EVALUATING THE EFFECTS OF GEOGRAPHIC CONTEXTS ON INDIVIDUAL ACCESSIBILITY: A MULTILEVEL APPROACH[1]

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Abstract: Centrality within a city and neighborhood characteristics have often been used as indicators of access to employment and services in statements about urban form and accessibility, but there are reasons to question the appropriateness of doing so. This paper evaluates the importance of geographic context within the urban environment (both location within cities as well as neighborhoods characteristics) for individuals in Portland, Oregon. Because conventional accessibility measures cannot incorporate individual characteristics, space-time individual accessibility measures were used with multilevel modeling to isolate the effects of individual level variations from that of geographical context. The results show that the influence of context on individual accessibility is weak, as accessibility tends to reflect individual and household characteristics rather than the local urban environment. Accessibility cannot be determined from location within cities, or from land uses around an individual's home, implying that the use of urban design to influence accessibility is inappropriate. [Key words: accessibility, local context, New Urbanism.]

The existence of links between accessibility and urban form has long been assumed in geography, and in fact is built into standard models of urban form by assuming that accessibility will be greatest nearer to the CBD or polycentric centers. The use of aggregate accessibility measures has shown that location near large employment concentrations or central locations in cities is associated with higher accessibility (for example, Muraco, 1972; Knox, 1978, 1982; Hanson and Schwab, 1987). However, it is clear both from recent changes in urban patterns as well as from increasing concern over the utility of conventional aggregate accessibility measures that the relationship between access and urban form should remain open to question, and in fact may be of little importance.

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A number of reasons exist for this situation. The continued relevance of traditional monocentric and polycentric models of urban form has been strongly questioned in recent decades due to the observed inability of distance from the center(s) to determine land uses (Erickson and Gentry, 1985; Giuliano, 1989; Heikkila et al., 1989; Archer and Smith, 1993; Hoch and Waddell, 1993; Waddell et al., 1993; Waddell and Shukla, 1993). Other views of cities have therefore emerged that do not privilege distance (Dear and Flusty, 1997, 1998, 1999; Hall, 1998; Dear, 2000). The ability of distance to influence human behavior, such as commuting, shopping, or housing choice and relocation, has also been questioned (Hamilton, 1982; Giuliano, 1989; Small and Song, 1992), as have many other behavioral assumptions of these models (Clark and Burt, 1980; Hanson and Pratt, 1988, 1992; Giuliano, 1989, 1991, 1995; Giuliano and Small, 1993; Wachs et al., 1993; Lowe, 1998). Rather than households being homogenous and selecting tradeoffs based on distance, there are likely to be a range of other factors shaping behavior and choices, including individual and household characteristics such as age, race, gender, income, occupation, and the social environment of neighborhoods (Hanson and Pratt, 1988). There is therefore a need to examine whether statements about distance are still relevant to accessibility.

The ability of proximity-based accessibility measures to evaluate the relationship between urban form and individual accessibility has also been questioned.[3] The fundamental issue is that these measures typically require the definition of point or zonal locations (typically the home) from which proximity to opportunities is to be assessed. Measuring access to employment or services from these locations assumes that they are the center of an individual's daily activities and the origin of each individual's daily travel, but this is not necessarily a valid assumption (Kwan, 1998, 1999). This assumption ignores differences among households and individuals by requiring that everyone living in the same zone or at the same point must necessarily have the same accessibility, and are affected in the same way by changes in accessibility (Kwan, 1998; Talen and Anselin, 1998). The result is that even when accessibility inequalities are found within a city using conventional accessibility measures (as by Wachs and Kumagai, 1973; Black and Conroy, 1977; Knox, 1978, 1982; Talen, 1997), it is not clear for whom these inequalities may be a problem or how they are distributed among the population. Not all individuals represented by a point or zone will share the same characteristics, activities, constraints, or preferences, raising the question of for whom such access is important or relevant.

These issues are important because of growing interest in using land uses to influence travel and activity behavior, and therefore potentially accessibility. In contrast to traditional low-density, suburban, automobile-oriented development, which limits the efficiency and usefulness of non-auto modes while forcing people to travel considerable

[3] The concept of accessibility can be applied to both individuals and places. In the first case the goal is to identify people's ability to move around and reach particular locations within their time and mobility constraints, while in the second case the ease with which particular places can be reached is being evaluated (Hanson, 1995). It has been shown that conventional aggregate proximity based measures (such as gravity and cumulative opportunity measures) are effectively place measures, as they refer to points or zones, while the disaggregate space-time measures used in this paper refer to the accessibility of individuals (Kwan, 1998). The surfaces and figures in this paper therefore represent the accessibility of individuals living at particular locations in Portland, though their accessibility may be based on movement throughout the city.

distances to employment or activity locations, planners who favor Neo-Traditional Development (or the New Urbanism) hold that designing pedestrian and transit-friendly urban environments can (among other things) improve accessibility to employment and especially retail activities (Bookout, 1992; Handy, 1992; Boarnet and Crane, 2001). Designing residential areas using grid street patterns with shopping opportunities located within the neighborhood is thought to reduce the number of trips required by households, as well as shifting travel away from a dependence on autos and allowing easier access to shopping and services (Handy, 1992), though the effects of Neo-Traditional Development, and land-use patterns in general, on travel behavior are uncertain (Ewing et al., 1994; Friedman et al., 1994; Steiner, 1994; Crane, 1996; Handy, 1996a, 1996b; Boarnet and Crane, 2001).

A range of reasons clearly exists to question the extent to which individual accessibility to employment, shopping, or other services can be read off from a household's residential location within a city or the characteristics of their surrounding environment. Yet the ability to do so has been widely assumed, and in fact is being built into the design of many new neighborhoods. If accessibility is not reducible to location, than these plans may not succeed as intended, and in fact could potentially lead to people being worse off than before.

This study therefore seeks to evaluate and isolate the effects of geographical context, and particularly the influence of different types of urban forms and neighborhoods, from individual or household attributes on accessibility. It attempts to go beyond the assumption of a simple relationship between urban form and individual accessibility that is common in much of contemporary understanding of urban geographies. It calls attention to complexities and factors that emanate from the life situations of particular individuals—especially the structure of space-time constraint across multiple axes of difference such as gender, race and class. In order to be able to do this, not only are accessibility measures that can take into account individual difference needed, but also analytical methods that can help isolate the effect of context from personal or household attributes.

Space-time accessibility measures are used in the study, as these do not experience the limitations of conventional measures and so allow the individual differences and experiences to be directly reflected in their accessibility. Because these measures are based on the activities and movements of individuals throughout the day, they are rooted in the local urban environment and therefore incorporate individual contexts into accessibility. Because two neighbors may share a similar set of potential opportunities within their neighborhood but have very different activity schedules or time and mobility constraints, it is necessary isolate the effect of individual characteristics and geographic context on individual accessibility. Multilevel modeling is therefore used to disentangle the ways in which individual behavior and the urban environment create accessibility. This methodology identifies relationships both among individuals as well as between areas, and incorporates both individual and area level data, and so is ideally suited for isolating the relationship of each to individual access. Although this procedure has found a variety of applications in geography, it has not yet been applied to accessibility.

The next section of this paper will discuss the study area of Portland, Oregon, and the individual-level data set used to construct measures of individual accessibility. Because space-time measures cannot be represented by equations as can conventional proximity based measures, the geocomputation of these measures within a GIS environment is

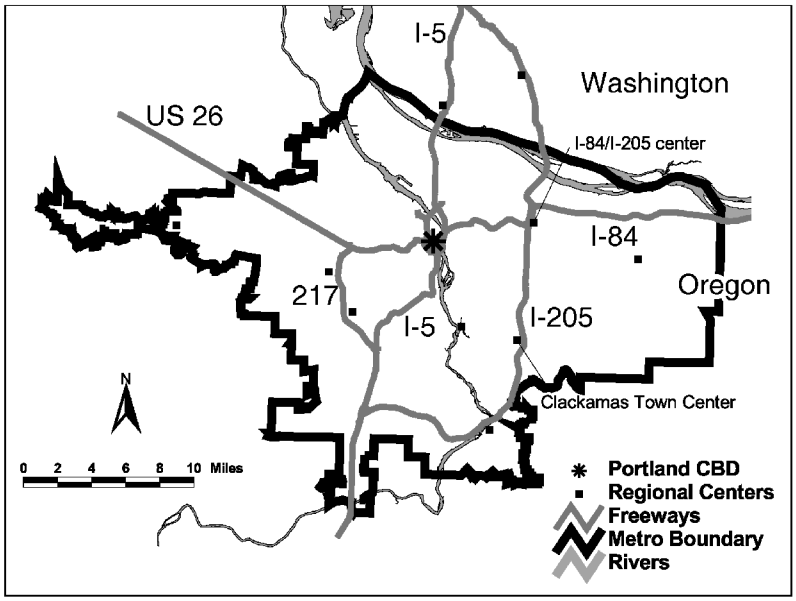

Fig. 1. Portland, Oregon study area and major polycentric employment and retail centers.

discussed in detail in a separate section. A crucial step in this research is the selection of individual and contextual variables, and the definition of geographical zones within which to measure this context, and these issues are discussed with exactly how and why context can be expected to matter to individual accessibility. Next, the ability of contextual features to explain individual accessibility within Portland are assessed using a multivariate regression framework. Because contextual effects may vary among different areas within Portland, multilevel modeling is then used to isolate variations in the effects of contextual variables as well as variations in individual accessibility across Portland. The results of this modeling and an assessment of the importance of context to accessibility are discussed in the final section.

STUDY AREA AND DATA

The study area for this research consists of that part of the Portland, Oregon, metropolitan area that is included within the urban growth boundary of the Portland Metropolitan Service District (commonly known as Metro), which is the local metropolitan planning organization (MPO) (Cambridge Systematics, 1996; Metro, 1997). The boundary for this organization includes most of Multnomah County and the urban sections of Clackamas and Washington counties (Fig. 1), and because it bounds the urbanized area it provides an effective study area boundary for this research.

The use of space-time measures of individual accessibility requires disaggregate individual activity data showing the kinds of activities individuals engage in (regardless of whether travel is required), where they take place, and the means of travel to and from these activities. These data were obtained for the Portland study area from the Household Activity and Travel Behavior Survey, a travel-activity diary survey collected in 1994 and 1995 (Cambridge Systematics, 1996). This survey collected activity and travel information from 4,451 households and 10,084 individuals throughout the Portland area over a

two-day period. The survey obtained a wide range of data from the respondents, including household and personal characteristics, and details of all out-of-home activities as well as in-home activities lasting at least 30 minutes. These activities were collected in a travel diary format, so that individuals were asked to record activity information as they engaged in them (including the location of each activity, mode of travel, the time activities began and ended, and the purpose of the activity). Each individual in the sample recorded activities and movements during a two-day period assigned them. The travel-activity data set therefore provides detailed and disaggregate information about the activities and movements of a large number of individuals during the course of several days. After the data were collected and assembled by Metro, the household and activity location was geographically referenced to an accuracy of 200 feet, making possible the accurate representation of an individual's movements through space.

Although the Portland travel diary survey included individuals traveling by a variety (and combination) of transportation modes, only those traveling by private automobile were used in this research. This ensures that variations in accessibility are not due to transport mode while greatly simplifying the computation of accessibility, as no scheduling considerations are involved. The individuals used for this research were further restricted to those adults living inside the Metro urban growth boundary with at least one fixed activity (in or out of the home) each day, and with all activities taking place within the Portland MSA counties on weekdays. A total of 755 individuals from 598 households met these conditions and were used in this research. These individuals engaged in an average of six activities each day. This sample is split roughly equally between men and women (52.7% male) and is overwhelmingly (94.7%) White. Employment status of the individuals sampled is slightly more diverse, with 77.6% employed full time, 13.7% part time, 2.6% are full-time homemakers, 1.5% retired, and 4.3% are not employed.

To represent activity opportunities, the location and characteristics of all potential employment, retail, entertainment, and other opportunities in the Portland urban area were needed. To provide this information, a data set containing all property parcels in the Portland area was assembled from local land-use data. Unfortunately, the data set did not allow for a high degree of disaggregation by land-use type, so those parcels classified as commercial or industrial were used to represent potential activity opportunities. Following Kwan (1998, 1999), this polygonal parcel data set was converted to point data by computing the centroids of each polygon, resulting in a point data set containing a total of 27,749 parcel centroids.

GEOCOMPUTATION OF SPACE-TIME ACCESSIBILITY

Space-time measures are originally derived from Hägerstrand's (1970) time geography concepts, which provide a framework for analyzing individual movement through space and time. The initial foundation for time geography is that "in time-space the individual describes a path, starting at the point of birth and ending at the point of death … the concept of a life path (or parts of it such as the day path, week path, etc.) can easily be shown graphically if we agree to collapse three-dimensional space into a two-dimensional plain or even a one-dimensional island, and use perpendicular direction to represent time" (Hägerstrand, 1970, p. 10). Movement through space-time will not be random or unconstrained, as the physical limits of mobility and biology and the need for

individuals to be in certain places for certain lengths of time will limit mobility. This time geographic framework has found wide applications in geography, including the study of accessibility (Burns, 1979; Villoria, 1989; Kwan, 1998, 1999; Kwan and Hong, 1998; Forer and Huisman, 1998; Huisman and Forer, 1998; Recker et al., 2001).

Space-time measures of accessibility make use of an individual's daily path through time and space and are based on showing the area an individual can move about in (and the potential activities which exist inside that area) within the time and mobility available to him or her. This concept can best be explained through the example of an individual with a daily activity schedule. His or her schedule will contain a number of activities that must be carried out over the course of the day at varying locations. Some of these activities will have to be carried out at a particular place at a definite time (and often for a certain length of time), and so can be considered to be fixed activities. The individual must accept the time and place of such fixed activities, which commonly include work, school, medical appointments, or childcare responsibilities. These fixed activities provide the spatial and temporal framework for the individual's day as they determine where and when he or she must be, and for how long. Other activities can only be engaged in during the time available (if any) between these fixed activities. If successive fixed activities are not at the same location then the time spent moving between these activity locations will further reduce the time available to engage in other activities (and the slower the mode of transportation, the less time will be available). Other activities will allow more freedom, as the individual can choose among a range of locations or times to engage in that particular activity, or skip it altogether. These can be considered to be flexible activities, and could include grocery shopping, choosing a gas station, visiting a post office, or renting a video. However, an individual's ability to choose among locations or times for flexible activities will still be limited by the time available to them between fixed activities and the limits of their mobility.

The time and mobility available to individuals are therefore vital to their ability to engage in a range of flexible activities. This ability has been assessed in a variety of applications (Lenntorp, 1978; Forer and Kivell, 1981; Miller, 1982), though not for contemporary American cities. Accessibility can be measured by evaluating the area individuals can potentially reach within their time and mobility limits, or their Potential Path Area (PPA) (Lenntorp, 1976, 1978; Burns, 1979). The PPA contains all possible combinations of routes one could traverse while traveling between activities (from the location of the previous fixed activity to the location of the next fixed activity) within the time available (A PPA of 20 minutes duration is shown in Fig. 2). Only those potential activities that can be found within the PPA are available to them. As individuals who engage in a number of activities will have several PPAs over the course of each day (one less than the number of fixed activities that day), the sum of their daily PPAs (or DPPA) can be taken to represent their daily accessibility. The importance of location within these studies can be shown by the extent to which individuals living or working in different areas possess different accessibilities. Although one study identified accessibility variations between inner suburbs and central-city zones in a Philippines city (Villoria, 1989), space-time studies carried out within North American cities have used small samples and have not focused explicitly on the importance of place (Kwan, 1998, 1999; Kwan and Hong, 1998).

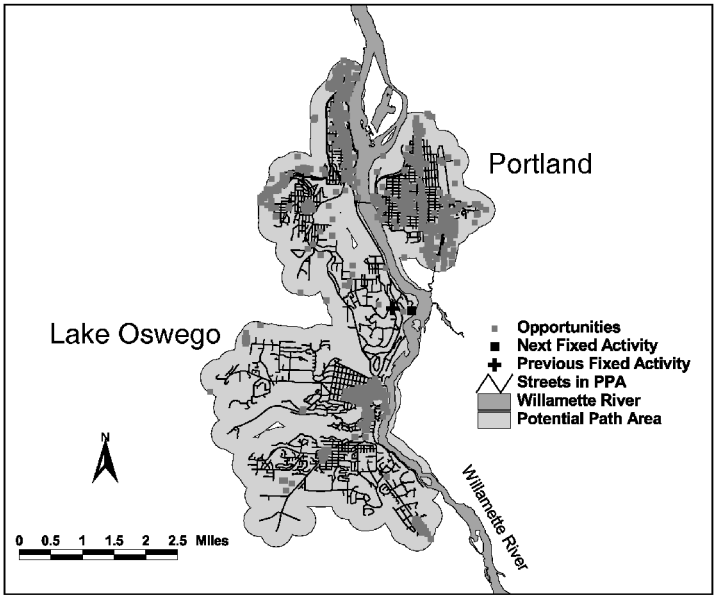

Fig. 2. Example of Potential Path Area (PPA) of 20 minutes duration.

PPAs were computed for each person in the sample based on their daily activity schedules, and then summed to create DPPAs for each of the two days they recorded their activities. The PPAs computed in this research are based on movement through an urban street network, reflecting driving times through the street network during free flow and evening congested conditions (Weber, 2001; Weber and Kwan, 2002). As a result, they reflect varying speeds over street and freeways and therefore tend to be highly irregularly shaped, rather than the ellipses common when calculating them using straight-line distance (Burns, 1979; Villoria, 1989; Newsome et al., 1998). Several algorithms exist to carry out this procedure (Miller, 1991, 1999; Kwan and Hong, 1998), and an extension of the Kwan and Hong algorithm was used due to its computational efficiency when run in ArcView 3.2 GIS on a standard PC.

Five accessibility measures were created for each individual based on the two-day average of their DPPAs. The first is the number of miles of street present within an individual's daily potential path area (labeled MILES in this research). This measure assumes that the greater the street mileage an individual can move around in between subsequent fixed activities, the greater that individual's accessibility. The mileage will reflect both density of streets as well as driving speeds, and so will be sensitive to location and congestion.

A second measure counts the number of opportunities present within the daily PPA to allow the uneven distribution of employment, retail, entertainment, or other services within a city to influence individual accessibility (using the commercial and industrial property parcel data set discussed above to represent these opportunities). This measure (labeled OPPORTUNITIES) therefore counts the number of potential activity opportunities available to the individual and takes into account the fact that individuals with high mobility will not necessarily be able to reach a large number of opportunities, especially if they are traveling in an area with limited commercial development.

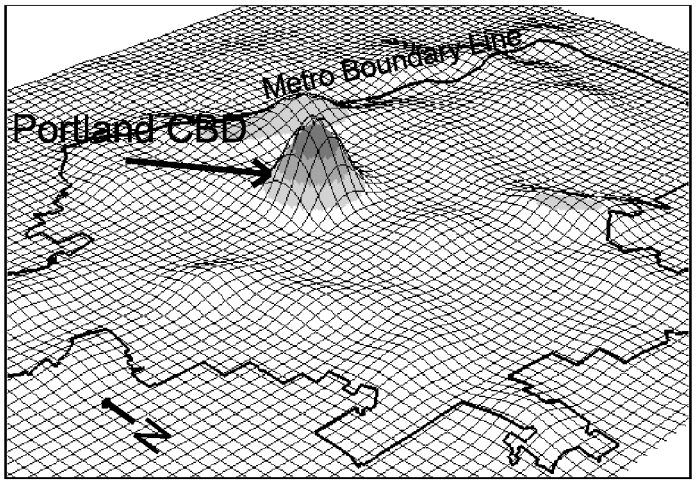

Fig. 3. Weighted opportunity density surface of Portland study area.

As in other space-time accessibility analyses (Kwan, 1998, 1999; Kwan and Hong, 1998) the relative importance and attractiveness of opportunities was also taken into account by weighting them according to the square footage of the individual parcels (floor area of buildings on the lot was not consistently available and so this could not be used). This measure (called AREA) takes into consideration that some activity opportunities are considerably larger and therefore more important or attractive to individuals than are others. This is likely to have the effect of weighting accessibility in favor of areas with large shopping centers (especially shopping malls) or business establishments. Because buildings located in downtown Portland commonly have multiple floors and higher building to-parcel-size-ratios, the square footage of these parcels was weighted, as were lesser concentrations of multistory buildings identified outside the Portland CBD. This weighting created a second measure of the attractiveness of opportunities (here called WEIGHTED AREA). As can be seen, the distribution of weighted opportunities in Portland clearly shows a monocentric pattern (Fig. 3).

Finally, a fifth accessibility measure was devised in an attempt to represent the temporal availability of potential opportunities. This measure used the WEIGHTED AREA measure but also incorporated a representation of business hours, so that opportunities that were closed at the time an individual was traveling were not counted as part of that person's accessibility.[4] This temporally weighted measure (called TIMED AREA) should therefore more realistically portray that the accessibility of those individuals who engage in many activities at night or at favorable times of the day will therefore be as important to accessibility as mobility.

[4] It has been shown that incorporating time of day into the geocomputation of accessibility measures makes a significant difference to an individual's accessibility, and prevents the overestimation of opportunities available at night when few establishments are open (Weber and Kwan, 2002). Because the land-use data used to construct the opportunity data set do not contain business hours, all parcels representing potential activity opportunities were assumed to be available from 9:00 a.m. to 6:00 p.m.

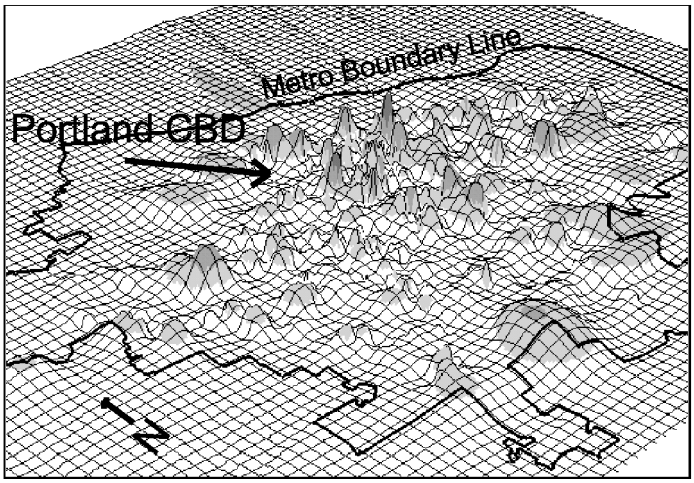

Fig. 4. Weighted opportunity individual accessibility surface for Portland study area.

Individual accessibility patterns in the Portland area can be visualized as a continuous surface interpolated from points representing individual's home locations. Though each of the measures is different, the surfaces all show a strikingly similar pattern, as seen by the surface for WEIGHTED AREA (Fig. 4). Because of the nature of space-time accessibility measures, this surface cannot be interpreted in the same manner as those for conventional accessibility measures. Rather than the elevation of a point on the surface representing the accessibility of that location, it represents the accessibility of an individual living at a particular location, though of course his or her access to services may derive from travel throughout the city. Accessibility values vary greatly within short distances, and although individuals with high access to employment and services can be identified, there is no clear pattern of accessibility variation by distance from the CBD or other central locations. Neither are the urban growth boundary nor the role of terrain, rivers, or freeways in constraining accessibility evident from these surfaces. The lack of high access on the part of individuals living close to the Portland CBD is striking, given its dominance within the distribution of potential activity opportunities and its importance as a job and activity center. Some of the highest accessibility values are actually observable among individuals living on the periphery of the study area.

In the following sections, these space-time accessibility measures will be used as the dependent variables in a set of models, first at a single level using regression, then with multilevel modeling, designed to explain variations using individual level characteristics as well as the characteristics of local geographic areas. These explanatory variables representing individual or household and contextual characteristics will be discussed in the next section, along with a discussion of the geographic zones used.

IDENTIFYING VARIABLES AND ZONES FOR THE STUDY

The importance of context to individual accessibility was first evaluated by testing each of the five accessibility measures using multivariate stepwise regression with a range of explanatory variables. A range of socioeconomic variables was included to help isolate important characteristics of individuals and their households that can be expected

to be important influences on mobility, and therefore accessibility (Villoria, 1989, England, 1993; Blumen, 1994; Kwan, 1998). These include gender, age, race, whether the individual is head of their household, relation to the head of their household, household size, number of children in the household, the individual's employment status (not working, part time, full time), number of hours worked per week, and household income (within $5,000 intervals).

A number of variables were used to evaluate the characteristics of people's urban environments. The monocentric and polycentric models lead to the expectation that accessibility should be higher in areas closer to the center(s) of the city, so the distance (measured through the street network using travel times) from each individual's home to the CBD and each of 11 major suburban retail and employment centers within the Portland metropolitan area was included (these centers are identified in Fig. 1).[5] Because locations closer to the center should have greater population and housing densities, attributes representing population density, housing density, the proportion of homes that are detached (representing single family homes), and the density of potential activity opportunities within each zone (the weighted area of opportunity parcels divided by acreage of the neighborhood) were also selected for testing. Because peripheral suburban areas are commonly associated with higher incomes and home values, accessibility should also decrease with higher average housing values, a larger proportion of housing units that are owner occupied, and newer homes (represented here by the proportion of housing built before 1970), variables measuring these characteristics were also included.

The proponents of Neo-Traditional Development and the New Urbanism also make strong claims about the influence of different types of urban forms on travel behavior and accessibility (Boarnet and Crane, 2001). As with the monocentric and polycentric views, higher densities should be associated with higher accessibilities because individuals would be expected to live much closer to a greater range of potential activity opportunities (though there would not necessarily be any expectation that these opportunities would be concentrated in a downtown location), and so should be able to reach more of these locations. Older residential areas would be indicative of higher densities and more dispersed employment and retail opportunities (representing actual "traditional" developments rather than Neo-Traditional imitations), and people living in these areas should therefore have higher accessibilities.[6]

There can also be an expectation, especially among those who argue for updated urban models (such as Dear and Flusty, 1997, 1998, 1999; Dear, 2000), that accessibility would be greatest in areas of higher income and status, regardless of location within the city. Accessibility should therefore increase with higher average housing values, a larger proportion of housing units that are owner occupied, and newer homes. Higher

[5] The 2040 Growth Plan for the Portland area was used to identify major suburban centers (Metro, 1997). This plan designates a hierarchy of centers throughout the metropolitan area, including the Portland CBD, regional centers, and smaller town centers. The 11 large regional centers are intended to be large mixed land-use developments, representing a concentration of employment, retail, and recreational opportunities, and include the downtowns of several major suburbs, including Milwaukee, Gresham, Hillsboro, Oregon City, Beaverton, and Vancouver, Washington (Fig. 1). Others are large suburban employment and retail areas include the Washington Square Center, Clackamas Town Center, the I-84/205 center, the Vancouver Mall, and Salmon Creek in Washington.

population and housing densities would likely be associated with lower incomes and less desirable areas, so would have lower accessibility. Greater densities of opportunities would certainly be expected to result in higher accessibilities, though with the expectation that these opportunity densities exist in part because of the desirability of these areas of the city. Areas with higher household incomes and occupied primarily by white collar workers and those with greater educational attainment would also be expected to have higher accessibilities. Additional variables were created to measure these characteristics.

Geographic contexts may also be important to accessibility because places are not just empty spatial containers but are instead active entities influencing human behavior and knowledge (Hanson and Pratt, 1988; Wyly, 1998). This possibility has been explored particularly in the context of the weaknesses of the monocentric model in conceptualizing women's employment possibilities, and the ways in which the community can be important in providing information about jobs and support services such as day care, transportation, or recreation opportunities (Hanson and Pratt, 1988; Wyly, 1998). The residential community is also important because of "the socialization process by which certain work-related attitudes, skills, and goals are passed from one generation to the next" (Hanson and Pratt, 1988, p. 309). These happen not only within the home "but also within the neighborhood via schools and social interaction" (Hanson and Pratt, 1988, p. 309). Because certain occupations (professional and managerial jobs) have higher mobility and different residential selection processes than others, the importance of local communities could vary among social groups (Hanson and Pratt, 1988). Information representing occupation and income could therefore be used as proxy variables for social values within neighborhoods.

Additionally, areas with a higher proportion of workers commuting to work in single-occupancy vehicles may have greater mobility and knowledge of the city, and therefore potentially higher accessibility. This could also serve as a surrogate for a lack of transit dependence, which would certainly be expected to result in lower accessibility. Although the sample used in this research is exclusively auto based, certain individuals may have been selected from areas with relatively low auto usage and therefore lower average accessibility. Dual-earning households may however become more involved in

[6] It is important to note that individual accessibility is affected by the prior choices that people make to commit to certain fixed activities. These choices may be made in consideration of one's willingness to travel longer distance and to adapt to the chosen locations for their fixed activities. In this particular sense, urban structure still matters. In response to this suggestion, we provide the following caveats to assist the interpretation of the results.

First, even when prior locational choices are made with consideration of the urban structure, the decision-making process and the materialization of one's preferences are fraught with "imperfections." For instance, a range of factors render such kind of locational adjustment or behavioral adaptation difficult— such as one's preference for particular destinations, locational choice within the household, barriers (e.g. racism) in the housing market, etc. Factors like these not only make the adjustment process difficult for certain individuals, they may also lead to considerable deviation from the expected relationship between urban form, individual travel and accessibility. In other words, a perfect adjustment process predicated on the freedom of individual choice may not be found at certain (if not most of the) times for a particular individual, and the individual may still face a particular structure of constraint despite prior choices.

Second, the structure of space-time constraints a person faces emanates largely from particular life situations and personal attributes, which include one's work schedule and household responsibility (which in turn is affected by the gender division of household labor). This person-specific structure of constraints will circumscribe the choices available to an individual independent of the urban structure or geographical context.

work-based social contacts than neighborhood contacts and so become less influenced by the neighborhood context (Hanson and Pratt, 1988). Areas that are predominantly occupied by married child-raising households may therefore be expected to have little effect on accessibility, while those with large proportions of single-person households would be more likely to be an influence. Finally, low residential turnover might suggest a lack of residential mobility, which Hanson and Pratt (1988) have shown to be important for the influence of home environment on decisions about work, and therefore accessibility.

One critical problem is how to define neighborhoods units. In this research, discrete zones were used, though this raises issues discussed in later sections. Neighborhoods were defined using existing neighborhood entities designated by the Portland metropolitan planning agency (Metro). These comprise 259 subdivisions of the area within the Portland Urban Growth Boundary. Because sampled individuals were present in relatively few of these neighborhoods, these units were aggregated into two sets of zones using physical features, freeways and political boundaries to isolate relatively homogenous areas at two levels of aggregation, NBO1 with 21 neighborhoods, and NBO2 with 12. Additionally, a third set of neighborhood zones was created by aggregating the Metro zones according to an interpretation of neighborhood types within Portland discussed by Abbott (1983). Abbott distinguished four distinct types of neighborhoods within the city of Portland, beginning with the older neighborhoods in the vicinity of the CBD. These originally provided cheap housing for recent arrivals to Portland before they moved on to more desirable neighborhoods. Beyond these are large residential areas originally developed in the late 19th and early 20th centuries, which tend to consist of high-density single-family homes, and have remained stable communities during the automobile era. Highland neighborhoods are present in a few scattered hilly areas, which were developed in the early 20th century and are stable high-income residential enclaves within the city. Finally, the postwar automobile era neighborhoods extend beyond these older areas and outside the city limits of Portland in Multnomah, Clackamas, and Washington counties. Neighborhood units corresponding to the areas defined were aggregated to create four different neighborhood units (called ABBOTT).

Census data representing contextual variables were transferred from census block group units to these neighborhood units using pycnophylactic interpolation. This method allows values from adjacent zones to influence the values of a source zone (Lam, 1983), replacing the assumption that phenomena are evenly distributed within block groups with the expectation that they are constantly varying across space. ANOVA testing identified significant differences in individual accessibility for all measures within each set of zones, except the TIMED AREA measure using the ABBOTT zones. This indicates that average accessibilities within different geographic areas in each set of zones differ considerably from the mean accessibility in other areas. Although this does not necessarily indicate that each neighborhood within Portland has a significantly different level of individual accessibility, it does show that these zones are capable of capturing geographic variations in individual accessibility. To the extent that these differences reflect substantial differences between areas, the use of these contextual variables for geographic zones can be expected to help explain individual accessibility. This will be discussed in the next section.

EVALUATING THE EFFECTS OF GEOGRAPHICAL CONTEXT USING MULTIPLE REGRESSION ANALYSIS

These variables were used to predict each of the five accessibility measures (each standardized to a mean of 100) using stepwise regression, with the results of the best fitting models shown in Table 1.[7] As can be seen, although distance variables are present in all models, only one contextual variable appears. The proportion of housing within each zone that is detached (representing single-family homes) is related to the number of OPPORTUNITIES available at the scale of NBO1 and NBO2, and the TIMED AREA accessible at the NBO1 level. In all cases the effects are positive, so that individuals living within areas with a larger proportion of single-family homes tend to have higher accessibility. With the OPPORTUNITIES measure this indicates that the number of potential activity locations is greater with an increasing proportion of detached homes, while for TIMED AREA it indicates that the weighted area of opportunities reachable during daytime hours is greater with an increasing proportion of these homes. However, mobility (as measured by MILES) and the area of opportunities reachable at any time of the day or night do not show any relationship to neighborhood characteristics. These results run counter to the expectations of Neo-Traditional Development, as households in low density areas tend to have higher accessibility. The absence of other variables is striking, as it indicates accessibility is not related to income, housing age, population density, or many other factors. The absence of these variables from the models highlights the importance of behavior to individual accessibility, and the fact that much of an individual's access to opportunities is influenced by where they work or engage in out-of-home activities. This of course is not to say that individuals truly desire this pattern of accessibility or that it is in any way optimal, but that it is the result of employment, transportation, and activity decision-making by companies, governments, and households that is unlikely to be easily reversed.

Variables describing location by distance within the city appear more consistently within the models. Distance to the Portland CBD, the Clackamas Town Center, and the I-84/205 center appear. Given the strongly monocentric distribution of potential activities, the importance of the Portland CBD was surprisingly small. Of the five measures, only the number of activities accessible (OPPORTUNITIES) declined with distance from this location. This finding is consistent with monocentric model and suggests that individuals living nearer the CBD do in fact possess higher accessibility.

However, this conclusion must be modified by the significance of distance to other locations. OPPORTUNITIES, AREA, and WEIGHTED AREA all decline with distance from the I-84/205 regional center, while distance from the Clackamas Town Center is important for MILES and TIMED AREA. For MILES this shows that mobility declines with distance from this location. Individuals living farther from the Clackamas Town

[7] These variables were used to predict each of the five accessibility measures (standardized to a mean of 100) using forward stepwise regression with a tolerance of 0.0001. The use of stepwise regression eliminates the likelihood of multicollinearity among the independent variables, and the possibility of nonlinear relationships was taken into account by examining scatterplots of the relationships between the five accessibility measures and the explanatory variables. No strong indication of nonlinearity was apparent, so the following discussion is based on the assumption that all relationships can be adequately modeled linearly.

TABLE 1. REGRESSION RESULTS WITH INDIVIDUAL AND CONTEXTUAL VARIABLES

Dependent variable	Independent variable	Coefficient	Standard error	Standardized coefficient	Significance level	R^2	Adjusted R^2
MILES	Constant	201.11	16.41		0.000	0.055	0.051
	Distance to Clackamas Center	–1.63	0.35	–0.17	0.000		
	Hours worked	–1.25	0.28	–0.16	0.000		
	Household size	–5.90	2.74	–0.08	0.031		
OPPORTUNITIES	Constant	150.18	17.76		0.000	0.101	0.096
	Distance to Portland CBD	–1.44	0.43	–0.16	0.001		
	Distance to I-84/205 Center	–1.29	0.37	–0.16	0.000		
	Hours worked	–0.89	0.22	–0.14	0.000		
	Proportion of homes detached (NBO1)	54.79	23.64	0.84	0.021		
	Constant	143.89	21.20		0.000	0.1	0.095
	Distance to Portland CBD	–1.39	0.42	–0.15	0.000		
	Distance to I-84/205 Center	–1.28	0.37	–0.16	0.001		
	Hours worked	–0.89	0.22	–0.14	0.000		
	Proportion of homes detached (NBO2)	62.78	29.33	0.08	0.033		
AREA	Constant	175.40	11.58		0.000	0.066	0.063
	Distance to I-84/205 Center	–1.94	0.31	–0.22	0.000		
	Hours worked	–1.02	0.25	–0.14	0.000		
WEIGHTED AREA	Constant	174.08	11.33		0.000	0.067	0.054
	Distance to I-84/205 Center	–1.91	0.31	–0.22	0.000		
	Hours worked	–1.00	0.24	–0.14	0.000		
TIMED AREA	Constant	206.71	37.38		0.000	0.11	0.106
	Distance to Clackamas Center	–1.81	0.57	–0.11	0.001		
	Hours worked	–3.81	0.44	–0.30	0.000		
	Proportion detached (NBO1)	112.85	45.14	0.09	0.013		

Center tend to be able to move over a smaller street mileage than those living closer. The fact that the TIMED AREA measure is linked to this center while the other two area measures respond to the I-84/205 center clearly shows the importance of travel behavior. The Clackamas Town Center has a greater influence on daytime activities while the I-84/205 center has a greater influence on all activities. This result shows that incorporating temporal constraints on the availability of activities is important not just for the way it reduces accessibility but because it alters the geography of this accessibility. In this case, eliminating nighttime activities from consideration changes the center from which distance should be measured to explain accessibility. As the WEIGHTED AREA and TIMED AREA measures are identical except for the absence of nighttime activities, this difference must be due to travel behavior. Rather than distance determining access or behavior, the reverse actually appears to be the case, with the activity and travel choices of individuals strongly influencing the importance of distance in Portland.

Two socioeconomic variables were also useful. The results with these variables are striking for the importance of the number of hours worked per week and household size to accessibility. Accessibility declines with an increasing number of hours worked for all five accessibility measures, the only explanatory variable which does so, while the number of MILES available declines with increasing household size. The importance of hours worked shows clearly that employment status is fundamental to accessibility (and in fact when hours worked was excluded the employment status variable did appear in the model). Given the additional time constraints imposed by more time spent working, it is not surprising that accessibility should tend to decrease with additional hours spent working. It is particularly interesting that this effect holds true for mobility (MILES) as well as access to both a high density (OPPORTUNITIES) and area (AREA and WEIGHTED AREA) of potential activities. Increasing hours spent working is therefore a universal reducer of accessibility, suggesting that individuals have little ability to overcome a reduction in accessibility by altering their behavior. That increasing the hours worked would reduce the daytime accessibility (as evaluated by TIMED AREA) is to be expected, as it is most likely to be daytime hours which are taken up with additional work hours. However, while employment status and hours worked reduce accessibility, it must also be remembered that low accessibility could hinder the search for new employment and therefore limit a change in employment status (as the spatial mismatch literature points out). Accessibility and employment status can therefore be expected to have a mutually reinforcing effect rather than one of unidirectional causality.

That accessibility also decreases with increasing household size is also to be expected, as many explanations for travel behavior highlight the constraints of child care responsibilities, whether by having to spend time at home caring for children or providing transportation to and from school or other activities. Such responsibilities appear to be resulting in lower accessibilities for individuals in Portland. However, it is interesting that while increasing household size is associated with a reduction in mobility (and therefore the number of MILES reachable), it is not associated with a reduction in the density or area of activities reachable. This indicates that reductions in mobility are not necessarily associated with a reduction in the number of activities to which individuals can gain access. Whether this is because individuals with larger households tend to live close to areas with a greater density and size of activities (such as those living near the Clackamas Town Center) and therefore see no significant reduction in access to those activities on

the periphery of their PPAs, or whether these individuals are altering their travel and activity behavior patterns so as to maximize what they have access to despite their low mobility, remains unclear at this point. If it is the latter possibility, then it indicates a crucial difference in how household size and hours worked per week affect accessibility. While individuals may be able to offset a reduction in mobility resulting from heavy childcare responsibilities and so retain access to desired services, individuals working longer hours may have no such options. This is likely because the time constraints of working long hours offer less temporal flexibility than the responsibilities involved in caring for larger households (such as child care, engaging in frequent trips to pick up or drop people off, or making more frequent and varied shopping trips).

These results clearly do not support the importance of location in the traditional monocentric urban model, and while they do appear to provide superficial support for the related polycentric model, the reasons for the observed spatial patterns actually strongly undermine both models. Distance from the center(s) does not determine accessibility, and in fact the importance of distance appears to be more a result than cause of travel and activity behavior. Travel behavior and especially interactions between activities and time of day are neither invisible nor irrelevant. The importance of the local neighborhood, whether in terms of the built environment or social characteristics, also appears quite weak and does not support the arguments of the New Urbanism.

EVALUATING THE EFFECTS OF GEOGRAPHICAL CONTEXT USING MULTILEVEL MODELING

From the above analysis, context is clearly of little importance to individual accessibility when evaluated by space-time measures, regardless of whether context is represented by distance from central locations or neighborhood characteristics. However, the regression models assume that the observed relationships are constant throughout the metropolitan area, but it may be that travel behavior and household characteristics will differ among neighborhoods. And there is the problem that it cannot be known for sure whether it is the characteristics of the location or of the people's activities (or both) that have created these relationships. Although ANOVA testing has shown there are significant accessibility differences between different areas of Portland, socioeconomic variations within the city makes statements about the influence of location on accessibility problematic, as it cannot be known for certain whether it is the characteristics of the location or of the people's activities (or both) that have created this difference. So while households living in a certain area may have above average accessibility, it is difficult to directly determine whether this is because of their behavior or because their location has allowed them high mobility and provides them with a large choice of potential activities.

In order to help resolve this issue, multilevel modeling was used to identify differences that may exist. This methodology is an extension of multivariate regression in which macro (zonal) and micro (individual) level models are estimated separately and then together in a final model, allowing the use of both area and individual information (Jones, 1991a, 1991b; Paterson and Goldstein, 1991; Jones and Duncan, 1996; Bullen et al., 1997; Goldstein, 1998; Kreft and de Leeuw, 1998). This method allows the isolation of variations resulting from variability in the population (compositional effects) from those

resulting from differences between areas (contextual effects), while also avoiding the risk of ecological fallacies by using disaggregate data (Jones, 1991b).

The relationships found with stepwise regression in the previous section were repeated as multilevel models (using the MLwin software package) to identify whether the use of these methods can help identify differences (Table 2). The output and interpretation of multilevel models is similar to that of multivariate regression, with a constant, parameter coefficients, and indicators of goodness of fit. The latter is represented by the reduction in deviance from a null model, or one that has no explanatory variables included, and is also known as the 2 log likelihood. The intercept shows the average individual accessibility within Portland, while the random terms (level 1 and level 2 variances) show variations among individuals (level 1 in the model) and neighborhoods (level 2).

The results are striking, as regression parameters remain fairly consistent for all models when put into multilevel form, indicating that incorporating a multilevel structure makes little difference to the results. Further, in all cases the level 2 (neighborhood level) variances are less than two, which is the usual cutoff level for indicating significant variation. This indicates that there are no significant differences in accessibility among neighborhoods when the characteristics of individuals are accounted for, so that spatial variations in accessibility are due to individual differences and not contextual characteristics. Differences in accessibility among neighborhoods are therefore due to population composition (differing travel behavior or time constraints) rather than context, so the relationship between accessibility and explanatory characteristics can therefore be adequately modeled at a single (individual) level (such as when using regression). This is not to say that neighborhoods are homogenous (they are clearly not), but that when measuring accessibility using space-time measures the characteristics of an individual's home environment or location is of little use in predicting their overall level of accessibility. Given that individuals may range widely throughout the city in the course of their daily activities, this is hardly surprising.

One important potential limitation of multilevel modeling is the reliance on zones to represent neighborhoods. While most multilevel research has been carried out at interurban or regional scales with politically designated boundaries, this is not necessarily possible at the intraurban level where relatively intangible areas such as commutersheds or neighborhoods are more relevant. It can be argued that this is an inappropriate conceptualization of neighborhoods or local contexts within cities, because it is assumed that all individuals living within a polygon will have the same experience of the city. The use of neighborhood areas or local contexts based on individual activities or experiences (Hanson et al., 1997) or on the shared spatial familiarity of areas on the part of local residents (Aitken and Prosser, 1990; Aitken et al., 1993; Talen, 1999) would therefore be useful.

A test of this approach to conceptualizing local context was used with contexts defined as those areas reachable within five minutes free-flow driving time from each individual's home location. The resulting areas differed greatly in size and shape, depending on location within the city and proximity to freeways and streets with fast driving speeds. Contextual variables were created for these areas by interpolating census data as before. However, when used with stepwise regression to explain accessibility, only one useful model was found, showing that the number of OPPORTUNITIES accessible to individuals varied with the distance to the CBD, the distance to the I-84/205 center, the number of hours worked per week, and the density of opportunities within five

TABLE 2. RESULTS OF MULTILEVEL MODELS WITH INDIVIDUAL CHARACTERISTICS

	Abbott		NBO1		NBO2	
Variable	Estimate	Estimate/ standard error	Estimate	Estimate/ standard error	Estimate	Estimate/ standard error
MILES						
Distance to Clackamas Center	201.11	12.29	200.69	11.84	201.83	11.84
Hours worked	–1.63	–4.65	–1.58	–4.16	–1.63	–4.22
Household size	–1.25	–4.57	–1.26	–4.60	–1.26	–4.59
Level 1 variance	10414.79	19.43	10337.41	19.18	10361.74	19.29
Level 2 variance	0.00	0.00	74.78	0.68	54.66	0.62
Deviance	9127.09		9126.24		9126.62	
Reduction from null	41.34		36.64		37.11	
OPPORTUNITIES						
Intercept			150.34	8.40	144.19	6.77
Distance to CBD			–1.43	–3.29	–1.38	–3.23
Distance to I-84/105 Center			–1.29	–3.47	–1.28	–3.45
Hours worked			–0.89	–4.05	–0.89	–4.05
Proportion homes detached			54.17	2.26	62.36	2.11
Level 1 variance			6869.12	19.19	6878.92	19.29
Level 2 variance			6.80	0.12	4.24	0.10
Deviance			8813.60		8814.40	
Reduction from null			51.89		44.93	
AREA						
Intercept	175.40	15.17	174.64	14.37	176.16	14.24
Distance to I-84/105 Center	–1.94	–6.22	–1.91	–5.60	–1.98	–5.53
Hours worked	–1.02	–4.08	–1.02	–4.11	–1.02	–4.11
Level 1 variance	8839.74	19.43	8767.93	19.18	8779.04	19.28
Level 2 variance	0.00	0.00	68.62	0.72	61.93	0.76
Deviance	9003.29		9002.26		9002.42	
Reduction from null	46.61		38.28		34.02	
WEIGHTED AREA						
Intercept	174.08	15.40	173.49	14.58	174.94	14.42
Distance to I-84/105 Center	–1.91	–6.26	–1.88	–5.63	–1.93	–5.49
Hours worked	–1.00	–4.10	–1.01	–4.14	–1.00	–4.13
Level 1 variance	8453.43	19.43	8382.24	19.18	8392.22	19.28
Level 2 variance	0.00	0.00	67.38	0.73	62.55	0.78
Deviance	8969.56		8968.42		8968.60	
Reduction from null	46.00		38.44		34.60	
TIMED AREA						
Intercept			208.36	5.32		
Distance to Clackamas Center			–1.77	–2.96		
Hours worked			–3.82	–8.74		
Proportion of homes detached			109.48	2.27		
Level 1 variance			26956.15	19.19		
Level 2 variance			133.99	0.51		
Deviance			9848.50			
Reduction from null			83.26			

TABLE 3. REGRESSION RESULTS WITH FIVE-MINUTE DRIVING TIME AREAS

Dependent variable	Independent variable	Coefficient	Standard error	Standardized coefficient	Significance level	R^2	Adjusted R^2
OPPORTUNITIES	Constant	201.977	13.982		0.000	0.099	0.095
	Distance to CBD	–1.315	0.417	–0.146	0.002		
	Distance to I-84/ 205 center	–1.625	0.384	–0.204	0.000		
	Hours worked	–0.939	0.22	–0.148	0.000		
	Local density of opportunities	–79.55	38.085	–0.084	0.037		

minutes driving time of each individual's home location (Table 3). The coefficients for hours and distance variables are as before, while the local density of opportunities has a negative influence on accessibility. This is very interesting, as higher densities of opportunities close to home is actually related to lower accessibilities! This is unexpected and the opposite of what would be predicted according to the New Urbanism and the traditional monocentric and polycentric models. However, because people living in low-density areas of the city may need to drive farther to reach activities, it is also a striking indication of the ways in which space-time measures take into account the activities and movements of people rather than simply evaluate the proximity of employment or retail activities. When represented in multilevel form at the level of neighborhoods, there is very little difference in the models (Table 4), except that the density of opportunities has a slightly greater influence with larger neighborhood units. Although the reduction in deviances shows that there is a significant gain in model fit by adding this variable, the lack of significant neighborhood-level differences shows that there is again no need for a multilevel model.

DISCUSSION AND CONCLUSION

The goal of this research was to identify the relevance of urban form to individual accessibility among those reliant on auto travel. The use of contextual characteristics with space-time accessibility measures leads to several conclusions. First, the influence of geographic context on individual accessibility appears to be quite weak, regardless of whether context is represented by distance from centers or neighborhood characteristics. Where people live, and what and whom they live around, has little to do with their accessibility. These results provide evidence against the expectations of the traditional monocentric and polycentric urban models, and also counter the assertions of the New Urbanism as there is only limited support for linking accessibility to land use or urban form. However, the neighborhood units used in this research are much larger than a typical subdivision, so these results cannot be interpreted as applying directly to Neo-Traditional developments. Further, a number of these developments have been initiated since

TABLE 4. MULTILEVEL RESULTS USING LOCAL ZONES

Variable	NBO1		NBO2	
	Estimate	Estimate/ Standard error	Estimate	Estimate/ Standard error
OPPORTUNITIES				
Intercept	200.34	13.86	202.35	13.75
Distance to CBD	–1.28	–2.78	–1.32	–2.81
Distance to I-84 Center	–1.60	–3.87	–1.61	–3.78
Hours worked	–0.94	–4.30	–0.94	–4.28
Density of local opportunities	–77.13	–1.98	–80.71	–2.06
Level 1 variance	6846.34	19.19	6848.45	19.29
Level 2 variance	37.71	0.55	37.18	0.63
Deviance	8814.11		8814.07	
Reduction from null	51.38		51.42	

the activity-travel data were collected, so that additional analysis of the effectiveness of this strategy in influencing travel behavior and accessibility is in order. And because this study focused on travel exclusively on auto, it may well be that there the geography of transit or pedestrian accessibility may show more sensitivity to local conditions, though this remains to be assessed. Nonetheless, these are clearly significant findings given the strength of these assertions or assumptions in geography.

Individual accessibility cannot simply be read off from the characteristics of neighborhoods or cities, or even from the local land uses around an individual's home, but will be more likely to reflect individual and household characteristics rather than those of common spatial units. This is an important point, as while individual accessibility statistically varies among neighborhoods within Portland, it does so to a large extent because people and households vary in their activity schedules and because they face particular sets of constraints from a variety of sources, not because of distance from specified central points or even because of the uneven urban environment. This is therefore not to deny there is a geography of accessibility, but rather that people not only make their own accessibility through their daily activities (within their space-time limits), but that this accessibility will reflect their spatial behavior within cities. Using the built form of cities to attempt to alter accessibility is not likely to be straightforward, especially if these attempts are based on assumptions about the role of distance in shaping behavior. Variations within households and among daily activity schedules appear to be more important than variations among neighborhoods, which indicates that differences across multiple axes of individual variation, such as age, race, gender, income, or occupation, are crucial to understanding accessibility. Attempting to isolate households with a particular socioeconomic status or stage in the life course will not eliminate individual differences in

accessibility as these will still continue to vary within households (Kwan, 1998). Access clearly cannot be determined simply from a household's location within a city, and it is difficult to imagine how urban areas could be designed to homogenize or maximize the accessibility of all household members. While there is no shortage of evidence that past urban designs are increasingly inadequate given changing social and economic conditions, we should not be too hasty to redesign cities around new conditions that may be equally short-lived. Given a situation of increasingly elderly populations, the continuing demise of "traditional" gender roles and evolving household structures, it is clear that cities and neighborhood designs should remain flexible in order to accommodate the changing accessibility patterns that must be expected to occur in the future.

Because accessibility is an attribute of individuals, it should be studied at this level. Not only do household characteristics appear to influence the importance of distance to selected features, it may also be that these household characteristics may also influence the importance of the local urban environment, though this requires more study. These results also suggest that selecting different neighborhood boundaries would be unlikely to affect the parameter estimates or model fit, so that the spatial configuration of the neighborhood zones plays a small part, if any, in the results. Rather, space-time accessibility measures are essentially frameless in that they appear to have little correspondence or relation to common spatial frameworks such as city boundaries and neighborhood units. For this reason the Modifiable Areal Unit Problem (MAUP) is unlikely to be a problem for space-time measures, which provides additional incentive for their use.

It has been suggested that "families create their own 'cities' out of the destinations they can reach (usually traveling by car) in a reasonable length of time... The pattern formed by these destinations represents 'the city' for that particular family or individual. The more varied one's destinations, the richer and more diverse is one's personal 'city'" (Fishman, 1990, p. 38). The results of this research strongly support this view. Due to the manner in which space-time measures make use of the daily activity schedules and movements of people, each individual and household will likely possess a very different personal city than their neighbors, and these personal cities will be very unlikely to correspond to traditional boundaries or categories, and equally unlikely to be amenable to changing neighborhood designs.

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