Home-Based Locational Accessibility to Essential Urban Services: The Case of Wake County, North Carolina, USA

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Abstract: Accessibility is an important concept in urban studies and planning, especially on issues related to sustainable transportation planning and urban spatial structure. This paper develops an optimization model to examine the accessibility from single family homes to major urban facilities for services or amenities using geographical information systems. The home-based accessibility to facilities is based upon the point to point direct distance from sampled homes to sampled facilities. Descriptive statistics about the accessibility, such as min/max, mean/median, and standard deviation/variance were computed. Variations of accessibility for a range of categories by home price and year built were also examined. Multivariate linear regression models examining the housing value with respect to home-facility accessibility by facility types were implemented. The results show that desirable urban facilities, which are also more frequently used for livability, enjoy better accessibility than undesirable urban facilities. The home-based accessibility’s positive or negative associations with home price along with year built and/or residential lot size exist for most facilities in general, and by confirming to the literature, the home-facility accessibility in particular does strongly impact home values as evidenced by fair to excellent $R^2$ values. Accordingly, this research provides evidence-based recommendations for sustainable urban mobility and urban planning.

Keywords: accessibility; single family home; facility; desirable and undesirable; direct distance; multivariate regression; mean/median; year built; home value; GIS

1. Introduction

Today, more than 50% of the world population live in cities. In developed countries, such as the United States, Germany, Japan, and Singapore, more than 85% of the population live in urbanized areas and work in diverse non-farming businesses [1]. The major attraction of a city is attributed to better jobs, more quality services, and greener environment [2]. In cities, most working residents commute to workplaces, get services from urban facilities, and enjoy social/cultural well-being at urban amenities. All these urban living functions make home-based trips inevitable [3,4]. This research takes on Wake County, North Carolina of the United States, as a test bed to study the home-based accessibility to major urban facilities and amenities as a way to comprehend the urban spatial
form for home-based travel. Wake County is a well-urbanized county with Raleigh as the capital city for both the county and the State of North Carolina.

Urban residents live in various types of homes, including single family homes or villas, apartments, townhouses, or condominiums, regardless in low-rise, middle-rise, or high-rises buildings. In the United States, about 65% of the households live in single family homes or villas, while the rest live in apartments, townhouses, or condominiums, owned or rented [5]. In this research, the focus is on single family homes or villas located in Wake County only. Similar to homes or villas, there are also various urban facilities and amenities, such as schools, libraries, parks, shopping centers and offices to provide various essential services and amenities in education, recreation, shopping, working, and others critical to high quality urban living.

Homes are the origins and destinations for a normal daily life cycle while urban facilities are intermediate stops to provide services or amenities. Therefore, home-based travel to and from urban facilities is an essential function with spatial and social dimensions for city living. Indeed, spatial relationships between homes and facilities in a city are critical to almost all planning issues, land use policies, and zoning regulations, which together affect the city’s urban structure and travel pattern [6,7]. For instance, in transportation or residential planning, home-to-work travel is much affected by relative locations of homes and offices [3,6,8,9]. In school district planning, home and school locations are essential elements in planning school boundaries and bus routes [10–12]. In environmental planning, locations of undesirable facilities in closer proximity with respect to low-income housing and minority population have spawned intense debates on social equity [13–15].

Although various spatial relationships about home-facility can be studied, this research emphasis on the spatial relationship between a home and a facility, or more formally, the home-based accessibility to urban facilities for essential services and amenities. The following questions are particularly pertinent to this research. (1) What are the min/max, mean/median, and standard/variance of the shortest distances from single family homes to common urban facilities, as calculated by the optimization based assignment model developed in this research? Answers to this question would help local planning agencies make policies regarding commuting to work places, routing for school buses, locating fire stations, etc.; (2) What accessibility disparity, if any, exist among single family homes of different value brackets or built at different type periods from 1790 to 2020? Findings to this inquiry are valuable to the environmental justice concern and equitable urban growth both for the current metro county and for its future urban planning; (3) Is home-based accessibility a good explanatory factor for the single family home value using a hedonic price model for homes of different value brackets and build at various time periods? Insights into this question can certainly help infill for mixed income housing development and determination of property tax rates, among others. Accordingly, this research provides evidence-based findings and policy recommendations on sustainable urban planning for Wake County and its major cities, especially regarding residential and facility locations and associated mobility and equity aspects.

This paper is organized as follows. After the introduction in Section one, Section two provides a concise review of the relevant literature. Section three presents the optimization model, in which model assumption, notation, formulation, database, and modeling steps are discussed. Section four summarizes the results and highlights the findings. Conclusions and remarks are given in Section five.

2. Literature Review

The accessibility concept was generally proposed long time ago (Hansen, 1959) [16] and today competing definitions of accessibility exist in the literature [17–21]. Yet Bhat, et al. (2000, p.1) [22] perhaps defined accessibility in a broadest way as “a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time.” Today, accessibility has been well developed from various perspectives, by different methods, and for diverse applications, such as in Geurs and Van Wee [6], Farrington [23], Curl, et al. [8], Martens [14] and Geurs, et al. [4], to name but a few. A concise review of common accessibility measures and
applications is provided below, followed by a brief discussion of the home-based locational accessibility used in this research.

2.1. Accessibility Measures

Various models and measures can be found in the literature: (1) The isochronal measure of accessibility [24–26] is based on the number of destinations within a set of specified travel time or distance ranges from a home, for example, the number of parks some distance away from the home. It is simple, but arbitrarily excludes facilities beyond a certain distance. (2) The gravitation measure of accessibility [16] is based upon the gravitation push and pull between homes and facilities. Accessibility is expected to decline further apart from homes to facilities. While conceptually simple, this accessibility measure largely depends on the impedance factor and the weights for the facilities (i.e., number of shops, number of jobs, or gross leasable areas). (3) The utility measure of accessibility considers travel behaviors [17,27,28] and incorporates individual traveler preferences into accessibility measure, which, for example, can be used to examine urban parks chosen as utility-maximized destinations. (4) The constraint measure of accessibility examines the activities to be carried out and the resources (i.e., time) allocable to these activities [29,30]. This measure combines space-time and utility measures in a more complicated way with superimposed constraints. (5) data-driven measure of accessibility fully utilizes detailed location data in various ways, such as digital points of interests, cell phone or GPS data, or physical parcel-building level data [15,31–33].

2.2. Accessibility Applications

Accessibility has been applied to various planning and policy studies, including on property values by Srour, et al. [34] and Giuliano, et al., [35] on positive impacts of accessibility on housing value together with other home and neighborhood attributes; housing-jobs balance for commuting and congestion by Cervero, et al. [3], Horner [36], Johson, et al. [9]; social equity and environmental justice issues on accessibility to schools [11], to green spaces, parks, and playgrounds by Bowen, et al. [13], Talen and Anselin [37], Coutts [38], Boone, et al., [39], Rigolon [40], and Iraegui, et al. [41], to health care facilities by Khan [42], Luo and Wang [43], Bissonnette, et al. [44], and Bell, et al., [45], to transportation and transit facilities by Paul [46], Vandebona and Tsukaguchi [47], and Jang, et al. [48]; and to various kinds of urban services and/or amenities by Mladenka [49], Hewko, et al. [50], and Gonzalez-Feliu, et al., [51].

2.3. Locational Accessibility as Used in This Research

Accessibility depends on home and facility locations and can be measured by travel distance, time, or cost. Hence, it is a spatial or locational indicator for potential trips between origins and destinations [36,52]. Based on the direct home-facility distance [17,33] rather than the traditional graph theoretic link connectivity or network path impedance as used in Taaffe and Gauthier this research is concerned with the aggregated distance or accessibility from all single family homes to all facilities for any given type of facility [53]. Given the spatial scale of the urbanized areas being at the Wake County level and the aggregate nature of this study, it is reasonable to use direct distance, rather than network distance, to quickly and sufficiently capture the general spatial patterns of home-facility accessibility for tens of thousands of homes and hundreds of facilities sampled.

The location accessibility from single family homes to facilities is modeled through a shortest facility distance or accessibility from all single family homes to all facilities. The contrary is true for undesirable facilities that people prefer not to live close to (i.e., solid waste landfill sites, heavy industrial plants, airports).

If a subgroup of single family homes (i.e., less expensive in value, older by year built) experiences consistent worse accessibility for most desirable and/or undesirable facilities, it raises a
red flag on possible patterns of questionable land uses, biased zoning practices (i.e., exclusionary zoning), unequal environmental justice, or neighborhood social inequity (i.e., including gentrification) [13,38,43].

For instance, in transportation or land use planning, jobs-housing travel is much influenced by household size, car ownership rate, road network, as well as by relative locations of homes and work places [4,6,9]. In school district planning [12], home and school locations and their distances are critical factors for optimal school bus routing [55]. In environmental planning, some evidences on undesirable facilities closer to low-income communities have caused heart-searching debates among all stake-holders [7]. In health care planning, locations and connections of homes and hospitals and health clinics can profoundly affect people’s health [38,45,52,56].

The above review indicates that almost all models on accessibility found in the literature, regardless of place or people based, are based upon distance or its equivalent time or cost measure, yet only a few models [33,52] are similar to the assignment based optimization model used in this research. Also, the number of facilities considered in the literature is small, varying from one single type of facilities (i.e., park, school, bus stop) to a few, either positive (desirable) or negative (undesirable), while this research consider almost two dozens of facilities in total, both positive and negative, the most compared to models reviewed. Further, regressions on both property value brackets and year built intervals make it possible to examine in detail value and time effects on accessibility. These three major features distinguish this research, especially its model, from those in the literature.

3. Methodology

3.1. Model Assumptions

Several important assumptions are made in this study. First, an urban facility can be classified into either desirable or undesirable. Desirable facilities provide physical-economic-social services or amenities on education, healthcare, safety, recreation, or employment, such as banks, churches, schools, colleges, museums, daycare centers, health care and medical clinics, hospitals, recreation facilities, libraries, restaurants, stores, shopping centers and supermarkets. In general, people prefer to live closer to these facilities. Undesirable facilities offer employment, manufacturing, transportation, and waste processing services, but at the same time, may pose life disturbing or threatening risks. These may include heavy manufacturing plants, airports, landfill sites or solid waste centers, hazardous materials processing factories. It should be noted that the undesirable facilities are all needed for cities to offer quality life just the same way as desirable facilities. Their distinction here is mainly for classification and discussion purposes.

Second, individual facilities of the same type would provide the same quantity and quality services to different people or households. For example, it is believed that all supermarkets would be the same in providing quality and variety shopping services, hence, the best one to a home is the closest supermarket. Third, with the same logic, each single-family home needs to access only one facility of each type. For example, since all banks are assumed to be the same, the household living in a single-family home only goes to the closest one. Fourth, the home-facility accessibility can be measured by descriptive statistics of the direct air distances between all homes and the facilities of the same type (Figure 1).

The use of direct home-facility distance is mainly for modeling convenience and simplicity. More realistic alternatives would be to use the Wake County’s real road network. Then, networked trip distances, times, or costs would have to take into account many network factors, such as traffic flow, volume, and capacity, speed limit, link and path geometries, in addition to home and facility locations. However, this research focuses on the aggregated accessibility patterns for entire Wake County centered around its central city Raleigh. The use of direct distance between homes and facilities is assumed to be able to fulfill the research questions, as they are county-wide, involve homes in tens of thousands and facilities up to hundreds, and primarily are based on mean or median
distances for each type of facilities. In other words, the research questions are answered not for single home or single facility type.

Here, classing desirable and undesirable facilities is arbitrary. Also, other than services, desirable and undesirable facilities may all bring opposite effects. For instance, while living near heavy manufacturing factories may expose more to noise, dust, or odor, it provides better access to industrial jobs. Similarly, residing close to a recreational park or playground encourages more entertainment or physical activities, yet most people would rather reside not next to such facilities for possible through traffic, especially from outside the neighborhood, and other reasons.

3.2. Model Formulation

Denote \( i \in I \) as the facility \( i = \{1, 2, 3, \ldots \} \) in facility index, \( I \). Similarly, denote \( l \in L \) as the type of facility, \( l = \{1, 2, 3, \ldots \} \) in facility type index, \( L \). Define \( j \in J \) as the single family home unit \( j = \{1, 2, 3, \ldots \} \) in home index, \( J \). Similarly, define \( k \in K \) as the type of home \( k = \{1, 2, 3, \ldots \} \) in home type index, \( K \). Also, define decision variable \( X_{ij}^{lk} = 1 \) if facility \( i \) of facility type \( l \) serves home unit \( j \) of home type \( k \); \( = 0 \), otherwise. \( D_{ij}^{lk} \) = direct air distance from home unit \( j \) to facility \( i \). Note that \( D_{ij}^{lk} \) can be measured by using the shortest distance between \( i \) and \( j \) in the real transportation network. \( C^{lk} \) = objective function value:

\[
\text{Min: } C^{lk} = \sum_i \sum_j D_{ij}^{lk} X_{ij}^{lk}, 
\]

\[
\text{St.: } \sum_j X_{ij}^{lk} = J^k, \tag{2}
\]

\[
1 \leq \sum_j X_{ij}^{lk} \leq M, \tag{3}
\]

\[
\sum_i X_{ij}^{lk} = 1, \tag{4}
\]

\( i \in I, j \in J, k \in K, l \in L \)

The objective function in (1) is to minimize the total distance \((C^{lk})\) from all single-family homes to all facilities of all types. The constraint in (2) ensures that all single-family homes be assigned to the facilities of a given type. Constraint (3) ensures that each facility is signed to at least one but not more than \( M \) homes (can be set at a very high number). The constraint in (4) guarantees that each home is assigned to one and only one facility. Some key descriptive statistics based on optimal results (labeled with *) from the model (1)–(4) are calculated below.

Aggregated average or mean distance:

\[
T_{avg}^{lk} = C^{lk} / \sum_i \sum_j X_{ij}^{lk}, \tag{5}
\]

Maximum distance:
\[ T_{\text{max}}^{ik} = \text{Max}(D_{ij}^{ik}X_{ij}^{ik}), \text{where } X_{ij}^{ik} = 1, \]  

Minimum distance:
\[ T_{\text{min}}^{ik} = \text{Min}(D_{ij}^{ik}X_{ij}^{ik}), \text{where } X_{ij}^{ik} = 1, \]

Sample standard deviation:
\[ T_{\text{sd}}^{ik} = \sqrt{\frac{\sum_i \sum_j (D_{ij}^{ik}X_{ij}^{ik} - D_{\text{avg}}^{ik})^2}{(J^k - 1)}} \text{, where } X_{ij}^{ik} = 1 \]  

3.3. Study Site and Database

Wake County land parcel database was used. Wake contains the City of Raleigh, the Capital of NC, and the Research Triangle Park formed by Duke, UNC-Chapel Hill, and NCSU (see Figure 2). Other major cities include Apex, Cary, Chapel Hill, Wake Forest, and a few other small towns.

![Figure 2](image-url)  

Figure 2. The Location of Wake County in North Carolina, USA.

The Wake County land parcel and building data were in two files and not perfect, necessary data processing and sampling were performed to ensure complete and correct data. This process includes polygon-to-centroid translation, geo-coding, and address matching. The final data are in ArcGIS format and include: (1) countywide land parcel centroid GIS layer with attributes including parcel identification number (PIN) and (2) countywide building attribute table with the same PIN, which were used to join the parcel centroid GIS layer. It should be noted that not all facilities of a certain type were used, nor were all single-family homes in each price or year built category. Samples were randomly drawn based on number of criteria, such as data completeness (i.e., no zeros for key attributes), the total property value (i.e., $50k < $20 million), number of building or structure on a parcel (i.e., =1), etc. Figure 3 visually maps the home and facility samples (large dots in different colors for facilities and grey for single family homes) along with city (light blue) and county (cream) boundaries and road networks (green blue).
3.4. Modeling Procedure

Figure 4 summarizes the modeling procedure. The first step is to turn parcels or structure blueprints polygons into their centroids by using the polygon-to-centroid procedure in ArcGIS.

The next step is to link building attribute table to the parcel centroid layer to sort out single family homes and facilities by land use codes. The outcome from the step two is used as input to the optimal assignment model in Equations (1)–(4). The third step is to input the optimal assignment model output into SPSS to compute descriptive statistics as designed in Equations (5)–(8).
4. Results and Discussions

4.1. Key Statistics for Accessibility

The descriptive statistics of overall locational accessibility for Wake County are summarized in Table 1, which is organized by the numbers and types of facilities, which are generally classified into four groups—(1) Environmental, Health, and Rescue; (2) Cultural, Recreational, and Educational; (3) Auto, Food, Shopping, and Other Business; and (4) Manufacturing, Waste Management, and Transportation services.

Table 1. Descriptive Statistics of Overall Locational Accessibility

| Facility Type                     | Number | Min   | Max   | Mean   | Median  | Std. Dev. |
|-----------------------------------|--------|-------|-------|--------|---------|-----------|
| 1. For Environmental, Health, and Rescue Services |        |       |       |        |         |           |
| Hospital                          | 11     | 286.53| 76,689.13| 17,955.57| 15,803.93| 10,287.93 |
| Medical Clinic                    | 98     | 89.92 | 68,740.91| 10,718.26| 7940.29  | 8323.12   |
| Nursing Home                      | 18     | 247.53| 80,411.53| 15,946.60| 13,549.54| 10,797.36 |
| Fire Station                      | 50     | 90.64 | 50,908.50| 8109.94  | 6820.35  | 5281.50   |
| **2. For Cultural, Recreational, and Educational Services** |        |       |       |        |         |           |
| Daycare Center                    | 76     | 97.25 | 6684.57 | 8820.28 | 6212.95 | 7556.96   |
| Elementary School                 | 76     | 17.82 | 48,479.62| 6589.45  | 5081.21  | 5184.24   |
| Middle School                     | 22     | 30.76 | 68,228.97| 11,877.17| 10,119.14| 7961.07   |
| High School                       | 15     | 160.48| 67,813.10| 13,548.65| 11,441.80| 8425.99   |
| Church                            | 454    | 43.17 | 18,318.39| 3170.53  | 2744.24  | 2121.99   |
| Library                           | 17     | 26.75 | 74,353.04| 13,627.16| 11,392.39| 9050.61   |
| Park                              | 17     | 60.39 | 54,411.34| 15,957.97| 15,075.14| 8123.12   |
| Gym and Sports                    | 26     | 98.98 | 73,702.58| 14,580.26| 10,986.14| 11,930.28 |
| Theater                           | 5      | 306.59| 94,440.04| 29,806.50| 25,269.30| 20,802.51 |
| **3. For Auto, Food, Shopping, and Other Business Services** |        |       |       |        |         |           |
| Bank                              | 138    | 93.75 | 64,567.70| 8778.47  | 5776.70  | 7785.93   |
| Community Shopping Center         | 72     | 182.10| 65,499.29| 9471.35  | 6069.10  | 8632.97   |
| Neighborhood Shopping Center      | 42     | 164.91| 64,556.54| 12,070.07| 8649.34  | 9399.92   |
| Regional Shopping Center          | 2      | 1227.62| 115,819.10|42,632.23 | 36,380.51| 24,334.71 |
| Supermarket                       | 19     | 109.45| 84,561.00| 17,126.21| 11,965.78| 14,665.02 |
| Restaurant                        | 105    | 97.84 | 68,096.04| 9876.25  | 7351.71  | 7842.14   |
| **4. For Manufacturing, Waste Management, and Transportation Services** |        |       |       |        |         |           |
| Airport                           | 1      | 7202.66| 137,358.28| 58,645.84| 53,252.05| 25,959.90 |
| Heavy Manufacturing,              | 3      | 1155.38| 96,215.82| 32,351.88| 29,479.66| 21,048.51 |
| Landfill                          | 11     | 163.02| 59,422.03| 23,741.26| 22,734.43| 9983.33   |
| Truck Terminal                    | 16     | 329.31| 82,522.07| 25,361.52| 20,354.66| 16,627.83 |

The facilities in the first three groups are considered as desirable while the facilities in the last group are regarded as undesirable. The mean distances from homes to frequently used facilities, such as Restaurants, Shopping centers (neighborhood and community), Banks, Churches, Daycare Centers, Libraries, and Elementary Schools, are shorter than the mean distances to other less frequently used facilities. The mean distances to the Airport, Heavy Manufacturing plants, Truck Terminals, Theaters, and Landfill sites are much longer than that to other types of facilities. Churches have the highest accessibility with mean distance at 3170.53 feet, followed by Elementary Schools (6589.45 feet), Fire Stations (8109.94 feet), Banks (8778.47 feet) and Daycare (8820.28 feet). The Airport has the lowest accessibility with mean distances at 58,645.84 feet, followed by Regional Shopping Centers (42,632.23 feet), Heavy Industrial Mfg. (32,351.88 feet), and Theater (29,806.50 feet). Undesirable facilities are generally further away from homes than desirable facilities.

It makes sense that the mean accessibility to schools decreases from Elementary to Middle to High Schools because there are more schools from the primary to middle, and to high school levels and
because the spatial distributions of single family homes and schools are corresponding through urban planning. The similar pattern can be seen for Community, Neighborhood, and Regional Shopping Centers. In general, the larger the number of facilities, the shorter the local accessibility from homes. For example, the Church had the largest number at 454 while we only have 1 Airport, making their median distances to be 2744.24 feet and 53,252.05 feet, respectively. These patterns hold true for min, max, median, and even standard deviation. One interesting observation is that some homes were located very closely to some desirable facilities, such as the min accessibility value for Elementary School (17.8 feet) and Middle School (30.76 feet) while others were a bit away, such as for Airport (7202.66 feet) and Regional Shopping Center (1227.62 feet). Similar patterns can be seen for, for accessibility values, for example, for Airport (137,358.28 feet), Regional Shopping Centers (115,819.10 feet) and Heavy Manufacturing (96,215.82 feet). Finally, it is worth mentioning that the percentage of homes located in the 100-year Flood Plain was 3.63%.

The about results can be used to partially explain locations of homes and facilities and the urban spatial structure. Facilities and homes can be regarded as the joint products of the private market equilibrium and the public regulatory control under certain levels of safety, health, and livability for the population in Wake County. An aggregated locational accessibility measured by the shortest distances from homes to all facilities of a type roughly represents the service or amenity catchment for that type of facility. Different types of facilities would have different catchment sizes due to facility capacity, the nature of service or amenity provided, people’s lifestyles, and of course, their relative spatial relations, assuming other factors being equal. These catchments and relations, while change over time, largely form the spatial structure of the much-urbanized Wake County.

Figure 5 is a series of ArcGIS visualization images illustrating the service catchments formed by shortest distance-based accessibility for 18 desirable facilities, four undesirable facilities and the flood plain. Each image is shown with Wake County boundary, shortest distances from tens of thousands of single-family homes to facilities of different numbers, ranking from 1 for Airport to 138 for Bank to 454 for Church. The 22 images show color-code accessibility grouped into five classes using Jenks natural breaks classification. The first four images show the locations of facilities (in red) providing Environmental, Health, and Rescue services or amenities, and corresponding spider lines representing five classes of home-facility accessibility in light to dark blue colors. The facilities include hospital, medical clinic, nursing home, and fire stations. The second 9 images depict facilities (in dark blue) for Cultural, Recreational, and Educational services or amenities, and five classes of home-facility accessibility in light yellow to dark blue colors. These facilities include School, Library, Bank, and Church, etc. Clearly, the Theater has the smallest number (5) while the Church has the large number, their accessibility catchments are quite different in sizes. The similar patterns can also be seen for Auto, Food, Shopping, and Other Business facilities and manufacturing, Waste Management, and Transportation facilities, whose relatabilities are visually represented by lines from yellow to red or dark blown colors, respectively. Figure 6 shows three close-up images for visualization. Small grey or black dots represent homes, larger red or dark blue dots for Hospitals, Churches, and homes in Flood Plain, which is in light yellow. Color coded home-hospital and home-church accessibility maps are drawn using mean distances in feet classified into five groups with Jenks natural breaks.
To Hospital
To Medical Clinics
To Nursing Homes

To Fire Stations
To Daycare Centers
To Elementary Schools

To Middle Schools
To High Schools
To Libraries

To Churches
To Major Parks
To Gym and Sports
To Movie Theaters
To Banks
To Community SCs

To Neighborhood SCs
To Regional SCs
To Super Markets

To Restaurants
To Airport
To Heavy Ind. & Mfg

To Landfill Sites
To Truck Terminals
Homes in and out of Flood Plain

**Figure 5.** Home-Facility Accessibility in Spider Diagrams and Home in and out of Flood Plain.
Figure 6. Close-up Views of Home-Facility Accessibility and Home in and out of Flood Plain.

Figure 7 shows the frequency distribution of locational accessibility by shortest home-facility distances. Each chart’s vertical axis represents for frequency and horizontal axis is for distance ranges. Clearly almost all of them are not distributed in perfect bell-shape nor normal distribution. The distributions are more or less right-skewed, which indicates that of all the distance categories, the mean is located to the right of the mode or the highest histogram bar. The practical meaning is there are lots of shorter distances than longer ones, especially due to more extreme shorter distances. For example, Medical Clinics, Daycare Centers, Schools, Churches, Banks, Community and Neighborhood Shopping Centers, Supermarkets and Restaurants, indicating that these relatively use-frequency, for instance, necessary daily visit or a few times visits per week, enjoy better accessibility than the mean or median accessibility indicates in Table 1.

Interestingly though, some distributions are roughly close to the normal bell shape, such as the Parks. Heavy Manufacturing and Landfill have a bimodal like distribution with two modes or peaks. However, a closer looking at them indicate the two peaks are very close and can be literally regarded as semi-normal distributions. The last distribution in Figure 7 is really a value distribution for homes located within the Flood Plain. Clearly, it is fairly right-skewed, with the majority of these homes are lower values and only a handful of homes are expensive ones, raising a red flag implying potential environmental justice issue to be further studied.
4.2. Accessibility Disparity by Home Value and Year Built?

The descriptive statistics in Table 1 only portray an aggregated picture of home-facility accessibility or catchments for urban services or urban spatial structure. Tables 2 and 3 provide more detailed views of the accessibility by home value and year-built categories. In Table 2, for homes from low to high values for: (1) Environmental, Health, and Rescue services, the mean accessibility to Medical Clinics (12,444.23 to 6327.46 feet) is generally getting better faster, followed by Hospitals (18,360.48 to 14,845.34 feet), to Fire Station is fairly stable, to Nursing Homes fluctuates; for (2) Cultural, Recreational, and Educational Services, the mean accessibility to Theaters improves quickly (40,832.12 to 18,554.67 feet), to Elementary schools (7564.93 to 4901.31 feet) and Middle Schools (14,594.33 to 8177.71 feet) gets better fairly, and to Churches (2563.47 to 3326.87 feet) becomes slightly worse, and to Library, Gym-Sports, and Parks is oscillating; for (3) Auto, Food, Shopping, and Other Business, the average accessibility to Regional Shopping Centers (62,285.97 to 23,328.71 feet) and Supermarkets (22,444.86 to 9722.37 feet) progresses faster, to all others becomes better through ups and downs; and for (4) Manufacturing, Waste Management, and Transportation services, the mean accessibility becomes much better from 50 k–125 k (84,175.32 feet) until home values reach 350 k–450

Figure 7. Distance Distribution of Accessibility.
k (44,930.41 feet) and flattens thereafter for >700 k (to 44,983.76 feet), to Heavy Manufacturing (38,571.07 to 21,315.49 feet) and Truck Terminals (35,315.39 to 20,663.82 feet) improves similarly, to Landfill, however, downs slightly to 275 k–350 k (23,587.33 to 22,545.14 feet) and ups thereafter to 700 k (28,325.06 feet). For convenience, the average home values for all price categories and the sampled homes are also given at the bottom of Table 2.

### Table 2. Home-Facility Accessibility by Home Value (in feet).

| Facility Type | Facility Type | Facility Type | Facility Type | Facility Type |
|---------------|---------------|---------------|---------------|---------------|
| Hospitals     | 50 k–125 k    | 125 k–200 k   | 200 k–275 k   | 275 k–350 k   |
|               | 18,360.48     | 19,793.90    | 18,931.54    | 17,356.94    |
| Medical Clinic| 12,444.23     | 11,996.88    | 12,024.41    | 10,000.47    |
| Nursing Home  | 14,534.09     | 13,347.44    | 15,912.32    | 17,355.55    |
| Fire Station  | 7995.51       | 7762.26      | 8261.98      | 8209.36      |

#### 1. For Environmental, Health, and Rescue Services

- **Daycare Center**: 9809.03, 8830.10, 9119.62, 8030.86, 7809.81, 8970.98, 8009.06, 7828.34
- **Elementary School**: 7564.93, 6939.77, 6972.22, 6372.15, 5844.14, 5895.90, 5640.94, 4901.31
- **Middle School**: 14,594.33, 13,690.69, 12,817.30, 10,431.53, 10,521.30, 11,163.99, 9956.03, 8177.71
- **High School**: 14,299.25, 14,323.72, 13,996.90, 12,216.02, 12,783.88, 13,744.32, 12,937.14, 11,546.26
- **Church**: 2563.47, 2962.92, 3200.28, 3130.25, 3137.13, 3422.89, 3239.55, 3236.87
- **Library**: 12,809.65, 11,963.96, 13,613.41, 13,528.04, 14,024.46, 15,020.65, 13,477.21, 11,963.87
- **Park**: 18,704.84, 18,419.21, 16,084.12, 13,722.33, 13,647.49, 14,543.07, 15,400.00, 17,865.30
- **Gym-Sports**: 17,949.50, 14,852.12, 15,166.82, 13,355.45, 13,648.69, 14,261.13, 12,578.82, 10,692.15
- **Theater**: 40,832.12, 34,950.32, 32,363.21, 28,115.43, 25,270.92, 24,043.48, 21,200.65, 18,554.67

#### 2. For Cultural, Recreational, and Educational Services

- **Bank**: 10,019.63, 10,023.41, 9552.10, 8217.68, 7490.47, 7820.22, 6703.38, 6033.47
- **Community Shopping Center**: 12,005.66, 10,923.71, 10,114.54, 8735.50, 7933.47, 8215.89, 7158.39, 6710.60
- **Neighborhood Shopping Center**: 14,197.91, 14,282.21, 12,978.24, 10,587.41, 10,189.56, 11,099.05, 9899.91, 8362.06
- **Regional Shopping Center**: 62,285.97, 55,874.60, 47,743.96, 37,425.85, 33,917.74, 33,573.00, 29,210.06, 23,328.71
- **Supermarket**: 22,444.86, 22,552.46, 21,134.51, 14,626.38, 12,265.49, 12,296.49, 10,917.26, 9722.37
- **Restaurant**: 11,135.52, 8967.47, 10,519.71, 9601.65, 8892.17, 9460.39, 8301.55, 7334.37

#### 3. For Auto, Food, Shopping, and Other Business Services

- **Airport**: 84,175.32, 79,076.05, 64,598.41, 49,195.74, 44,930.41, 44,859.06, 44,681.77, 44,983.76
- **Heavy Manufacturing**: 38,571.07, 36,416.28, 34,717.20, 30,156.19, 30,362.60, 30,664.16, 25,896.31, 21,315.49
- **Landfill**: 23,587.33, 23,810.63, 22,758.53, 22,545.14, 24,403.82, 24,686.57, 25,034.67, 28,325.06
- **Truck Terminal**: 35,315.39, 29,875.02, 26,719.30, 23,939.80, 21,524.59, 21,603.65, 20,725.44, 20,663.82

#### 4. For Manufacturing, Waste Management, and Transportation Services

- **Average Home Value ($)**: 102,343, 168,017, 237,420, 311,417, 384,998, 457,646, 580,067, 1,037,187
- **Number of Homes**: 3576, 19,241, 20,765, 19,698, 15,378, 8560, 7898, 4987

Table 3 summarizes the mean home-facility accessibility for homes built from 1790 to 1990 by fifty-year intervals, 1990–2020 over three decades and for the entire period. Please note that the sample for homes between 1790–2020 removes those homes without year built from the total samples used in Table 1. Clearly, from 1790 to 2020, to (1) Environmental, Health, and Rescue facilities, the mean distances all increased from 1790–1840 (i.e., 15,896.45 to 20,615.40 feet for Hospital), but all dropped until 1890 for Medical Clinic (i.e., 12,013.69 to 7,930.89 feet); then all increased to 2020 (i.e., 5181.64 to 9401.95 feet for Fire Station); to (2) Cultural, Recreational, and Educational facilities, similar mean accessibility patterns can be observed with various period growth or decline rates (i.e., large ups and downs for Theaters and minor changes for Churches), except for Parks and Daycare Centers; to (3) Auto, Food, Shopping, and Other Business facilities, again, similar mean accessibility patterns prevail with larger changes to Regional Shopping Centers and mild fluctuations for all other facility types; and to (4) Manufacturing, Waste Management, and Transportation facilities, all mean distances went up or down from period to period without much overall increases or decreases. The periodical
dynamics of mean accessibility for all facilities indicate the dynamic nature of urban spatial development mainly by homes and facilities. It is very likely that they were largely developed separately yet referenced each other in terms of spatial location choices influenced by developers and consumers.

Table 3. Home-Facility Accessibility in Mean Distance by Year Built (in feet).

1. For Environmental, Health, and Rescue Services

| Facility Type        | 1790–1840 | 1840–1890 | 1890–1940 | 1940–1990 | 1990–2020 | 1790–2020 |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Hospital             | 15,896.45 | 20,615.40 | 15,283.27 | 17,023.73 | 19,448.09 | 17,702.79 |
| Medical Clinic       | 6232.55   | 12,013.69 | 7391.49   | 9969.50   | 11,964.91 | 10,469.82 |
| Nursing Home         | 10,726.70 | 15,163.54 | 9792.99   | 15,603.10 | 17,039.02 | 15,745.78 |
| Fire Station         | 5612.03   | 7923.20   | 5181.64   | 7511.95   | 9401.95   | 7979.54   |

2. For Cultural, Recreational, and Educational Services

| Facility Type        | 1790–1840 | 1840–1890 | 1890–1940 | 1940–1990 | 1990–2020 | 1790–2020 |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Daycare Center       | 7692.28   | 11,192.52 | 8311.07   | 7832.49   | 9961.74   | 8542.69   |
| Elementary School    | 5531.52   | 7960.39   | 4574.54   | 6177.35   | 7172.59   | 6147.44   |
| Middle School        | 9422.34   | 13,718.10 | 9292.99   | 11,493.94 | 12,339.82 | 11,654.06 |
| High School          | 9574.68   | 12,224.89 | 9757.55   | 12,945.86 | 14,652.73 | 13,320.67 |
| Church               | 2736.84   | 2700.04   | 1698.36   | 3086.24   | 3477.55   | 3129.47   |
| Library              | 7314.18   | 13,778.79 | 7986.59   | 12,600.23 | 17,784.48 | 13,350.73 |
| Park                 | 19,879.73 | 20,266.31 | 20,851.72 | 15,134.66 | 15,993.47 | 15,736.87 |
| Gym-Sports           | 9779.04   | 17,441.29 | 10,955.99 | 13,186.16 | 16,617.12 | 14,163.39 |
| Theater              | 34,615.52 | 36,525.82 | 22,447.74 | 26,378.28 | 35,517.19 | 29,064.56 |

3. For Auto, Food, Shopping, and Other Business Services

| Facility Type                  | 1790–1840 | 1840–1890 | 1890–1940 | 1940–1990 | 1990–2020 | 1790–2020 |
|-------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Bank                          | 4321.58   | 9814.65   | 5377.84   | 8218.19   | 9739.57   | 8550.94   |
| Neighborhood Shopping Center  | 12,660.96 | 13,357.60 | 7915.06   | 8704.60   | 10,363.51 | 9202.88   |
| Regional Shopping Center      | 8580.74   | 14,734.55 | 8166.16   | 11,119.37 | 13,652.64 | 11,769.33 |
| Supermarket                   | 45,950.94 | 51,431.94 | 37,833.16 | 40,011.44 | 46,307.70 | 41,925.95 |
| Restaurant                    | 13,382.03 | 18,972.32 | 11,304.90 | 16,437.05 | 18,177.20 | 16,731.04 |
| Airport                       | 6708.80   | 10,964.37 | 6614.38   | 9008.64   | 11,283.59 | 9602.51   |

4. For Manufacturing, Waste Management, and Transportation Services

| Facility Type                   | 1790–1840 | 1840–1890 | 1890–1940 | 1940–1990 | 1990–2020 | 1790–2020 |
|--------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Airport                        | 61,260.28 | 71,494.49 | 61,641.13 | 57,022.76 | 59,051.20 | 57,969.60 |
| Heavy Manufacturing            | 23,249.44 | 30,962.91 | 20,837.20 | 31,924.00 | 33,851.77 | 31,928.90 |
| Landfill                       | 23,247.05 | 23,599.27 | 20,837.20 | 31,924.00 | 33,851.77 | 31,928.90 |
| Truck Terminal                 | 30,707.68 | 29,174.58 | 22,366.30 | 24,682.58 | 25,926.90 | 24,965.48 |

Figure 8 provides three snap charts illustrating median accessibility for all homes, mean accessibility for homes built between 1990 and 2020, and homes valued between 275 k and 350 k. What striking is the overall patterns in terms of home-facility distances are very consistent, for example, the distances to undesirable facilities in Airport, Heavy Manufacturing, and Truck Terminals are larger than to most other desirable facilities. Also, among the desirable facilities, distances to Regional Shopping Centers, Theaters, and Hospitals are longer. Moreover, accessibility to Churches, Banks, Elementary Schools, Daycare Centers, and Restaurants is likely the most convenient. These results are very much related to the use-frequencies for homes to get services from the facilities and likely be reinforced by private development practice and public planning regulation. Overall, they should reflect the spatial lifestyles for people in Wake County.
4.3. Home-Based Accessibility Good to Explain Home Value?

Various studies have reported the positive or negative impact of accessibility to home value [26,35,43]. The relevant literature concludes that the accessibility to desirable facilities from homes can boost home values and the undesirable facilities can negatively influence home values. This section conducts several such home value impact analyses using multivariate linear regression. The basic idea is to use the total home value, including land and building, as the dependent variable and use home-facility accessibility as independent variables. One such regression model is run for each of the four facility groups and one for all facilities listed in Table 1. The five regression models are executed for all sampled homes and facilities. For each model, a backward elimination process was used until final significant variables were selected under 95% significance except for a couple of variables. Since linear regression works better over a normal distribution of data points, most of the variables listed in Figure 7 were transformed into their logarithmic equivalents except Parks, Regional Shopping Centers, Heavy Manufacturing, and Airport, whose distributions were relatively similar to normal distribution.

Table 4 summarizes the regression results. B represents the variable coefficients. Beta values are the standardized coefficients telling the positive or negative effective strength of individual variables on dependent variables. The standard outputs from SPSS (IBM, Armonk, NY, USA) also include standard deviations, t-statistics, and lower and upper bounds of B, which are computed at p-values <0.05.

| Model | B (Constant) | Std. Error | Beta | t | p-Value | 95% Lower Bound | 95% Upper Bound |
|-------|--------------|------------|------|---|---------|-----------------|----------------|
|       | 10,537,491.04 | 2,039,917.80 | 5.166 | 0.000 | 6,536,837.347 | 14,538,144.751 |
|       | 63,399,366 | 17,442,643 | 0.083 | 3.635 | 0.000 | 29,191,137 | 97,607,594 |
|       | 44,026,303 | 19,480,733 | 0.064 | 2.260 | 0.024 | 5821,006 | 82,231,601 |
|       | 763,338,120 | 35,988,365 | 0.080 | 21.211 | 0.000 | 692,758,322 | 833,917,919 |
|       | -4,529,704.81 | -622,837.410 | -0.087 | -7.273 | 0.000 | -5,751,203,438 | -3,308,206,187 |
|       | 3628.210 | 913.030 | 0.039 | 3.974 | 0.000 | 1837.591 | 5418.829 |

| Model | B (Constant) | Std. Error | Beta | t | p-Value | 95% Lower Bound | 95% Upper Bound |
|-------|--------------|------------|------|---|---------|-----------------|----------------|
|       | 696,439,465 | 38,394,512 | 18.139 | 0.000 | 621,140,724 | 771,738,207 |
|       | 20,932,169 | 1049,556 | 0.389 | 19.944 | 0.000 | 18,873,794 | 22,990,543 |
|       | -129,466,088 | 9489.656 | -0.389 | -13.643 | 0.000 | -148,077,059 | -110,855,117 |
|             | Coefficient | Standard Error | t-Value | p-Value |
|-------------|-------------|----------------|---------|---------|
| Mid School  | -24,886.061 | 7945.451       | -0.070  | 0.000   |
| High School | -24,813.866 | 9134.774       | -0.620  | 0.007   |
| Church      | 79,757.722  | 8562.618       | 0.243   | 0.000   |
| Library     | -76,733.050 | 8506.764       | -0.212  | 0.000   |
| Theater     | 28,015.321  | 8261.531       | 0.074   | 0.000   |

(Continued)

|             | Coefficient | Standard Error | t-Value | p-Value |
|-------------|-------------|----------------|---------|---------|
| Lot in Acreage | 21,893.977  | 971.933        | 0.407   | 0.000   |
| Community SC | 99,051.137  | 8813.436       | 0.216   | 0.000   |
| Neighborhood SC | 24,663.137 | 7579.339       | 0.074   | 0.000   |
| Regional SC  | -3.095      | 0.131          | -0.060  | 0.000   |
| Supermarket  | -56,594.102 | 9837.902       | -0.178  | 0.000   |
| Restaurant   | 42,231.256  | 10,510.125     | 0.128   | 0.000   |
| Lot in Acreage | 26,651.897  | 1933.851       | 0.277   | 0.000   |
| Year Built   | 592.352     | 244.745        | 0.051   | 0.000   |
| Airport      | -3.175      | 0.205          | -0.383  | 0.000   |
| Heavy Mfg    | -0.754      | 0.299          | -0.065  | 0.000   |
| Fire Station | -1,981.241  | 630.960        | -0.038  | 0.000   |
| Daycare      | 33,523.447  | 8284.433       | 0.045   | 0.000   |
| Mid School   | -23,350.438 | 6529.418       | -0.388  | 0.000   |
| Church       | -27,551.898 | 8107.681       | -0.049  | 0.001   |
| Library      | -18,571.753 | 7240.981       | -0.256  | 0.000   |
| Gym Sports   | -18,290.680 | 7903.165       | -0.084  | 0.000   |
| Community SC | -30,188.389 | 8057.958       | 0.051   | 0.000   |
| Regional SC  | -76,820.515 | 12,298.848     | -0.103  | 0.000   |
| Restaurant   | 22,151.197  | 7756.190       | 0.039   | 0.000   |
| Airport      | 191,011.564 | 16,504.213     | 0.179   | 0.000   |
| Truck Terminal | 22,229.354 | 8519.143       | 0.037   | 0.000   |

R² = 0.634

R² = 0.460

R² = 0.926

Fair to excellent R² values (from 0.45 to 0.914) for the five models indicate that the locational accessibility based on home-facility distances is a good predictor for property values. Also, each model yields some coefficient whose signs do not directly make logic sense or as expected due to partial collinearity between some variables, non-linearity of some variables, and/or their right-skewed distribution. Finally, for each model, we added year built and lot size by acreage as non-distance independent variables. In any case, comparison studies with the literature and improved accessibility or regression models are needed to further justify the accessibility’s impact to property values.

Specifically, with R² = 0.835, most facilities in the Environmental, Healthy, and Rescue category were significant with some expected and surprising coefficient signs. For example, the larger the size of a residential lot size, the higher the property value. Also, Fire Station was assumed as desirable facility type, hence, closer accessibility would positively affect property value. However, this was not the case for assumed desirable Hospital, Medical Clinics, and Nursing Homes, meaning people actually prefer reasonable distances away from them perhaps due to associated from and to traffic and other perceived specific negative characteristics internal to these facilities and/or their services.

With R² = 0.545, seven out of nine variables in the Cultural, Recreational, and Education category were significant and most of their coefficient signs were expected. For example, in addition to parcel lot size in acreage, all the schools and Library were statistically proper to be regarded as desirable facilities to which living near-by could boost property value. However, Theater and Church are surprises as they have positive coefficients, meaning the further away was preferred as the property
values were higher. What is more surprising is the missing of Parks and Gym-sports in the final regression variable selection, perhaps indicating low demand for these recreational outdoor and indoor facilities in Wake County.

Five out of six predictors from the category of Auto, Food, Shopping, and Other Business Services are identified as significant for $R^2 = 0.634$. Normally, Regional Shopping Centers and Supermarkets are larger in size and more in merchandise selections. These features perhaps helped these facilities preferred by people to live in close proximity. However, contrary to expectation, presumed desirable Restaurant, Community and Neighborhood Shopping Centers had positive coefficients, indicating property owners preferred to living further away from these facilities. If so, perhaps the shopping traffic and zoning policies separating local residential and commercial land uses might have played a role.

Three out of five undesirable facility types were statistically significant at the adjusted $R^2 = 0.456$, the lowest of all. Lot in acreage and year built were expected to have positive signs, meaning the newer and the larger a property lot is, the higher the property price becomes. However, Airport and Heavy Manufacturing facilities are out of expectation with negative signs, indicating these facilities would be reconsidered as desirable facilities, rather than undesirable facilities.

Finally, when all predictors were considered together, the best $R^2 = 0.926$. Significant variables in regressions by category were mostly selected as well with expected positive or negative signs for coefficients, such as for lot, Hospital, Clinic, Restaurant, Library, Shopping Centers, etc. However, some new variables were selected, such as Daycare, Gym-Sports, and Truck Terminal. Only Gym-sports had the expected signs while Daycare and Truck Terminal had not, indicating assumed desirability by facilities are worth of a second consideration, especially together with frequencies for facility visits linked to people’s lifestyles or lifecycles. Also, some significant variables selected in different regression models changed coefficient signs, such as Church, Airport, indicating that the role of accessibility as a predictor for property valuation is really relative, depending on the factors to be considered.

5. Conclusions and Remarks

Using Wake County as the testbed and relevant parcel and building GIS databases, this research developed an assignment model to derive shortest direct distances from single family homes to desirable and undesirable facilities to measure home-facility accessibility. Corresponding descriptive statistics, such as min/max, mean/median, and standard deviation/variances, were calculated as aggregated indicators for home-based locational accessibility, which is also viewed as a way to understand the spatial structure of the urbanized areas in Wake County. Snap shots of the home-facility accessibility by home value and year built were also examined. Selected GIS visualizations of the home-facility accessibility, at the county level, in close-up view, or by distance frequency, were selectively presented.

The results show that home-based accessibility does yield some insights on accessibility for services/amenities and the urban spatial structure. Specifically, first, within the fixed space in Wake County, the accessibility in general depends on the number of facilities, the supply side of urban services/amenities, and in specific varies by actual locations of the facilities and single family homes, the demand side of urban services/amenities. The larger the number of facilities of a given type, the shorter the distance-based accessibility. Second, the facilities in relatively large numbers, such as Church, School, Bank, Shopping Centers, or Restaurant, provide services/amenities what are needed more frequently, for example, daily, weekly, etc. The opposite is true as well. For example, people to the facilities in relatively smaller numbers, such as Theaters, Hospitals, or the Airport, have to travel longer distances, hence, lower in accessibility. Third, undesirable facilities, such as Airport, Landfill, Truck Terminals, and Heavy Manufacturing, are typically handful in quantity, large in size, and negative in some aspect (i.e., noise, dust, waste) to human health and safety. They are located further away from homes and, hence, lower in accessibility than that for desirable facilities. Finally, the aggregated mean or median accessibility is only a general indicator of home-facility accessibility as the distributions of the distances are almost all right-skewed, some are extremely right-skewed. The
distance skewedness indicates that more homes enjoy better accessibility than the mean or median accessibility indicates. These accessibility patterns and distributions correspond well with the classic location and land use theories [6,16,24,46,57] and reported practice for recreational and leisure facilities [8,37,39–41,56], physical activity [38], and health care facilities [41–45], among others, and for mobility [46–48,55] and equity [7,13–15,21,40] policies in planning.

The mild to strong association results from the five multivariate linear regression models tell that home-based accessibility is a good predictor of home value across space. This is consistent with some existing studies in the literature [26,34,35]. However, this consistency varies by facility type, number, and frequency in demand for service. The variations also exist along with combinations of variables considered, for example, by category or cross categories. The degree of consistency or variation implies the complexity and scale of property value-accessibility association or relationship, especially when the accessibility is measured at the county level. More specifically, the existing studies showing stronger accessibility-property value relations focus more on a specific location, a neighborhood, or a limited spatial area of a city while the accessibility is treated more for a specific type of facility, not across a range of facilities as considered in this research.

Nevertheless, the model developed in this research, including the sample data, shortest paths, descriptive statistics, and the regression model, can certainly be further refined. For example, perhaps single shortest direct distance from home to facility can be expanded to include multiple instead of just one to better reflect the household behavior, which tend to use more than one facility or service/amenity. In this case, the constraint (4) in the model (1)–(4) can be relaxed, $\sum_j x_{ij}^{lk} = p$, where $p$ can be any specified number to reflect policy orientation. Similarly, we can take the facility capacity into consideration in future research by specifying corresponding service threshold in constraint (3), $N \leq \sum_j x_{ij}^{lk} \leq M$, where $N$ and $M$ can be specified to match facility’s size or handling capacity. Of course, other than using direct distance, network distance from home to facility can also be considered in future improvement of the model by using real street networks. The model input data can also be further defined and selected, including facility groupings and functions. Moreover, facility classifications other than binary desirable or non-desirable and their visit frequencies depending on people’s lifecycle and life styles should be considered for realistic accessibility modeling. Finally, more interesting reverse analyses of facility’s desirability using accessibility.

Facilities were classified according to their main service functions. Single family homes were defined by county land parcel and structure records. The major limitation of the binary desirable or un-desirable classification or definition is that it poorly handles mixed uses or functions of facilities and homes and ignores other housing types [33]. The research is also limited to Wake County in North Carolina. The utility of the optimization model is yet to be seen when applied to other cities or counties, regardless urban sizes, so refinements of the model, especially on comparing it with other existing models and cases, can be achieved.

The findings from this research confirm classic theories, policies, and practices on urban spatial structure and development from the home-facility location and accessibility perspective. Theoretical confirmations include the land rent theory balancing between land and transportation expenditure for households and businesses [19,46,57], decaying urban or population density from centers to peripherals [2,16], and multiple nuclei urban model by Harris and Ullman [58] and single urban center model [26,58]. Similar validations of policies can be found in Wilson et al. on zoning [7,33], land use [16], and mobility [25]. The findings also well reflect long-held urban planning practices stressing for equity [40,56], environmental justice [7,39,49], and jobs-housing balance [3]. Perhaps the most important take-away from this research is that good theories, policies, and practices on zoning, land use, facility location, and site selection for more balanced location and accessibility patterns are necessary for any city in general and for Wake County and its associated cities, for example, the capital City of Raleigh, in particular.

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