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Individual accessibility and distance from major employment centers: An examination using space-time measures

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Abstract. Distance has often been assumed to be an influence on intraurban accessibility, whether in traditional proximity-based measures of accessibility, or through expectations about distance-minimizing travel behavior and the logic of the monocentric model. This paper examines the importance of distance from major employment centers to individual accessibility in Portland, Oregon, using space-time accessibility measures computed using GIS. The results of this research indicate that distance from these locations has mixed results on individual accessibility. This appears to reflect the importance of time, both the time of day activities are scheduled as well as time constraints, to individual activity patterns.

Key words: Accessibility, time geography, distance, monocentric model

JEL classification: R40, C63, C21

1 Introduction

Distance has long been a major component of the concept of accessibility. Overcoming the friction of distance to gain access to workplaces and services has been a preoccupation for most urban residents since the 19th century, when for most individuals the home and workplace became separate locations (Vance 1966; Fishman 1987). Conventional proximity-based accessibility measures are well suited for evaluating the access of locations to employment, as they measure accessibility to be the proximity of one location (or set of locations) to other locations. They differ largely in whether they are based on straight line distances (Ingram 1971), distances (whether in miles, travel time or cost) through a transportation network (Garrison 1960; Gauthier 1968; Muraco 1972; Marchand 1973; Murayama 1994; Spence and

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Linneker 1994; Lee and Lee 1998), or whether a form of distance decay is utilized to reduce the importance of farther destinations, as in cumulative opportunity (Wachs and Kumagi 1973) and gravity measures (Stewart 1942; Carrothers 1956; Knox 1978, 1982; Guy 1983; Geertman and Van Eck 1995). Although a range of possibilities exists for calculating distances (Weber and Kwan 2002), it remains a fundamental component of these measures. These measures therefore represent the accessibility of places rather than people, and all tend to produce similar spatial patterns as well (Kwan 1998).

The importance attached to proximity in accessibility measures can be justified by the widespread reliance on urban models that are oriented around major employment centers such as downtowns or suburban 'edge cities', as access within such models is a function of the distance from a particular location to the center(s). While this is a useful strategy for measuring the access of individual places, it may not necessarily work for measuring the accessibility of individuals to employment or services. People living at a particular location can be expected to move around the city throughout the course of the day, and so the location of their home will not likely be a reliable indicator of accessibility to employment. Space-time accessibility measures, which are based on showing people's daily movements and activities, can potentially reveal the importance of proximity to individual accessibility by reflecting travel behavior and urban form in more realistic ways. If assumptions about distance are correct, then these measures will produce similar patterns to those of proximity-based measures, and there will be no difference between the access of people and that of places.

This paper will therefore examine the importance and role of distance to major employment concentrations within a polycentric city to individual accessibility. The use of Geographic Information Systems (GIS) is fundamental to this task, as not only can point to point distances be measured within a street network using estimates of travel times within GIS, but these measures of distance can be used with individual level data to construct several space-time accessibility measures based on each individual's own daily activities and travel through the city. The use of these space-time accessibility measures within a GIS environment provides an ideal means of evaluating accessibility, as it also allows the disaggregate representations of each potential employment opportunity or service location, allowing a detailed representation of urban form. This will also have implications for the impact of city and neighborhood planning efforts for which distance is an important component, as will be discussed in the final section.

2 Accessibility and distance

The importance of distance to accessibility shows up in a variety of ways through its influences on urban form and travel behavior. The notion that accessibility can be reduced to proximity has been built into the standard urban models as throughout much of the last century the monocentric model and its extensions has been the leading model of urban form (Burgess 1925; Hoyt 1939; Harris and Ullman 1945; Alonso 1964; Muth 1969). This model includes a Central Business District (CBD) that contains all employment and retail activity, and so is the focus of both work and non-work travel. The CBD is surrounded by industrial and residential land uses, with densities decreasing away from the center as households seek to locate at a distance that provides a tradeoff between commuting costs (linearly related to distance) and housing costs. More recently this logic has incorporated the presence of multiple employment centers within a city, creating a multi-centered or polycentric model. Each of the centers in a polycentric city functions as a separate monocentric city, producing a metropolitan area with separate urban realms or commutersheds (Vance 1964; Hartshorn and Muller 1989, 1992; Muller 1989, 1995).

Within these models accessibility refers to proximity to the CBD (or suburban centers) and therefore declines with distance away from this location. Those living nearer a center would have higher access to employment and services located there. Because both models would expect incomes to increase with distance from the centers, low-income populations adjacent to employment centers should actually have the greatest accessibility (McLafferty 1982). The trend toward polycentrism should improve this accessibility of low income populations by providing greater opportunity to seek out residential locations near employment centers (Gordon and Wong 1985; Gordon et al. 1986, 1989a, b).

That these models no longer adequately describe urban form has been suggested by the increasing dispersion of employment (Waddell and Shukla 1993; Gordon and Richardson 1996) as well as the apparently weakened power of distance from the urban center to influence land uses (Giuliani 1989). A range of features may be of greater influence to land values than distance to downtown, such as major shopping centers, airports, freeway interchanges, universities, the beach, and even proximity to major streets (Erickson and Gentry 1985; Heikkila et al. 1989; Hoch and Waddell 1993; Waddell et al. 1993). Further, the characteristics of homes and neighborhoods may be more significant predictors of housing value or rent than distance, emphasizing the importance of local contexts and socioeconomic variations (Giuliano 1989; Archer and Smith 1993; Hoch and Waddell 1993; Waddell et al. 1993). As a result, it may be that contemporary cities are organized in fundamentally different ways than by distance, requiring entirely new perspectives (Dear and Flusty 1999; Dear 2000).

Despite these issues, the logic of the monocentric and polycentric models continue to influence discussion of urban patterns (Bookout 1992; Davis 1998; Newsome et al. 1998; Marshall 2000) and even appear in recent urban planning concepts. The concept of Neo-Traditional Development (NTD, also called the New Urbanism and closely related to the idea of transit villages) includes the ideas of building higher density residential communities with centralized retail stores and a grid street pattern in order to promote the use of non-auto travel for many trips (Handy 1992). Implicit within this concept is the importance of distance minimization behavior and attempting to increase accessibility to many services by increasing their proximity, though the extent of changes to travel patterns, urban land uses, or accessibility within NTD communities is so far uncertain (Ewing et al. 1994; Friedman et al. 1994; Steiner 1994; Crane 1996; Handy 1996a, 1996b; Boarnet and Crane 2001).

In addition to the reliance of distance in urban models, distance could also affect accessibility by influencing travel behavior. This is seen not just in the expectations of the monocentric models that people will seek to locate near the workplace so as to minimize their commute, but also in related concepts, such as excess commuting (Hamilton 1982; Small and Song 1992; Horner 2002), jobs/housing balances (Cervero 1989, 1996; Giuliano 1991), and spatial mismatches (Kain 1968; Ihlandfeldt and Sjoquist 1990; Taylor and Ong 1995; Holloway 1996). Each of these concepts requires the idea of distance minimization between home and work, and hold that the absence of such minimization is evidence that a problem exists (though the spatial mismatch concept strongly argues against the notion that low income populations will have the greatest accessibility). In each of these cases accessibility to employment is reduced to distance from potential workplaces, while commuting length has also been used to make statements about urban form, as the observation that commuting times have remained relatively constant has been used as evidence in favor of polycentric cities (Gordon et al. 1991, Song 1992; Levinson and Kumar 1994; Levinson 1998).

But people do not necessarily minimize their commute length (Hamilton 1982; Small and Song 1992), in large part because households are not dimensionless points but are confronted with a large range of factors to consider when finding a job as well as a residential location (Clark and Burt 1980; Hanson and Pratt 1988, 1992; Giuliano 1989, 1991, 1995; England 1991; Giuliano and Small 1993; Wachs et al. 1993; Hanson et al. 1997; Lowe 1998). Because of the difficulty and costs inherent in relocating, household locations may not be automatically adjusted to reflect changing employment locations or opportunities (Hanson and Pratt 1988, 1992; England 1993). This could lead to a situation where "at any given time, a large number of (rational) household and employment locations may in fact be 'suboptimal'" (Giuliano 1989, p 152). This clearly indicates that reducing accessibility to proximity is not likely to adequately capture either human behavior or urban form, and therefore the importance of distance to individual accessibility is questionable. This importance will be examined for Portland, Oregon, using space-time measures of accessibility that allow both behavior and urban form to influence accessibility, and will thereby reveal the extent to which distance may be an important factor in individual access.

3 Study area and data

The Portland, Oregon, metropolitan area provides an ideal case for evaluating the importance of distance to an individual's access to employment, shopping, and other services. While this moderately sized metropolitan area has experienced considerable suburban development, it still possesses a strong downtown area that accounts for about 20% of all metropolitan area employment and is a freeway and transit hub for the city (Metro 1997). The utility of the Portland area as a study location is increased by the presence of an urban growth boundary (Fig. 1), which is required of all urban areas in Oregon and was implemented in 1979 (Nelson 1994; Metro 1997). This boundary defines a useful study area that includes the city of Portland as well as many suburban municipalities within Multnomah, Clackamas, and eastern Washington counties (Clark county, Washington, is outside the growth boundary but is also included within the study area).

Although the city appears monocentric, the current urban planning effort for the Portland area (the 2040 Growth Plan) designates a hierarchy of

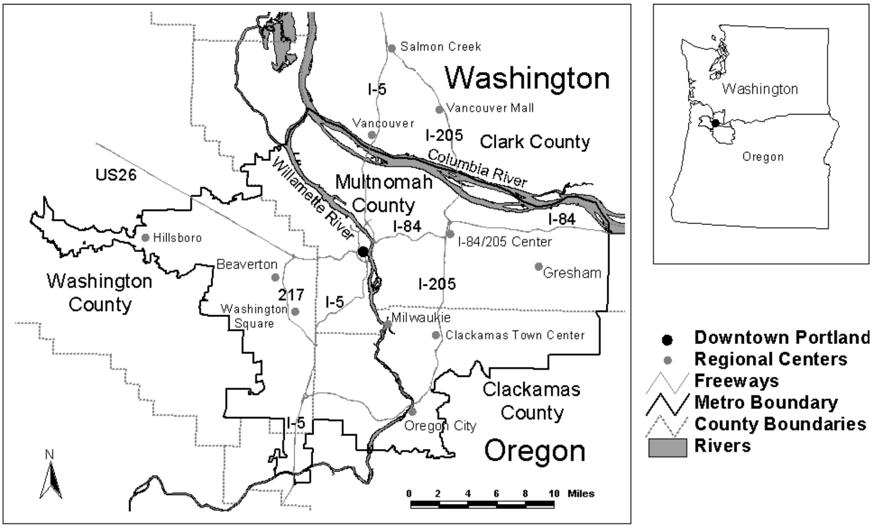

Fig. 1. Portland, Oregon, study area

centers throughout the metropolitan area, including the Portland CBD and 11 regional centers, as well as a number of smaller town centers (Metro 1997). Regional centers are defined as large mixed land use developments, representing a concentration of employment, retail, and recreational opportunities, and therefore function as polycentric centers. Although downtown Portland remains the dominant center in the city, represented by the density of commercial and industrial property parcels (Fig. 2), the regional centers should become more prominent when they are fully developed over the next several decades. They are to be pedestrian friendly walking environments, and should possess a jobs/housing balance that allows a considerable population to live within easy walking or biking distance of their workplace (as well as nearby shopping and entertainment facilities). These areas should therefore possess a high accessibility within the Portland area (though not as high as the CBD) as the city becomes more polycentric in nature. The 11 regional centers include the downtowns of several major suburbs, including Milwaukie, Gresham, Hillsboro, Oregon City, Beaverton, and Vancouver, Washington. Others are large suburban employment and retail areas, including the Washington Square Center, Clackamas Town Center, the I-84/205 center, and the Vancouver Mall, although the remaining center, Salmon Creek in Washington, is much smaller. Because the Portland CBD and these regional centers are important centers within the metropolitan area, the extent to which proximity to these locations influences accessibility is an important indicator of the extent to which monocentric or polycentric forces are still operating within American cities. Portland is therefore an ideal setting for testing the continued utility of distance in structuring urban form, individual behavior, and accessibility.

In order to carry out the study disaggregate travel data was required. This individual level travel data was obtained from a travel-activity diary survey conducted in 1994 and 1995 by the Portland Metropolitan Service District,

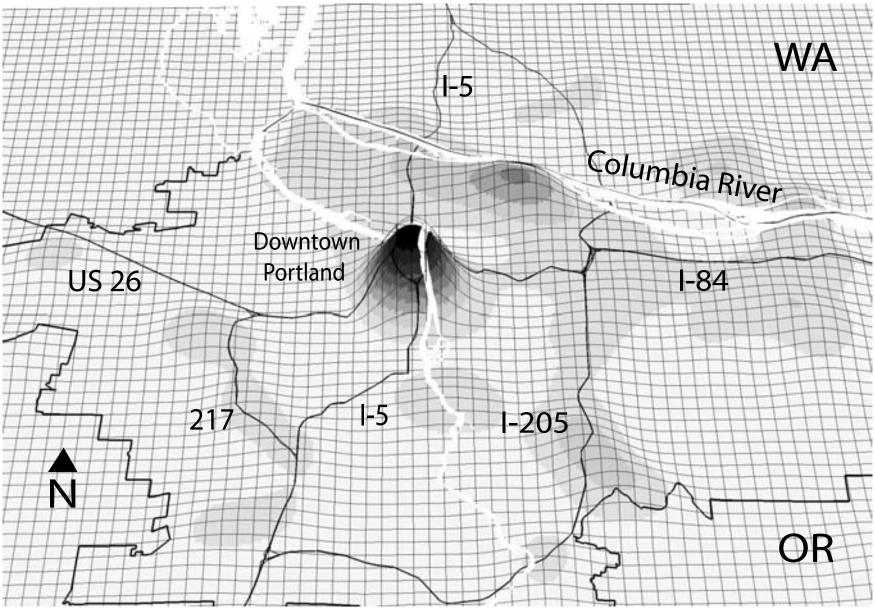

Fig. 2. Weighted area of industrial and commercial property parcels, showing dominance of Portland Central Business District (CBD)

or Metro (Cambridge Systematics 1996). This survey collected data from a total of 10,084 individuals from 4,451 households and provided information about all out of home activities (as well as in-home activities over 30 min duration) for two consecutive days, including each activity's location, the transport mode used to get there, and the beginning and ending time of each activity. The survey also includes a range of personal and household data. For this research a sub-sample of 775 adults traveling exclusively by auto, residing within the Portland Metro urban growth boundary, and engaging in activities during weekdays was selected. This data was used with local land use and transportation data obtained from Metro to geocompute space-time accessibility measures in a GIS environment.

4 Geocomputation of individual accessibility

The concept of space-time accessibility is based on Hagerstrand's (1970) time geography and the later use of this idea to formulate measures of accessibility based on individual's constraints on their daily movements. Rather than examining people's freedom to move around, Hagerstrand was concerned with the role of constraints in limiting their opportunities to reach certain areas at particular times. These constraints arise from the limits to physical mobility, as well as the need to be at particular places at certain times of the day (such as a workplace). Because of these constraints most individuals can only occupy or move within a relatively small area of a city during the course of a day. This space is termed their space-time prism, and occupies two geographical dimensions as well as a third time dimension (Burns 1979;

Villoria 1989). This prism can be used to create a measure of accessibility through the idea of a Potential Path Area (PPA), a two dimensional mapping of the geographic area contained within the space-time prism (Lenntorp 1976).

The specification of these PPAs can be explained through the use of a simple example. For most individuals there will be particular activities that they must take part in during a typical day, usually at specific places for certain lengths of time. These activities can be considered fixed, and would usually include work as well as doctor's appointments or childcare tasks. Other activities are more flexible in that an individual can more readily change where and when and for how long they take place (such as visiting a video store or eating lunch). These flexible activities could only be engaged in at times that are not occupied by fixed activities and at locations that can be reached within the time available between successive fixed activities. This area reachable between two fixed activities represents the Potential Path Area (PPA), and includes all locations accessible to the individual, as seen in Fig. 3 for an individual with 20 min of time available for travel from the origin (location of the last fixed activity) to their destination (location of their next fixed activity). PPAs can be computed between each pair of fixed activities during the day, and summed to create a daily PPA (or DPPA) for each individual, which is used here to create accessibility measures that refer to individual people, rather than locations within the city.

Although computing space-time measures in Euclidean space is relatively straightforward (Burns 1979, Villoria 1989), using distances measured through the street network will more accurately represent the ability of individuals to move around through the city. Several GIS algorithms have been developed for computing PPAs within network space (Miller 1991; Kwan and Hong 1998; Weber and Kwan 2002), and the Weber and Kwan procedure is followed here. This makes use of a street network database with free flow and congested travel times (used for travel during evening

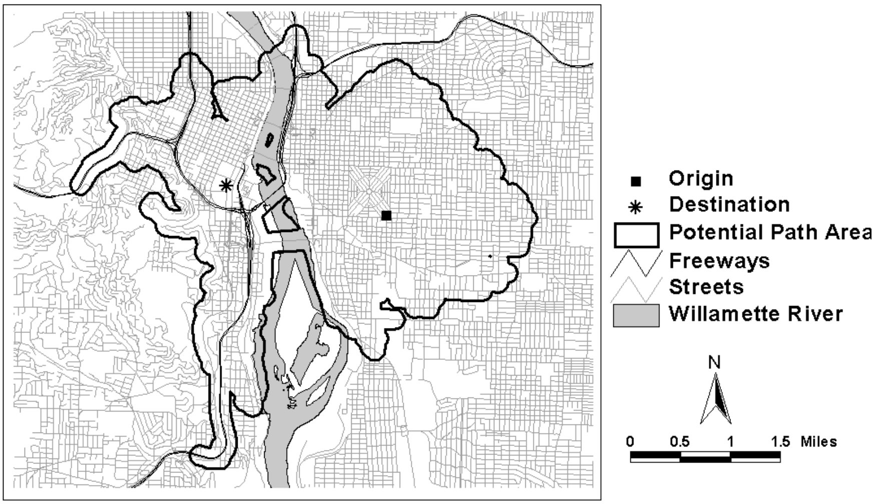

Fig. 3. Example of Potential Path Area (PPA)

congestion) that was assembled from Metro's Regional Land Information System (RLIS) GIS database and other local planning data.

These DPPAs were used to create five space-time accessibility measures. The first (called MILES) simply counts the street mileage contained within each individual's DPPA. This reflects their mobility, including the amount of open time they have between fixed activities as well as the driving speeds or presence of congestion in the areas of the city they drive in. Because the fixity of activities is not specified in the travel diary data set, activities coded as 'work' and 'school' in the Portland data set were treated as fixed activities. Additionally, activities coded as 'medical care', and 'professional services' were treated as fixed because of their importance to the individual and the likely inflexibility in scheduling. Finally, activities labeled 'pick up/drop off passengers' were treated as fixed because this category will include work, school, or day care related activities that individuals will have little scheduling control over.

The OPPORTUNITIES measure counts the number of potential activity opportunities contained within their DPPA. To represent opportunities all commercial and industrial property parcels were selected from the RLIS database and represented by their centroids, resulting in a data set of 27,749 opportunities. Individual who can reach a greater number of these opportunities will have greater accessibility, which could be expected to advantage individuals living in denser parts of Portland.

Three measures were used that took into account the relative size or importance of these activity opportunities. AREA counts the acreage of parcels within PPAs to represent the size or importance of each opportunity. Because many buildings in downtown Portland have multiple floors and therefore a greater size than their parcel acreage would suggest, the WEIGHTED AREA measure weights the area of downtown parcels by a factor of 10 to create an accessibility measure that more accurately depicts the importance of these central opportunities (as seen in Fig. 2). Because most businesses will not be open at night, the area of these opportunities should not count towards the accessibility of individuals traveling during those hours. For this reason, the TIMED AREA measure counts the weighted area of opportunities only for travel conducted between 9:00 a.m. and 6:00 p.m.

Average accessibility values for each of the 5 measures can be seen in Table 1. Because each of the measures are in different units (MILES represents mileage of streets, OPPORTUNITIES shows the number of parcels, and the area measures all provide values for the square footage of parcels accessible to individuals) these values have been standardized to a mean of 100. This allows meaningful comparisons between the measures and can be used to discuss differences between particular groups of individuals as well. Males and females within the study sample have very similar levels of accessibility, except for the TIMED AREA measure, for which women have a greater (and above average) value. This is surprising, because other research has shown that men tend to possess higher accessibility than women (Kwan 1998, 1999b). A similar situation exists with race, as non-whites possess significantly greater (and very high above average) access than whites, especially for the TIMED AREA measure. For both race and gender, it is time of day variation in travel behavior that accounts for this difference,

Table 1. Accessibility characteristics

	N	Miles	Opportunities	Area	Weighted area	Timed area
Avg personal accessibility	755	2587.40	12035.24	13533.53	14432.31	5514.57
Standardized accessibility		100.00	100.00	100.00	100.00	100.00
Gender						
Males	398	100.63	99.19	99.17	99.21	**86.46**
Females	357	99.30	100.91	100.92	100.88	**115.10**
Race						
White	715	98.97	99.31	99.04	99.11	**96.96**
Non-White	40	118.48	112.34	117.20	115.93	**154.41**
Employment status						
All full time workers	606	**94.61**	**95.28**	**95.16**	**95.20**	*76.96*
All part time workers	104	**119.67**	**118.10**	**118.54**	**118.21**	*179.37*
All retired/unemployed	45	**127.14**	**121.78**	**122.28**	**122.54**	*226.81*
Full time males	347	**96.01**	**96.14**	95.66	**95.72**	*72.73*
Other males	51	**132.04**	**119.91**	123.08	**122.98**	*179.83*
Full time females	259	**92.73**	**94.11**	94.49	**94.50**	*82.63*
Other females	98	**116.66**	**118.85**	117.90	**117.72**	*200.91*
Place of residence						
Portland City Limits	424	*113.33*	*119.21*	*115.50*	*115.80*	*117.67*
Other Multnomah County	83	*72.44*	*75.16*	*83.29*	*81.43*	*63.05*
Washington County	101	*95.91*	*85.07*	*91.19*	*90.44*	*115.98*
Clackamas County	147	*79.92*	*68.88*	*70.77*	*71.48*	*58.92*

Note: **Bold indicates** differences are significant at $p < 0.05$;
Italics indicates differences are significant at $p < 0.01$

as those with higher accessibility values are doing a greater share of their travel during daytime hours. The fact that individuals did not define the fixity of their activities in this study may help account for the lack of gender variation by masking gender differences in activity types and the extent to which men and women lacked flexibility to reschedule or skip their activities (Blumen 1994; Kwan 1999a).

Employment status and location also make a difference to accessibility. Full time workers have less (and below average) access than part time workers according to all of the measures, and those not working have the highest accessibility of all. This is due to the importance of time constraints within space-time measures and time geography, as those working longer hours have less time to move around, and so tend to possess less accessibility (Villoria 1989). Significant differences also exist among individuals living in different political jurisdictions in the Portland area. Those living within the Portland city limits have the highest accessibility by all measures, suggesting a higher level of mobility and greater density of potential activities than available elsewhere (though it could also indicate differing travel behavior). Residents of eastern Washington County, a prosperous and rapidly growing area, were second in levels of access, but except for TIMED AREA these values were below the study area average. Values for those living in Clackamas County and those outside of the city of Portland but still within Multnomah County were considerably lower. Residents of Clackamas County had the lowest level of accessibility, except for MILES, suggesting a much lower density of potential activity opportunities.

In order to help visualize individual accessibility patterns, each of the measures was interpolated from points representing individual's home locations to a continuous surface, as represented by the WEIGHTED AREA measure in Fig. 4. Because the accessibility values were standardized to a mean of 100, the heights show deviations from an average accessibility value. This surface shows the accessibility of people residing in particular locations, rather than mapping out the accessibility of fixed places (as would be the case for conventional accessibility measures). Variations in accessibility therefore depend a great deal on people's daily travel behavior. Despite the monocentric pattern of opportunities in Portland, there is no simple variation between individual accessibility and distance from the CBD for any of the measures. However, because of the potential importance of polycentric centers in Portland, and the possibility for interactions between the importance of distance and employment status or other individual level variables, this relationship will be examined in greater detail to determine to what extent accessibility variations in Portland can be explained by distance.

5 Explaining individual accessibility patterns in Portland

Although plotting average accessibility by distance from downtown or other locations as shown that there is no simple relationship between distance and accessibility (Weber and Kwan 2002), this does not provide any explanation for these patterns. The ability of distance to explain individual accessibility patterns was therefore tested in this research using multivariate regression. The goal was to use distance to multiple centers to explain the observed accessibility variations within Portland, and compare the influence of

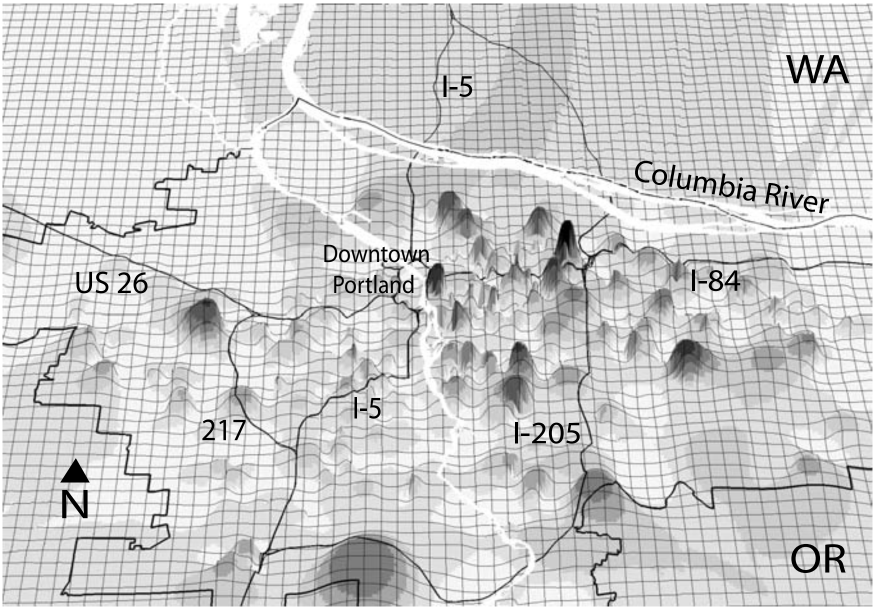

Fig. 4. Individual accessibility surface for WEIGHTED AREA measure

distance to that of socioeconomic characteristics of individuals and households, which may provide a higher level of explanation given the apparent decline in the importance of distance. The distance to the Portland CBD and the 11 major regional centers identified in the 2040 plan were included in the models. These distances were measured through the street network from each individual's home location using free flow driving times. A variety of socioeconomic data was also used, including each individual's age, gender, race, status as head of household and relation to the head of the household, the number of hours per week they work, their household's income, the number of children present in the household, and the total household size. Each of these can be expected to have an influence on household travel behavior and therefore accessibility (Hanson and Pratt 1988; Villoria 1989, England 1993; Blumen 1994; Kwan 1998).

Each of the five measures of individual accessibility was predicted by this set of variables using stepwise regression to identify the best fitting models (Table 2). As can be seen, only 3 of the distance variables were present in the final models, representing distance to the Portland CBD, the Clackamas Town Center, and the I-84/205 center. Despite the monocentric pattern of potential activity opportunities in Portland, distance to the CBD is of surprisingly little importance to individual accessibility, with only the number of opportunities declining away from this location. This decline in the number of parcels accessible could be due to a reduction in the density of parcels or mobility towards the periphery of the city, or to a greater level of time constraints with increasing distance from the CBD. The first interpretation is the most consistent with monocentric model and suggests that individuals living nearer the CBD do in fact possess higher accessibility.

Table 2. Results of regression analysis

Dependent variable	Independent variable	Coefficient	Std error	Standardized coefficient	Significance level	Adjusted rsquare
Miles	Constant	201.11	16.41		0.000	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	183.19	10.70		0.000	0.091
	Distance to Portland CBD	−1.19	0.41	−0.13	0.004	
	Distance to I-84/205 Center	−1.37	0.37	−0.17	0.000	
	Hours worked	−0.93	0.22	−0.15	0.000	
Area	Constant	175.40	11.58		0.000	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	0.064
	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	281.89	22.27		0.000	0.1
	Distance to Clackamas Center	−1.83	0.57	−0.11	0.001	
	Hours worked	−3.90	0.44	−0.31	0.000	

However, it is also clear that the CBD is not the only employment center that has some influence, as the OPPORTUNITIES, AREA, and WEIGHTED AREA accessible to individuals also tend to decline with distance away from the I-84/205 center. In addition to a reduction in the density of opportunities, the results for AREA and WEIGHTED AREA indicate that the size of activity parcels also declines with distance from a central location, though of course this is not the CBD. Given the peripheral location of the CBD within Portland, the importance of the I-84/205 center likely reflects its greater geographic centrality within the city, especially on the highway network. Travel times may therefore favor this location over the CBD. The logic of the monocentric and polycentric models are weakly supported, though again it is not possible to directly identify whether this is because of the distribution of activities, variations in mobility, or differences in travel behavior among different areas of the city.

The number of MILES accessible declines with distance from the Clackamas Town Center, showing that mobility decreases away from this location. This could again be due to differences in mobility or travel behavior. Likewise, the area of potential daytime activities (TIMED AREA) tends to decrease with distance from this center. It is noteworthy that these measures are related to distance from this center while the I-84/205 center is a greater influence on the other measures. Because the TIMED AREA measure reflects the timing of travel activity, this difference reveals that travel behavior (and time of day variation in travel) is an important component of the influence of distance.

Among the individual and household socioeconomic variables, only two appear within the regression models. The number of MILES reachable is inversely related to household size, which indicated that individuals from larger households are more restricted in their mobility, perhaps because of greater household responsibilities (and therefore time constraints) or less access to a vehicle. The number of hours worked per week is an influence on all five of the accessibility measures, as in each case a greater number of hours worked is related to lower accessibility. Because a greater number of working hours would indicate a greater amount of time spent in a fixed activity and less time available for travel or flexible activities, this is to be expected, although it is interesting that this is as true for mobility (MILES) as for the density of opportunities (OPPORTUNITIES) and their area (AREA and WEIGHTED AREA). Working longer hours is therefore the most consistent factor that reduces accessibility, which is consistent with other work on space-time measures and time geography in general.

While the importance of centrality is apparent in these results, it is actually proximity to several centers, and these vary according to the particular accessibility measure. Despite the widespread distribution of individuals in the sample there are no outlying centers (particularly in Gresham or eastern Washington County) that have any significant influence on individual accessibility. The area of greatest activity density is not necessarily the area of greatest mobility, the area of the largest activities, or of the greatest daytime travel. This strongly suggests that these centers have little real influence on accessibility, and are simply surrogates for centrality within Portland. It is likely that a number of other points could have been picked from along the freeway network within this area to produce similar results, though of course it must be remembered that these centers represent important and well known concentrations of retail and employment activities within Portland. So while centrality has a role in explaining accessibility, it is highly sensitive to automobile mobility, travel behavior, density of potential activities, and the area of those activities. Each of these factors involved in accessibility appears to respond differently to distance, so that it is not possible to point unambiguously to a single center as being important to all elements of accessibility. The importance of centrality within the city also likely changes considerably over the course of the day, depending on congestion and changing travel and activity behavior patterns, emphasizing the importance of time to accessibility. Because distances were measured to the centers using uncongested driving speeds, this does not necessarily reflect their proximity at certain times of the day. This may help explain the unevenness of the importance of centrality to accessibility. So while the results superficially support the monocentric and polycentric models, it can be argued that there is actually little evidence for the importance of distance.

6 Conclusions

This research has examined the utility of relying on distance from major employment centers as an explanation for individual accessibility patterns within cities. While the Portland CBD is clearly a major employment and service center, as well as a multimodal transport hub, this dominance is not reflected in observed accessibility patterns. Not only was distance to the CBD and most major regional centers within Portland of limited explanatory ability, but the significance of these centers fluctuated according to which measure was being tested. Living near a center is less likely to consistently influence a person's accessibility than their activity schedule. Time of day variations in carrying out activities and travel appear to account for some of these variations, leading to the conclusion that travel behavior is strongly influencing not only accessibility but also the importance of distance within Portland. This reverses the assumptions of the monocentric and polycentric models that proximity determines accessibility and further emphasizes the importance of time when discussing individual accessibility.

This is not to say that distance is irrelevant to individuals, but that the relationship between distance and access is more complicated than simply assessing the proximity of a person's home location within a monocentric or polycentric city. While it can be said that "families create their own 'cities' out of the destinations they can reach (usually travelling by car) in a reasonable length of time....The pattern formed by these destinations represents 'the city' for that particular family or individual" (Fishman 1990, p 38), individuals must still negotiate spatio-temporal tradeoffs between the desirability of engaging in an activity at a particular location and the amount of time available to get there. Rather than focusing on proximity or distance, these results suggest that an emphasis on travel times and time constraints will be more useful for understanding individual's movements and access. Location within the urban environment, not only of the home and workplace but also the activity space of individuals, will clearly influence the distance to desired activity locations and can also be expected to be an important component of individuals' experiences of the city (Weber and Kwan 2003).

This research supports other work that has examined the importance of time to accessibility (Weber and Kwan 2002). This is significant, as while new technologies such as the Internet are often credited with reducing or eliminating the importance of distance (Graham 1998; Kitchin 1998), such technology could have a greater effect on accessibility due to its ability to reduce the importance of time constraints, and particularly the need for fixed activities outside the home (Mitchell 1995, 1999). By allowing otherwise fixed activities (such as banking or classes) to be shifted to evening or weekend hours, considerable flexibility in a daily schedule could be gained and accessibility could be increased. Such gains would not be evenly distributed, as access to the Internet clearly varies among neighborhoods as well as within households (Kwan 2001; Warf 2001). This is contrary to the expectations of the monocentric that the possible accessibility gains allowed by new technology would be spread evenly throughout the city and its population (Hodge et al. 1996; Nilles 1991; Hanson 1998; Graham 1998).

These findings should be evaluated in the context of the Portland urban growth boundary and the 2040 growth plan. Because an important goal of the growth boundary is to prevent low-density sprawl and help direct attention towards infill developments and increasing residential and commercial densities (Metro 1997), it may have significant consequences on accessibility. The presence of the growth boundary may in fact be reducing variations in accessibility by confining peripheral development. This is especially the case because this development would likely favor certain areas, such as along US 26 in eastern Washington County, producing greater heterogeneity than currently exists within the boundary. Comparisons with other metropolitan areas that have not attempted to limit growth in this fashion would be very interesting for helping to reveal the significance of a growth boundary on accessibility. Given the debate over urban sprawl and increasing support for growth controls, the potential impacts of limiting urban growth or influencing land uses should be studied so that they do not reduce access to employment or services or exacerbate intraurban accessibility variations.

Although only two of the 11 regional centers were of any significance in explaining accessibility in Portland, the regional centers identified in the 2040 growth plan are in the process of being developed into higher density residential and commercial centers, and are to some degree provisionary. Some, such as the Clackamas Town Center or the Washington Square area (which was not significant in the regression results) are already large and highly visible areas. Others, including the Salmon Creek center in northern Clark County and the Oregon City CBD, would appear to have significantly less promise for future development. Should the 2040 plan succeed in transforming these into major employment and activity centers, than over the next few decades individual accessibility patterns may indeed come to reflect proximity to these centers. While the results for the 11 regional centers tend to support some (weak) polycentrism in Portland, it is unclear exactly what relationship a well developed polycentric hierarchy will have on actual travel and activity patterns. Evidence for shopping trips in other polycentric cities suggests that there will be little tendency for people to shop only within their own polycentric realm (Fujii and Hartshorn 1995; Pickus and Gober 1988). However, it must be remembered that the Portland 2040 plan relies heavily on non-auto modes, particularly walking and bicycling within centers and bus and light rail between centers, while this study has made use only of those traveling exclusively by auto, so distances to these centers may be considerably more important to non-auto travelers.

At the present time, proximity to major employment centers has a mixed influence on the accessibility of those relaying on automobiles in Portland, in large part because distance does not appear to determine individual behavior, mobility and urban land uses. In fact, it can be argued that the influence of distance may be more a result than cause of travel and activity behavior. Socioeconomic characteristics in the form of time constraints are a more consistent and likely a more useful direction for understanding accessibility patterns. That this is the case with the relative freedom of automobile travel must lead us to expect that transit usage will be even more strongly related to household time constraints and the time of day variations in mobility. This should be investigated, as should the impacts of new telecommunications technology on mobility, activity patterns, and accessibility (Adams 2000; Kwan 2000, 2001). Space-time measures of accessibility are well suited for these tasks, and their coupling with the geocomputational capabilities of GIS will likely be crucial in assessing and visualizing accessibility in ways that more directly reveal the influences of (and interactions between) time and behavior, and also by helping to integrate the real and virtual realms (Weber and Kwan forthcoming).

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