HUMAN FACTORS REQUIREMENTS FOR REAL-TIME MOTORIST INFORMATION DISPLAYS

Vol. 5 BIBLIOGRAPHY AND SELECTED ANNOTATIONS: AUDIO SYSTEMS

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16. Abstract
This report provides a review of past studies concerned with motorist information presentation using audio and mixed mode (visual and audio) signing techniques. The first part of the report presents a bibliography (through 1976) sub-divided into the following topic areas:

A. Real-Time Motorist Information By Audio Systems
B. Highway Radio Systems
C. Speech, Hearing, and Communication Techniques
D. Audio Information: Presentation Rates, Length, Context, Format, Style
E. Masking, Loudness, and Audio Intelligibility

The latter part of the report contains selected annotations of directly relevant studies involving audio and mixed mode information presentation.

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PREFACE

This document is part of a seventeen-volume report entitled, Human Factors Requirements For Real-Time Motorist Information Displays. Titles of all volumes are shown below.

<table>
<thead>
<tr>
<th>Volume</th>
<th>FHWA-RD Number</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>78-5</td>
<td>Design Guide</td>
</tr>
<tr>
<td>2</td>
<td>78-6</td>
<td>State of the Art: Messages and Displays in Freeway Corridors</td>
</tr>
<tr>
<td>3</td>
<td>78-7</td>
<td>Summary of Systems in the United States</td>
</tr>
<tr>
<td>4</td>
<td>78-8</td>
<td>Bibliography and Selected Annotations: Visual Systems</td>
</tr>
<tr>
<td>5</td>
<td>78-9</td>
<td>Bibliography and Selected Annotations: Audio Systems</td>
</tr>
<tr>
<td>6</td>
<td>78-10</td>
<td>Questionnaire Survey of Motorist Route Selection Criteria</td>
</tr>
<tr>
<td>7</td>
<td>78-11</td>
<td>Analysis of Driver Requirements for Intercity Trips</td>
</tr>
<tr>
<td>8</td>
<td>78-12</td>
<td>Analysis of Driver Requirements for Intracity Trips</td>
</tr>
<tr>
<td>9</td>
<td>78-13</td>
<td>A Study of Physical Design Requirements for Motorist Information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Matrix Signs</td>
</tr>
<tr>
<td>10</td>
<td>78-14</td>
<td>Human Factors Evaluation of Traffic State Descriptor Variables</td>
</tr>
<tr>
<td>11</td>
<td>78-15</td>
<td>Human Factors Evaluation of Route Diversion and Guidance Variables</td>
</tr>
<tr>
<td>12</td>
<td>78-16</td>
<td>Supplement to Traffic State Descriptors and Route Diversion and Guidance Studies</td>
</tr>
<tr>
<td>13</td>
<td>78-17</td>
<td>Human Factors Evaluation of Audio and Mixed Modal Variables</td>
</tr>
<tr>
<td>14</td>
<td>78-18</td>
<td>Point Diversion for Special Events Field Studies</td>
</tr>
<tr>
<td>15</td>
<td>78-19</td>
<td>Freeway Incident Management Field Studies</td>
</tr>
<tr>
<td>16</td>
<td>78-20</td>
<td>Feasibility of Audio Signing Techniques</td>
</tr>
<tr>
<td>17</td>
<td>78-21</td>
<td>Driver Response to Diversionary Information</td>
</tr>
</tbody>
</table>
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The author also wishes to express his appreciation to Dr. Conrad L. Dudek, the Project Principal Investigator, for his advice, guidance, and review of the report.
INTRODUCTION

The first part of the report is an initial listing of references identified by the research staff as possibly having some information and data relevant to the project research objectives concerned with audio and mixed mode signing. The list of references is divided into the following classifications.

A. Real-Time Motorists Information by Audio Communication
B. Highway Radio Systems
C. Speech, Hearing, and Communication Techniques
D. Audio Information: Presentation Rates, Length, Context, Format, Style
E. Masking, Loudness, and Audio Intelligibility

The latter section of this report contains annotations of selected references. It is anticipated that additional references may be identified and annotated as the project needs dictate.
BIBLIOGRAPHY

A. Real-Time Motorist Information by Audio Communication


B. Highway Radio Systems


C. Speech, Hearing, and Communication Techniques


D. Audio Information: Presentation Rates, Length, Context, Format, Style


E. **Masking, Loudness, and Audio Intelligibility**


A. REAL-TIME MOTORIST INFORMATION BY AUDIO COMMUNICATION


A new communications system has been recently developed by the General Motors Research Laboratories for use as a driving safety aid. This system affords a means of bringing into a vehicle voice messages pertaining to emergency road conditions ahead. It utilizes the hitherto neglected induction field as a means of signal propagation and avoids the possibility of interfering with other radio services by operating at frequencies in the vicinity of 10,000 cycles per second. (author)


Communication of voice messages to motorists passing roadside stations has long been considered as an aid to safer highway travel. Electromagnetic radiation would be convenient for such a link. However, the inability to confine radiation to the exclusive use of a select group of vehicles defeats its practicality. Microwaves are more directional, but not simple.

A communication system consisting of an induction radio link operating in the vlf band may be the answer to the driver aid problem. Termed Hy-Com, the system was conceived by the General Motors Research Laboratories and uses a loop transmitting antenna alongside the road to set to an amplitude-modulated magnetic induction field over the highway adjacent to the loop. Vehicles with receivers pick up the message as they pass through the field. (author)


Although the initial freeways concept was developed on the premise that traffic would operate unhindered by traffic controls, it is now apparent that properly designed control systems will improve the freeway's ability to service the ever-increasing traffic demand. This research was initiated to consider closed-loop control systems. The surveillance schemes utilized must be capable of diverting the traffic attempting to use the congested facility onto alternate routes. Three types of closed-loop surveillance systems have been studied in depth.

Of particular interest is the second surveillance system which concerns the effectiveness of using an airborne observer to control traffic. Radio broadcasts were used to inform the motorists of the most desirable traffic routing and cost studies were made utilizing a light airplane and a helicopter.

To broaden the application of real-time freeway operations systems, the Texas Transportation Institute and the Texas Highway Department, in cooperation with the U. S. Department of Transportation, began a research project entitled "Freeway Control and Information Systems". One of the objectives of the project was to develop functional requirements for a freeway communications system. Toward this end, a questionnaire survey was conducted in the cities of Houston and Dallas. This report discusses the results of the survey which was directed at the evaluation of the following:

1. Driver attitudes toward the need for real-time freeway information
2. Potential use of and response to real-time freeway information
3. Driver preferences for mode of communication
4. The type of information desired by the freeway driver
5. Driver priorities regarding the locations where information would be most useful
6. Driver comprehension of and preferences for visual displays

(author)


This study reports on the testing and evaluation of various candidate message formats eventually to be used in audio and sign advance freeway traffic advisory systems. It also reports on subsequent interrogation of drivers tested on the UCLA Sign Tester, in the Audience Studies, Inc. Preview House, and in the UCLA Driving Simulation Laboratory. The following is a summary of conclusions.

(a) Drivers overwhelmingly approved of the concept of an advance freeway traffic advisory system despite its obvious cost.
(b) Drivers evaluated both sign and audio systems more favorably than unfavorably, but consistently indicated a preference for a sign system over an audio system.
(c) Either system will favorably modify driving behavior of the majority of drivers, but the "authoritative" nature of the sign system exhibited the greatest level of behavior modification, including frustration reduction.
(d) The content of the messages should be short, simple and contain specific, actionable information.
(e) Driver preferences for types of information to be given were (in order): lane blockage, distance to blockage or problem, length of delay, reason for delay, location of problem by ramp name.

(f) Lane numbers confused drivers (lane #1 was identified as both median and outside lane).

(g) "Middle lanes" confused drivers (identified as both median lanes and center lanes in your direction of travel).

(h) Drivers prefer the word "normal" to a blank sign as the latter was seen as being too ambiguous.

(i) It will be difficult to prepare audio messages which are neither so repetitive as to be boring, nor so complex as to be misunderstood.

(j) Messages including a reference to specific miles-per-hour tend to elicit dangerous overreaction (deceleration) from drivers.


A study of urban traffic operations was conducted on the Gulf Freeway in Houston. The study investigated those areas which give greatest promise for immediate implementation to relieve traffic congestion and to improve safety for the largest number of urban motorists. The major areas of study were: traffic control, detection and clearance of disabled vehicles, and driver communications. Although not all objectives were completed, a review of the accomplishments of the studies is presented with references to the 13 reports, five papers, and other material prepared during the course of the project. (author)


This paper is intended to serve as a technical aid in the understanding of the design of highway communication systems (also referred to as traffic surveillance and control systems). It is expected to provide background and insight into the many technical decisions which must be made for a good system design. It presents design alternatives in most cases and provides a rationale for selecting the approach which is hopefully best for any given system.

A second purpose of this paper is to indicate the present state-of-the-art (accepted techniques or practices) of the communications aspects of traffic surveillance, control, and motorist information systems.

The paper is organized into three major topics: (1) Information and Data Sources; (2) Displays; and (3) Communications. This organization
presents the reader and user with an orderly approach to the subject. Additional emphasis is placed on the topic of communications, since a detailed coverage of it was a major objective in writing this paper. (author)


Four studies on auditory messages to motorists are reported. The results in Studies 1 and 2 indicate that drivers can handle up to four units of route information successfully. When the messages contain more than four units of information, drivers make unacceptably large numbers of errors when attempting to follow a route. Study 3 showed that drivers could choose and retain general information from auditory messages in which they had an interest and that the difficulty of the message was increased as exit and route numbers were increased. Study 4 developed information on the lead distances that visual signs alerting motorists of the availability of auditory information need to be placed from the broadcast areas. (author)


Navigational messages containing from two to seven units of information were presented to three groups of subjects. One group of subjects received the messages after they had seen an alerting sign and, in response to the sign, tuned the radio to a specified frequency to receive the message (manual group). A second group received the messages automatically and aurally (automatic group). The third group received the information visually. The manual group did consistently poorer on message retention than the other two groups. There was no difference in message retention between the aural automatic group and the visual group. (author)


Various methods of providing information to the driver: a) before beginning his trip; b) during his trip to the freeway; and c) while on the freeway, have been considered and/or implemented. This report documents one of these methods: pre-trip information via a dial-in information system.

Since various information sources were available through the ongoing corridor control project, implementation and testing of this system was enhanced. Although not originally considered in the corridor project development, the sponsor's desire to test such a system was readily incorporated into the overall study. (author)

This study consists of a review of the factors which need to be considered in a complete audio transmission system which consists of the warning and the verbal message, along with any repetition of the verbal message. The general topics discussed are detection of an audio signal, intelligibility, understandability, behavior modification of drivers by verbal message, and driver opinion of audio signing.

In determining the warning tone, careful consideration must be devoted to frequency, intensity, and type of tone. Intelligibility can be improved by increasing contextual cues, avoiding bad sound combinations, and manipulating physical parameters. Comprehension is concerned with the ability of the listener to understand the meaning of the messages. The format of the message should be formal and avoid using colloquialisms. The only parameter for which the audio system rated more favorably than signs for the total audience was that for providing the most up-to-date information.


Highway advisory radio systems operating at standard broadcast frequencies offer a practical means of communicating information to motorists since perhaps more than 90 percent of all vehicles in the U. S. today are equipped with standard AM receivers. The development of such a highway radio system is, therefore, only that of the roadside transmitting system which involves the application of several well-established principles of antenna and network theory and radio-wave propagation.

The purpose of this paper is to present a brief review of the technical and engineering aspects that should be considered in the design and installation of low-power transmitting systems that are to operate at standard broadcast band frequencies. (author)


The subject of this paper is directed primarily to the mode of operation and results obtained by an integrated, multi-function, cable system for driver information and traffic surveillance. The system utilizes a specialized form of triaxial cable designed for direct burial in earth on the side of the highway, or within the roadway structure itself. Such a system has now been in successful public operation at the Los Angeles International Airport for the past year. Application of the same type of system on freeways or other heavily traveled highways also is given consideration in this paper. (author)
B. HIGHWAY RADIO SYSTEMS


While standard broadcast stations in the larger cities have been employed to supply motorists with general reports on traffic conditions, more effective methods reside in the application of localized, restricted-range transmission systems which may be installed at strategic points along highways and operated directly by the traffic authorities who carry the responsibility for control of traffic movements on specific highways. Localized radio transmission systems of this general type which confine their effective signals within a designated zone along a highway by utilizing the induction field that surrounds a wayside cable on which radio-frequency energy is impressed, have been termed "induction radio" systems. Drivers are alerted to the presence of the induction radio system and advised of the frequency employed by a distinctive sign or series of signs in advance of the radio zone. Applications of this system of information transmittal are extensive and far-reaching.


This paper discusses the Federal Communications Commission actions toward the development of radio traffic signal control. The contention is that this would proceed in a more orderly manner if specific frequencies were allocated for this purpose through the establishment of a new service. This new Traffic Signal Control Radio Service would be allocated certain frequencies or frequency bands. The main context of this article is concerned with what frequencies or frequency bands should be requested.


Driver preferences were measured through a questionnaire survey to evaluate the potential of commercial radio for providing real-time freeway traffic information to drivers in urban areas. In addition, traffic reports given by three radio stations in the Houston area were monitored to evaluate the reliability, accuracy, and timeliness of current traffic broadcasts. The results of the study suggest that commercial radio could play an important role as part of an effective real-time traffic information system for urban freeway drivers. However, traffic reports as currently broadcast by the three radio stations monitored in Houston would not be completely satisfactory for the system being considered. Improvements in the reliability and timeliness of the traffic information provided would be necessary. (author)

A method of driver-roadside communication was tested on the Atlanta Freeway System during daytime and nighttime driving activities in 1964 and 1965. The two related studies attempted to evaluate the effectiveness of roadside radio communication on behavior of the driver as related to his execution of a diverging maneuver from a freeway traffic system. The radio system, called Hy-Com, provides radio communications from the roadside to the driver and consists of a car-mounted receiver and a roadside transmitter.

Volunteer participants were randomly assigned to any one of various test conditions. Each test condition provided guidance information of varying degrees of advance and exit information by using highway signing, radio communication or combination of both. While information was being given to participants in each test condition, data on traffic characteristics of the driver were collected at various positions along the freeway and the deceleration lane prior to an exit ramp selected for the study. Time-lapse motion photography, the BPR traffic analyzer, and manual recording were used.

Analysis of variance and multiple range test techniques were used to determine differences between driver performances under different levels of information provided during the running of each test condition. The results indicated that audio messages were as effective as visual messages and when given together, the performance of test drivers was generally better than that of test drivers with only visual or audio messages. Indications were that a radio-signing system which will provide the necessary information where needed, can be effective and at the same time, avoid extensive over-signing. Additional research is required to determine the use of radio as a communication device on a system basis.

(author)


The need for a method to provide surveillance of roadways has generated research for many agencies, including the General Motors Research Laboratories (GMR). The Detroit Department of Streets and Traffic is currently operating the GM-sponsored CB Radio Driver Aid Network. This system makes possible the reporting of traffic-related information such as accidents and traffic flow interference. On the basis of earlier demonstration efforts, the system has been expanded to cover the entire Detroit system of surface streets and freeways. The specific functional aspects of the system and a description of its major technical equipment are given.
The paper discusses the results of the earlier operations, presents data on current operational activities, findings of a questionnaire survey, and reactions and conclusions resulting from these efforts. The system is viewed as providing a feasible interim solution to the problem of roadway surveillance, incident reporting, and action implementation to provide safe and efficient traffic flow. (author)


Ramp metering has proven to be an effective means of improving the operational efficiency of an over-crowded urban freeway. Freeway control systems can now prevent a breakdown under "normal" conditions. However, adequate control of demand under "abnormal" conditions, such as accidents or lane blockages, is not feasible. Real-time driver communications is therefore, necessary to increase safety and efficiency.

One method of transmitting information to the driver is through the use of commercial radio. This study discusses the results of a questionnaire survey directed toward the evaluation of commercial radio for real-time freeway communications. The conclusion is reached that commercial radio could play a vital role as part of an effective real-time traffic information system for urban freeways. (author)


The author briefly reviews the communications systems currently in operation and those proposed by highway departments for users of American highways who find themselves stranded or in need of information. The paper reports on the volunteer two-way mobile voice radio system that has been developing in the U. S. in the 27 MHz Citizens Radio Service. The author proposes that a highway communication radio service be set up by federal agencies. The principal intent of this service is for aid to the motorist and for contact with him by highway, law enforcement, and other public service agencies. It is suggested that this service be implemented on an interim basis in the 26 to 30 MHz band using voice communication and readily available, inexpensive transceivers for communication on the emergency channel 9 of the CRS and on a minimum of five adjacent channels. No change in FCC citizens Class D license should be required. In conclusion, recommendations are made for the development of the hardware and implementation of the radio system. (author)

This paper describes the experimental statewide emergency communications network utilizing the Citizens Radio Service conducted in Ohio during 1970-1971. A joint project of REACT National Headquarters and the Ohio State Highway Patrol, the program known as the Ohio REACT Emergency Network, was established as an experimental two-year program to test the effectiveness of volunteer citizens monitoring emergency communications and providing assistance to motorists in accordance with the Federal Communications Commission's establishment of channel 9 as the official emergency channel. A state director was appointed for REACT and districts were established, based on the Highway Patrol district boundaries. A district coordinator was appointed for both the Highway Patrol and REACT volunteers in each district to provide comparable levels of contact and authority. Log reports of calls received for emergencies and motorists' assistance are tabulated by computer at General Motors Research Laboratories. This paper describes the organization, presents the data gathered in the program's first year of operation, and establishes goals for the second year. (author)


The need for communication with the motorist has been concluded in various studies and analyses conducted under government sponsorship during the last decade. Collectively, the studies are diverse in subject and scope, covering many aspects of highway communication and ranging from the fundamental need to receive information to accident detection and location, reporting highway hazards, and coordination of public service agencies. It has been conservatively estimated that 50 to 75 percent of rural highway deaths need not have occurred if prompt and experienced emergency medical service had been available. Motorist communications must be provided for safety and efficiency in highway travel, in addition to the other potential benefits to the American public.

The ultimate solution to the accident assistance problem lies in a system that will enable the motorist to summon assistance from his car and be warned of hazardous conditions before reaching the point of danger. The system should also provide automatic detection and location for accidents, even if vehicle occupants are unable to do so; vehicle-to-vehicle communication to warn of approaching ambulances, fire trucks, and the like; and the capability for the highway safety system to communicate at will with vehicles requiring assistance.

Electronic advances and state-of-the-art developments can now meet these needs. The crucial task of integrating these developments into an effective national system is more political, institutional, administrative, and managerial than technical. The need is clearly demonstrated by activity of volunteer citizen groups such as REACT, who, once given the means
to communicate via two-way radio, have instinctively developed their own highway communications system. (author)


A complete Highway Advisory Information Radio (HAIR) system was developed for audibly conveying traffic advisory and emergency information to the motoring public using a low power, limited coverage roadside transmitter at dedicated frequencies of 530 kHz and 1606 kHz. Types of information conveyed include emergency messages, warning tones indicating the approach of an emergency vehicle, advisory messages to alert motorists of anomalies ahead and alternate routes, and trip needs such as information pertaining to gas, food, and lodging services. A major objective of the program was the development of special automotive receivers permitting the motorist to automatically receive the traffic messages while listening to his favorite AM or FM broadcast station. The radio transmission system utilized audio tone codes to achieve control of the automatic receivers; however, the system also permitted message reception with over 90 percent of existing AM automobile radios.

Surveys of commercial automotive AM receivers were made to determine tuning range limits and receiving sensitivities at 530 kHz and 1606 kHz. It was found that the capability of automotive AM radios to receive out-of-band signals depends almost entirely on field strength and not on the limits of tuning range. (author)


In August 1973, the Los Angeles Department of Airports initiated a program with the University of Southern California Research Center for Safety and Systems Management, to evaluate the Restricted Range Radio Information Service at Los Angeles International Airport. The intent of the study may be briefly stated in terms of the following objectives, namely:

(a) Determine the public's acceptance of the Restricted Range Radio Information System at Los Angeles International Airport.

(b) Evaluate the effectiveness of the Auditory Displays (broadcasts) as they affect traffic at Los Angeles International Airport.

(c) Provide recommendations for improvement to the present system.
For this evaluation, questionnaire-type surveys, both at the Airport and at the Pre Vue House in Hollywood, were conducted to determine the user's knowledge of the service and to gain his reactions as to its usefulness. Additionally, direct observations and tests were conducted at the Airport in an attempt to assess the listener population on a given day. The results of these findings, along with attendant conclusions and recommendations, are presented in this report.

In terms of acceptance, better than 75 percent of the "listener drivers" found the service useful, while approximately 55 percent of all motorists felt it would be useful to them in the future. Of this same sample, 52.3 percent said they would recommend the service to others. Another sample, which included a large fraction of frequent private auto motorists, indicated that 75 percent would recommend the service. Additionally, more than 56 percent of the frequent users rated the radio service good to excellent, while 19 percent rated it as having limited value, and 5 percent, no value.

The utility of the radio information system for purposes of traffic control is directly proportional to its listening audience. In this regard, the need for increasing the "knowledgeable driver" population is critical if this service is to fulfill its expectation. This is needed to insure a large enough "listening driver" population among all motorists during the peak traffic periods. Precisely the periods for which the radio information service was intended and for which times its impact for improving traffic flows is critical.


A two-year study of the performance of Ohio REACT volunteer monitors using Citizens Band (CB) radio to provide a highway and emergency communication service has been completed. The report describes how CB radio is used for aid and information purposes. Measured performance data are used to analyze monitoring coverage in the state. It is shown that in Ohio volunteer CB monitors annually contribute a public service having an economic value of approximately $10.2 million. (author)
C. SPEECH, HEARING, AND COMMUNICATION TECHNIQUES


   The theory that the interpretation of speech sounds is largely dependent upon differential sensitivity, i.e., the ability of the ear to detect small changes of pitch and intensity, is used as a basis for predicting the results of intelligibility tests. By use of empirical methods, a functional relation is obtained between the energy distribution of speech, the differential sensitivity of the ear, the masking properties of sounds, and the number of correctly perceived syllables in an articulation test. A comparison is made of the empirical functions and the corresponding fundamental speech and hearing characteristics. It was found that in most instances, computed intelligibility compared favorably with experimental results, but in a few cases large discrepancies were noted. (author)


   A method is presented for calculating the ability of a communication system to transmit speech intelligibly in the presence of noise. The total speech arriving at the ear of a listener is determined by adding the orthotelephonic gain of the system to the speech spectrum which would be produced by a talker at the eardrum of a listener at a distance of one meter. The total noise arriving at the ear is determined in terms of its spectrum level from measurements of the noise pickup of the microphone and the acoustic attenuation of the earphone cushions. The area lying between the spectrum level of the peaks of the speech and the spectrum level of the total noise arriving at the eardrum when plotted on a distorted frequency scale, determines a quantity called articulation index which can be correlated with articulation scores. Methods for determining the maximum gain permissible in the system are discussed. The validity of the method is established by comparison of calculated, with carefully measured articulation, scores. (author)


   Although the perception of speech is a psychological problem, it remained for telephone engineers interested in the adequacy of their equipment to develop procedures for the quantitative investigation of speech perception. These procedures were evolved, principally by the Bell Telephone Laboratories, without reference to the traditional problems and methods of experimental psychology. The concern was with intelligibility rather than perception, and the results were used to evaluate equipment rather than listeners.
The following topics were investigated:

(a) Acoustic Characteristics of Speech
(b) Quantitative Evaluation of Intelligibility
(c) Relation Between Intensity and Intelligibility
(d) The Masking of Speech
(e) Empirical Equation for Articulation
(f) Amplitude Selectivity
(g) Individual Differences
(h) Practical Applications

All significant findings are presented in graphical and tabular form.


Chapters 4, 15, 16, and 18 discuss the topics of acoustical speech powers, methods of measuring the recognition aspect of speech, proficiencies of talker-listener pairs, and effects of distortion on individual speech sounds. Of particular interest are the relationships exhibited between men's and women's voices as to pitch, quality, and voice power. Detailed studies are reviewed and results graphically elaborated.


This chapter is specifically concerned with speech recognition. During speech, our vocal organs produce sound waves with many different characteristics: different intensities, different durations, and different spectral components. Just because our vocal organs produce a variety of features, does not mean that they are all needed for intelligibility. What conditions are necessary for satisfactory speech recognition? Are all the components of the speech spectrum essential to recognition and, if not, which are the important ones? How far can we reduce the intensity of the speech wave without undermining intelligibility? These and similar questions are all discussed in this chapter.

Experiments for pin-pointing the speech wave features important to speech recognition were also performed. These fall into two classes. First, there are experiments in which we use the speech waves produced by a person speaking normally. We alter some of the acoustic features of this naturally produced speech, and ask someone to listen to the modified sound to determine how far its intelligibility differs from that of the original speech. In the second class of experiments, we generate a speech-like wave artificially. With little trouble, we can
separately adjust each acoustic feature of this artificially produced speech. Consequently, artificial (synthesized) speech is particularly suitable for speech recognition studies. (author)


This chapter is primarily interested in the auditory system (ear and associated neurology) from the standpoint that this is an unalterable fact; therefore, sound systems (radio transmissions) should be designed to conform most efficiently to the auditory system. Background auditory information fundamental to the development and application of these principles is reviewed.


Audio techniques for the display of information have not been utilized to the fullest extent in equipment design. Auditory signals in conjunction with visual signals, however, in some instances have demonstrated a decided advantage over either type of signal alone. The major advantage of auditory signals is the fact that an operator can act upon the information he receives without physically facing the source of the signal. The human auditory-perception system is a very capable discriminator of wanted versus unwanted sound and is ideal for sorting usable signals from noise. Certain cautions must be taken in the use of the auditory display, however.

This chapter discussed proper and improper auditory display techniques.


When feasible, of course, speech communications should be carried out under favorable conditions, uncluttered with noise. However, in many circumstances, it is not possible to reduce noise at its source. Under these and other circumstances it is necessary to look to other elements of the total communication system, rather than to the noise source, itself, for possibilities of improving the intelligibility of speech. On the engineering design side of the coin, the possibilities to consider are those of minimizing the transmission of noise if possible, improving the design of the communication equipment, and modifying the nature of the messages to be used; and on the personnel side of the coin, the possibilities are those of selection and training of talkers and receivers, where these are feasible.
The speech chain comprises different forms or levels in which a spoken message is transmitted, including a linguistic and physiological level of the speaker, an acoustic level of the transmission system, and a physiological and linguistic level of the receiver. The types of phonemes that can be generated by the human speech mechanisms are:

(a) plosives, or stops
(b) fricatives, or spirants
(c) laterals
(d) trills
(e) vowels

The English language has about 38 phonemes out of many hundreds that people can generate. Phonemes vary from one another in their spectral characteristics, including the combination of frequencies and intensities.

Speech intelligibility tests can serve such purposes as (a) to evaluate the adequacy of a communication system, (b) to determine the communication efficiency of individuals within a system, and (c) to determine hearing loss or speech.

In evaluating the adequacy of communication systems, the AI can be used to estimate the intelligibility of speech. An AI, in turn, can be converted into an intelligibility score, which is the estimated percentage of the spoken material that can be understood under a given set of conditions.

The SIL is an index of noise level (specifically the average of three octave bands); it is used as a measure of the destructiveness of noise in the reception of speech.

The NC curves are sometimes used as the basis for recommendations of permissible noise levels for specific communication situations. The intelligibility of speech under adverse conditions depends in part on the nature of the message, including its vocabulary, its context, and its phonetics.

Different types of distortion of speech can be caused (intentionally or unintentionally) by the transmission system; however, the intelligibility of speech does not depend on high fidelity. The effects of filtering depend on the frequencies that are filtered out by either high-pass or low-pass filters. Center clipping affects intelligibility much more than peak clipping.

Chapter 4 emphasizes hearing and the presentation of auditory signals. Guidelines are provided for when and how to present each type of auditory or other sensory information. The perception of sound, the problems of masking and its reduction, and the choice of single and multiple signals are covered. Some information is given on other senses as media for information presentation. Speech as a mode of information presentation is discussed in detail.

Criteria for equipment design to enable human speech communication are the major concern of Chapter 5. Measurements of fundamental speech sounds—their pressure, range, and level, as well as ways of measuring intelligibility through actual testing or through calculation, are presented. Problems of noise and reverberation, and protection against them, are also discussed as well as how components can aid intelligibility through gain control and peak clipping. Special design problems covering requirements of multi-channel listening, communication in unusual environments, through masks, and using bandwidth compression, are all considered, concluding with the human criteria of communication performance, trainability of persons, language factors influencing intelligibility, and the necessity for feedback.


A new method of roadside communication with the driver incorporates car-mounted receivers and roadside transmitter installations. The primary aims of the research project were to measure the effectiveness of this as a traffic control and driver information device, to judge its acceptability by the driving public, and to arrive at a preliminary cost for the implementation of such a system.

Half the vehicles selected were used as test group and half as control group for each of three experiments in which the test group drivers received radio information on accidents and typical maintenance activities. In the route information experiment no control group was used. Both test and control group drivers received similar information from signs and other signals where they were employed. Data on traffic flow were collected using time-lapse motion picture photography at locations just beyond the points of information reception. In addition, test vehicle operators were interviewed at the end of 10 miles of the test section to determine their reaction to the radio communication.

Results of the experiments showed that radio communication is effective in controlling vehicle speed in hazardous areas. The difference in the lateral placement distribution between the test and control vehicles immediately prior to the hazardous areas was significant in some of the experiments. The route information given in one of the experiments was
considered by drivers to be helpful and a possible future use of the radio system. Interview data revealed that the motorists considered radio communication useful and that it should be used in a variety of situations to provide a variety of information. Driver acceptance was indicated by the amount drivers were willing to pay for a radio receiver capable of receiving roadside communication, based on the assumption that this receiver would be constructed as an integral part of the usual car radio and would operate if the car radio was on or off. (author)
D. AUDIO INFORMATION: PRESENTATION RATES, LENGTH, CONTEXT, FORMAT, STYLE


The principles of effective radio speaking are set down in this paper primarily considering the important statements, studies and experiments from 1920 to 1930, concerning speaking over radio, as well as the tabulation of answers on questionnaires filled out by radio listeners. The results are discussed and presented in appendix form with interest on choice of subject, unity, sentence structure, speech length, vocabulary, volume, extraneous noises, pitch, enunciation, and pronunciation.


There is a need for research to determine the factors which influence successful styles of radio speaking. The three following problems are discussed in detail:

(a) What is the relationship between formal and informal broadcasting presentation and dialogue as to effectiveness of giving information over the radio?

(b) What is the best rate for speaking over the radio? Does it vary with the individual? For the same individual, does it vary with the material? Does it vary with the desired audience response?

(c) Should the radio speaker use a uniform rate? Or should he vary the rate as much as possible?


In this study the average syllable and word rates of speech for persons talking over the radio were determined. The average syllable rate was roughly 240 per minute and the word rate 160 per minute. Slight differences were shown to exist between the rates of delivery for speakers addressing adults and those addressing school children. Figures for news talks showed that they were delivered at a faster rate than other talks. Variations in rates were roughly the same for all classes of talks studied. (author)


The purpose of this paper is to describe a procedure for investigating the resonance properties of the vocal cavities and to summarize data
already secured. In general, the procedure involved a determination of the harmonic structure of waves selected from among those within single pitch vibrato cycles of sustained vowels. The analytical data were then treated in such a way as to throw light on the characteristics of the vocal resonators. (author)


A training program was devised for improving the intelligibility of Army-Air Force personnel in talking over the interphone and radio. The contents of the course, amount of training required, and the training requirements were determined experimentally. This paper summarizes the results of the over-all program and compares them with the improvements that accompanied "partial" training, particularly in voice loudness and precision of articulation. (author)


The author comments extensively, from his many years of experience, on the qualifications and characteristics of a good radio announcer or commentator. The problems and pitfalls of radio announcing are discussed with two critical areas being that of false impression and effective communication of ideas.


A quantitative definition for verbal context is described in this study in terms of dependent probabilities. The definition is used to construct lists of words with varying degrees of contextual determination. When short-range contextual dependencies are preserved in nonsense material, the nonsense is as readily recalled as is meaningful material. From this result it is argued that contextual dependencies extending over five or six words permit positive transfer, and that it is these familiar dependencies, rather than the meaning per se, that facilitate learning.


For many years communication engineers have used a psychophysical method called the "articulation test". An announcer reads lists of syllables,
words, or sentences to a group of listeners who report what they hear. The articulation score is the percentage of discrete test units reported correctly by the listeners. This method gives a quantitative evaluation of the performance of a speech communication system.

There are three classes of variables involved in an articulation test: the personnel, talkers and listeners; the test materials, syllables, words, sentences, or continuous discourse; and the communication equipment, rooms, microphones, amplifiers, radios, earphones, etc. The present paper is directed toward the second of these classes of variables, the test materials. The central concern can be stated as follows: Why is a stimulus configuration, a word, heard correctly in one context and incorrectly in another?

Three kinds of contexts are explored:

(a) context supplies by the knowledge that the test item is one of a small vocabulary of items,
(b) context supplied by the items that precede or follow a given item in a word or sentence,
(c) context supplied by the knowledge that the item is a repetition of the immediately preceding item.

All three kinds of context enable the listener to limit the range of alternatives from which he selects his response. The experimental problem varied the nature and amount of this contextual knowledge in order to study its influence upon perceptual accuracy. (author)


Workers in the field of speech have long been concerned with the relationship of certain variables to comprehension of meaningful material. This experiment was designed to investigate the influence of four factors which might affect the communication of such material; (1) method of presentation, whether oral or visual; (2) vocal skill of the reader in oral presentation; (3) difficulty of material presented; and (4) organization of material presented. (author)


Previous studies have shown that the amount of information transmitted with a simple one-dimensional auditory display is relatively small. This paper considers three conditions designed to increase the information transmission with elementary auditory displays. The three conditions or
variables were (1) the frequency range of tones investigated; (2) the utilization of objective reference tones presented with the unknown tone; and (3) the "dimensionality" of the display - the number of independently varying stimulus aspects of the display. Little additional gain in information transmission is associated with the first factor; a moderate gain is associated with the second; and a relatively substantial gain is associated with the third. (author)


The information transmission associated with elementary auditory displays consisting of a large number of independent stimulus aspects, e.g., the frequency or the sound level of a tone, was examined. In general, multiple stimulus encoding is a satisfactory procedure for increasing the information transmission associated with elementary auditory displays. Further, extreme subdivision of each stimulus aspect fails to produce substantial improvement in the information transmission. (author)


Experiment I studies short-term memory (STM) for auditorily-presented five-word sequences as a function of acoustic and semantic similarity. There was a large adverse effect of acoustic similarity on STM (72.5 percent) which was significantly greater (p<0.001) than the small (6.3 percent), but reliable effect (p<0.05) of semantic similarity.

Experiment II compared STM for sequences of words which had a similar letter structure (formal similarity), but were pronounced differently, with acoustically similar, but formally dissimilar words, and with control sequences. There was a significant effect of acoustic, but not of formal similarity.

Experiment III replicated the acoustic similarity effect found in Experiment I using visual, instead of auditory presentation. Again, a large and significant effect of acoustic similarity was shown. (author)


Man could not perceive speech well if each phoneme were cued by a unit sound. In fact, many phonemes are encoded so that a single acoustic cue carries information in parallel about successive phonemic segments. This reduces the rate at which discrete sounds must be perceived, but at the price of a complex relation between cue and phoneme: cues vary greatly
with context, and there are, in these cases, no commutable acoustic segments of phonemic size. Phoneme perception, therefore, requires a special decoder. A possible model supposes that the encoding occurs below the level of the (invariant) neuromotor commands to the articulatory muscles. The decoder may then identify phonemes by referring the incoming speech sounds to those commands. (author)


Lists of letters varying in length and in acoustic confusability were presented for immediate probed recall. Presentation was either visual (with nonarticulation or silent articulation). It was found that recent visual items which were articulated gave acoustic confusability effects intermediate between the heavy effects obtained when retrieval was ostensibly from an auditory after-echo and the negligible effects obtained when retrieval was ostensibly based on visual memory. These results suggest that articulation enhances the discriminability, particularly of recent items in STM, and also that visual or auditory STM can be investigated independently of STM for speech-coded information. (author)


Performance in a memory-span task using eight-letter sequences was explored as a function of presentation rate (.5, .75, 1.0, 2.0, and 3.0 sec/item) and presentation mode (visual, auditory, simultaneous visual and auditory, and mixed visual and auditory). Results indicate that performance in the mixed mode was inferior to the other three modes, but the other modes did not differ from each other. As presentation rate decreased, performance improved. These results are consistent with current theories of memory and indicate that the mode in which alphanumeric information is displayed is unimportant, provided the modes are not mixed. (author)


This chapter discusses several variables to be evaluated in the use of auditory displays. A summary of the main points is as follows:

(a) In the use of auditory displays, the signal-to-noise ratio is a more critical factor in detection of signals than signal intensity is.
(b) Auditory signals usually are more attention-getting than visual signals and, thus, lend themselves to use as warning signals.

(c) Audio warning signals in some circumstances (such as for certain Air Force systems) need to perform three functions, namely, attract attention, indicate the general nature of the emergency, and indicate the specific conditions, or suggest appropriate action. When the situation requires such a warning system, one signal component can perform the first two in combination, followed by a second signal to perform the third function.

(d) In the design of auditory displays, various principles can serve as guidelines where they are appropriate. Some of the most important are the following: compatibility (using signals that already have meaning for the purpose at hand), dissociability (discernibility from any other ongoing audio input), forced entry (signal should be such that the receiver cannot ignore any aspect of it), and invariances (the same signal should designate the same information at all times).
E. MASKING, LOUDNESS, AND AUDIO INTELLIGIBILITY


The waves of speech sounds are characterized by three quantities, amplitude, frequency and phase, all three of which are essential to the correct recognition of the sounds by an auditor. In general, the term distortion refers to relative changes in one or more of these quantities, in the process of transmitting the sound waves from speaker to auditor. Recognition in the sense used here refers to the correctness with which an auditor identifies the sound that he hears as being one, or some combination of, the fundamental speech sounds, when the combinations have no thought or meaning.

Distortion not only affects the recognizability of speech sounds, but the tonal character or naturalness of the sounds as well. The former aspect admits of a quantitative determination by means of the so-called articulation test. The latter aspect is considerably less definite and does not appear to be very simply related, at least, to the recognizability. This paper is chiefly concerned with the effects of some of the more common types of distortion, and also the effects of the presence of extraneous sound waves, such as noise, upon the recognition of speech sounds. (author)


This paper discusses a quantitative relationship which has been between loudness and masking and which has enabled the development of a formula for calculating the loudness of sound. Although this formula seems to have general application to all types of sounds, it is particularly well-suited to the complicated types which approach a continuous spectrum. The method can also be applied to single frequency tones, or sounds having only a few components, but in these cases it is more difficult to obtain the masking audiogram accurately.


Articulation tests were conducted with a large number of communication systems having band widths ranging from about one-half octave to a system covering the entire range of speech frequencies. The systems were linear and their responses were approximately uniform over the pass band, with sharp cut-offs at either end. The acoustic gain of the systems was expressed relative to the transmission of speech through one meter of air.
between talker and listener. Two spectra of masking noise were used, and each system was tested over a wide range of speech-to-noise ratios. In one group of experiments the speech was filtered before mixing with noise and in the other group both the speech and the noise were passed through the same filter. For each of the band-pass systems, a relation between syllable articulation and level of received speech was obtained. From these gain functions, families of equal articulation contours may be derived. These contours show, for example, how the gain must be changed for a given change in the band width of a system in order to maintain a constant articulation score. (author)


The characteristics of speech, hearing, and noise are discussed in relation to the recognition of speech sounds by the ear. It is shown that the intelligibility of these sounds is related to a quantity called articulation index which can be computed from the intensities of speech and unwanted sounds received by the ear, both as a function of frequency. Relationships developed for this purpose are presented. Results calculated from these relations are compared with the results of tests of the subjective effects on intelligibility of varying the intensity of the received speech, altering its normal intensity-frequency relations and adding noise. (author)


Knowledge of the ear's susceptibility to interference is obviously a matter of considerable practical value. Much of our present knowledge has grown out of the job of developing the telephone, although research on speech-communication problems in World War II has supplemented the earlier investigations. In the course of this research many different sounds were studied to determine the interference they might produce, and a review of the results shows the masking of speech to depend on three characteristics of the masking sound: (1) its intensity relative to the intensity of the speech, (2) its acoustic spectrum, and (3) its temporal continuity. A variety of sounds are reviewed which are, or might be, encountered, and in every case the disruption of vocal communication is determined by these three attributes. Human speech is most seriously masked by an uninterrupted noise which has its power concentrated in the lower third of a spectrum covering the frequency-range from 100 to 4000 or 5000 cycles. (author)

This paper concerns the effects of interrupting speech waves - turning them on and off intermittently or masking them with intermittent noise - upon their intelligibility. The effects were studied with various rates of interruption and with the speech left undisturbed various percentages of the time. Tests were conducted (1) with speech turned on and off in quiet, (2) with continuous speech masked by interrupted white noise, and (3) with speech and noise interrupted alternately, the speech wave being turned on as the noise wave was turned off, and vice versa.

(1) When the speech wave is turned on and off infrequently, the percentage of the message that is missed is approximately the same as the percentage of time the speech is off. When the interruptions are periodic and occur more often than 10,000 times per second, the interruptions do not interfere with the reception of the message. In the quiet it is easy to understand conversational speech so long as the interruptions occur more than 10 times per second.

(2) When continuous speech waves are masked by noise that is interrupted more than 200 times per second, intelligibility is independent of the interruption frequency and of the percentage of time the noise is on, provided the ratio of average speech power to average noise power is held constant. Interrupted masking noise impairs intelligibility least if the frequency of interruption is about 15 per second.

(3) When interrupted speech and interrupted noise alternate at frequencies below 10 alternations per second, the noise does not impair intelligibility. At higher frequencies of alternation the temporal spread of masking becomes appreciable.

The general features of the results are approximately the same whether the interruptions occur periodically or at random. (author)


The masking audiogram of a pure tone is complicated by phenomena that arise from the interaction of the test tone with the masking stimulus. The production of beats and of different tones results in a masking audiogram that does not represent the pattern of activity in the cochlea or nerve due to a simple masking stimulus. In the present experiments a narrow band of noise was used to mask pure tones. The "beat" heard in the immediate vicinity of the masking noise is not prominent, and a test tone higher in frequency than the band of noise is detected in terms of the characteristic pitch of that tone rather than by means of a different tone.

The extensive use of voice in present-day communications pointed to the importance of investigating the practical limits of speeded speech. This study was conducted at the University of Virginia, under contract with the United States Air Force, to determine the feasibility of speeding up speech in voice communications.

Earlier methods of speeding up recorded speech have lacked efficiency in that the intelligibility of the speech was substantially lowered by the distortion effects resulting from a frequency shift which accompanied the speed-up of the record. The analysis of the intelligibility of abbreviated speech patterns presented in this study originated out of an effort to determine an efficient method for speeding up recorded speech. In these particular experiments portions of the speech pattern were removed by means of an electronic chopping switch.


Measurements were made of the intelligibility of speech heard in noise and produced by different amounts of vocal force. Vocal force ranged from the weakest voiced whisper to a very heavy shout. The results show less than five percent deterioration in intelligibility over the range from a moderately low voice to a very loud voice (55 to 78 db in a free field at one m from the lips). Beyond these points intelligibility decreases abruptly and in a linear relation to decibel change in vocal intensity. Listener's errors are analyzed to determine the effects of the extremes of vocal force on the intelligibility of different parts of the syllable and of different vowels. (author)


For more than a decade it has been known, in a qualitative way, that the long-time average power of a speech signal in an amplitude-limited communications system can be increased materially by clipping the peaks of the speech wave and amplifying the remainder until the new peaks have the maximum allowable amplitude. This power increase can be computed from the statistical distribution for the instantaneous amplitudes of speech. Some of the available distributions have been collected and compared, and upon their showing good agreement, one of them has been used for the computation. Simple formulas show that the power increase can be neither greater than the amount of clipping, nor greater than the peak factor of speech. For 24 db of peak clipping, the power gain is about 12 db. The exact value depends upon the choice of peak factor for unclipped speech.
In practice, the actual gain in signal-to-noise ratio on peak-limited communications systems (e.g., AM and DSB radio) will be less than that computed here. (author).