Highway Network Minimum Path Selection Applied to Health Facility Planning

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EFFECTIVE PLANNING for health facilities in our increasingly urbanized society requires that planning agencies anticipate the demand for facilities, rather than merely react to present gaps in services or instances of unnecessary duplication. Both the convenience of the patients and the dispersion of physicians throughout a community should be considered in the spacing of facilities to encourage rational personal health service patterns. Knowledge of the residences of patients and their flow pattern is essential to the continuing planning process, and the hospital utilization research project has reported previously on the use of computer graphics techniques in conducting patient origin studies (*1*).

Questions of convenience for users and providers of service are not restricted to health facility planning. In city planning such questions arise with respect to the location of a wide variety of services, both private and public. Health services planning may be seen as only part of a broader spectrum of facility location planning. Theories of urban land use location, particularly market concepts and central place theory, are believed to be applicable.

In central place theory, a functional hierarchy of centers is recognized. Because of differing varieties of services offered at each center, every individual center is functionally related to the other centers; thus their market areas overlap. The lowest level centers, offering basic services, are most numerous. The highest level center offers basic services and also the widest possible range of specialized services at any one location within the total urban area. The general assumption is that consumers travel only as far as is necessary to obtain the service desired. The time spent in traveling has been found to be more important than the actual mileage involved. It is assumed that the choice of personal services (including medical services) never depends entirely on considerations of economy and convenience.

The application of travel time criteria to community institutions is one of the general policies established by the California Department of Public Health in the administration of its Hill-Harris planning program for hospitals and related facilities. A limit of 1 hour of travel time is recommended for areas of low population density, and a limit of 30 minutes of travel time is given for areas of higher population density. These criteria are considered in the establishment of hospital planning areas (*2*). The distribution of matching State and Federal funds is dependent upon a ranking of these areas in accordance with a determination of need for additional facilities and the modernization of existing institutions.

Not all groups or investigators use the same time criteria or attach the same importance to travel time. Cincinnati uses a 25-minute travel time in considerations of the need for new hospitals (*3*). Travel time is important to patients, physicians, and visitors, as Blumberg has

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pointed out (*4*). Voluntary health facility planning organizations have to take travel time into account in making decisions on hospital locations. These include social policy considerations which cannot be avoided. Such decisions should be made after analysis and conscious deliberation.

It was decided to test whether or not travel time, as indicated by urban land allocation theories, is a pertinent factor which can be quantified in the use of hospitals by patients and physicians in Santa Clara County, Calif., the area being studied.

The problem was to do this in a manner which could be replicated in other geographic areas and would allow for road network changes in the county with the passage of time. The method selected is used in general community and transportation planning to determine travel time between any two designated points within an area and is basic to many of the mathematical models used for predictive purposes. The work was done in cooperation with the State of California Division of Highways and the Santa Clara County Planning Department (*5*). A simplification of the technique used in the highway division's transportation studies was employed.

Some studies in the health field have investigated the use of facilities in relation to distance. For example, Jehlick and McNamara in a Missouri study reported in 1952 that distance appeared to be a factor in the use of physicians (*6*). Altman, in a study of western Pennsylvania, found that distance was a statistically significant factor (*7*).

A recent study of the use of public hospitals in a region of France investigated the relationship between patients' use of hospitals and highway distance from home to hospital. The authors found that a hospital's ability to attract patients decreased with distance and varied for specific services, dependent upon individual technical level and reputations. One conclusion of the study was that it would be desirable to analyze the elements composing "the cost of movement" (*8*). Cardwell and co-workers regarded the development of a method for quantifying accessibility as a necessary subject for exploration by other researchers concerned with hospital utilization (*9*).

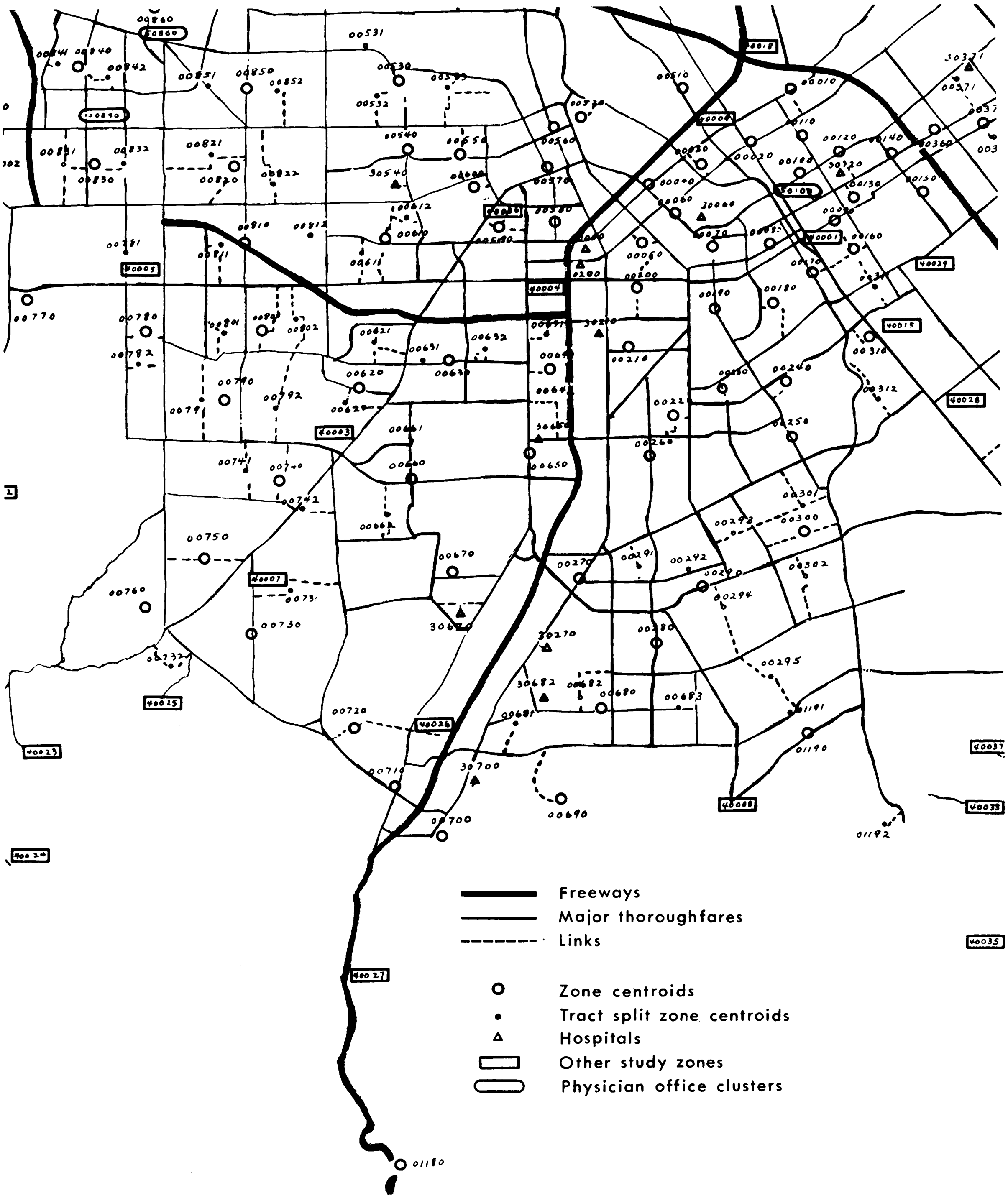
Travel time as the pertinent factor, rather than highway distance, is customarily used in transportation studies in approximating the cost of movement (*10*). The concept that distance or travel time has an effect upon the use of facilities is, of course, not new. A study of retail trade, reported in 1929, related distance and size of facility to the use of alternative shopping facilities (*11*). In part, the selection of health facility sites, appropriate to serve a given area, should reflect the size and range of services of individual facilities, the distribution of the population, and the highway network. Such factors, related to the utilization of physicians, were discussed by Garrison and co-workers in their study of highway development (*12*).

The use of transportation and travel time information in hospital and health facility planning was suggested by the American Hospital Association and the Public Health Service in a joint 1961 report (*13*). The Public Health Service noted that such information should be obtained for both the present and future, if possible (*14*).

Travel time between two points will vary with the time of day, being slower during morning and evening rush hours when the most cars are on the road. It also will vary with changes in the highway network. It is possible to prepare time-distance networks for an area both for the present and for some future date that indicate the time accessibility of any designated point to any other designated point. The preparation of such travel time networks is an essential part of most transportation studies. In California, such studies are underway in the Los Angeles, San Diego, and the San Francisco areas which contain about three-fourths of the State's population. Nationally, studies have been completed or are underway in nearly all of the larger metropolitan areas of the United States (*15*).

In this phase of the hospital utilization research project in California we have been concerned primarily with the adaptation of this more scientific method of quantifying the explanatory variable of travel time as part of the development and testing of a model of consumer spatial behavior. We have taken the existing major thoroughfare system in Santa Clara

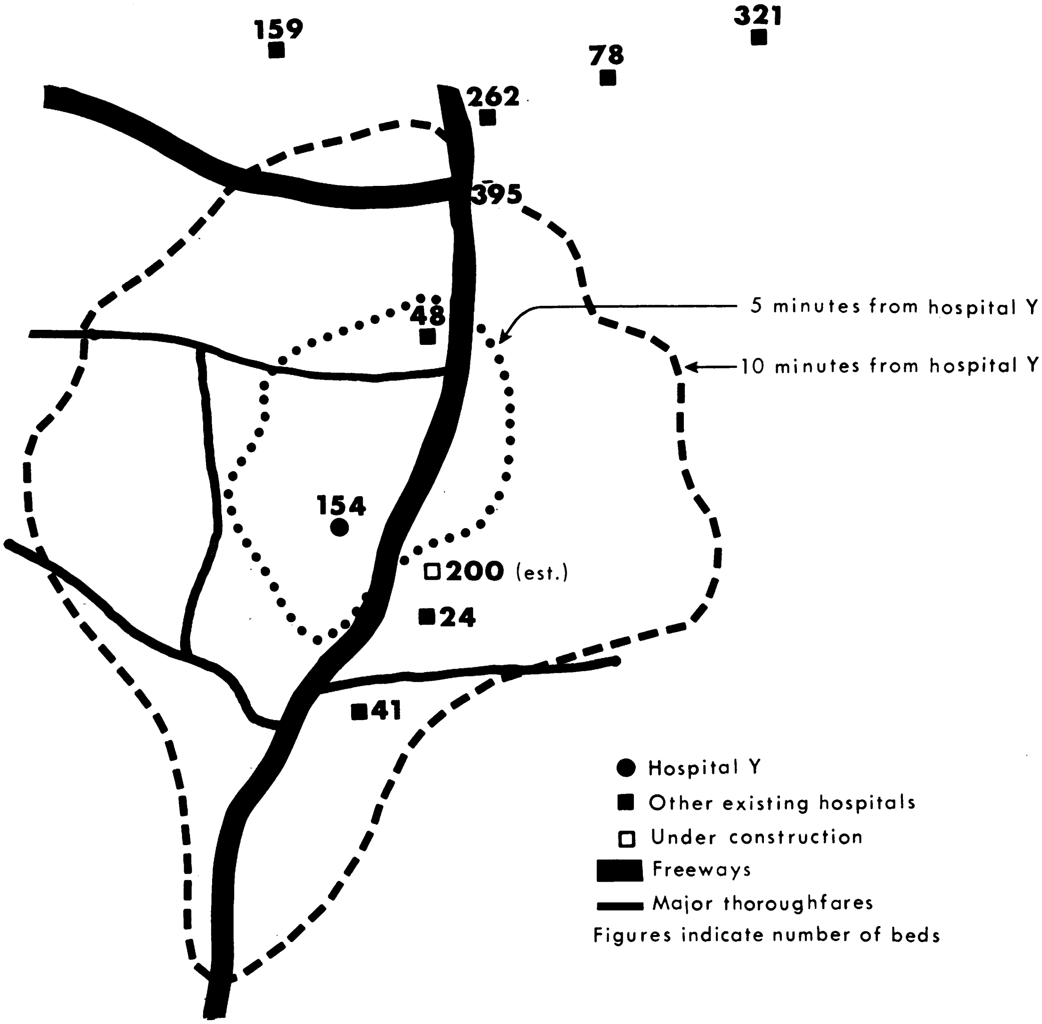
Figure 1. Portion of the Santa Clara County highway network



County with major additions to be completed by the end of 1965. The speed value of each segment of each traffic artery in the network was obtained. This network was used as the basis to determine travel paths in terms of time and distance from one point to another. These points represent study zones. The zones are based on 1960 census tracts and proposals for splitting rapidly growing tracts into two or more areas, each of which is expected to be a full census tract in the 1970 census.

Centers of population density were designated in each tract. We defined all the points leading in and out of the county as stations to be mapped. Also mapped were the existing hospitals and those under construction. Significant physician office clusters, shopping centers, colleges, parks, and other uses considered important to the community in terms of time-distance relationships were also included. Where these points were not on or close to the networks, they were connected to it by

Figure 2. Isochrons showing 5 and 10 minutes of travel time from hospital Y in Santa Clara County, Calif.



NOTE: Figures indicate acute short-term beds in hospitals. The isochrons are drawn by plotting the time values from the hospital for the mapped points shown in figure 1. By selecting those values ranging around 5 and 10 minutes, with interpolation, a sufficient number of plots are obtained to allow their connection as shown above.

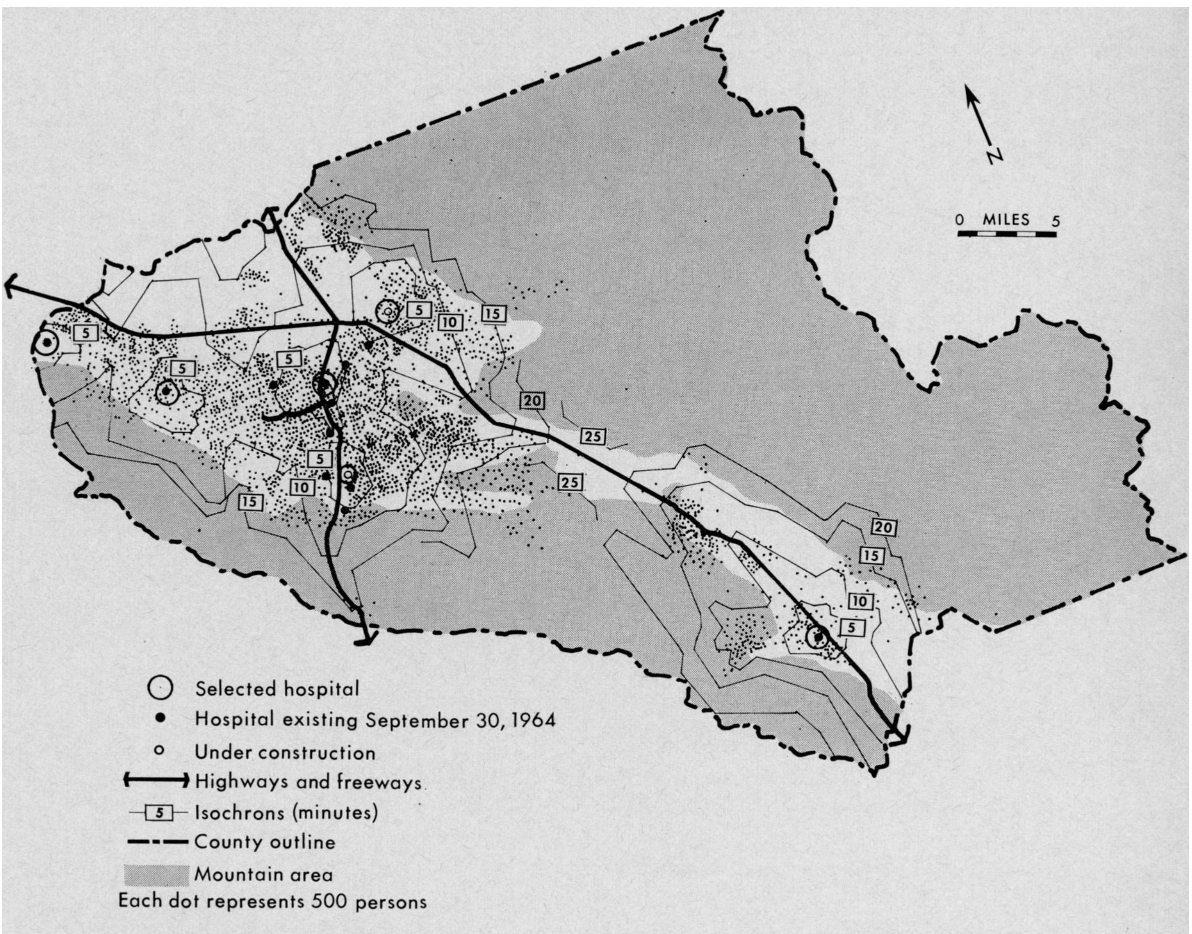
links. A total of 275 mapping points were designated in this county, which now has 127 census tracts.

After the preparation of base maps and an assignment of symbols and numbers, we transcribed the basic data on recording forms for a computer program. A portion of a finished map is shown as figure 1. The map format is suitable for use with our technique for computer mapping of data relating to hospital utilization in the county.

In this study emphasis was placed on average speed during the hour of peak traffic. Average peak-hour speed may be higher than the speed during the short time when the absolute number of vehicles on the road is greatest. "Peak-hour" speed assignments contained in this study were based upon existing data supplemented by expert judgment of local engineers and planners where data were lacking. Some automotive test runs were made as checks. More precise, standardized procedures are available (*16*). We have not differentiated for the fact that the peak hour on one segment of the network may be in the morning in one direction and in another direction in the evening. Thus, travel time is considered to be the same in both directions.

We have also simplified the situation by assuming that if two roads intersect, access is provided in all directions. This may not always be true. For example, actual road construction may allow an east-to-north movement but not allow for a north-to-east movement.

Figure 3. Computed travel time isochrons from selected hospitals in Santa Clara County, Calif., with expected 1985 distribution of population [1]



[1] Distribution as projected by the Santa Clara County Planning Department in 1959.

Using a 704 IBM computer program, a printout was obtained of all values from each 1 of the 275 mapped points to all others. What the computer did, in essence, was to choose a path from the maze of possible alternative routes, at the peak travel hour from each point out to all other points, and it is programed to choose the path taking the least time, within legal speed limits, to reach each point. Our first interest was in the elapsed time from hospitals. Figure 2 shows a sample of the application of mapping information obtained by this program. Elapsed time is shown by the lines connecting points of equal travel time, called isochrons, at 5- and 10-minute intervals. These isochrons are drawn by plotting the true values from the hospital for the mapped points shown in figure 1. By selecting the values ranging around 5 and 10 minutes, a sufficient number of plot points are obtained to allow their being connected as shown in the figure. The proximity of some existing hospitals and of one now under construction is clear.

The travel time output from the computer may also be in punchcard or tape format for additional computer use relating travel time directly to hospital utilization data and general county demographic data. In addition, it is possible to have the isochronic lines drawn by a computer-actuated data plotter. The larger metropolitan areas may find these techniques economical.

This study revealed that within the northern valley portion of the county, where some 97 percent of the people live, the maximum travel time from the eastern to western extremes of the valley is 43 to 45 minutes. Almost all of these people are within 30 minutes of each other. There were 12 general hospitals in the northern valley by September 1964, with 2 others under construction. Most of these hospitals have been built or added to since the availability of a road network plan for the county which included maps of the expected population distribution for 1985 and the roadway network expected to be in service at that date (*17*).

Figure 3 shows the location of the 14 hospitals superimposed on a simplified version of the expected 1985 distribution of population with composite isochrons from only 6 of the hospitals. These 6 were selected for their peripheral locations within the county or because they represented clusters of hospitals. The map indicates clearly that most of the future population will be within 10 minutes of 1 of these 6 hospitals and only a small percentage will be beyond 15 minutes of travel time. If composite isochrons had been drawn to include all hospitals, it is obvious that more of the population would be within 10 minutes of a hospital and much of it within 5 minutes of travel time.

The map also raises the question of whether or not the hospitals are as well located as they might be to serve the future population. The concentration of hospitals in the central portion of the northern valley does not appear to approach a pattern which relates hospital site location to the expected population distribution. Indeed, it may be expected that future population growth may lead to pressure for the establishment of new hospitals or the further expansion of existing hospitals more closely related to areas of future population growth. The use of travel time information by an areawide health facility planning agency should be helpful in putting such proposals into proper perspective within the county. A proper balance must be struck between a multiplicity of locations for small-sized and possibly inefficient distinctive patient facilities and a potentially increased travel time to larger, but fewer points of service, where economies of scale may be realized (*18*).

During the past year the Public Health Service has recognized that a formula for determining need that is based upon utilization of services is more realistic than solely the calculation of number of beds in relation to population. This emphasis upon services to people presents both an opportunity and a challenge to plan more effectively and efficiently. Certainly, not all services should be available at equal distances from a population at risk. Since the incidence of disease varies and the cost of providing specialized services and the necessary armamentarium to support them is expensive, a concept of a hierarchy of services with differing travel times seems imperative.

The method described, which has been applied primarily to an existing transportation network, can also be applied to a future network for the prediction of future travel time. One can then get an approximation of the impact of this upon travel time to health facilities from anticipated centers of population or medical office buildings. This technique will also be useful in planning ambulance and emergency room services, and centralized laboratory and other services, which in the future may be outside the walls of most hospitals. Similarly, specialized rare-event services which justify large population thresholds and longer travel times may be located to minimize average travel time for the future population. Such a locational pattern would be consistent with a policy of maximizing the use of scarce medical personnel resources and costly capital investment in installations. In this way health facility planning can prepare not only to meet present needs but may look beyond the immediate organization of the urban environment to a future when patterns of community service are improved significantly.

Summary

Effective health facility and services planning requires considerations of relative convenience for patients, physicians, and others in their travel times to alternative hospital locations. Social policy decisions regarding this call for knowledge of the locations of patients' residences, physicians' offices, and the transportation network linking them with hospitals.

Planning for personal health services may be regarded as a special instance of providing public and semipublic facilities. Urban land use location theories indicate the existence of a hierarchy of centers with differing travel times and usage rates and appear pertinent for the health field. The utilization of specific health services, quantified with respect to travel times, will allow for the formulation of predictive models as data are compiled in a variety of situations.

The computer technique used for this purpose for Santa Clara County, Calif., is essentially that used by transportation planning agencies throughout the nation. The preparation of inputs and their updating are a normal part of continuing transportation planning. Travel times have been calculated among 275 points within the county. The points include census tracts as loci of patient origins, significant clusters of physicians' offices, and hospital locations. The computer format allows the ready inclusion of roads which are not yet built.

Voluntary health planning organizations and State agencies can consider suggested alternative locations of hospitals in relation to present and expected future population distributions. This should also facilitate the selection of appropriate locations for specialized services. If the average size of hospitals in our urbanized society becomes larger to take advantage of the economies of scale, then reliable, detailed travel time information becomes even more necessary.

REFERENCES

(*1*) Drosness, D. L., Reed, I. M., and Lubin, J. W.: The application of computer graphics to patient origin study techniques. Public Health Rep 80: 33–40, January 1965.

(*2*) State of California, Department of Public Health: Hospitals for California. Berkeley August 1965, p. 15.

(*3*) Marrinson, R.: Hospital service areas: time replaces space. Hospitals 38: 52–54, Jan. 16, 1964.

(*4*) Blumberg, M. S.: The effects of size and specialism on utilization of urban hospitals. Hospitals 39: 43–47, May 16, 1965.

(*5*) State of California, Highway Transportation Agency, Division of Highways, Urban Planning Department: Work manual for computer traffic assignment program. Sacramento, Nov. 29, 1961.

(*6*) Jehlik, P. F., and McNamara, R. L.: The relation of distance to the differential use of certain health personnel and facilities and to the extent of bed illness. Rural Sociol 17: 261–265, September 1952.

(*7*) U.S. Public Health Service: Medical service areas and distances traveled for physician care in western Pennsylvania. Pt. II. PHS Publication No. 248. U.S. Government Printing Office, Washington, D.C., 1954.

(*8*) Mizrahi, A., Mizrahi, A., and Rösch G.: Les champs d'action des équipements hôpitaliers. Reprinted from Consommation—Ann Centre Recherches et Documenta No. 3, July–September 1963. Dunod, Paris, undated, p. 4.

(*9*) Cardwell, R. L., Reid, M. G., and Shain, M.: Hospital utilization in a major metropolitan area. Hospital Planning Council for Metropolitan Chicago, 1964, p. 148.

(*10*) Haikalis, G.: Economic analysis of roadway improvements. Chicago Area Transportation Study, Chicago, Dec. 31, 1962, pp. 1–2.

(11) Reilly, W. J.: Methods for the study of retail relationships. Bull. No. 2994. University of Texas, Austin, November 1929.

(12) Garrison, W. L., et al.: Studies of highway development and geographic change. Sec. V. University of Washington Press, Seattle, 1959.

(13) U.S. Public Health Service: Areawide planning for hospitals and related health facilities. PHS Publication No. 855. U.S. Government Printing Office, Washington, D.C., July 1961, p. 28.

(14) U.S. Public Health Service: Procedures for areawide health facility planning; a guide for planning agencies. PHS Publication No. 930–B–3. U.S. Government Printing Office, Washington, D.C., September 1963, p. 14.

(15) Zettel, R. M., and Carll, R. R.: Summary review of major metropolitan area transportation studies in the United States. University of California, Institute of Transportation and Traffic Engineering, Berkeley, November 1962, p. 6.

(16) National Committee on Urban Transportation: Determining travel time. Public Administration Service, Chicago, 1958.

(17) DeLeuw, Cather & Co.: Trafficways plan for Santa Clara County, California. San Francisco, January 1959 (Front pocket map and plate 9).

(18) Klarman, H. E.: The economics of health. Columbia University Press, New York, 1965, pp. 142–143.

Electronic Medical Files

In the electronic future it will be possible to maintain a complete medical profile of every person in the community and in the nation. The record, begun at birth, will be constantly updated in a central community or regional computer for instant access to the physician or hospital as required. Because so many factors will have been tabulated in advance, examination and diagnosis will be easier, more comprehensive, and more revealing than by traditional methods.

Taken together, these individual reports will form the basis of a continuing, up-to-the-minute health profile of the entire country. Any trends that may affect the public health will be noted without delay and their meaning swiftly interpreted. This could include the recurrence of certain symptoms which are the warning prelude to an epidemic.

On a longer-range basis, the correlation of vast quantities of data would facilitate definitive research not only on specific diseases but on possible relations between air pollution and cancer, or the relationship of nutrition to health and longevity, or an analysis of drug effects. Medical progress anywhere will become easily available everywhere.

By maintaining a current file on every known ailment, its symptoms, diagnosis, and treatment, the computer will also enable physicians to keep up with the flood of new medical information that overwhelms even the most dedicated among them today. It will be possible for a doctor to communicate the symptoms to the computer center and to receive at once a printed response indicating the diseases with which such symptoms are associated. Where the findings are not conclusive, the computer will request more definite information; if the symptoms are conflicting, it will suggest further tests . . . these automatic helps will not cancel out the importance of the gifted practitioner. Relieved of many routine and repetitive tasks, his time and energies will be conserved for the highly personalized functions engaging his unique skills and understanding.—*Excerpted from an address by David Sarnoff, chairman of the board, Radio Corporation of America to the American Bankers Association, National Automation Conference, New York World's Fair, July 16, 1964.*