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FOREWORD

The Ninth National ISA Biomedical Sciences Instrumentation Symposium was held in Milwaukee, Wisconsin, August 30 - September 1, 1971. It was sponsored jointly by the Biomedical Sciences Division and the Research Committee of the Instrument Society of America, with local arrangements made by the Milwaukee ISA Section. Five half-day sessions were devoted to those hybrid sciences that evolve at the interface where physical and medical sciences meet. A round table discussion group on the conference topics was held during the last, half-day session. This volume is a compilation of the papers delivered at the symposium.

The variety of subject matter reflects the extensive spread in Research and Application that has encompassed the field in the current year. The main research themes in this symposium were physiological monitoring and remote sensing. A special two- and one-half hour session was devoted to a panel discussion of the physiological applications of impedance plethysmography (the panel results will be published separately). Specialized technologies in clinical mass spectrometry and gas chromatography, as well as computer and display devices, were professionally covered. Important contributions were also given on the biomedical applications of pressure transducers, miniature pH electrodes, active electrodes with monolithic amplifiers, as well as the important topic of medical electrical safety.

By design, nearly all papers were selected, and all sessions were chaired and moderated, by authorities in their respective fields. It is hoped that the material covered and presented will not only bridge the communication gap between physicists and engineers on the one hand, and physicians and surgeons on the other hand, but also will find its ultimate application in the various medical and life sciences. Stimulation for this conference came from Jack Mortley, Director of the Biomed Division and Norm Huston, Vice President of the Education and Research Division. The efforts of the session chairmen (Dr. Wen Ko, Dr. Eugene Ackerman, Dr. R. D. Allison, Dr. Ken Mylrea and Dr. Roger Mark), panel moderators, and speakers made this conference the complete success that it was.

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CONSIDERATIONS IN THE DEVELOPMENT OF REMOTE HEALTH CARE SYSTEMS

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ABSTRACT

This paper presents the various factors which should be considered in the development of a system for the delivery of health care to remote areas. Future trends in health care such as the changing role of community hospitals, the acceptance and use of physician's assistants and the concept of health maintenance organizations are described. The health care requirements of a prospective user are outlined along with the characteristics of a system which would satisfy these requirements. Of major importance is the allocation of equipment and personnel according to potential usage and such that the skills and training of individuals are used to best advantage.

There is available today sufficient technology to establish practical health care systems for remote areas. However carefully designed studies are required to determine the cost-effectiveness of various combinations of personnel, equipment, communications and transportation for health care delivery. As the information becomes available health care systems can be planned to satisfy the complete health care needs of a community.

Introduction

The major problems of the health care system in our country at the present time are skyrocketing costs and unequal availability of care. Considerable national and local effort is being directed at ways to modify the health care system so as to insure that costs will not preclude the possibility of medical care for certain segments of the population. Cost is not the only factor which limits the availability of care to certain groups, however. Many rural communities and certain areas within large cities find it virtually impossible to attract and retain physicians. The reasons for this are complex, but reflect both a relative shortage of practicing physicians and their unequal distribution. The modern physician tends to avoid rural areas for a variety of social, economic, and professional reasons--hence, there are a relative lack of physicians in these areas. In general, cities have the highest concentration of physicians, but even there they tend to be unevenly distributed--resulting in certain urban population groups with less than optimal access to medical care (nursing home patients, urban poor, minority ghettos, etc.).

Clearly, improved methods for health care delivery are needed which will more effectively and efficiently utilize presently available personnel and technology.

Future Trends in Health Care Delivery

The developing pressures for improvement in the present mode of health care delivery have created considerable incentive to coordinate local, state, and federal efforts to produce a more optimal system. Trends for change are beginning to become visible.

One trend which appears to be favored by the present governmental administration is the establishment of health maintenance organizations (HMO's) for the delivery of health care. These organizations bring together a comprehensive collection of medical services which are provided to subscribers for a fixed fee paid in advance. It is felt that subscribers receive better quality health care at lower cost due in part to more optimal allocation of health care personnel and other resources within the HMO. Furthermore, the concept of prepayment establishes a built-in pressure to lower costs for care. (It would appear that competition among HMO's would be required to build in a pressure for high quality.) The systematized approach of HMO's does not in itself solve the problem of providing health care to all Americans. An additional effort is required in developing new systems for providing remote health care. The HMO concept, however, may form the basic organizational structure for such a remote health care system, and may encourage a more serious appraisal of the various mechanisms which can be utilized to extend health care coverage.

A second change which appears to be inevitable is a modification of the role of small hospitals in a large system for health care delivery. Because of the increasing complexity and cost of instrumentation, devices, and expertise required for secondary and tertiary medical care, many smaller hospitals will be financially unable to maintain their capability in these areas. It is unlikely, therefore, that smaller hospitals will continue to serve as centers for the delivery of complete medical care. Instead they will probably operate as primary health care centers with larger medical centers providing back up.

Another and possibly more significant trend is the growing acceptance by the medical profession of physician assistants. These specially trained health professionals are able to relieve physicians of many time-consuming and routine duties, thus significantly increasing the number of patients who can receive effective health care through each physician. Physician assistants are trained to obtain and assimilate data necessary for a diagnosis--including the taking of a medical history and the performance of a physical examination. In some cases, a physician assistant may be authorized to diagnose and treat patients where his competence permits, and refer more complex cases to the physician. It would appear that the more widespread use of physician assistants could result in more efficient use of equipment and personnel. However, the increased prevalence of such paraprofessionals raises problems of adequate supervision and quality control in the resultant medical care system.

A System for Delivering Health Care

From the point of view of the user, a health care system should provide the following service:

1. A program of preventive medicine which would not only act to prevent certain classes of disease through proper sanitation, immunization, and epidemiologic controls; but would also detect early signs of illness so that complications may be minimized or avoided.

2. A simple, rapid means for obtaining evaluation and treatment for minor medical problems and routine follow-up examinations. This type of care should be easily accessible, inexpensive, but thorough enough to detect the presence of more serious pathology.

3. A mechanism for obtaining more sophisticated medical care if needed. The system should include provisions for transferring patients to appropriate medical centers where required expertise and equipment is available. This implies a preplanned hierarchy of treatment centers each with the full compliment of expertise and equipment necessary for its designated capability.

4. An effective emergency care system. In case of accidents and other medical emergencies, the patient must be assured of prompt and skilled attention at the site, followed by effective transportation to an appropriate medical center.

In many regions of the country--particularly in rural communities--these requirements are not met for reasons discussed above. It is possible, however, through the capabilities of modern communications and transportation technology, and through increased use of physician assistants, to design a system of medical care for such areas which would satisfy the user requirements quite well. The system would have the following characteristics:

1. The public must have easy access to the system--i.e., by whatever means of transportation or communication are normally available the prospective user should be able to quickly and easily enter the system and receive appropriate health care. For emergency cases, the patient should enter the system at the site of the emergency and appropriate means for delivering medical care should be supplied along with transportation if necessary.

2. Dependable methods of triage should be built into the system. All requests for medical care do not require interaction with a physician. Thus, the system should ascertain as quickly as possible the status of the patient so that appropriate followup may be arranged.

3. All pertinent diagnostic and therapeutic capability should be available to the patient if required. Transportation and/or communication should be available as required to minimize patient inconvenience and expense.

4. The health care system should include a mechanism for assuring continuing interaction and education of the health care personnel.

5. Lastly, and perhaps most important is the need for a preset mode of action which insures optimal use of technology and personnel. This implies an overall set of rules under which the system operates. Personnel and institution responsibilities and limitations should be clearly defined. Furthermore, a constant monitor of "quality of care" should be incorporated into the system.

As implied previously, a system may optimize the use of existing health manpower and facilities by (1) providing a means of task separation which allows the skills and training of individuals to be used to best advantage, and (2) by allocating facilities according to potential usage.

Physicians, because of their extensive expertise will be most efficient in delivering medical care if they have ready access to the expanding armamentarium of biomedical instruments and procedures. Therefore, physicians should be located close to or in large medical centers. Patients requiring elaborate diagnostic or therapeutic procedures or extended surveillance can be moved to the medical centers where both physicians and equipment will be available.(1) Such a policy implies a screening process (triage) to determine which patients need to see a physician, what medical specialty should be consulted, and whether or not the patient needs to be transported to a different facility for further tests or treatment. A health care station in the local community manned by physician assistants and paramedical persons could operate as the front line of the health care system. It would perform triage and deliver health care to the limit of its ability. As the entry point into the system, each remote station should be capable of handling most of the routine medical care requirements which currently require a significant time committment from physicians. (Minor complaints, routine follow-up visits, well-baby check-ups, etc.) In a certain fraction of cases, the physician assistant will need a consultation with a physician. This may be obtained via a telecommunications link. The bandwidth requirements of such a link remain to be established, and are probably a function of the specific system design. Experience has already been acquired using narrow band systems, such as telephone and radio, and also wideband links (two-way interactive video).(2, 3) The communications channel not only permits consultation but also supervision and quality control by the more centrally located group of physicians. Within the next few years, there is likely to be a large increase in the number of automated procedures which can be used to obtain and analyze information from patients. As these new techniques and instruments come into being, the potential of the remote care station may be enhanced. However, the degree to which technology becomes decentralized must be decided on the basis of cost-effectiveness planning. It is not obvious, for example, that each remote clinic would be equipped with x-ray capability. On the other hand, EKG capability would seem reasonable.

Problems for Future Research

The establishment of a health care system of the sort described is not a technological problem. In general, modern bio-instrumentation, computer technology, communications technology and transportation systems are more than adequate. A careful and comprehensive systems analysis of various configurations is required to answer such questions as the following:

1. What are the bandwidth requirements for the communications channel? Clearly, this will be a function of the skill of the physician assistant, the nature of the disease population, the nature of the geography of the area, the system operating policy, etc.

2. What are the capabilities of a physician assistant? Specifically, what percentage of input patients could the physician assistant handle alone? With the added capability of remote physician consultation?

3. What are the capabilities of a system of telemedicine in medical or surgical emergencies?

4. Is there any benefit to having a physician interact with patients at a remote station via telecommunications or should all patients who require attention beyond the competence of the remote station be transported to a larger medical facility?

5. What would be the acceptibility of telemedicine to patients? M.D.'s?

6. How could the system best provide for continuing interaction among the various echelons of the medical care system for the purpose of continuing education? For example, how could a university-bound cardiologist offer an opinion on a subtle murmur in a remote patient?

These are but a few of the questions which could be answered by carefully designed studies to determine the actual requirements of the health care system. Some answers may be suggested through setting up theoretical models and simulations using the techniques of operations research. Other data will be available only from real-life situations.

Obviously, there are many factors to consider in planning a remote health care system. Furthermore, a system which satisfies the needs of a particular community of given population density, distance to medical centers, and available medical facilities may not be optimal for a different community with a different set of circumstances. What is important however, is that the systems be designed to satisfy the complete health care needs of a community by whatever combination of communications, transportation, and medical facilities is optimally cost-effective for that area.

Finally, whatever system appears most feasible or produces the greatest benefits we must remember that change is slow and laborious procedure. Thus, any methods considered for application or testing must be compatable with existing methods of health care delivery and offer assistance through modification.

Key Words

remote, health care, medical, system, planning, rural, evaluation, future, requirements, triage, transportation, personnel, hospitals, physicians, physicians assistants, health maintenance,

considerations,complete, interaction, education, telecommunications, telemedicine.

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THE AMBULATORY CARE SERVICE: NEW TOOLS FOR MEDICAL CARE DELIVERY*

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ABSTRACT

We have the conviction that patients with chronic diseases can be managed in ambulatory medical care facilities with fewer physician encounters than are traditionally required. When the medical content of chronic disease management is pre-specified in a detailed, logical format, the essential observations and activities of a patient visit can be carried out by health workers who do not require a high level of medical training, making manpower substitution possible.

Diabetes and hypertension management protocols are being tested at Beth Israel Hospital. A health worker, interacting with a computer terminal, is guided while collecting and recording clinical medical history, physical examination and laboratory examination. The physical examination items are restricted to those that can be taught and performed by people with limited medical experience. The outcome of the visit will be the decision to send the patient home or that the patient see a physician with a degree of urgency contingent on the medical condition. It is expected that the significant fraction of outcomes will be a decision to send the patient home.

Our primary objective is to permit the saving of patient-physician visits while providing high quality medical care. This must be accomplished at low cost and to the satisfaction of patient and physician. The system has a number of potential secondary benefits including the savings of time during those encounters requiring his attention; a legible, organized record; an opportunity for patient education as troublesome symptoms manifest themselves; an opportunity to educate the physician as the patient presents new medical problems; a dynamic data base for clinical research; and a means for rapidly disseminating new medical information.

In addition to chronic disease management, the same technique can be applied to the analysis and treatment of common new complaints. Examples of the work-up of abdominal discomfort will be discussed.

The detailed structure of a protocol, including its inputs and outputs, incorporates considerations of physician acceptance, psychosocial support for the patient, the limited capabilities of the health worker, and the requirement that protocols be mutually compatible. Because of these considerations, the development of a protocol is a substantial task.

Finally, the need will be established for three new instruments which would be widely used, if available: a non-threatening blood pressure determining device; a non-invasive method for establishing blood glucose; a non-invasive, non-hazardous method for establishing the existence of congestive heart failure.

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"VITAL FUNCTION TELEMETRY AS PART OF A MOBILE EMERGENCY MEDICAL CARE SYSTEM"

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ABSTRACT

This report describes a state wide communications network which can be utilized for improving the emergency medical care available to persons injured in traffic accidents on the state's highways. The report describes a radio telemetry system which has been tested in conjunction with the communication facility to relay vital function parameters from the patient to a medical center during the time the patient is enroute to the hospital.

INTRODUCTION

The National Academy of Sciences Report on Accidental Death and Disability of September 1966 emphasized the increase in highway accidents with death and injury. The State of Nebraska is presently engaged in developing a system of services designed for notification of, response to, and treatment for highway accident victims. In this system, vital function telemetry, is designed to play an intergral part in treatment of highway accident victims.

Vital function telemetry involves the transmission of various physiological parameters from an accident victim in an ambulance; ground or airborne, to a monitoring computer and physician manned monitoring station. These parameters include the ECG, heart rate, blood pressure, respiration rate and peripheral blood flow. With this information the physician will then be able to radio instructions on immediate treatment back to the ambulance and prepare a hospital emergency room for prompt action once the ambulance arrives. The computer will be used to monitor constantly the condition of the patient enroute to the hospital and signal when a dangerous trend or condition develops. Although this report deals with a feasibility study, it is hoped that the implementation of this concept of patient treatment on a day to day basis will reduce the number of fatalities occurring on Nebraska highways.

System Specifications

The principal problems effecting system development are transmission distance, bandwidth and frequency allocation, available transducers, and computer software. Each problem is discussed in detail in the following paragraphs.

Transmission Distance

Included in the total effort for aid to traffic accident victims is a consolidated state-wide communications system. This system was initially planned to serve all the communications requirements of state government.

Implicit in its design was the capability of redirecting the usage of the system during times of emergency to fulfill the total communication needs of any possible emergency situation.

The state-wide network when eventually completed will consist of a more or less elliptically shaped microwave backbone in the state with towers strategically placed such that a mobile station anywhere within the perimeter of the state may always contact one of the microwave entry points.

Ideally this would insure that a moving vehicle in one part of the state, no matter how remote, could be in continuous communications with a central monitoring facility in a hospital in any other part of the state.

Bandwidth and Frequency Allocations

Since at the present time regular voice channel circuits only may be utilized, the data channel bandwidth must be within a 300 to 3000 Hz range. This narrow band imposes significant limitations on the multiplexing of data channels. In addition to the bandwidth limitation at the present time only one frequency is officially allocated in Nebraska for both data and voice communications. Ideally the system should have one frequency for voice communications and a second duplex frequency for data. This would allow for reverse signaling to the ambulance without necessitating an interruption of data transmission. Special licensing from the FCC is necessary, however, to transmit data over voice channels.

Transducers

The use of ambulance attendant type personnel for performance of all technical operations at the accident site as well as during transportation dictates the use of simple transducer devices. In particular the use of non-distructive or non-penetrating type instrumentation is especially important.

Computer Software

The use of computer based monitoring in this application parallels the use of such machines in other kinds of intensive care monitoring facilites. The idea is, of course, to use the computer not only to monitor signals and report their deviation outside of preset limits but to correlate different kinds of data such as blood pressure, heart rate and skin temperature in such a fashion as to give warning of the development of a dangerous trend.

We have followed carefully the progress of others in the field of multiple parameter correlation but have limited our computer practice to this point to but one parameter, namely the ECG.

Hardware

(1) Radio

Considering the system specifications listed above, the mobile radio can be any FM, simplex, two-way unit available from several major manufacturers. It should be solid state, however, to allow for continuous transmission operation. The allocated frequency in the State of Nebraska at this time is 39.82 MHz. From the standpoint of atmospheric interference and long distance skip interference this is not an ideal frequency and would be clearly unusable in densly populated areas. This and closely related frequencies were dictated to us by the already existing system. The only equipment modifications required were impedance matching transformers used to match modulator and demodulator modules to the radio.

(2) Modulator and Demodulator

Although only one voice channel was available, up to four channels of physiologic data may be transmitted simultaneously using FM sub carrier multiplexing. In our system this was accomplished by using a mixer to combine the outputs of four voltage controlled oscillators. The four voltage controlled oscillators (VCO's) had sub-carrier frequencies of 1075, 1535, 1935 and 2365 Hz. Six channels may be accommodated with some reduction in data channel bandwidth. A signal of ±1v applied to the oscillators causes a frequency deviation of ±50 Hz. The four outputs of these FM modulators are combined to give a composite signal that is applied to the transmitter of the mobile radio. On the receiving end, there is a radio interface which consists of a 4-channel FM demodulator for recording the physiologic data and a computer interface for recording control signal logic and numeric information transmitted from a touch tone pad.

(3) Computer

An IBM 1800 computer was used in conjunction with this project. Since it is a process control computer it can effect outside operations by controlling switches in response to the program logic. This technique is used to control reverse signalling to the ambulance using coded tones in the 400 to 600 Hz range.

Operating Procedure

To activate the receiving end from the ambulance, a 483 Hz tone is transmitted. A discriminator on the receiving end detects the tone and causes the radio interface to "answer", which activates the 4-channel demodulator. With the use of the touch tone pad on the data transceiver, numeric patient information is entered and the computer is activated. At this time, the analog channels are entered into an A/D converter. At specific points in time the computer causes a reverse signal to be transmitted to verify to the ambulance that the inforamtion is being received and processed. Once the transmission of data has been completed, the receiving end of the system is disconnected by the computer. The disconnect is caused by a timing circuit in the radio interface which activates on receipt of a tone from the ambulance.

Transducers

Physiological parameters to be measured are the ECG, heart rate, blood pressure, respiration rate, and peripheral blood flow rate.

(1) ECG and Heart Rate

Much work has been done in a number of cities concerning telemetry of the ECG from an ambulance. Most of this work to date has been limited to transmission of one lead of ECG data. Our system will transmit the three Frank vector leads simultaneously when a comprehensive computer ECG analysis is required.

The electrodes used are similar to the type used by NASA for recording the ECG's of astronauts. Heart rate is derived from the ECG in the usual way. Each data channel has a bandwidth of 0 to 100 Hz and can be used interchangably for any of the other physiologic parameters to be transmitted.

(2) Respiration Rate and Blood Flow Rate

Respiration rate and depth can generally be measured by a thoracic pneumograph. Impedance techniques are simpler from the standpoint of application but more troublesome from the standpoint of artifact. Airway thermister probes have also been used with fair success.

Relative changes in cutaneous blood flow can be detected by a transcutaneous doppler flow meter or great toe temperature. The efficiency of these techniques and the usefulness of the transduced information have yet to be fully explored.

Computer Software

A comprehensive program for the analysis of ECG's has been in use in this laboratory on a regular basis for some time.[1] It is anticipated that future programming for the analysis of other parameters will yield similar outputs, that is, English language diagnostic statements. Modifications of this program to suit the requirements of an intermittent to continuous monitoring situation are currently being made.

CONCLUSION

Field trials of this system have been attempted from the extremities of the consolidated communications network which at this time is approximately 300 miles. The most significant problem encountered with land mobile communication and which was exaggerated with helicopter communication is interception of the mobile signal by more than one entry point simultaneously. This is true only if one frequency is employed as is the case in our tests. Multiple frequency assignments on higher frequencies should eleminate this problem.

KEY WORDS

Ambulance telemetry

Computer monitoring

Communications network

Emergency medical care

Traffic accidents

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MODELS OF REMOTE HEALTH CARE SYSTEMS

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ABSTRACT

The rationale for telemedicine systems is given and the use of queueing models in planning such systems is illustrated. One model is explored in some detail, providing estimates of the personnel requirements and capacities of telemedicine networks in terms of the skill levels of the paramedicals and the performance of the system technology. It is apparent that even rather simple analytical models can provide valuable qualitative and quantitative guidelines for system design.

INTRODUCTION

The demands on America's medical resources are large and growing. Further, a pattern of uneven distribution has emerged, with doctors and hospitals clustered in metropolitan areas, leaving large regions of the Nation in some degree of medical isolation. The problem is most acute in rural areas but even more settled regions can find themselves medically, if not physically, remote. One index of the uneven distribution of medical talent is the dependence of doctor/population ratios on population density, as shown in Figure 1. The curve shows that the most populous counties have more than three times as many physcians per capita as the least populous. There are strong personal, familial, and economic pressures supporting this urbanization of medical resources. In addition, professional concerns work against dispersion of doctors, as modern medicine becomes more dependent on the technology massed in urban centers and the quality of care becomes more dependent on intraprofessional cooperation. Increasingly, medical care delivered in isolation becomes less than optimal care.

It is widely accepted that in order to improve the quality and availability of care for all citizens, new distribution systems must evolve. Such systems must significantly extend the capabilities of individual physicians both geographically and in terms of the number of patients each can serve. It is also generally agreed that one key to success in such systems lies in the more effective use of physician assistants and other allied health workers. Technology, particularly telecommunications and data processing, may also play a significant role in the development of innovative systems for providing medical care.

One such combination of physicians, physician assistants, and communications technology has become known as "telemedicine." Telemedicine may be defined as any system which permits a physician to provide medical care at a distance. In general, this is accomplished by coupling a series of remote clinics manned by physician assistants to a supervising physician via communication channels and transportation links. Considerable responsibility for initial patient care is delegated to the physician assistant. In many cases, no direct physician involvement may be necessary. Many minor problems or routine follow-up examinations could be completely managed by the physician assistant. The communication link would function to provide adequate physician supervision, consultation, and quality control. Furthermore, the communication network may also provide for a convenient export of centrally located medical expertise, making quality care for a number of problems much more accessible than it would otherwise be in remote regions.

Telemedicine is thus an intriguing technological "fix" for a very complex and important problem. It has already been proposed as the best solution to the problem of providing medical care to remote areas of New Mexico (1). However, telemedicine systems are as yet little more than gleams in the eyes of a few innovators.

The military, of course, has practiced a form of telemedicine in emergency situations for some time, and their medics are the prototypical physician assistants. The military experience adds credibility to the concept of telemedicine but is not sufficient to justify the deployment of telemedicine systems for the purposes of

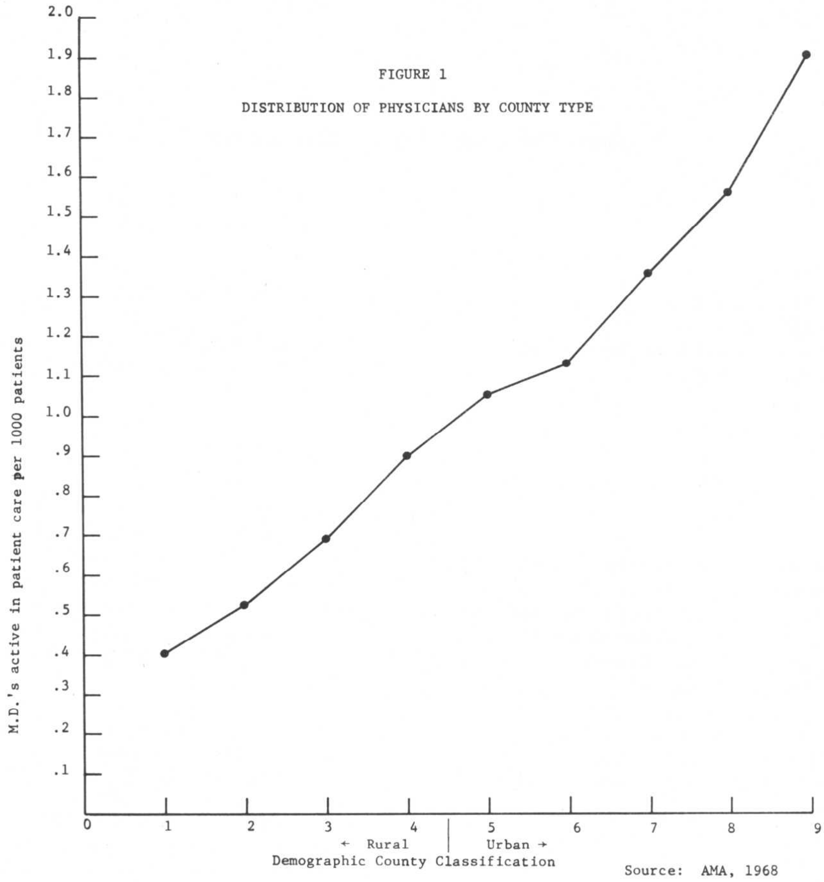

FIGURE 1

DISTRIBUTION OF PHYSICIANS BY COUNTY TYPE

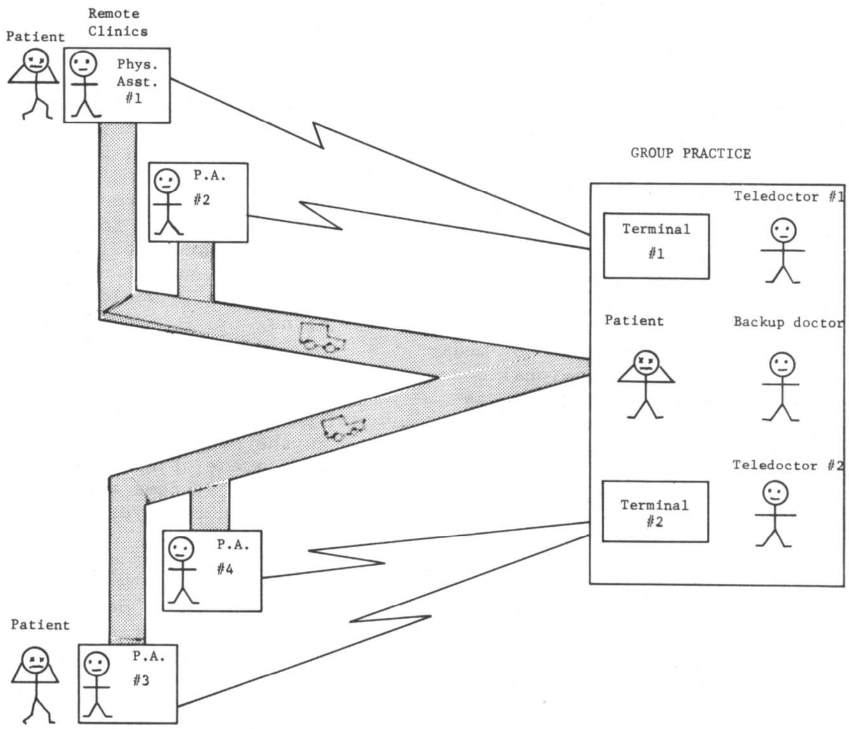

FIGURE 2 SCHEME OF A TELEMEDICINE SYSTEM

primary ambulatory care of civilian populations.

A recent experiment has seen the establishment of a two-way interactive television link between the Massachusetts General Hospital and the Logan Airport medical station, which is staffed by specially trained nurses (2). This experiment has done much to prove the clinical effectiveness of telemedicine as a vehicle of primary care for civilians.

There are a number of important open questions, however, concerning this particular marriage of bio-engineering technology and medicine. Given that telemedicine has promise, what kinds of instrumentation and communications equipment should be used in the system ? What is the relative importance of the capability of the physician assistant compared to the bandwidth of the channel linking him to his supervising teledoctor ? How does a health planner match a telemedicine system to the health needs of an area. On what bases should decisions be made ? The ultimate measure of performance of any health care system is the improvement it effects in the health of the people served. Unfortunately, in many cases such improvements may be most difficult to credit to a particular system or features of a system. Further, there are basic ambiguities in the definitions and measures of health itself. Further still, some benefits, as in preventive medicine, are dependent on the non-existence of certain conditions or the non-occurrence of certain events, and are therefore rather resistant to measurement.

More accessible to analysis are comparisons of the operational characteristics of health care systems. If given two systems which we feel will improve the health of a population, we may be able to discover before deployment that one or the other is so ornate, or so sluggish, or so inflexible, or so expensive as to be of relatively little use, and the health planning decision could be made on an operational basis. The operational criteria with which to judge systems might include the following: the number of patients per unit time who can benefit from the system; the time the patients must wait to receive care; the extent to which the system capitalizes on the special skills of its personnel; the dollar costs for the staff and hardware in the system.

Of course, these operational measures must be weighted by the goals and values of the medical decision maker. There is a fundamental trade-off between the efficient use of physician time and the efficient use of patient time which must be resolved. Intangibles are everywhere in the planning process, and hard decisions, say between two telecommunication systems, may be subject to soft and fuzzy notions of effectiveness. In this light, it is unlikely that something even as primitive as hardware evaluation can always be made clearly and simply.

Having noted the need for operations analysis of telemedicine and also the limitations of analysis, we can describe some results from a simple model of telemedicine systems.

The outstanding characteristic of telemedicine systems is that they do not exist. Hence, models can be at best planning tools for the preliminary evaluation of concepts. Hard data for model parameters will in general not be available, and experimental verification will in general be impossible. Nevertheless, models can be very valuable for exploring the consequences of guesses and preliminary decisions. Furthermore, they provide a rational guide for planning experiments and formulating questions.

THE MODEL

A simple model based on the concepts of queueing theory has been formulated for telemedicine networks. It provides quantitative estimates of many of the operational measures mentioned above, such as the throughput capacity of a given system, the expected time a patient must wait to be treated, and the idle times of the medical personnel. With the model, one can explore the sensitivities of these measures to parameters which represent the capabilities of the personnel and the hardware in a proposed realization. Many simplifying assumptions were required to make the model analytical tractable; more detailed predictions of the performance of telemedicine systems must come from computer simulation, using the analytical model as a guide.

It should be emphasized that the model we are presenting here is only one of many possible conceptions of telemedicine. A schematic diagram of our model telemedicine system is given in Figure 2. Note that the system includes medical personnel, communications channels, and a transportation network.

We imagine that several physicians united in a group practice near a small city wish to supervise the provision of primary medical care in surrounding rural areas. Satellite clinics staffed by physician assistants are established in rural communities lacking adequate medical coverage. These clinics are linked by communication channels of some sort to "terminals" (which might be anything from simple telephones to color television and data consoles) located in the group practice offices.

Some members of the group practice will be assumed to stand by at these terminals. These physicians will be called "teledoctors." In practice, each doctor in the group might serve as a teledoctor for a three-hour period, after which time he would be replaced by a colleague, who then becomes the teledoctor. For purposes of analytical simplicity, we assume that each terminal is always