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The Temporal and Social Dimension of Accessibility for New York City Residents

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16. Abstract

While serving as an important measure in the transportation planning process, the calculation of accessibility typically does not take into account the temporal constraints faced by individuals. When temporal constraints are considered, the resulting accessibility can be vastly different for people of different demographic profiles, including gender, income, geographical location, and ethnicity. The objective of this project is to create a temporal-based accessibility measure and analyze the correlation between accessibility and one's demographic profile, using the New York City Residents Sample from the 1997/98 regional household travel survey.

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The Temporal and Social Dimension of Accessibility for New York City Residents

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1. Introduction

Accessibility, defined as the potential to reach opportunity sites, is being used mostly as a place-based measure. Placed-based accessibility implicitly assumes that accessibility to opportunities is a function of places, not individuals. The exclusion of individuals in calculating accessibility is unrealistic because individuals facing different time constraints will have varying levels of accessibility to opportunities, even though they reside in the same place. Females' accessibility might be different from males, because the time constraints they face are different. Therefore, accessibility is a function of places and individuals.

The account of individuals in accessibility suggests that there is also a social dimension of accessibility. Differences in time constraints can result in differences in accessibility, which will then lead to varying levels of accessibility for various social groups. Understanding in the temporal and social dimension of accessibility is important, because if the deficiency in one's accessibility is related to his or her temporal and social characteristics, the recent movement in changing the built environment in order to improve accessibility would be ineffective.

The temporal and social dimension of accessibility also relates to the social equity aspect in the transportation planning process. Currently, although social equity is stated as one of the goals in the planning process, it is largely ignored in the actual process. At times, such omission can be challenged in court. The lawsuit filed by transit riders' group in Los Angeles (LA) against LA Metropolitan Transportation Authority in the 1990s is an example. MPOs (Metropolitan Planning

Organizations) would benefit if a simple individual and place based accessibility measure can be developed to allow them understand the social aspect of accessibility.

The primary objective of the proposed study is to develop a space-time accessibility measure and apply it to a sample of New York City residents. Based on this space-time accessibility measure, we will compare accessibility to various opportunities (e.g., employment, open space etc.) by people with different demographic profile (e.g., gender, ethnicity, etc.).

The rest of this report is organized as follows. In Section 2, we provide a literature review on the development of accessibility measures. In Section 3, we describe the empirical datasets used for this project. In Section 4, we describe our methodology to calculate space-time accessibility, given the limitations of the data available to us. The results are presented in Section 5.

2. A Review on Accessibility Measures

In an effort to operationalize the accessibility concept, Ingram (1971) categorized two types of measures: relative accessibility and integral accessibility. Relative accessibility relates to the notion of centrality in which accessibility is measured by a generalized cost function (e.g., distance) from a location of interest to the CBD of an area. The integral index, on the other hand, measures accessibility not in relation to the center but to all other places in an area. Relative accessibility is appropriate when the city was in a monocentric form in the old days. Today, when many cities are polycentric and there is often more than one worker in each household, integral accessibility gradually replaces relative accessibility.

Regardless the number of locations it references to (relative accessibility is in reference to a single center while integral accessibility is in reference to multiple centers), both relative and integral accessibility measures have a single reference point, for example, home location point or a zone. Earliest integral measures are place-based, representing a property of a place, indicating how attractive a zone is. It simply counts the number of different types of opportunities (e.g., employment) within a pre-defined travel time or distance (Handy and Niemeier, 1997). Examples of this type of measure include McKenzie (1984), Sherman et al. (1974), Wachs and Kumagai (1973) and Wickstrom (1971). An expansive form of this measurement is called cumulative-opportunity measures, or isochronic indices, by summing up weighted opportunities with their attractions (Black et al., 1982; Breheny, 1978; Hanson and Schwab, 1987; Oberg, 1976). A later, more complex and popular set of zone-based measures were developed, called gravity based accessibility measures, incorporating the number of attractions and a impedance function between a location of interest and every other location in an area. These measures are essentially the weighted sum of generalized travel cost functions. Following Handy and Niemeier (1997)'s notation, the accessibility A_i for residents living in zone i can be calculated as: $A_i = \sum_j a_j f(t_{ij})$, where a_j is the number of opportunities for activity type j, t_{ij} is the generalized travel cost (e.g., travel cost, travel distance etc.) from zone i to zone j, and $f(t_{ij})$ is the inverse function of generalized travel cost. This gravity based accessibility measure can be calculated for a particular type of activity or for a particular mode of transportation. The capture of its variability by time is implicit; both peak-hour and non-peak-hour accessibility measures can be calculated by applying peak-hour and non-peak-hour network time correspondingly. There have been numerous applications of this gravity based accessibility measure in the field, for example, Hansen (1959), Vickerman (1974), and Wilson (1971).

These place-based integral measures are useful in characterizing the inter-connectedness between a place and other places and comparing accessibility between different places, yet a number of concerns have been raised (Kwan, 1998). The single focus on one reference point (e.g., home) ignores that fact that not all trips start from the same reference point, like home. In fact, one's daily trip pattern is made of a sequence of trips connected in time and space. This single focus also misses the temporal and spatial constraints faced by an individual. In the calculation of these placed-based integral measures, the choice of geographical scale and shape is often based on administrative units and thus rather arbitrary. Past studies have observed the sensitivity of these measures to zone size and zone configuration (Dalvi and Martin, 1976; Davidson, 1977). When a place is aggregated to a zone (e.g., census tract, or a Transportation Analysis Zone, TAZ), there are also issues on the accuracy of inter and intra-zonal travel times (Geertman and Ritsema van Eck, 1995). Finally, such a placed-based integral measure hides individual differences, which may be measured by their desires, needs, tastes, and abilities etc.

In response to these concerns, a utility-based integral measure was developed. Ben Akiva and Lerman (Ben Akiva and Lerman, 1977) constructed the accessibility index, logsum, from an microeconomic perspective, based on the widely accepted random utility theory applied on destination choices, in which the probability of an individual's choosing a particular destination depends on the utility he/she obtains from that particular destination relative to the utilities he/she obtains from all available alternatives. We follow Handy and Niemeier (1997)'s notation by expressing the accessibility for individual n is: $A_n = \ln[\sum_{V \in C_n} \exp(V_{n(c)})]$, where $V_{n(c)}$ is the systematic utility of alternative c for individual n, and C_n is the choice set for person n. Small (1992) noted that A_n, as an accessibility measure, indicates the desirability of all alternatives within the choice set for individual n. Compared with place-based integral accessibility, this utility-based accessibility measure is sensitive to individual differences, represented by their tastes etc. Geurs and van Wee (2004) noted that this utility based integral measure is also able to handle competition effects and is sensitive to changes in the supply capacity (e.g., hospital beds and job vacancies etc.).

The utility-based accessibility still belongs to the category of integral measures, and therefore can not avoid its main property: the single focus on one reference point. The measure derived from a destination choice model in which there exists a single reference point (e.g., home location) to all alternative locations. It shares the same problem as its earlier versions from this perspective. Another problem of this measure relates to its units, which are utils. This makes the comparison between different studies difficult. Ben-Akiva and Lerman (1985) proposed to overcome this difficult by dividing A_n by a travel cost coefficient, such that the units are converted from utils to monetary terms (e.g., dollars). Such a conversion, of course, highly depends on the accuracy of the model and representativeness of the dataset. Another criticism comes from the time-geographic point of view (Hagerstrand, 1970). Because there are often temporal and spatial fixities associated with a number of activities that an individual must do (e.g., a person must start working at a particular time at a particular location), there are often pockets of time that are available for an individual to perform a non-spatially and temporally fixed activity (e.g., shopping activity) at various time points and various places. These temporal constraints are not dealt with in such a utility-based accessibility measure (Geurs and van Wee, 2004).

The concern for incorporating temporal and spatial constraints motivated the recent development of space-time accessibility, which involves the calculation of potential path space (PPS). These measures are based on the concepts of space-time prisms (Hagerstrand, 1970; Lenntorp, 1976; Burns, 1979) and developed by Miller’s framework (1991). The operating and implementation of this measurement is infeasible until recently, with the tool of GIS and information from travel dairies. The operating method is described thoroughly by Kwan and her colleagues (Kwan and Hong, 1998; Kwan, 1998, 1999; Kwan and Weber, 2003; Kim and Kwan, 2003; Kwan, Murray et al., 2003). Following the notation used by Kwan (1998), the PPS for a fixed pair of locations i and j can be defined as: $PPS = \{(k,t) \mid t_i + \frac{d_{ik}}{v} \le t \le t_j - \frac{d_{kj}}{v}\}$, where t_i is the latest ending time of the activity at location i, t_j is the earliest starting time of the activity at location j, v is the average travel speed on the network, d_{ik} is the distance from location i to location k, d_{kj} is the distance from location k to location j, and location k is where the flexible activity is conducted. Aggregation of all PPAs for all pairs of consecutive fixed pairs of locations results in a daily PPA (DPPA) for a person, representing the opportunities one can reach within a day.

3. Empirical Dataset

The empirical dataset for this study is the 1997/1998 Regional Household Travel Survey conducted in the New York Metropolitan Region, comprising twenty-eight counties in New York, New Jersey and Connecticut. The entire sample includes 11,264 households in the 28-county region, conducting about 118,132 trips in the region. For the purpose of this project, we extracted a sample of 6,896 individuals making 27,705 trips in total.

Table 1. Gender Information of NYC Residents

	Number	Percentage
Male	3,200	46
Female	3,676	53
Don't know or refused	20	1
Total	6,896	100

Table 2. Employment Status of NYC Residents

	Number	Percentage
Employed – full time	2,862	41.5
Employed – part time	516	7.5
Not employed	2,021	29.3
Don't know or refused	91	1.3
Missing	1,406	20.3
Total	6,896	100

Table 1 shows that 46% of the New York City sample are males and 53% are females. Table 2 shows that 41.5% of the sample NYC residents are employed full-time; 7.5% are employed part time and 29.3% are not employed. These statistics should be viewed in conjunction with the fact that 20% of the records are missing.

In addition to the 1997/98 regional household travel survey dataset, we also acquired land use information at the TAZ level and the 2001 Taz-to-Taz travel time by auto, transit and non-motorized modes (no-build scenario). This information will be used to identify tazes that fall within subjects' travel time budget (to be defined later) and calculate space-time based accessibility for people in different social groups.

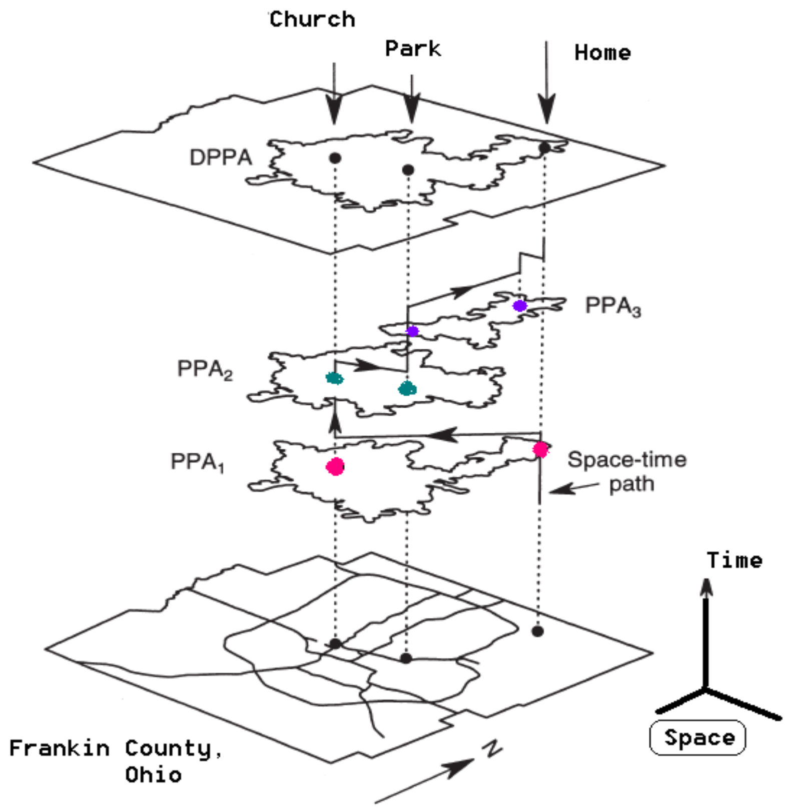
4. Methodology for the Calculation of Space-time Accessibility

According to the space-time prism concept, some activities are spatially and temporally fixed (Hagerstrand, 1970; Burns, 1979; Lenntorp, 1976). For example, work or work-related activities are often fixed for most employed individuals since these activities are conducted at fixed locations, start at fixed times, and last for fixed duration. These activities are considered spatially and temporally fixed. Because of the existence of these spatially and temporally fixed activities, a person's ability to conduct flexible activities is spatially and temporally constrained by the fixed activities. From this time-geographic point of view, whether a flexible activity can be performed and how long it can last are often constrained by the time available between the prior and the next spatially fixed activities and how fast one can travel. How easy it is for an individual to access an activity therefore depends heavily on the spatial and temporal constraints that one encounters during the day, and its calculation should take these constraints into account. As mentioned earlier, an accessibility measure calculated based on one's space-time constraints is called space-time accessibility, which is the one used in this study.

A space-time prism is generally represented in three-dimensional space, called Potential Path Space (PPS), in which the x-y plane represents an individual's geographical position and the *z* axis represents time of day. For computational purpose, this three-dimensional Potential Path Space is projected onto a two-dimensional space, creating Potential Path Area (PPA) on the planar geographical x-y coordinate system (Kwan, 1998). A PPA represents the geographical area in which an individual could travel within the space-time constraints defined by two consecutive fixed activities. It contains all potential facilities that a person can reach given the two fixed activities. Summing up all PPAs over a day generates Daily PPA. Figure 1 shows 3 PPAs generated from a person's daily travel diary in Ohio.

Figure 1: Generation of PPAs for a Sample Person in Ohio State

(Courtesy of Kwan, 1999)



A PPA can be identified when one or several flexible activities are performed between two consecutive fixed activities conducted at location i and location j. The individual can only visit location k for a flexible activity after finishing the prior fixed activity at location i and before the required starting time of the subsequent fixed activity at location j. Furthermore, the sum of the travel time from location i to location k, from k to j, and the duration of the flexible activity at location k must be within the time budget. The time budget can be calculated as the difference between the starting time of the fixed activity at location j and the ending time of the fixed activity at location i. Mathematically, the PPS for a pair of fixed activities at location i and location j can be defined as an opportunity set:

$$PPS = \{(k,t) \mid t_i + t_{ik} \le t \le t_j - t_{kj}\}, \qquad \text{(Equation 1)}$$

where t_i is the latest ending time of the activity at location i, t_j is the earliest starting time of the activity at location j, t_{ik} is the travel time from location i to location k, t_{kj} is the travel time from location k to location j. As mentioned earlier, a PPS is three-dimensional and can be converted to PPA by projecting it onto a two-dimensional plane. The daily PPA is then derived through finding the union of all opportunity sets represented by the PPAs in a particular day.

Because the land use information available to us is at the TAZ level, the travel time we use in this project is zone-to-zone travel time, instead of point-to-point travel time. More specifically, t_{ik} is the travel time from taz i to taz k and t_{kj} is the travel time from taz k to taz j.

Three types of data are required for the calculation of PPA. The first one is the geographical distribution of opportunities in the area. We mentioned earlier that the land use information that is available to us is at the TAZ level. The second one is the taz-to-taz travel time by auto, transit, and non-motorized modes. The third one is the temporal and spatial information of the fixed activities, including time budget, starting locations and ending locations. While the starting and ending locations of activities are provided in the regional household travel survey, data on time budget are not directly available in the survey since people do not always leave or arrive exactly at the required time (Thill and Horowitz, 1997).

An important variable that needs to be calculated is the time budget for each consecutive pair of fixed activities. An individual time budget is the difference between the latest departure time of the first fixed activity and the earliest starting time of the second fixed activity. For practical purposes, we assume that the observed departure and arrival times of two consecutive fixed activities in the travel diary data are the latest departure time from location i and the earliest arrival time at location j. Another important assumption made in this study is that, for a given origin and destination, all trips are made along the shortest route - although people do not always travel along the shortest route (Garling and Garling, 1988). With these two assumptions, we further infer that if no flexible activity is observed between two fixed activities, the difference between the latest departure time from location i and the earliest arrival time at location j is exactly equal to the travel time on a shortest path between location i and location j. Therefore, the time budget for the performance of a flexible activity will be equal to zero. In that case, there will be no PPA between location i and location j because there is no time for undertaking any flexible activity between the two fixed activities.

Another assumption relates to the concept of the minimum activity duration time. The time budget between two fixed activities comprises travel time from the first fixed activity to the opportunity site, travel time from the opportunity site to the next fixed activity site, and the minimum duration time for the flexible activity at the opportunity site (Kim and Kwan, 2003). We assume that the minimum duration time for a flexible activity is 10 minutes, so the time budget for undertaking one flexible activity within a PPA is: $TB_{ij} = t_j - t_i - 10$ min; while the time budget for performing m consecutive flexible activities between i and j (both are fixed activities) is: $TB_{ij} = t_j - t_i - m * 10$ min.

More specifically, the computational procedures comprise three main steps: data preparation, identification of all potential tazes that fall within a person's travel time budget, and selection of the feasible set. In the first step, we identify all pairs of consecutive fixed activities in the travel diary dataset, and calculate the observed time budget for each pair. In the second step, we add the calculated travel time from taz i to each taz k, t1, and the travel time from taz k to taz j, t2, using the uncongested taz-to-taz travel time for 2001 provided by New York Metropolitan Transportation Council (NYMTC). We applied equation 1 to determine the feasibility of every potential taz k for each subject in the sample. This procedure is applied to three groups of subjects: those using auto, transit or non-motorized modes.

5. Results

Our analysis in identifying all feasible tazes for each subject reveals that within the five-county New York City area, our subjects can reach most of the area by either auto or transit. Thus, the expected difference in accessibility by social groups will not be significant. We investigated this unexpected result, which appears to be caused by an unusually large travel time budget possessed by our sample subjects. The average travel time budget calculated based on equation 1 is 338 minutes for a pair of two fixed activities, or 415 minutes per day per subject. On average, each subject only has 1.23 pairs of fixed activities, translating into 1.845 fixed activities per subject. Such a large travel time budget makes traveling between any two zones within the five-county New York City area possible. These numbers are significantly larger than those calculated for the Puget Sound Household Travel Survey, which the PI used for another study. In the Puget Sound Sample, the average travel time budget is only 99 minutes per day per subject.

We further investigated the cause of such a large travel time budget for the New York City sample. The 1997/98 regional household travel survey has 16 different types of activities, including: drop off/pick up, visit, eat, social/recreation, shop, doctor/dentist, other family/personal business, religious/civic, work at home, work at regular location, work at other place, school, school activity at other place, sleep, other in-home activities, and other. We identify the following activities as fixed activities: drop off/pick up, doctor/dentist, other family/personal business, religious/civic, work at regular location, work at other place, school, and school activity at other place.

Table 3. Descriptive Statistics of Fixed Activities in the Sample

Fixed activities	N	Mean	Std. deviation	Min	Max
Work and work related activities	1,452	14.67	8.41	10	107
Drop off and pick up activities	789	1.67	0.94	1	8
Doctor/dentist appointment	413	6.58	1.82	6	18
Family and personal business	1,035	11.91	11.25	7	91
Religious or civic activities	1,170	11.94	10.84	7	91
School or school related activities	553	13.58	4.58	12	49

Table 3 shows the respective descriptive statistics for six different fixed activities. The column "N" denotes the number of individuals in the sample that show an at-least-greater-than-zero time allocation to the corresponding activity. For example, 1,452 people have spent sometime on working, with an average duration of 14.67 minutes, a standard deviation of 8.41, a minimum of 10 minutes and a maximum of 107 minutes. A maximum of 107 minutes is equivalent of less than 2 hours, which is well below a conventional work day: 8 hours. The little time spent on fixed activities by the majority of our sample subjects results in an unusually large travel time budget, which then leads to a universally high level of accessibility for virtually every one in our sample.

6. Conclusions

This study unexpectedly reveals an unusual sub-sample of the regional household travel survey in the New York Metropolitan Region. This sample spends an unusually small amount of time on fixed activities, leading to a large travel time budget and a high accessibility to all kinds of activities in the city.

This result is unexpected. It is also highly suspicious that the New Yorkers have a high level of accessibility to all kinds of activities, given that the average journey-to-work time remains one of the highest in the country and many of them (e.g., immigrants) juggle between multiple jobs. The data quality of this particular sample is most likely responsible for this unexpected result. It is possible that the selected sample is not representative of all the New Yorkers. Issues related to sample selection and data quality for the city of New York will be raised to the New York Metropolitan Transportation Council (NYMTC) as they prepare their next large-scale household travel survey.