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Measuring Physical Accessibility with Space-Time Prisms in a GIS: A Case Study of Access to Health-Care Facilities

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Measuring Physical Accessibility with Space-Time Prisms in a GIS: A Case Study of Access to Health-Care Facilities

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Abstract

Physical accessibility is a measurement of opportunities available to people in a geographical region. The purpose of such a measurement is for the redirection of regional and transportation policies toward the provision of quality of life. Public policies should provide individuals with more options to choose from, and these options should be more equally distributed among the population. A physical accessibility measure can reflect the efficiency of policies in addressing these issues. This paper presents a framework that implements the concept of space-time prisms in a Geographic Information System (GIS) for measurement of physical accessibility. The novelty of the framework is in its use of information technologies and its strength is in the ease of implementation. The analytical procedure begins with preparation of databases. An algorithm operating with a GIS is developed to define feasible opportunities within various space-time prisms by allowing spatial and temporal constraints to vary. While this enables the modeling of individual accessibility, it can also be applied to measure the traditional zonal measures. A case study utilizing data from Portland, Oregon illustrates the processes of database preparation and measurement of zonal accessibility. A hypothetical example demonstrates how individual accessibility can be measured by the proposed approach.

INTRODUCTION

Physical accessibility is a measurement of opportunities available to people in a

geographical region. Planners traditionally consider provision of accessibility to different

groups of the population as an important characteristic of an ideal transportation system.

The use of accessibility to evaluate impacts of transportation policies is being accentuated

as integrated land-use, transportation, and air quality planning gradually becomes a

common practice in metropolitan areas. Supporters of integrated planning argue that

automobile travel (i.e., a major source of air pollution) can be reduced by a smart zoning

system that provides better accessibility to shopping and services. Despite the popularity

of the concept, it is interesting to note that accessibility has historically been measured in

different ways depending on the context of the application (see Pirie, 1979 and Handy

and Niemeier, 1997 for an extensive review). In an earlier attempt to quantify

accessibility as an explanatory variable in urban growth models, Ingram (1971) measured

the accessibility of a place as a function of the physical separation (e.g., straight line

distance) from this place to other destinations of interest. This view of accessibility treats

each destination with equal importance and neglects the fact that some places may offer

more activities and services than others. Often used in spatial interaction models, the

"gravity" type of accessibility measurement devised by Hansen (1959) is conceptualized

as " the intensity of possibility for interaction" and measured by a function of both the

magnitude of activities around a place and the ease of reaching each of these activities.

Wach and Kumagai (1973) recognized that accessibility as a measurement of the quality

of urban living had received relatively little attention in regional studies as both Ingram's

and Hansen's measurements are intended for studies of geographic patterns of spatial

interaction and growth, rather than for the evaluation of transportation policies. Wach

and Kumagai proposed to measure accessibility by counting the number of opportunities

that can be reached within a given travel time or distance from a residential zone. Often

termed cumulative opportunities measures, the intention of such a measurement is to

indicate the physical accessibility of population groups to a variety of opportunities for

the redirection of regional policies toward the provision of quality of life. Although their

approach was often cited in research literature, not many planning agencies replicated it

in practice (Handy and Niemeier, 1997), as limitations in available data and operational

computer programs created difficulty for implementation on a larger scale.

Pirie (1979) noted that although the aforementioned accessibility measurements exhibit a

series of incremental improvements, they fail to account for the impacts of time

constraints imposed by both the opening hours of services and a person's daily schedules.

For example, a store within 30 minutes from one's residence can be utilized only when

the store is open and the person is free from other daily engagements. Hanson and

Schwab (1987) also observed that these measurements were often attained on an

aggregated zonal basis, which inevitably restricted their meaning and usefulness. Parallel

to the development of the above three types of measurement, Hägerstrand (1970) initiated

the time-geography approach for studies of spatial interaction with the view that

individuals rather than places are the agents migrating in time and space. Within the

framework, Hägerstrand devised space-time prisms as the analytical constructs for

visualizing the bounded region of an individual's physical reach on planar space.

Lenntorp (1976) applied space-time prisms to the measurement of accessibility which determines the number and locations of opportunities open to an individual having a particular activity program. A range of hypothetical daily activity programs were then assigned to different groups of the population so as to evaluate if the policies of interest provide good accessibility to the population groups in regions of a city. Lenntorp acknowledged that incorporating temporal elements into accessibility measures places a severe demand on data, which inevitably limits the applicability of such an approach to small-scale research or planning projects.

In the past decade, information technologies have experienced an exponential advancement in computational capability and availability of digital data. One particular branch of the technology, Geographic Information Systems (GIS), is especially suited for analysis and measurement of accessibility because of its ability to accurately represent the characteristics of transportation and activity systems in the computational processes. In addition, accompanying the rapid advancement of GIS is the profusion of digital data on opportunities of activities and services that can be easily incorporated into the analysis. Miller (1991 and 1999) and Kwan (1998) both developed sophisticated algorithms that are capable of measuring space-time accessibility with a GIS. Weber and Kwan (2002) demonstrated that measuring accessibility in a GIS can realistically account for travel time variation due to congestion in a network. O'Sullivan et al. (2000) designed a GIS application that uses isochrones (lines of equal travel time) to measure both aggregate and space-time accessibility by public transport. Drawing experience and inspiration from these applications, the objective of this paper is to present an analytical

framework that utilizes the modern information technologies for measurement of space-time accessibility on a metropolitan scale. It is proposed here to derive data on opportunities of activities and services from prevalent digital yellow-page databases. A simple algorithm that utilizes existing GIS functions is developed. While the algorithm enables the modeling of accessibility within space-time prisms, it can also be applied to conventional cumulative opportunities measures. A case study of accessibility to health-care facilities in Portland, Oregon is set up to illustrate the framework. Aggregated zonal measures replicating those designed by Wach and Kumagai are first implemented. The fallacy of the aggregate measures is illustrated with results of the analysis. The second part of the case study follows Lenntorp by setting up hypothetical activity programs to illustrate how space-time accessibility can be measured for individuals.

THE ANALYTICAL FRAMEWORK

The framework utilizes analytical functions that can be found in a typical GIS, rendering its practical applicability in regional and transportation analyses. It allows the measurement of physical accessibility to be integrated in regional transportation models. The framework can be divided into two relatively distinct processes, including the preparation of the databases and a GIS algorithm that facilitate the measurement of physical accessibility based on space-time prisms.

Databases

Three sets of input data are required for representation of the physical environment in the analysis: (1) the locations of travel origin and destination, (2) the locations and characteristics of activity opportunities, and (3) the characteristics of the travel

environment. The locations of travel origins and destinations are given by analysts as the parameters of the physical accessibility measurement and represented in the street network by the nearest nodes to their actual locations. The origin is the place around which accessibility is measured and the destinations represent the establishments containing activities or services to which accessibility is measured (e.g., accessibility to medical-care services). Inventories of opportunities to various activities and services are identified from yellow-page databases that have become a convenient and inexpensive data source in the Internet era. In such a database, businesses and services are typically categorized by the Standard Industrial Classification (SIC) code (Office of Management and Budget, 1987) in these databases. By systematically establishing a linkage between activity types and SIC categories, activities and services relevant to accessibility measurement can be identified. The locations of businesses establishments can then be geo-coded by address-matching in a GIS. Databases representing the street networks can be obtained from traffic assignment networks used in regional travel models. A traffic assignment network contains links and nodes representing streets and intersections of the actual roadway network. Each link in the network is characterized by the auto travel times required to traverse the entire length of the link in the peak and non-peak hours. A well calibrated network should reflect, to a certain degree, the variation of link travel time due to congestion. If the measurement of accessibility by other travel modes (e.g., transit) is of interest, links traveled by these alternative modes should also be coded accordingly. In this study, locations of travel origins and destinations are assigned to the closest network nodes in order to accelerate the computation process. For example, an integer field called "Hospital" is attached to the node database. The value in this field

indicates the number of hospitals closest to this node. With this special code in the network node table, measurement of physical accessibility can be implemented in a GIS as an iterative search process. It is noted that assigning points of interest to the closest network nodes inevitably diminishes the precision of travel time measurement. Some GIS provide network analysis capabilities that can measure network travel time directly from point to point thus the assignment of places to the closest nodes is not necessary.

The Algorithm

The algorithm for measuring physical accessibility is based on concepts of space-time prisms that can identify feasible opportunities under different scenarios of complex travel behavior. The algorithm is developed as an simple alternative to its more sophisticated counterparts mentioned earlier. The algorithm bootstraps two common functions in a GIS, "select by circle" and "shortest path". Given a point in space as center and a radius for searching, "select by circle" returns geographic features that are within the specified circle. "Shortest path" works with a network consisting of nodes and links. It takes two or a series of nodes as input then outputs the shortest path connecting the given nodes on the network. The algorithm first selects network nodes with relevant facilities within the vicinity of the origin using "select by circle". The shortest path connecting the origin, a selected node, and the destination is used to estimate the travel time required to reach the destination. If the travel time is within a pre-defined "budget", the destination is considered "feasible" and then contributes to a better level of accessibility. It is important to note that the use of shortest paths for feasibility checks does not necessarily reflect that individuals would always use shortest paths. The concern is to determine if a location can be physically reached. If a facility is not feasible by the shortest path, it certainly

cannot be reached within the specified travel time budget. The algorithm proceeds to examine more relevant nodes by increasing the radius of the search circle until no node satisfies the constraints. This basic principle is generally applicable for modeling various shapes of space-time prisms (i.e., each corresponding to a distinct travel pattern). Nevertheless, details of the implementation vary slightly from prism to prism. The following description of the algorithm is based on the space-time prism in Figure 1 in which the person has to return to the origin. Figure 2 illustrates the flow chart of this algorithm.

Origin coincides destination

1. Create two empty selection sets. Name one "Temporary" and the other "Feasible".

2. Locate the network node closest to the origin. Let this node be the center of the initial search circle. The radius of the initial search circle, R, is set as:

$$R = \frac{1}{2} * (\frac{Travel\ Time\ Budget}{60}) * Average\ Network\ Travel\ Speed,$$

   Travel time budget = Total time budget - Minimum duration for the activity.
   Travel time budget, total time budget, and minimum duration are in minutes. Average network travel speed is in miles per hour.

3. Select network nodes containing facilities of interest within the boundary of the search circle into the set "Temporary". If there is no facility of interest within this circle, increase the search radius arbitrarily until at least one node is selected.

4. For each node in "Temporary", calculate the network shortest path connecting the origin, the "Temporary" node, and back to the origin. Evaluate travel time on the shortest path. If it is less than the travel time budget, the node is feasible. Otherwise, it is not feasible. Add the feasible nodes into "Feasible". In cases where no additional node is selected, the algorithm terminates and concludes that nodes currently in "Feasible" are the final results.

5. Find the minimum length of the shortest paths (i.e., origin, a "Temporary" node, and the destination). If it is less than the travel time budget, it implies that there may still be other facilities outside of this circle that may meet the time constraint. Otherwise, the algorithm stops and nodes currently within "Feasible" are the final results.

6. Increase the radius of the search circle by an arbitrary length, d. Select nodes with facilities that are within the bigger circle but not in the initial search circle. This selection is essentially bounded in a ring that has a bandwidth equal to d. Replace nodes currently in "Temporary" with this selection (i.e., this selection becomes the new "Temporary"). If no node is within this ring, increase the bandwidth until at least one is selected.

7. Repeat step 4, 5, and 6 until no node in "Temporary" is in a shortest path that has a length less than the travel time budget. Nodes in "Feasible" are the final results.

Travel origins, total time budget, and durations for various activities are given by the analysts as parameters of the prisms. Because the individual has to come back to the origin at the end of the free time period, a certain portion of travel time budget is dedicated to the return trip. Thus, the radius of the initial search circle is defined as half the distance traveled in the travel time budget. The specification of the initial search circle is intended to reduce the computational time involved by incorporating extra information. A good estimate of the average network travel speed may help accelerate the algorithm. However, if such information is not available, the most appropriate assumption can be made by trial and error. The bandwidth, d, of the secondary search can also be determined by trial and error.

Origin does not coincide with destination
When the travel origin is different from the destination, changes need to be made to the second and forth steps in the algorithm. In the second step, the initial search circle needs to be modified. The network node closest to the destination also needs to be located.

The midpoint between the origin and destination is used as the center of the initial search circle. The search radius is half the Euclidean distance between the origin and the destination. In the forth step, the network shortest path is calculated by connecting the origin, a temporary destination, and then the destination.

Zonal Measurement

By definition, a zonal measurement of physical accessibility is the number of opportunities reached within a given travel time or distance from the zone centroid. Zonal measurement can be accommodated in the proposed space-time framework. Two factors in this framework are relaxed for this purpose. First, the existence of the subsequent activities is ignored. Second, the duration of staying at a location is not considered. A zonal measurement can be represented as a reversed cone in the space-time diagram (i.e., lower half of the prism in Figure 1). The number of opportunities within reach is thus enclosed in the cone's projection on the planar space, regardless if the expected activity durations extrude the cone. Because this prism is open at one end, it is treated as if the trip is not returning to the origin. In step 2 of the algorithm, the radius of the initial search circle is changed to (travel time budget / 60) * (average network travel speed). It has to be noted that the travel time budget here refers to the travel time that is used to count opportunities (e.g., 15 or 30 minutes). In step 4, for each temporary destination, the network shortest path connecting the origin and the temporary destination is evaluated. It is not required to connect back to the origin.

APPLICATIONS

Zonal Measurement of Physical Accessibility

Wachs and Kumagai (1973) applied the cumulative opportunities measures in a study of accessibility to health care services for two census tracts in Los Angeles. All relevant medical facilities in the study area were first identified and manually plotted on a map. Travel time contours were then manually plotted on the same map, originating from centroids of the census tracts. The contours enclosed all regions in the city that can be reached within 15 minutes and 30 minutes of travel from each tract. Two sets of contours were plotted, one for auto and the other for transit. Actual travel speeds on all major streets were obtained from field studies to estimate auto travel times. Published bus schedules were used to estimate transit travel times among bus stops. Additionally, a walking speed of 3 mph was used to estimate the travel times from a centroid to the closest stop and from a bus stop to a facility. Their results (Table 1) show that motorists enjoyed a much greater level of accessibility than transit riders. The authors concluded that this approach can be implemented to evaluate transportation and regional policies in a way different from conventional performance measures such as traffic volumes and travel times. It can help redirect policy-making toward provision of quality of life, which is essentially different from mobility.

The proposed framework is applied to revisit Wachs and Kumagai's measurement of zonal physical accessibility. The application also help to demonstrate the fallacy of aggregated zonal measures. Data from Portland, Oregon were used to set up a case study that illustrates the database preparation phase of the framework as well as the application

of the algorithm. All of the manual work involved was efficiently accomplished with a GIS. TransCAD (Caliper, 1996a) was adopted as the platform for its capability to combine fundamental GIS functionality with network analysis tools. It also provides a macro language for automating tasks (Caliper, 1996b). Using this language, the algorithm is programmed in a way that no manual interaction is required during the computational process. Two census tracts are selected to assess the difference in accessibility by auto and transit. The first one (census tract number 6602) is located in a suburb southwest of Portland, and the second (census tract number 31903) is located in the city of Tigard. These two tracts are approximately five miles apart (Figure 3). To measure accessibility by auto, the network database is derived from the planning network of the Portland metropolitan area. Each link is associated with peak and non-peak travel time estimated through traffic assignment analyses. A bus network is created from the transit schedules published by the Tri-County Metropolitan Transportation District of Oregon. Bus stops were geo-coded and the difference in the scheduled arrival times between two stops measures the travel time of this link. If two or more routes connect at a node, the time lag between two connecting routes is applied as a terminal time. It has to be noted that using bus schedules to estimate travel time may not be appropriate for peak hour measurements, if delay in rush hours is not reflected in the published schedules. Additional adjustment has to be made based on data collected during peak hours. Data on health care facilities are obtained from a yellow page database (CD USA, 1997). Establishments categorized with the SIC Industry Group Numbers, 801, 802, 803, 804, and 806 (clinics and offices of medical doctors, dentists, osteopathic physicians, other health practitioners, and hospitals, respectively) are included in the analysis as the health

care services provided in the physical environment. The locations of these facilities are pinpointed by the address-matching routine in a GIS. Using an enhanced street network published by the Portland METRO (Data Resource Center, 1997) as reference, selected listings were matched with a hit rate of approximately 90% (i.e., a "strict" matching criterion was adopted). All listings of health care providers are converted into a point layer after errors in the unmatched records were corrected. This layer was subsequently overlaid on top of the auto and transit networks to identify the network node closest to a health care facility on each network. If a network node is identified as closest to more than one facility, the number of health care opportunities is aggregated for the node. The network nodes closest to the centroids of the two Census tracts are identified as the origins of the measurement. The time selected for analysis is the morning peak period (i.e., 7 to 9 AM). The accessibility to health care services by auto and transit are assessed with 15 and 30 minutes of travel time budgets. The results of the analysis are summarized in Table 2. Health care facilities are grouped into 3 categories, hospital (SIC code 806), clinics of medical doctors (SIC code 801), and clinics of miscellaneous practitioners (SIC code 802, 803, and 804).

The results of the analysis show significant differences in accessibility to health care services by auto and transit. This result is similar to that found by Wachs and Kumagai in Los Angeles. Overall, residents in southwest Portland enjoy better accessibility to health care services by either mode than those in Tigard. The number of health care facilities reached by auto is much greater than that by bus. The significance of such a difference between auto and transit accessibility really depends on the extent to which

automobiles are available to those who might be seeking access to health care facilities.

Although it is not possible to make transit as mobile as auto, a way to improve the transit

system for increasing accessibility can be indicated by such an analysis. For example, for

the Census tract in Tigard, there is no hospital available within 15 minutes of transit

travel. The closest hospital is the Meridian Park Hospital in the city of Tualatin (see

Figure 3), which requires at least 28 minutes of travel time on bus alone. If it was

deemed necessary to provide people in this tract with quick access to at least one hospital

by transit, an express route offered by either the transit authority or the hospital could be

an option. In addition, because the analysis is based on the morning peak hours (during

which buses have shorter headways and the terminal time between routes is also shorter

than during off-peak hours), it can be expected that the number of health care facilities

reached by transit will decrease in the midday hours. However, this is when the non-

working population, particularly housewives and children, will most likely be left without

a car and would depend on transit to seek services. The headways of the routes leading to

major care providers thus need be adjusted to maintain accessibility during off-peak

hours.

Individual Physical Accessibility based on Space-Time Prisms
The case study in Portland illustrates how accessibility can be measured by locating

facilities within certain minutes of traveling. The strength of such a measurement is in its

ability to indicate the deficiency of the transportation/land-use systems in an aggregate

manner. It is noted that the proposed algorithm is not the only solution to the zonal

aggregate measurement. If the data on relevant facilities were identified as proposed here

(i.e., from yellow-page database), some existing GIS packages include built-in

procedures that can perform the same analysis by creating a buffer area of certain travel time or distance on a street network (ESRI, 1996). However, this operation only enables measurement of accessibility based on a single origin. There is not yet a commercial package that automates the process of locating feasible locations when the trip has to go back to the origin or to a different destination. Such capability is necessary if accessibility is to be measured at the individual level. The necessity of accounting for individual accessibility is manifested in the example of "housewives and children" discussed earlier. The aggregate measurement fails to account for the demographics of an individual household hence the inaccessibility of the non-working members is not revealed in the measurement. In addition, the availability of medical services to housewives and children is determined jointly by factors such as the list of things they have to do in the course of the day, the availability of a car, the available hours of the health care facilities, and the minimum time required for the service. If these factors were not taken into account, the importance of transit accessibility would be underestimated and the efficiency of the transit system would be overestimated.

A hypothetical example is given here to illustrate how to implement the proposed procedure to model individual accessibility based on discrete locations. In a hypothetical, one-car household, the working member of the household has to undertake a list of activities in a day (Table 3). It is assumed that this schedule represents physical constraints and cannot be relaxed. That is, 7:30 is the earliest time the person can leave home for work and the arrival time at work can be no later than 8:00. Similarly, the earliest departure time for lunch is 12:00 and the latest time to come back is 13:00. The

same principle also applies to the journey back home and the flexible hours in the evening. However, it is assumed that trips to and back from work require fewer minutes than those reserved for them. Hence, the worker can participate in activities on the way to and from work. The spouse has the entire eight hours free for participation in out-of-home activities. The activity programs of the couple can be represented in a space-time diagram as in Figure 4. The solid line segments parallel to the time axis represent times when that worker has to remain at certain places and the dashed lines represent those of the spouse. The occurrence of a prism indicates a time period in which the couple can participate in other activities n space. The slope of the non-worker's prism is steeper than that of the worker, since travel by transit is slower than auto. The proposed algorithm is applied to model opportunities available to the couple, while accounting for constraints entailed in the activity programs. A pair of locations is arbitrarily chosen as the hypothetical couple's home and work place. The home is located within the census tract 6602 (i.e., southwest Portland) and the work place is in downtown Portland. For the purpose of demonstration, it is assumed that medical services are available from 09:00 to 17:00 and an appointment is expected to take at least 40 minutes, although the real situation may vary depending on the types of services. Under this scenario, two prisms are available for the working member to receive medical services, the lunch break and journey back home. The former requires a trip back to the work place, while the latter begins at the work place and ends at home. Total time budgets for these two periods are both 60 minutes and travel time budgets are both 20 minutes. Different versions of the algorithm are applied to these two prisms based on the geographical coincidence of the

origin and destination. The result can be presented in a way similar to the cumulative opportunity measures (Table 4).

With an hour of free time available during lunch or on the way home, when open hours and other realistic constraints are taken into consideration, the space-time measures show a level of accessibility that is lower than the 15 minute zonal measures (see Table 2). The consequences of such an overestimation by the aggregate measure could be accentuated if there is a significant percentage of the population having similar activity programd. In addition, the non-worker's accessibility is presented as the number of hours required to reach at least one hospital. The minimum hours (2 hours) required to reach a hospital and return home represent the minimum level of disruption (i.e., the amount of time dedicated to travel to the activity and the activity itself) a non-working transit user from the vicinity of the hypothetical household would incur when medical-care services are sought. The larger the penalties and disruption, the less accessible a place (Pirie, 1979).

Efficiency Issues
The strength of the algorithm is the ease of implementation. Programming is inevitably necessary for automating data manipulation. Recognizing the lack of dedicated programming personnel in common planning organizations, the algorithm reduces the complexity of the program by utilizing typical GIS functions. On the other hand, this is accomplished with the cost of reduced efficiency. Considerable algorithm time is dedicated to the repeated shortest path search. Since the desired application for the proposed algorithm is accessibility measurement, a task requiring no real-time responses, the proposed algorithm trades efficiency for applicability. Instead of a formal complexity

analysis, the time required for the algorithm to work with real world data is reported here to demonstrate the algorithmic efficiency. The street network of Portland contains 18,238 links (i.e., a bi-directional street is represented by two one-way links) and 7,710 nodes, in which 754 nodes are labeled as facility nodes (i.e., medical services). During the search process of defining the 30-minute cumulative opportunities for tract 6602 (see Table2), the algorithm examined approximately 650 "Temporary" nodes. On a computer with a 400MHZ processor and 256MB of memory, this takes approximately 20 seconds. There are 328 Census Tracts in the Portland metropolitan area. Hence, the time required to extend the analysis to the whole area is less than 2 hours (i.e., 110 minutes). Although this may not be qualified as a "quick response" analysis, it should be adequate for most planning tasks with the ever-increasing computer speed.

SUMMARY AND CONCLUSIONS

A framework is developed here that applies the concept of space-time prisms to the measurement of physical accessibility at both zonal and individual levels. At the aggregate level, practitioners at Metropolitan Planning Organizations are currently engaged in the search for a practical way to include accessibility assessment as a formal step in their planning processes (Handy and Niemeier, 1997). The case study in Portland illustrates how the proposed framework can be implemented within a GIS to accomplish this. The procedure avoids a large level of effort in data preparation and programming, which is usually the obstacle in bridging the gap between research and practice. Although two databases, the transit network and health care facilities, have to be created for this analysis, such databases are becoming common in practice. There is an increasing number of transit authorities using GIS to plan routes. Geo-coded databases of various facilities and services are also becoming available. Evidence can be found on various web sites that allow users to lookup yellow-page listings and driving directions. The transportation network database is derived from a traffic assignment analysis and is used to estimate auto travel times, thus the measurement of accessibility by auto can be incorporated as an additional step in the conventional four-step planning process. This provides an alternative performance measure to traffic volumes for evaluating various transportation/land-use policies. If multi-modal planning is needed, the analysis of accessibility by transit can also be incorporated. It can reveal the deficiencies in the transit system and indicate potential ways for improvement.

In the past decade, conventional travel demand models experienced difficulties in meeting the strict requirements placed by legislation. Activity-based models, which originated from Hägerstrand's initial proposal, have emerged as a potential basis for the next generation of transportation forecasting models. For example, Portland METRO is currently testing an activity-based forecasting procedure (Los Alamos National Laboratory, 2001), which is capable of producing activity schedules. As demonstrated with the hypothetical activity program, the proposed procedure holds potential to be used as an instrument for accessibility assessment in an activity-based framework. Typical activity programs can be derived from activity/travel surveys for different groups of the population in parts of a city. Such an application can provide insight on how various policies affect the accessibility of individuals with certain socio-demographic characteristics. However, if appropriate programming support can be obtained, a more efficient and sophisticated algorithm such as those mentioned previously can be implemented within the program to handle the considerable number of individual records.

REFERENCES

Caliper Corporation.(1996a) *TransCAD Version 3.0 User's Guide*, Caliper Corporation, Newton, MA.

Caliper Corporation. (1996b) *GISDK Programmer's Guide*, Caliper Corporation, Newton, MA.

CD USA (1997) Yellow Pages USA Deluxe, CD USA Corporation, Omaha, NE.

Data Resource Center (1997) *Regional Land Information System Lite*. Data Resource Center, Portland Metro, Portland, Oregon

ESRI (1996) *ArcView Network Analyst* Environmental Systems Research Institute, Redland, CA.

Hägerstrand, T. (1970) What About People In Regional Science? *Papers of the Regional Science Association*, 24, pp. 7-21.

Handy, S. L., and Niemeier, D. A. (1997) Measuring Accessibility: An Exploration Of Issues And Alternatives. *Environment and Planning A*, 29, pp. 1175-1194.

Hansen, W.G. (1959) How Accessibility Shapes Land Use. *Journal of the American Institute of Planners* , 25, pp. 73-76.

Hanson, S. and Schwab, M. (1987) Accessibility and intraurban travel. *Environment and Planning A*, 19, pp. 735-748.

Ingram, D. R. (1971) The Concept of Accessibility: A Search for an Operational Form. *Regional Studies*, 5, pp. 101-107.

Kwan, M.-P. (1998) Space-Time And Integral Measures Of Individual Accessibility: A Comparative Analysis Using A Point-Based Framework. *Geographical Analysis*, Vol. 30, No. 3, pp. 191-216.

Lenntorp, B. (1976) Paths in space-time environments: a time-geography study of movement of possibilities of individuals. *Lund Studies in Geography*, B, 44. Gleerup, Lund, Sweden.

Los Alamos National Laboratory (2001) Transportation Analysis Simulation System Portland Study Report. Available for download at: http://transims.tsasa.lanl.gov

Miller, H. (1991) Modeling Accessibility Using Space-Time Prism Concepts Within Geographical Information Systems. *International Journal of Geographical Information Systems*, 5, pp. 287-301.

Miller, H. (1999) Measuring space-time accessibility benefits within transportation networks: basic theory and computational procedures. *Geographical Analysis*, v31, pp. 187-212.

Office of Management and Budget. (1987) *Standard Industrial Classification Manual.* Office of Management and Budget, Executive Office of the President, Washington, D. C.

O'Sullivan, D., Morrison, A., and Shearer, J. (2000) Using desktop GIS for the investigation of accessibility by public transport: An isochron approach. *International Journal of Geographical Information Science*, 14, 2002, pp. 85-104.

Pirie, G. H. (1979). "Measuring accessibility: A Review and Proposal." *Environment and Planning A*, Vol. 11, pp. 299-312.

Wachs, M. and Kumagai, T. G. (1973) Physical Accessibility As A Social Indicator. *Socio-Economic Planning Science*, 7, pp. 437-456.

Weber, J. and Kwan, M.-P. (2002) Brining time back in: a study on the influence of travel time variations and facility opening hours on individual accessibility. The Professional Geographer, 54(2), 2002, pp. 226-240.

TABLE 1 PHYSICAL ACCESSIBILITY TO HEALTH CARE OPPORTUNITIES FOR TWO SELECTED CENSUS TRACTS IN LOS ANGELES

15 MINUTES

ORIGIN	SOUTH CENTRAL LOS ANGELES (TRACT 2392)		BELL GARDENS (TRACT 5341)	
MODE	AUTO	TRANSIT	AUTO	TRANSIT
HOSP_CLINC[a]	335	11	285	18
GENERAL [b]	40	2	41	0
TOTAL [c]	375	13	326	18
30 MINUTES				
MODE	AUTO	TRANSIT	AUTO	TRANSIT
HOSP_CLINC	1534	112	1529	36
GENERAL	143	14	149	1
TOTAL	1677	126	1678	37

[a]Number of hospitals and clinics reached
[b]Number of general practitioners reached
[c]Total number of hospitals, clinics, and general practitioners reached

Source: Wachs and Kumagai (1973)

TABLE 2 PHYSICAL ACCESSIBILITY TO HEALTH-CARE OPPORTUNITIES FOR TWO SELECTED CENSUS TRACTS IN PORTLAND, OREGON

15 MINUTES

ORIGIN	SW PORTLAND (TRACT 6602)		TIGARD (TRACT 31903)	
MODE	AUTO	TRANSIT	AUTO	TRANSIT
HOSP [a]	14	1	5	0
MEDICAL [b]	179	17	141	19
MISCELL [c]	309	42	203	32

30 MINUTES

MODE	AUTO	TRANSIT	AUTO	TRANSIT
HOSP [a]	32	3	30	2
MEDICAL [b]	467	52	420	49
MISCELL [c]	635	124	570	112

[a]Number of hospitals reached
[b]Number of medical clinics reached
[c]Number of miscellaneous clinics reached

TABLE 3 ACTIVITY PROGRAMS OF THE HYPOTHETICAL COUPLE

TIME INTERVAL	WORKER			NON-WORKING SPOUSE		
	LOCATION	ACTIVITY	AVAILABLE MODE	LOCATION	ACTIVITY	AVAILABLE MODE
00:00 - 07:30	HOME	SLEEPING, BREAKFAST, AND VARIOUS HOME ACTIVITIES		HOME	SLEEPING, BREAKFAST, AND VARIOUS HOME ACTIVITIES	
07:30 - 08:00		JOURNEY TO WORK	AUTO	HOME	HOUSEKEEPING	
08:00 - 12:00	WORK PLACE	WORK	AUTO	FLEXIBLE	FLEXIBLE	TRANSIT
12:00 - 13:00	FLEXIBLE	LUNCH BREAK	AUTO	FLEXIBLE	LUNCH	TRANSIT
13:00 - 16:00	WORK PLACE	WORK	AUTO	FLEXIBLE	FLEXIBLE	TRANSIT
16:00 - 17:00		JOURNEY BACK HOME	AUTO	HOME	MEAL PREPARATION	
17:00 - 19:00	HOME	DINNER AND VARIOUS HOME ACTIVITIES		HOME	DINNER AND VARIOUS HOME ACTIVITIES	
19:00 - 21:00	FLEXIBLE	FLEXIBLE	AUTO/ TRANSIT	FLEXIBLE	FLEXIBLE	AUTO/ TRANSIT
21:00 - 24:00	HOME	VARIOUS HOME ACTIVITIES AND SLEEPING		HOME	VARIOUS HOME ACTIVITIES AND SLEEPING	

TABLE 4 ACCESSIBILITY TO HEALTH-CARE OPPORTUNITIES FOR THE INDIVIDUAL WITH THE HYPOTHETICAL ACTIVITY PROGRAM

|	WORKER		SPOUSE
TIME	**12:00 - 13:00**	**16:00 - 17:00**	**TWO HOURS BETWEEN 8:00 – 16:00**
ORIGIN	WORK PLACE	WORK PLACE	HOME
DESTINATION	WORK PLACE	HOME	HOME
MODE	AUTO	AUTO	TRANSIT
HOSP [a]	14	11	1
MEDICAL [b]	120	81	13
MISCELL [c]	176	136	25

[a]Number of hospitals reached
[b]Number of medical clinics reached
[c]Number of miscellaneous clinics reached
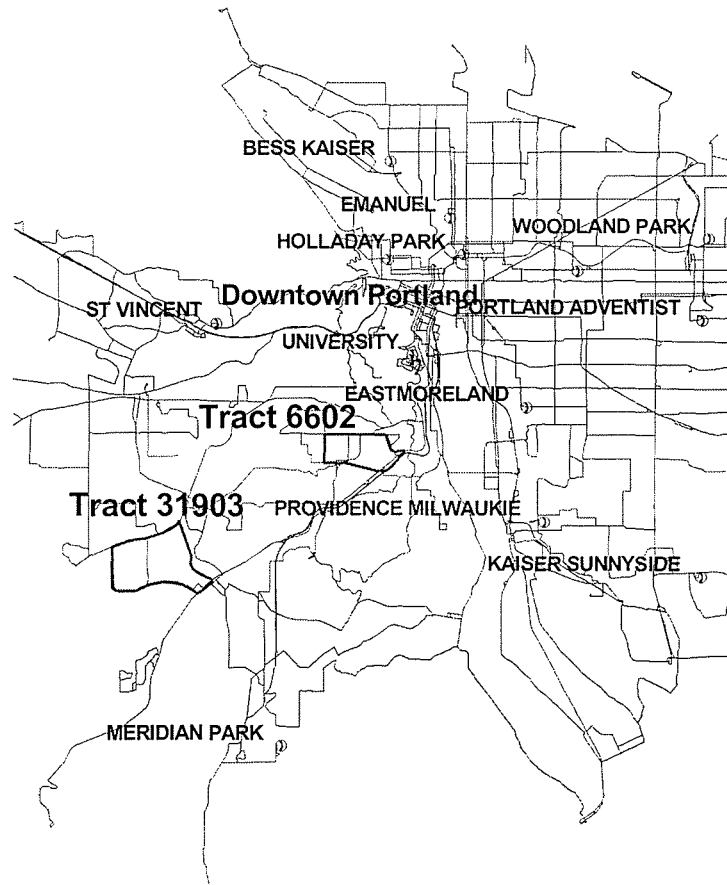
FIGURE 1 A SPACE-TIME PRISM IN WHICH THE ORIGIN COINCIDES
WITH THE DESTINATION
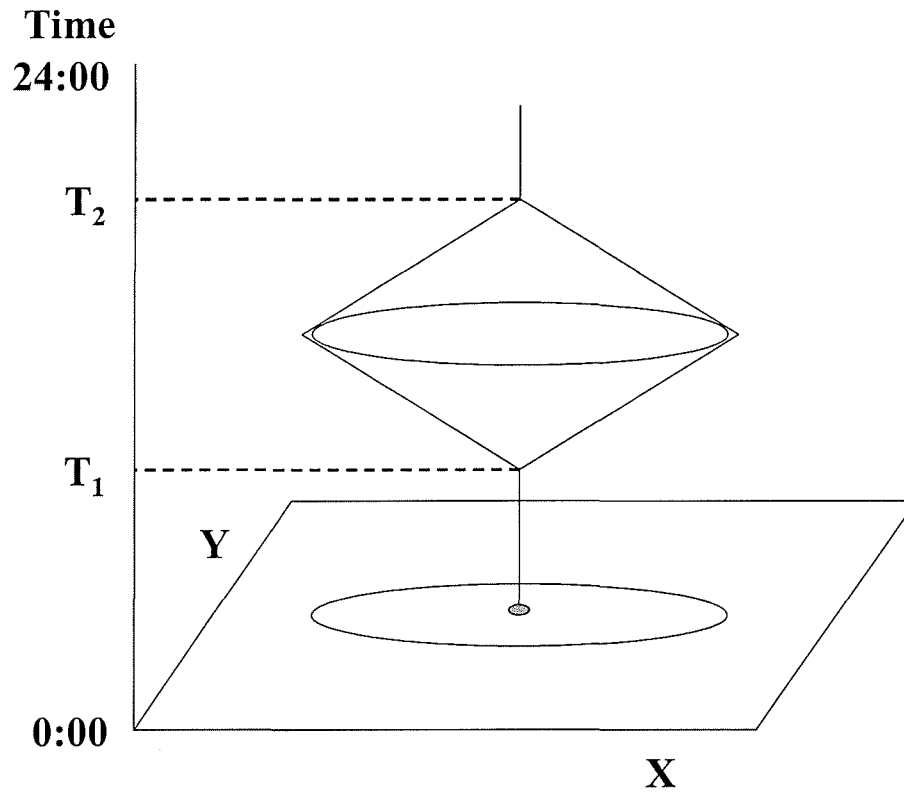
FIGURE 2 FLOW CHART OF THE ALGORITHM
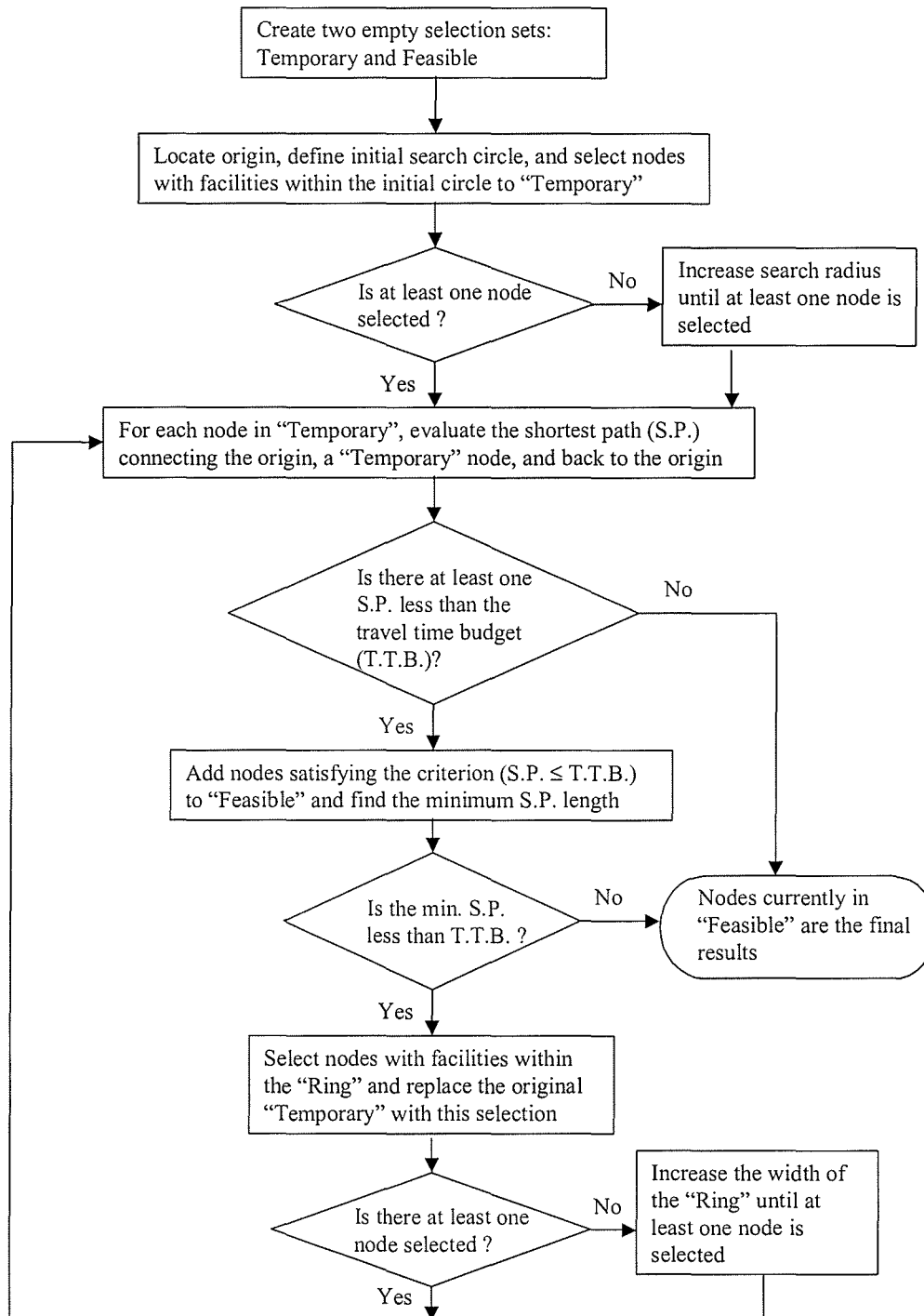
FIGURE 3   BUS ROUTES AND HOSPITALS IN PORTLAND, OREGON

FIGURE 4   SPACE-TIME DIAGRAM OF THE HYPOTHETICAL ACTIVITY PROGRAM