or Goubau line (9, 10).

The G-line consists of a circular cylindrical conducting tube with a dielectric jacket (Fig. 2). The dielectric jacket has the effect of reducing the phase velocity to less than the velocity of light, resulting in an exponential decay of the field in the direction normal to the surface of the line, even in the case of a perfectly conducting inner tube. The G-line is undoubtedly the single most important form of surface wave structure in terms of application. The principal mode is symmetrical about the line and has only an electric field component in the direction of propagation. The equations in Figure 2 give the variations of the field components of this mode along with the respective large argument approximations; the demonstration of the exponential decay is thus shown. The equations are valid outside the dielectric coating.

In the G-line configuration, as with any surface wave structure, the surface reactance (the ratio of E_z/H_θ in Fig. 2) that the wave experiences at the surface of the guiding structure is related to the phase velocity and hence to the radial decay coefficient, p. One of the important considerations in the design of a surface wave structure involves a choice of line parameters; the compromise in choice between dielectric constant, dielectric thickness, and inner conductor size must be made on the basis of tolerable attenuation, reasonable cost, and proximity of scattering objects in the field. A change in frequency can offset a change in any of these parameters. The difficult aspect of this stems from the fact that the interrelation between line parameters, frequency,



$$E_z = A K_0 (pr)\, e^{-i\beta z} \longrightarrow A\sqrt{\frac{\pi}{2pr}}\, e^{-pr}\, e^{-i\beta z}$$

$$E_r = i\frac{A\beta}{p} K_1 (pr)\, e^{-i\beta z} \longrightarrow iA\sqrt{\frac{\pi}{2pr}}\, \frac{\beta}{p}\, e^{-pr}\, e^{-i\beta z}$$

$$H_\theta = i\frac{A\omega\varepsilon}{p} K_1 (pr)\, e^{-i\beta z} \longrightarrow iA\sqrt{\frac{\pi}{2pr}}\, \frac{\omega\varepsilon}{p}\, e^{-pr}\, e^{-i\beta z}$$

$$pr = k_0 r \sqrt{\Delta - 1}\ , \qquad \Delta = \left(c/v_p\right)^2$$

Figure 2. Cylindrical surface wave line with expressions for the field quantities and the large argument approximations.

attenuation, and decay coefficient is very complicated and not amenable to analytic considerations. Hence graphical techniques must be used. We have found that 500 MHz is the approximate lower practical frequency for lines of interest.

EXPERIMENTAL RESULTS

The major problems anticipated in the early stages of development included the coupling problem and the unknown effects of the environment. The coupling problem seemed paramount because it involved the unknowns of how to couple energy from the main surface wave line to the mobile receiver without undue spurious radiation. In this respect the advantages of the surface wave concept become evident because the energy is carried largely in the region outside the guide structure; i. e., most of the energy is carried in the air but is guided by the surface wave line. Only a small percent of the energy actually travels in the dielectric region. Because of this, it is simple to visualize a receiving element on the moving vehicle which intercepts a specified percent of the energy. This can be accomplished, in fact, but one must be alert to the possibility of causing a significant scattered field in the process. The surface wave is bound to the guiding structure, but the proximity of any scattering article will cause spurious radiations. Hence, a receiving element intended to couple energy off the main line must introduce minimum discontinuity, insofar as the main line is concerned, to avoid unwanted radiations.

The coupling device that seems most logical is a second G-line, identical with the first, which then acts along a given length parallel to the main line and intercepts a percent of the energy in the main line. The degree of coupling depends on the nature of the lines, the frequency, the length of the mobile section, and the separation of the two lines.

An analysis has been made of the coupling using a coupled transmission line approach, wherein the two coupled G-lines are thought of as four transmission lines with suitable voltage and current in each. A transmission line is associated with the dielectric region in each G-line and a transmission line is associated with the air region surrounding

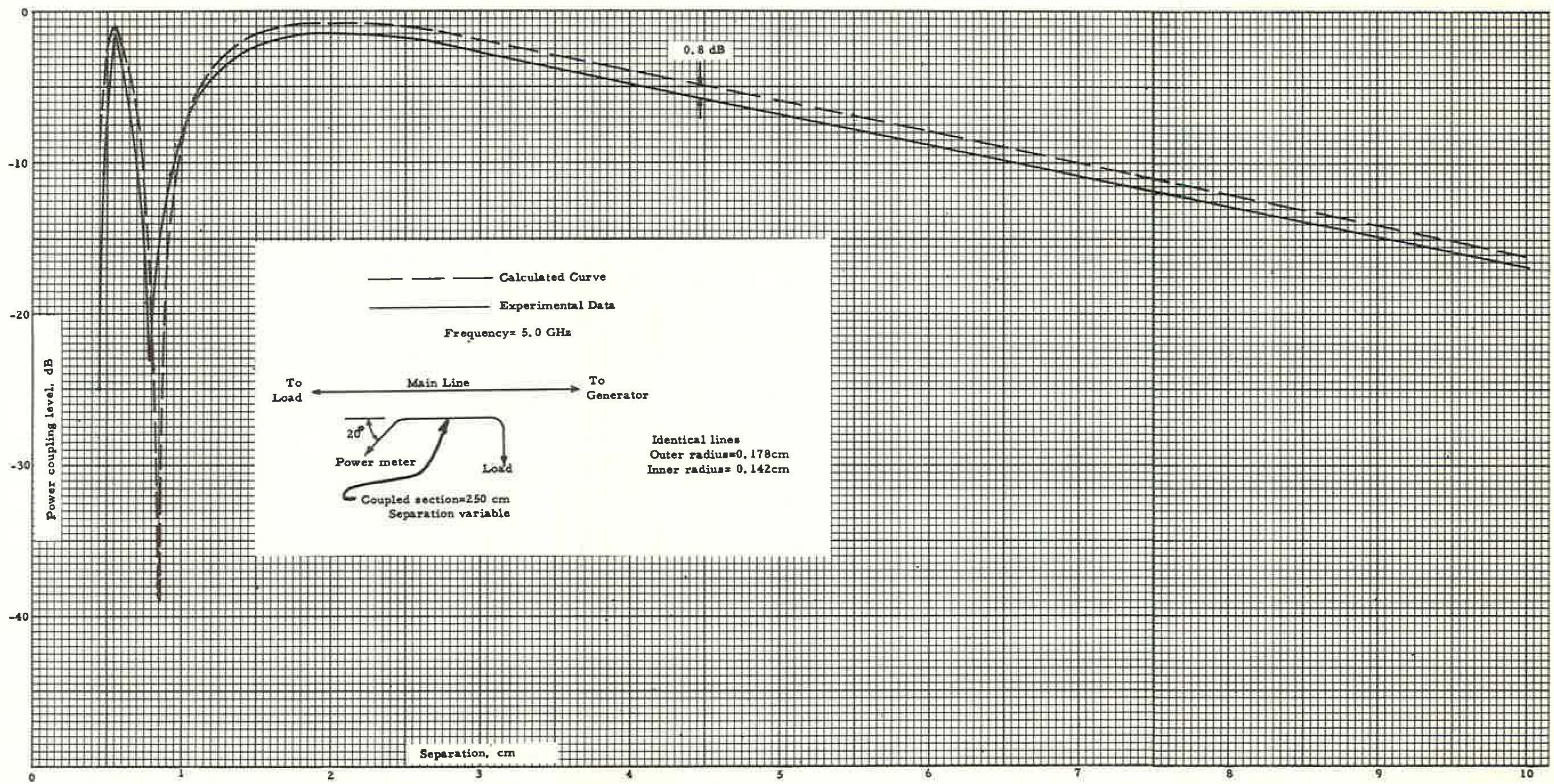


Figure 3. Theoretical and experimental data on the coupling between the main line and the mobile coupled section.

each G-line. The boundary conditions are then used to determine the unknown constants. This approach is possible because of the uniform nature of the lines in the propagation direction. The result of this approach is a description of the coupling between the two lines that depends on two hybird propagation constants; each represents a combination of effects because of the interaction between the two lines.

Data have been taken to demonstrate the feasibility of this technique with very encouraging results. Figure 3 shows the measured and the calculated coupling ratio as a function of separation. The experimental data were taken with a 20° corner as shown. The 0. 8 dB discrepancy is well within experimental tolerance. The data were taken at 5 GHz (λ_0 = 6 cm). The curve reflects a decrease in coupling level of about 12 dB per wavelength for separations of more than about a half-wavelength. This is quite typical for the lines considered. It is interesting to observe this linear dependence on separation. This is rather encouraging because of the implications concerning compensation for motion.

A TV picture has been used to test the fidelity of this coupling scheme, with rather good results. In the upper photograph of Figure 4, the picture was received from a commercial broadcast and cabled to a monitor about 500 ft from the receiver. For the lower photograph, the TV picture was put through the coupling loop, onto the main line, transmitted about 500 ft, received with a horn, and monitored. The difference in quality between the two is hardly noticeable. This was a live telecast and identical pictures could not be made. Television pictures were also observed for the case when the van with the coupling loop was in motion. The quality of the picture remained very high even though the guiding mechanism for the moving vehicle was quite crude.

Figure 4. Photographs showing live telecast as seen directly (upper) and through the mobile coupled section (lower).

The theoretical analysis made by Goubau was based on an infinite isolated line that was perfectly straight. Insofar as these conditions are satisfied, the mode, once launched, will propagate without radiation, the attenuation being due to the dielectric and conductivity losses. However, even in controlled laboratory situations, one has to admit bends and nearby objects. In the final system one has to admit atmospheric extremes also, which undoubtedly will influence the performance of the line as a transmission system.

Some data have been taken on the influence of rain on the line; it depends on the line parameters and the frequency, as expected. The data (Fig. 5) show an attenuation due to water accumulation that varies approximately as f^4 where f is the operating frequency.

The influence of birds and rain can be reduced or even eliminated by shielding the line. This forces the object to be sufficiently removed from the high field strength region and thus have small influence on the field. Since the field strength decay is exponential (at reasonable distances), the shield need not have a large radius. The shield considerations have many concomitants. A metallic shield would obviously shield the field electrically and the field inside the shield could not then be influenced by objects on the shield. However, there would have to be a longitudinal slit to permit coupling to

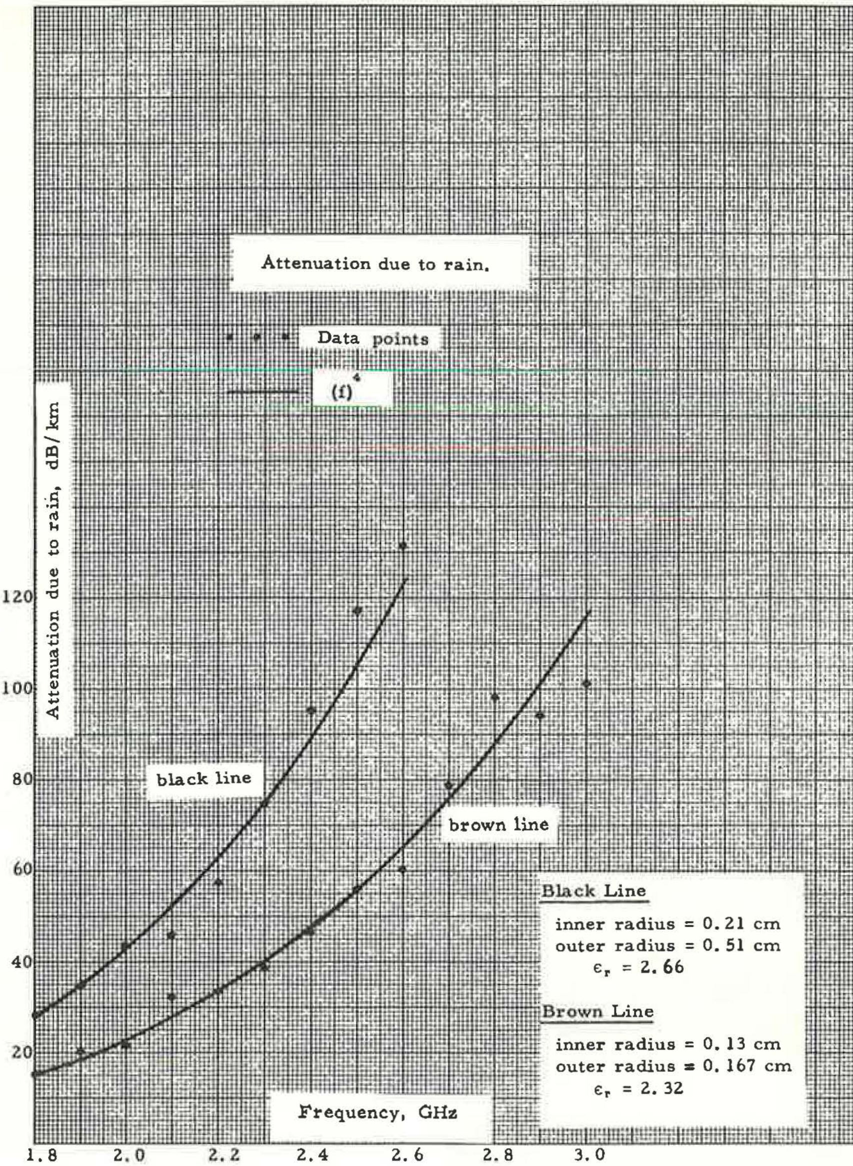


Figure 5. Data on attenuation of surface wave line due to rain.

the mobile line. In the slit region, the field would extend into the surrounding region and coupling could be accomplished. Alternately, a dielectric shield could be used that completely encloses the main line. Since the dielectric would not electrically contain the field, coupling could be accomplished in the usual manner through the shield. In either case, one changes the original line structure sufficiently that other modes could be supported and would propagate if excited. Data have been taken with a dielectric shield surrounding a G-line and the additional attenuation is small, being an additional 10 percent in one case tested. Coupling through the dielectric shield is also no problem, although higher order modes on the shield itself are known to be excited in some cases.

The radiation due to bends in the surface wave line need not be a problem. If the radius of curvature is maintained at a reasonable size, there is very little radiation at the bend. In fact, loss due to bends with 7-cm radius of curvature (which is much smaller than what would be encountered in practice) is a linear function of bend angle. For reasonable bends the loss is quite small. These data were taken using a small line at 5.0 GHz. The phase velocity reduction here was only about 2 percent, so the field decay coefficient was not as small as it might have been. The effects of rain or other objects and bends can be reduced considerably by reducing the phase velocity, thereby increasing the field concentration. This demonstrates the compromise one always faces—the choice of line parameters that gives a suitable balance between line attenuation and field concentration. Ideally, the field concentration should be sufficient to avoid substantial scattering by nearby objects and yet should be such that most of the energy is traveling in air. Indeed, the fact that the line will guide the energy with most of the energy actually existing in the surrounding air, is what makes the G-line so useful. As more and more of the energy is forced to travel in the dielectric jacket itself (by virtue of an increased field concentration factor), the losses increase because of the loss tangent of the dielectric.

CONCLUSION

The research program described here is addressed to the problem of providing a reliable communications link for high speed mass transport vehicles. The Office of High Speed Ground Transportation in the Department of Transportation, the sponsor of this work, is well aware of the crisis that exists in electromagnetic spectrum utilization; hence, they are seeking a communications link that does not radiate. The surface wave line appears to be quite promising in this respect. In this paper, data have been presented that tend to substantiate the feeling that a wired-wireless communications link with a substantial bandwidth can be provided.

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Pulse Code Modulation

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•CURRENTLY, highway communication is accomplished primarily by means of standard voice communications techniques, utilizing wire line and radio media. The capability of the voice system is being taxed to a higher and higher degree as the requirements for highway control are increased to meet the demands of our expanding highway complex. We are rapidly approaching complete saturation of the voice facilities, and we must, therefore, look to other more efficient communication techniques in order to satisfy the highway system requirements. The inherent highly redundant characteristics of voice or speech severely restrict the capability of any communications system. The amount of information transferred by voice is restricted by the nature of the speech, as well as the characteristics of the particular individual conveying the information.

A technique is required to pass reliably the maximum amount of information in the minimum time, without the necessity of a highly sophisticated communication media. The information to be transmitted will of necessity be alphanumeric information—information containing alphabet characters and numbers or numeric characters—that is, normal written or spoken information.

There are several techniques currently used to encode alphanumeric information into a form suitable for processing and/or transmission by means of a series of pulses. Some of these techniques are pulse code modulation—PCM; pulse position modulation—PPM; pulse numbers modulation—PNM; pulse amplitude modulation—PAM; and pulse duration modulation—PDM.

The pulse code modulation technique refers to the conversion of the alphanumeric information into a binary form so that the information can be represented by a series of pulses, each pulse exhibiting one of two possible levels—a binary "1" or a binary "0." These pulses are commonly referred to as "data bits" or simply "bits." PCM techniques seem to afford the best compromise from the standpoint of efficiency, bandwidth, compatibility, and ease of implementation, with respect to the other pulse techniques previously mentioned.

The pulse duration modulation technique depends on modulating or varying the relative widths of a series of pulses in a manner representing the information to be processed or transmitted. This technique and the similar pulse position modulation technique require a low distortion transmission media with a relatively wide bandpass in order to yield an acceptable error rate or transmission reliability.

The pulse numbers modulation technique is relatively inefficient, since the actual number of successive pulses is proportional to the information to be transmitted. For example, the decimal number 5 might be encoded as 5 successive pulses, or the decimal number 10 would be represented by 10 successive pulses. This technique is only used for a very limited number of applications due to the inefficiency.

The pulse amplitude modulation technique utilizes the relative amplitude of successive pulses as the information-bearing parameter. Therefore, this technique is very poor when used in an environment exhibiting excessive background or white noise. The noise also appears as amplitude changes and can be easily confused with the actual pulse amplitude. This is generally true of any type of amplitude system, and restricts its use to a relatively quiet or noise-free transmission media.

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Therefore, the PCM technique appears to be the optimum scheme because of (a) efficiency—information-carrying capability vs bandwidth; (b) immunity to noise and distortion—this is a two-level system and thus only the presence (binary "1") or absence (binary "0") of a pulse has to be detected in order to make the proper decision, which allows the data to be transmitted and received correctly over degraded or "noisy" transmission paths; (c) implementation—the modulation/demodulation and processing techniques associated with PCM are commonplace and equipment has been developed and proven for these applications; (d) compatibility—binary data is the common language of the current and future digital computer world, thereby affording a high degree of commonality and compatibility with existing digital data systems.

The PCM data or data bits are configured in a manner appropriate for the particular application or type of alphanumeric information to be processed or transmitted. The total number of bits assigned to represent the specific condition or range of alphanumeric information is a function of the required precision, resolution, or fidelity of reproduction. The number of bits assigned is called a "data word" or simply "word."

A data word of 2 bits can be arranged to represent 2^2 or 4 unique conditions; e.g., Condition 1—1,1; Condition 2—1,0; Condition 3—0,1; Condition 4—0,0. A data word of 3 bits represents 2^3 or 8 unique conditions; a data word of 4 bits represents 2^4 or 16 unique conditions, and so on. This progresses as powers of the number 2, and therefore the word length can be selected to represent as many distinct conditions as required.

Binary information has been found to be ideally suited for transmission over telephone-line facilities as well as VHF and UHF radio facilities. The information carrying capability and transmission rate can easily be expanded as future growth dictates, and the binary format can be arranged to provide the communicator with a universal language suitable for use with digital computers or processors, displays and controls, and most functions associated with a highway control and communication system. This will also allow a message to be addressed to a particular or discrete vehicle, and no other vehicle other than the addressee will respond to the message. A rather short binary coded address will provide a large number of different vehicle addresses. A 20-bit binary word would provide in excess of one million discrete addresses (2^{20} = 1,048,576 different combinations).

APPLICATIONS

The capacity of a typical two-way voice radio link, similar to the VHF and UHF systems currently used by police and metropolitan transportation systems, can be increased tremendously by utilizing a pulse code modulation technique in lieu of voice. The major problem associated with voice systems is saturation. Saturation occurs when one central or base station attempts to serve a large number of mobile units. The mobile units interfere with each other and the base station, resulting in an overall reduction in system information interchange.

Typically, a taxi communication system, which is inherently a high-traffic system, will approach saturation when one base station attempts to serve more than 70 or 80 mobile units; a metropolitan bus communication system, which is inherently a low-traffic system, will approach saturation when one base station attempts to serve more than 150 mobile units.

The incorporation of a pulse code, discrete address, polling technique can greatly increase this ratio of mobile units per base station.

The technique of sequential interrogation is a workable solution to implementing such a pulse code technique. This is accomplished by programming the central communications center or base station in a manner allowing the center to interrogate the vehicles or mobile units in predetermined sequence. The mobile unit is not permitted to transmit until the interrogation signal, containing the proper pulse code address, is received from the center or base station. The mobile unit then transmits a message, also in the form of a pulse code, to the center. When the first mobile unit completes the transmission, the center proceeds in a similar way to the second, third, and fourth unit and so forth, until all mobile units in the system have been interrogated.

This technique prevents more than one mobile unit being on the air at any one time, thereby reducing the interference and saturation problem, while allowing for the minimum exchange of information, from a large number of mobile units, to the center or base station.

In comparison to the previously mentioned metropolitan bus communication system, which approaches saturation with 150 mobile units, the application of sequential interrogation to this same system would increase the number of mobile units served by one base station from 150 to approximately 4000 units—an improvement in excess of 25-fold.

Some typical applications of PCM in highway communication and control systems might be route guidance, freeway ramp metering, passing aids on rural and other limited two-lane highways, emergency control and communications, driver assistance, overall adaptive freeway control, control of highway intersections associated with access to major highways in the urban grid, and national emergency.

Route Guidance

The implementation of a route guidance system would require some technique for identifying and locating all of the major highway intersections in the country, as well as locations along the roads or links connecting these intersections. This specific highway identification information could then be processed by a suitable computer and placed into permanent computer storage, for use in establishing optimum routing information for specific drivers and vehicles desiring to travel within the continental United States. This routing information could be supplied to the drivers prior to their embarking or actually delivered to them by electronic means throughout the duration of the travel as required.

This information could be presented in a number of ways, depending on the approach selected to identify the country's highway system.

Assuming we must identify some $4\frac{1}{2}$ million highway intersections or nodes, and the associated highways or connecting links, one approach would be to sequentially address the desired location on a specific highway in the following manner:

1. Specific state;
2. Specific zone within the state;
3. Specific intersection or node within the zone;
4. Specific highway or link accessing the intersection or node; and
5. Specific location on the highway or link.

This technique would clearly identify a specific location on any highway within the United States, by means of five basic pieces of information. This information could be converted to a pulse coded word for use in the system computers and for ease of transmission to the drivers.

The specific state could be identified by means of a 6-bit binary word—6 bits would yield 64 discrete combinations ($2^6 = 64$) which is more than adequate. The zone identification could use a 5-bit word yielding 32 possible zones. The specific intersection or node identification would require approximately 3000 addresses. This assumes equal distribution of $4\frac{1}{2}$ million intersections or nodes among the states and state zones. This would imply a binary word of 12 bits yielding approximately 4000 combinations ($2^{12} = 4096$).

The highways or links accessing the intersections or nodes may be represented by a 4-bit word yielding 16 possible combinations. The distance along the highway or link could be resolved into 2-mile increments—an 8-bit word would permit describing a distance up to 512 miles from the intersection or node ($2^8 = 256$, 256 times 2 = 512 miles). Therefore, the total binary word would contain 33 bits, as shown in Figure 1.

This 33-bit word would describe any location, on any major highway within the continental United States, to within a precision of 2 miles. Utilizing such a pulse code technique as the basis for a route guidance system would provide the driver with virtually foolproof guidance for cross-country travel, heretofore extremely difficult if not impossible to achieve.

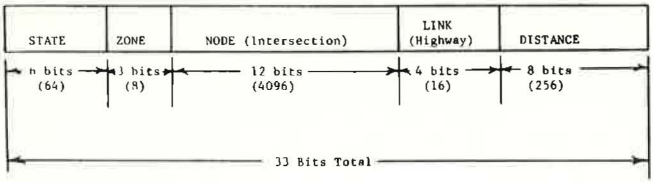

Figure 1. Highway location word.

Control of Highway Intersections

One facet of intersection control may consist of collecting information on the traffic flow, including speed, direction, and type of vehicle, and processing this information with respect to known parameters, such as road capacity, weather, and routing conditions. The results from this processed information might then be conveyed as action commands to initiate traffic patterns, allowing the driver of the vehicle to accomplish his desired goal in a simple and timely manner.

These commands must also be updated as a function of the driver response to the action commands, constituting a continuing process throughout the control cycle. Therefore, a highly reliable and economical communications system is required to deliver the necessary information or commands to the drivers of the vehicles.

The commands could be delivered to the driver via two basic routes—mass commands (the same command for a group of drivers presented on a roadside display) or commands to localized groups of drivers delivered directly to on-board visual or aural displays within the vehicle. The transmission media may be conventional radio or a proximity-coupled inductive radio. However, a pulse code technique is applicable to either media, and will provide a reliable and efficient means of encoding the information for transferral.

The on-board vehicle display may consist of a number of different "canned messages." Examples of the typical messages may be "move to left lane," "move to right lane," "remain in lane," "right turn next exit," "left turn next exit," "increase speed," "decrease speed," "stop at next intersection," "make right turn on red," "go," "stop," "proceed with caution," "ice," "accident ahead," "food and fuel ahead," and "rest area ahead."

A typical data word for controlling this display could be only 4 data bits in length, equal to 16 possible combinations. However, to allow for expansion and the necessary start/stop or synchronization functions, we may select a 9-bit word as shown in Figure 2. This word would permit the selection and display of 32 different canned or predetermined messages stored in the display unit.

The response time of the display system would be determined by the propagation time of the information, the data rate (number of bits per second transmitted), the word length, and the display reaction time. In actual practice the display reaction time would probably be the limiting factor, assuming the display to be an electromechanical device. A typical electromechanical display might be a rotating, multisided drum, comprising various film-type transparencies of the different messages. The drum would rotate the selected message into position for projection onto a frosted screen. When the drum is commanded to index, the projection source would be excited, and the selected message would appear on the screen. The total system response time would consist of the following:

1. Propagation Time—100 feet to vehicle (Negligible, Approximately 1/1000 second per 100 miles) . . . . 2×10^{-8} seconds
2. Data Word Time—9 bit word (Assume data rate of 75 bits per second) . . . . 0.12 seconds
3. Display Reaction Time (Assume 16 possible selections electromechanically, and each selection requires 0.01 seconds) . . . . 0.16 seconds

Total Time . . . . 0.28 seconds

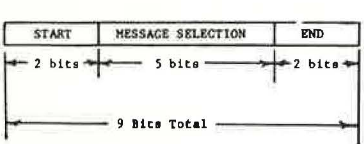

Figure 2. Vehicle display.

An extremely low data rate was selected for this example. A data rate of 75 bits per second is realizable over the most degraded transmission media; normally transmission rates in excess of 1200 bits per second are reliably achieved over a relatively poor telephone voice channel or circuit, commonly referred to as a 3KC voice circuit. Therefore, the data rate could be increased a minimum of 16 times, if required for system expansion, without a major upgrading of the transmission facility, whether telephone, radio, or inductive radio channel.

Emergency Control and Communications

The origin of emergency messages is assumed to be the vehicle or the immediate vicinity of the vehicle. The emergency communications would provide the occupants of a vehicle a means of soliciting help for various emergency conditions without leaving the vehicle or the immediate vicinity of the vehicle. This would be an invaluable aid when the emergency condition arises on a remote section of a highway in a sparsely populated area.

The messages can be "canned" or stored messages to insure a high degree of clarity, and minimize confusion. Normally, individuals involved in an emergency condition would be extremely nervous or in a state of shock and would not be able to compose and deliver a clear and meaningful aural message.

Therefore, the canned message or messages would appear to be the solution. These messages could be initiated by an individual simply depressing a push button—the button would be marked with the appropriate message heading or code. Some typical emergency messages might be "medical aid"—injury or sickness of vehicle occupant; "police"—criminal act committed, such as robbery; "stranded—send help"—vehicle immobile under extremely adverse and dangerous weather conditions; "accident"—requires medical and police aid; and "mechanical failure"—vehicle immobile due to tire or other mechanical failure, no real urgency. All of these messages should include location information as well as the type of vehicle involved. The location or position of the vehicle could be established by means of the aforementioned route guidance highway identification technique. The vehicle description—passenger car, bus, truck, etc.—could be "wired-in" the vehicle unit at the time of installation.

The same type of pulse code word as previously described for the intersection control messages would be applicable for the emergency system and would allow for future expansion. The actual method of transmission would be virtually independent of the pulse code modulation technique. However, the transmission could be by means of a VHF or UHF radio link, or could be accomplished by means of an antenna run along the actual highway. This antenna could be a single wire mounted on the roadside barricade, or actually buried beside or in the roadway. The transmission would be accomplished at an extremely low frequency in the vicinity of 12 to 500 kcs. The vehicle would contain a low-power transmitter only capable of coupling to the roadside antenna from a distance of 100 to 150 feet. The roadside antenna could couple into a remote roadside receiver or directly into a control center, if the center was physically near the highway under surveillance. Remotely located centers could have access to the receivers by means of devices connected to the low-frequency receivers, which would convert the receiver output into a form suitable for transmission over existing telephone line facilities. The center would then receive the information over these circuits.

Extending this philosophy further, the vehicle could also contain low-frequency receivers, and the roadside installations could be made to transmit as well as receive. This system could be used for voice as well as data communications, and the control center could also use an automatic interrogation technique (similar to radar ranging) to determine the distance, and hence location, of the vehicle. Any of these techniques would be extremely well suited for a pulse code modulation scheme.

Driver Assistance and National Emergency

The detail associated with communication requirements for driver assistance and national emergency operations will stem from system analysis efforts currently being performed. This analysis is intended to determine the communication requirements associated with the planning, construction, operation, and use of an integrated highway system.

However, the previously mentioned pulse code modulation techniques and applications of these techniques will surely lend themselves to the solution of any highway communication system problem.

SUMMARY

The capability of a highway communication and control system utilizing pulse code modulation techniques is virtually unlimited, and the sophistication of the system can be easily changed as future expansion dictates.

A PCM communication system can be implemented in a manner permitting economical expansion. The basic items of equipment can be designed in a manner that will prevent premature obsolescence by incorporating pulse code parameters several orders of magnitude in excess of the current requirements. The pulse code technique will provide this type of expansion capability, without the penalty of excessive cost, complexity, and physical size normally associated with system equipment employing other less-efficient data techniques.