Access beyond geographic accessibility: understanding opportunities to human needs in physical and mental space

Dissertation Proposal

May 6, 2021

Author:

- Jimmy Feng | Geography

Dissertation Advisor:

- Dr. Shih-Lung Shaw | Geography

Committee Members:

- Dr. Hyun Kim | Geography
- Dr. Madhuri Sharma | Geography
- Dr. Qiusheng Wu | Geography
- Dr. Wenjun Zhou | Business Analytics & Statistics

University of Tennessee, Knoxville | Department of Geography

Abstract: Disparities in access to human needs such as fresh food, quality medical care, and well-paying jobs is a contemporary social inequality. While access is conceptually understood to be comprised of multiple dimensions, research in this area has traditionally been explored with spatial accessibility measures that almost exclusively focus on the presence of (availability) or the travel time to providers (accessibility). Cost (affordability), provider practices (accommodation), and cultural perceptions (acceptability) also shape people's opportunities that can be and are accessed. These three aspatial dimensions also reflect the need to look beyond physical (absolute) space and include other conceptualizations of space which conventional GIS is ill-equipped to handle. An increasingly physical-virtual society owing to developments in information and communications technologies has reshaped how people can meet their needs. New technologies such as e-grocery and telehealth platforms enable people to carry out activities remotely and in less time. The temporal dimension is similarly important in understanding access as people are constrained in various ways that shape their ability to carry out various activities. Thus, this dissertation proposal describes (1) a new conceptual framework of access, (2) 'big' and small data sources and their implementation in an open-source GIS environment that reflect upon people's access, and (3) a new approach to understanding access that includes human perceptions in measures of access.

Contents

INTRODUCTION

Disparities in access to various human needs such as healthy food, quality medical services, quality education, well-paying jobs, and attractive green spaces pervade much of current society and a form of social inequality. Access in one regard can be understood as the degree of fit between people and the system, or between consumers and suppliers. It has been theorized to be comprised of five dimensions: availability, accessibility, affordability, accommodation, and acceptability (Penchansky & Thomas, 1981). These dimensions reflect different aspects related to people's access to various human needs such as medical care and food. In the academic geography literature, access is often explored and implicitly defined as geographic accessibility, or the ease of reaching particular destinations.

Understanding access however further requires the explicit inclusion of time and the temporal dimension. Torsten Hägerstrand's time geography framework offers an extensible base for which research can be built upon and simultaneously enables for investigation of individual behaviors (Hägerstrand, 1970, 1982). The five dimensions that comprise access may all vary with time, whether throughout a day or a longer duration. Explicitly recognizing time in access studies is necessary as supply, locational proximity and distance, while still very important, may not always capture the different situations of access for various needs, services, and amenities such as food, healthcare, and greenspace, as experienced by individuals. The time geography framework can offer a conceptual basis for researchers to capture, represent, model, and analyze the complexity of the geography of access and explore access at the individual level. This duality of space and time also gives rise to the notion of time-space convergence (Janelle, 1973), the reduction of average travel time necessary to reach a destination. The concept describes how people are not only able to reach physical destinations in less time but also to carry out activities more quickly and remotely, and access various needs, services, and amenities via virtual mediums. Rapid and continued developments in information and communications technologies (ICT) have reshaped how people meet their needs. People increasingly carry out their daily lives in virtual space (Couclelis & Getis, 2000; Janelle & Hodge, 2000; S.-L. Shaw & Yu, 2009; Yu & S.-L. Shaw, 2008), enabled by ICT such as the Internet and mobile phone applications. The increasing prevalence and adoption of the virtual space expands the opportunities available for individuals to carry out various human activities. In this sense, people's everyday lives are more and more "mediated, augmented, produced, and regulated by digital devices and networked systems powered by software" (Kitchin, 2017, p. 14). These digital technologies afford people the capacity to meet their needs and carry out various human activities and interactions virtually.

While human dynamics in today's so-called big data and mobile phone era are radically changing because of the aforementioned technologies, they are still not well-understood and simultaneously poorly represented in conventional GIS which often reifies absolute (physical) space in the Newtonian fashion, i.e. an immovable and infinite entity implemented based on Euclidean geometry and the Cartesian coordinate system (Shaw & Sui, 2019). This concept of absolute space is commonly adopted in research on access and accessibility. Access is comprised of multiple dimensions beyond the enumeration of a point of interest (POI) or measurement of some ratio of service or a cost or distance to specified locations that serve a need. The splatial framework proposed by (Shaw & Sui, 2018, 2019) describes multiple conceptualizations of space that can together complement and augment research in understanding human dynamics in

the current era and also be used to inquire into all five dimensions of access, including affordability, accommodation, and acceptability. Four concepts of absolute space, relative space, relational space, and mental space enable for the consideration of the different ways that shape access because of physical and relative location, context, relationships, and feelings/perceptions/thoughts.

New and extended concepts are required to both carry out research into and also improve understanding of the geography of access in a hybrid physical-virtual world and, simultaneously, across space and over time. My proposed dissertation draws from existing theories and conceptual frameworks, including (Penchansky & Thomas, 1981)'s five dimensions of access, (Shaw & Sui, 2019)'s four concepts of space, (Janelle & Hodge, 2000)'s notion of virtual space, and (Hägerstrand, 1970, 1982)'s time geography framework, to develop a new framework for a contemporary Geography of Access that relates together their different concepts. Focus is additionally given to identify how different types of data can be used for research into understanding the different dimensions of access and their conceptual extensions; and also how the proposed framework can be implemented with various methods to examine people's situations of access. A case study of food access will be used to apply these ideas in practice. The three major research objectives as summarized are to:

1. Improve understanding of the relationship between (Penchansky & Thomas, 1981)'s five dimensions of access—availability, accessibility, affordability, accommodation, and acceptability—and (Shaw & Sui, 2019)'s four concepts of space—absolute, relative, relational, and mental—, and (Hägerstrand, 1970, 1982)'s time-geographic conceptual framework in an increasingly physical-virtual society. In other words, *what is the relationship between access, space, and time?*
2. Explore the usefulness of various types of data for research in understanding the different components of access and their conceptual extensions from time geography and (Shaw & Sui, 2019)'s splatial framework. In other words, *how can various types of data be used for research in understanding the different dimensions of access and their conceptual extensions from time geography and* (Shaw & Sui, 2019)*'s splatial framework?*
3. Develop feasible approaches for implementing the new conceptual extensions of access with space-time GIS and other relevant methods to inquire upon people's access to various human needs such as food access. In other words, *what are feasible approaches for implementing the new conceptual extensions of access with space-time GIS and other relevant methods to inquire upon people's access to various human needs such as food access?*

LITERATURE REVIEW

Access as a social issue

Social inequalities in today's society remain rampant at different scales: intra-urban, regional, and national. Increasingly, social inequalities are urban inequalities (Brenner & Schmid, 2014; Harvey, 1974) and must be explored in the context of the city (Nijman & Wei, 2020). Urban inequality has various dimensions that are interrelated, such as medical deserts, food deserts, residential segregation, and spatial mismatch. The uneven degree to which opportunities of various kinds are accessed by different groups of people is related to the distribution of resources and services. Acknowledging urban inequality as manifest in these various problems also explicitly requires understanding that urban inequality is often spatial inequality, shaped by various geographical factors, including zoning, environment, and access to various human needs and services. Access is similarly one dimension of contemporary urban inequality that comes to bear on other dimensions of inequality. For instance, residential segregation along racial lines has typified the United States for much of the twentieth and twenty-first centuries (Reardon et al., 2009) and is closely intertwined with geographical accessibility to important human needs and services. The ease to which various locations and activities may be reached is an element of consideration in choosing a location to reside. "Residential location often determines access to products and services that affect one's quality of life and one's ability to earn a living" (Li et al., 2013, p. 2642).

Food, health care, green space, among others, are integral for human thriving and a good quality of life (QOL), yet many living around the world continue to experience limited or lack access to basic needs, services, and amenities. A growing volume of literature has emerged on food, medical, and greenspace deserts which describe areas with limited access to, respectively, healthy food options, appropriate medical care services, and attractive natural areas. Oftentimes, these studies posit that low-income and/or Black neighborhoods have comparatively lower access to these various needs, services, and amenities (Brown et al., 2016; Hilmers et al., 2012; Nesbitt et al., 2019; Shin, 2018). Equitable access to opportunities for affordable and healthy food, appropriate medical services, quality education, well-paying jobs, and attractive green spaces are still a formidable challenge, highlighted by a broadening set of literature on sociospatial inequities in access as well as various United Nations' Sustainable Development Goals (SDGs), including #2 – Zero Hunger, #3 – Good Health and Well-being, #4 – Quality Education, #8 – Decent Work and Economic Growth, and #10 – Reducing Inequality (United Nations, 2021). The collection of seventeen SDGs and one-hundred and sixty-nine targets put forth in the 2030 Agenda for Sustainable Development seeks "to realize the human rights of all and to achieve gender equality and the empowerment of all women and girls. They are integrated and indivisible and balance the three dimensions of sustainable development: the economic, social and environmental" (United Nations, 2017). Access therefore is a universal human right that many are not able to have. It was estimated as recently as July 2020 that more than three billion people were not able to afford a healthy diet and 8.9% of the global population were undernourished (FAO, 2020). Relatedly, health care systems around the world were immediately challenged by the COVID19 pandemic (Kruk et al., 2020), especially in the United States with hospitals operating beyond full capacity and medical personnel having to triage hundreds of thousands of patients with the virus (Cha et al., 2020; Glenza et al., 2020; Shammas et al., 2020). And as many organizations and agencies stress, a healthy diet can help protect against various health diseases, (Office of Disease Prevention and Health Promotion, 2020; World Health

Organization, 2020), timely medical care can mean the difference between life and death (Agency for Healthcare Research and Quality, 2018), and exposure to an outdoors space may provide both physical and mental benefits (Engemann et al., 2019; Laura Rocchio & Mike Carlowicz, 2019), such as decreases in diastolic blood pressure (Twohig-Bennett & Jones, 2018) and reductions in stress, depression, and anxiety (Beyer et al., 2014), and especially during pandemics (Slater, 2020). The equitable allocation of various human needs and services and their access is thus an important social determinant in a good quality of life for all.

The uneven degree to which opportunities of various kinds are accessed by different groups of people is related to the distribution of resources and services. There is much research in transportation science, urban planning, and geography focused on the sociospatial patterns of access to various needs and services. Investigating the differences in the opportunities available to population groups along different axes (geography, race-ethnicity, gender, age, and etcetera) is one pathway to further understanding of present-day social inequalities and effectively identifying underserved areas.

What is access?

If the goal is to understand access to various human needs and services and disparities between different groups of people, there needs to be greater emphasis, in addition to spatial accessibility, on other aspects that shape people's ability to fulfill them. Many researchers alike acknowledge access is a multi-dimensional concept comprising both spatial and aspatial factors. Defining and assessing access, however, are rather arduous tasks in such a dynamically evolving society and world. Access in one regard can be understood as the degree of fit between people and the system, or between consumers and suppliers, and in a similar regard as the ability and opportunities to meet one's needs. Penchansky and Thomas sought to disentangle the ambiguous notion of access to medical care services and was the first to propose a disaggregated concept comprised of five dimensions:

- *Availability*, the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs. It refers to the adequacy of the supply of physicians, dentists and other providers; of facilities such as clinics and hospitals; and of specialized programs and services such as mental health and emergency care.
- *Accessibility*, the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance, and cost.
- *Affordability*, the relationship of prices of services and providers' insurance or deposit requirements to the clients' income, ability to pay, and existing health insurance. Client perception of worth relative to total cost is a concern here, as is clients' knowledge of prices, total cost and possible credit arrangements.
- *Accommodation*, the relationship between the manner in which the supply resources are organized to accept clients (including appointment systems, hours of operation, walk-in facilities, telephone services) and the clients' ability to accommodate to these factors and the clients' perception of their appropriateness.
- *Acceptability*, the relationship of clients' attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics of clients. In the literature, the term appears to be used most often to refer to specific consumer reaction to such provider attributes as age, sex, ethnicity, type of facility, neighborhood of facility, or religious affiliation of facility or provider. In turn, providers have attitudes about the preferred attributes of clients or their financing mechanisms. Providers either may be unwilling to serve certain types of clients (e.g., welfare patients) or, through accommodation, make themselves more or less available (Penchansky & Thomas, 1981, pp. 128–129)

This concept of access explores the relationship between clients and providers in the medical care system and connotes the many different aspects contributing to an individual's opportunities

for various medical services. More generally, a*vailability* refers to adequate resources and supplies (e.g. supply of fresh produce and fruits), *accessibility* refers to geographic convenience (e.g. driving distance or time from one's location to a grocery store), *affordability* refers to cost (e.g. price of food), *accommodation* refers to various features (e.g. business operation hours, mediums of communication), and *acceptability* refers to consumers/clients' preferences and attitudes towards suppliers/providers (e.g. consumer preferences, cultural attitudes). In this respect, understanding and researching access requires the explicit consideration of the myriad ways in which people's (or consumer/client) access is influenced by their geography, socioeconomic status, physical abilities, demographic profile, perceptions, and also various characteristics of the supplier or provider. Caspi and colleagues further adopted and extended Penchansky and Thomas 1981's disaggregated definition in their literature review to describe the body of extant research on food access (Caspi et al., 2012). Both of these research works have received much support from the broader academic geography community and are commonly cited in studies on the geography of access to various health and medical care services as well as to food, with 2881 and 950 citations as of February 16, 2021 for, respectively, (Penchansky & Thomas, 1981) and (Caspi et al., 2012). The concept of access to medical care can arguably be adapted for a more general framework to understand access to various human needs and services, and ultimately the different abilities for groups of people to fulfill their needs for a good quality of life. In the extant literature, however, access is often assessed with measures of the first two dimensions of availability and accessibility and can be understood as *spatial (physical/geographic) accessibility*—the supply and/or ease to which a service or location can be reached. In contrast, the other dimensions of affordability, accommodation, and acceptability are comparatively less explored and understood as the aspatial dimensions of access (Khan & Bhardwaj, 1994). Furthermore, the literature also expresses two different ways to approach access, either as realized/revealed or potential access. Realized/revealed access describes the actual utilization of services whereas potential access describes the organization and capabilities of different sites and providers of services as well as the needs and desires of consumers. What follows is a review of literature on access as explored from dimensions of (i) affordability, (ii) accommodation, (iii) accommodation, and (iv) availability and accessibility. Then, both the temporal and spatial dimensions of access are further examined in an increasingly physical-virtual world.

Affordability: Costs to Access

- *Affordability*, the relationship of prices of services and providers' insurance or deposit requirements to the clients' income, ability to pay, and existing health insurance. Client perception of worth relative to total cost is a concern here, as is clients' knowledge of prices, total cost and possible credit arrangements.

Access to human needs almost always requires some cost to be overcome and/or the exchange of some monetary amount (or an equivalent.) This can be either or both objective and subjective. The former describes the supplier's price of the good or service while the latter reflects how people (i.e. consumers) weigh and perceive that price. For example, the cost of health-care services in parts of the world, such as the United States, is often mediated through an insurance provider or by the users themselves, in which individuals have to pay exorbitant amounts of money out-of-pocket for medicine, patient care, and the like. Besides generous provisions by soup kitchens, an individual or household acquires healthy and nutritious foods with their own money or some type of governmental assistance, such as Supplemental Nutrition

Assistance Program (SNAP) benefits (formerly known as food stamps), electronic benefits transfer (EBT), and Special Supplemental Nutrition Program for Women, Infants and Children (WIC). However, there are also other fiscal costs beyond a service itself, including for travel and time. There are external costs that must also be considered beyond the cost of the service itself, such as those induced with transportation as well as time use. In some cases, the allocation of some expenditure to travel or transportation might even be comparable to the cost of service, therein suggesting that different groups of people are affected differently by the necessary costs of using a service (Wachs & Kumagai, 1973). Equal access would mean that groups of people facing the same costs when consuming a good or service would also have equal opportunities (Hjortsberg & Mwikisa, 2002). Those reliant on public transit to reach a grocery store or physician's clinic would likely have to pay a fare while drivers may also need to pay for tolls, gas, and car-related deterioration. Similarly, if individuals are unable to take paid time off, they may have to forsake some of their income in order to take time off for appointments. Access is thus shaped by affordability, not only just with the cost of a good or service but the relative costs of travel, transportation, or telecommunication involved in their consumption.

In the literature, the dimension of affordability in access has been captured in various ways. Some studies have suggested that affordability may be of greater importance in access than the spatial dimensions of availability and affordability (Drewnowski et al., 2012). (Hjortsberg & Mwikisa, 2002) surveyed 889 Zambian households to understand their expenditures towards health care and inquired about their enrollment in pre-payment schemes, expenditures for health and preventative care services, and their satisfaction with these services. To measure the disparities in access between urban and rural households, they compared the total monetary cost of access to health care which they derived by adding together the sum of fees, travelling costs, and the time cost. In another study, (Bocarejo S. & Oviedo H., 2012) included both the relative percentage of transit fare with income and travel time from data gathered in a travel survey to measure job access. However, the researchers didn't account for the monetarized value of travel time in their study. Increasingly, the total travel monetary cost as the total sum of both transit fare and a monetary cost for travel time has been incorporated as the cost used to assess access to jobs and the issue of spatial mismatch; for some examples, see: (El-Geneidy et al., 2016; Ford et al., 2015; Liu & Kwan, 2020). Liu and Kwan also considers the effect of the total travel monetary cost as a percentage of income as the impedance factor in their gravity-based measure to provide better estimates of job accessibility for low-income and non-low-income peoples (Liu & Kwan, 2020). In other words, the number of jobs available to different groups of people by income is sensitive to the total cost required for their access.

However, while viewing travel in itself as a cost has been largely explored in the literature, other aspects related to affordability, such as the price of food and health care, alternative payment options, and subjective costs have not been as thoroughly explored. Gao and Kolak use principal component analysis on ten variables contributing to food access in Chicago to identify vulnerable populations with low access (Gao & Kolak, 2019). In their model, they included the percentage of people unemployed as well as those below the poverty line as indicators of affordability. While this study explicitly inquired into the dimension of affordability, it makes several assumptions that everyone identified as being in poverty or unemployed perceive affordance and costs the same way. There is greater need to include also how different location and service providers are perceived in terms of affordability.

Accommodation: Structure and Organization of Services

- *Accommodation*, the relationship between the manner in which the supply resources are organized to accept clients (including appointment systems, hours of operation, walk-in facilities, telephone services) and the clients' ability to accommodate to these factors and the clients' perception of their appropriateness.

The arrangement of goods and services must also be considered in understanding opportunities for people to meet their various needs. While one's economic situation is an important determinant of their ability to obtain nutritious foods, appropriate health care services, and the like, how they are organized also affects the degree to which they can be accessed. Accommodation can thus refer to the infrastructure and systems in place that enable individual consumers to reach and consume particular supply-side goods or services. This includes appointment systems that enable scheduling of activities, hours of operation that fit within the consumer's time budget, facilities with appropriate infrastructure that allow people with disabilities to easily navigate around (e.g. wheelchair ramps, clear visual markers and signs, parking spaces), and various mediums of communication to facilitate easy contact (e.g. telephone services, translation services).

In the research literature, researchers using space-time measures are good examples of integrating some aspect of accommodation in understand access to various human needs and services. These measures explicitly integrate the temporal dimension and the constraints-based time geographic framework in geographical analyses to investigate human movements, activities, and interactions at the individual level in assessing the feasible opportunities that can be reached by an individual (Kwan, 1998). One of the earliest and most significant contributions was by (Lenntorp, 1976 in H. J. Miller, 1991) who designed a computational model that incorporated transportation characteristics of the study area, locations and hours of operation of various opportunities, and hypothetical daily activity schedules of individuals. This would be used to measure access by calculating the feasible opportunities across the area that could be reached given the spatiotemporal structuring of one's day. An alternative approach such as in (Haggerty et al., 2011) surveys individuals with different subscales to understand the importance of various aspects of accommodation to health care providers from the patient perspective. A subscale is a scale for a category of information that is part of a larger scheme, and in this instance, these subscales reflected different dimensions of access. Among many questions, participants are asked about their ability to contact appropriate staff at different times throughout the day, scheduling suitable appointments that fit their time budgets, waiting time in waiting rooms, getting advice over the phone, and their likelihood of being seen at night. These survey results are then analyzed with factor analysis to identify dimensions that reflect how people perceive their access. In fact, most research that explores the dimension of accommodation, as well as the other dimensions of affordability and acceptability, in access are frequently assessed and measured with psychometric techniques (i.e. techniques for psychological measurement).

Acceptability: Cultural Attitudes and Preferences

- *Acceptability*, the relationship of clients' attitudes about personal and practice characteristics of providers to the actual characteristics of existing providers, as well as to provider attitudes about acceptable personal characteristics of clients. In the literature, the term appears to be used most often to refer to specific consumer reaction to such provider attributes as age, sex, ethnicity, type of facility, neighborhood of facility, or religious affiliation of facility or provider. In turn,

> providers have attitudes about the preferred attributes of clients or their financing mechanisms. Providers either may be unwilling to serve certain types of clients (e.g., welfare patients) or, through accommodation, make themselves more or less available

How people perceive of services and providers also influences whether they are truly accessed or not accessed. The dimension of acceptability brings into explicit consideration cultural, economic, social, and environmental forces that come to bear on the attitudes and preferences of individuals. People respond differently to the various characteristics of a service provider according but not limited to age, sex, race-ethnicity, religious affiliation, and the local environment in which the provider is situated. Conversely, the service provider also has attitudes about their clients and their ability to pay for the service. The duality of the relationship between individual users (demand-side) and service providers (supply-side) reflects the importance of understanding access beyond mere geographical relationships such as proximity and distance. Rather, it is important also to consider the individual as comprised of their various attributes that come to bear on their daily lived experience in the broader world. Conversely, different types of providers have different motives and goals that may affect the clients they try to target and attract. This dimension of access most closely reflects how people perceive of their access under the context of their broader environments and situations.

Utility-based measures (i.e. discrete choice models) are a good example of how acceptability has been attempted to be measured. They enable for more nuanced personal characteristics to be included in the parameterization and assume that people select the opportunity (or "alternative" as is described in the literature), among many, that provides the maximum utility (Ben-Akiva & Lerman, 1985). These utility-based measures are based on individual choice behavior and often premised on various theories, including Thurston's random utility theory and Luce's strict utility theory. The former postulates that the utility of all alternatives are stochastic (random) variables and the chosen alternative has the highest probability with the greatest utility among all others in the choice set (Ben-Akiva & Lerman, 1985). In contrast, the latter postulates that the probability of choosing a choice alternative is equal to the ratio of the utility of that choice alternative to the total utility of all choice alternatives in the choice set. Utility functions often take the form of a multinomial logit model and includes variables for the characteristics of alternatives in the choice set, the attractiveness of each alternative, the travel impedance, and socioeconomic characteristics of people. The logsum of the model is used to define an individual's access. Utility-based measures are frequently used to measure access because they can capture the randomness of users' preferences.

Gao and Kolak include the percentage of the population speaking English, "less than very well," as a variable reflecting the accommodation dimension in their principal component analysis of determinants of food access (Gao & Kolak, 2019). However, this implies that non-English speakers all face a similar difficulty and challenge in reaching a location or service. And arguably, this could also reflect upon acceptability as particular groups of people may feel more comfortable consuming at a similarly characterized grocery store or hospital. In reality, there may be ethnic and cultural providers (e.g. ethnic food stores and minority-run private physicians clinics) that minority groups may favor over other alternatives. And as discussed earlier, different people also perceive cost and affordability in different ways that come to shape access.

Spatial Accessibility: Availability and Accessibility

- *Availability*, the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs. It refers to the adequacy of the supply of physicians, dentists and other providers; of facilities such as clinics and hospitals; and of specialized programs and services such as mental health and emergency care.
- *Accessibility*, the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance, and cost.

"At the very least, the 'quality of life' in a city or region refers to the *accessibility* of its inhabitants to employment alternatives, educational and medical facilities, essential public social services, and 'nature' or extensive recreational open spaces" (Pred, 1977). In the research community, many evaluate the social equitability of access to various human needs (e.g. food) and social services (e.g. medical care), and identify potential areas of service deprivation or inequities in their provision based on measures of availability and accessibility. Availability can broadly be understood as the number of locations or service providers that a person or group of people can choose from while accessibility, as a dimension of access, can be understood as the separation between the aforementioned person or group of people and a location or service provider. Researchers typically explore the relationships between the geographic distribution of access and the geographic distribution of population groups along various demographic axes. One vein of research evaluates potential inequities and disparities in access between different demographic groups and areas (i.e. unfair and unjust distribution of resources between different groups of people), and for some examples, see: (Bosanac et al., 1976; Brown et al., 2016; Chen, 2017; McKinnon et al., 2009; Rong et al., 2020; Wang, 2012; Yin et al., 2018). There is also much literature assessing the distribution of resources and social services, including healthcare services (Apparicio et al., 2008, 2017; Knox, 1980; Lin et al., 2018; Luo, 2004; Luo & Wang, 2003; Luo & Whippo, 2012; Wang, 2012), food (Caspi et al., 2012; Chen, 2017; Ploeg et al., 2009; Yenerall et al., 2017), greenspace (Talen & Anselin, 1998), and jobs (Fieldhouse, 1999; Hansen, 1959; Hellerstein et al., 2008; McLafferty & Preston, 1992, 1996; Shen, 1998).

Oftentimes, research on access in transportation science, urban planning, and geography exclusively explores the supply of an activity or resource (i.e. availability) or the ease to which they could be reached (i.e. accessibility), and falls under the umbrella of *geographic* (or *physical*, *spatial* as is commonly employed throughout the literature) accessibility. However, what constitutes *accessibility* is greatly contested, without an objective definition nor measurement uniformly agreed upon by researchers and practitioners alike (Handy & Niemeier, 1997; Koenig, 1980; E. J. Miller, 2018). The following section refers to *accessibility* as *geographic | physical | spatial accessibility* as is often employed in geographic research. Often quoted, "accessibility… is a slippery notion, however; one of those common terms that everyone uses until faced with the problem of defining and measuring it!" (Gould, 1969, p. 64). There still remains much disparate interpretation of accessibility even decades after Penchansky and Thomas' proposed dimensions of access with an explicit definition for 'accessibility.' Notwithstanding, accessibility has a long tradition in transportation science, geography and urban planning but its conceptual nature varies based on the objective at hand (e.g. transportation planning, social equity, service provision, policy.)

Walter G. Hansen's adaptation of the gravity model to understand accessibility as the potential interaction between locations, and its role in shaping land use, or "the generalization of the connections of the population, reaching across distances" (Hansen, 1959, p. 78) is often

regarded as the seminal work in this broader field of research. He proposed that accessibility shapes land use; and thus that accessibility is a goal to be met for urban and economic development and an objective function of populations and their proximity and distance. To operationalize accessibility, (Ingram, 1971) further differentiated between what he coined *relative accessibility* and *integral accessibility*. Relative accessibility describes the degree of connectivity between two places as measured by the accessibility of one origin location to a destination based upon their physical separation. This is in contrast to integral accessibility which measures accessibility of a place from one location to all other locations, or the total accessibility of a location. Dalvi and Martin adopted (Ingram, 1971)'s definition of integral accessibility to analyze the importance of accessibility in trip demand models, suggesting that accessibility is additionally contextualized by the transport system (Dalvi & Martin, 1976). Despite its arbitrary nature, accessibility in one respect has been broadly understood as the ease of reaching a location, resource or service. Some other perspectives regard accessibility as a critical component of quality of life and social wellbeing (Knox, 1980, p. 369; Wachs & Kumagai, 1973). And more specifically in the context of transport geography, accessibility generally describes "the degree to which transport systems enable people to reach desired activity locations" (Neutens, 2015, p. 15). However, accessibility is more than ever premised also in virtual environments with the increasing digitalization of society and rapid developments in information and communication technologies (Couclelis & Getis, 2000; Janelle & Hodge, 2000). Generally speaking, (physical/spatial/geographic) accessibility in the context of this dissertation, focused on access, is understood as the ease to which individuals can reach desired activities under the context of the transportation system, land-use pattern, and virtual environment.

Concurrently, the operationalization of accessibility widely varies between research studies, and there exists no 'best' measure of accessibility as each accessibility measure is only useful if it is consistent with how people perceive and understand their own situations (Handy & Niemeier, 1997). Accessibility has been explored from the perspective of people and place, or person-based/individual accessibility and place-based accessibility. These different perspectives reflect different characteristics of people's opportunities to various human needs and services. Common measures of place accessibility can be broadly categorized as (1) simple distance measures, (2) cumulative opportunity measures, (3) gravity measures, and (4) utility-based measures while individual accessibility has been explored with (5) space-time measures.

Types of availability and accessibility measures: place-based measures

Simple distance measures have been operationalized as the Euclidean (straight-line) or network path-based distance between a supply and demand location. In other words, the time or cost needed to traverse from one location to another, or the physical length between two locations provide a point of comparison for whether a resource or service is or is not available. Accessibility in this instance is thus concerned with the spatial separation of one location to another. Network path-based distances are almost always preferred because the former are based on realistic transportation networks that takes also into consideration physical impediments and barriers (e.g. water bodies, buildings, train lines, etc.) Such measures can further be refined to account for the mode of travel, whether by foot, bike, car, or some form of public transit, and the time of day. They are often employed in research studies that establish time or geographic space as the unit of measurement, treated as (i) proximity: physical distance or travel time to the closest supply location (Ploeg et al., 2012; USDA Economic Research Service, 2019); (ii) diversity:

number of supply locations within a given time or distance threshold (i.e. service area) (Apparicio et al., 2007; dos Anjos Luis & Cabral, 2016), or (iii) variety: average distance to a specified number *n* of supply locations. The diversity measure is most in accordance with the *availability* dimension in Penchansky and Thomas' framework while both proximity and variety are more in accordance with the *accessibility* dimension. Similarly, travel time has been used to assess accessibility to food in the United States (Ploeg et al., 2009; Rhone et al., 2017), cities for rural populations globally (Weiss et al., 2018), hospitals (Bosanac et al., 1976), and other healthcare facilities (Weiss et al., 2020). In proximity and variety distance measures, longer travel times or physical separation would suggest lower accessibility while shorter travel times and physical distances would indicate greater accessibility. Meanwhile, a larger value for diversity would indicate greater availability as there would be more options available. However, it is recognized that the choice of distance measure can significantly impact the obtained results; thus, conclusions may be highly sensitive to the choice of measure of access (Talen & Anselin, 1998) as well as the method of aggregation, i.e. the selection of the spatial unit of analysis (Apparicio et al., 2017). Choosing only one of these measures does not adequately capture a population's spatial accessibility to a resource or service, and it is argued that no single simple distance measure can fully describe the geography of accessibility as they may reflect different aspects of opportunities for people to meet their various needs (Apparicio et al., 2007).

In the same vein of measurement as the diversity measure, cumulative opportunity measures assess spatial accessibility from the availability dimension—as the total amount of opportunities that can be reached from a person or population's origin location(s) within a particular travel time or distance threshold. See for example: (Wachs & Kumagai, 1973). Each potential activity location is weighted the same (i.e. equally.) For example, a population's availability would be contingent upon the number of possible health care facilities that could be reached within half an hour drive for that population's origin location. The availability of a good or service would increase as the number of opportunities also increases. While a travel impedance, as some form of physical separation or travel time, is used as a threshold in the determination of the available opportunities, the emphasis is given on the sum of potential opportunities and as suggested, provides information about the diversity, or number of stores, available to people. Cumulative opportunity measures however are highly sensitive to the specified cutoff travel distance or time and may thus affect the resulting availability metrics. They are a unique variant of gravity-based measures.

Adapted from Newton's law of gravity, gravity models are used to explain or predict spatial interactions—to measure the interaction between all locations—and have been modified in different ways to measure accessibility, such as in (Dalvi & Martin, 1976; Hansen, 1959; Kwan, 1998; Shen, 1998). Whereas the traditional gravity model measures spatial interactions between all possible pairs of locations, the potential model measures spatial interactions between a single location and all other locations. Hansen was one of the first to adapt the gravity model to study the relationship between the rate of residential development and accessibility to employment in Washington D.C. (Hansen, 1959). He proposed that the accessibility, or attractiveness of opportunities (e.g. jobs), of any individual zone could be obtained by discounting the available opportunities with the difficulty of reaching that zone. A distance decay effect, beta exponent, is often included to reflect varying levels of impedance and the ease to which the transport system facilitates interaction between locations. In other words, the attraction between two locations is proportional to the product of the importance of both locations divided

by their distance. Another popular variant is the two-step floating catchment area (2SFCA) method which has been used and further modified to measure accessibility to various health care services (Luo & Wang, 2003; Wang, 2012) and food locations (Chen, 2017). Accessibility is measured by the ratio of service opportunities (e.g. hospitals, grocery stores) to the population, and obtained by first determining the availability at supply locations as ratios of various services to the surrounding population and then these ratios are summed up around each demand location. In this respect, 2SFCA combines both availability and accessibility in measuring access. Results of these gravity measures are relatively easy to understand but in practice are often used for comparison between aggregated units which cannot be used to explain individual access. They further suffer from issues of aggregation and scale such that the unit of analysis would influence the obtained results.

Utility-based measures (i.e. discrete choice models) instead enable for more nuanced personal characteristics to be included in the parameterization and assume that people select the opportunity (or alternative as is described in the literature), among many, that provides the maximum utility (Ben-Akiva & Lerman, 1985). These utility-based measures are based on individual choice behavior and often premised on various theories, including Thurston's random utility theory and Luce's strict utility theory. The former postulates that the utility of all alternatives are stochastic (random) variables and the chosen alternative has the highest probability with the greatest utility among all others in the choice set (Ben-Akiva & Lerman, 1985). In contrast, the latter postulates that the probability of choosing a choice alternative is equal to the ratio of the utility of that choice alternative to the total utility of all choice alternatives in the choice set. Utility functions often take the form of a multinomial logit model and includes variables for the characteristics of alternatives in the choice set, the attractiveness of each alternative, the travel impedance, and socioeconomic characteristics of people. The logsum of the model is used to define an individual's accessibility.

Types of accessibility measures: space-time measures & Time Geography

In contrast to measures of place accessibility, space-time measures principled on the time-geographic framework by Torsten (Hägerstrand, 1970, 1982) determine geographic accessibility as the feasible opportunities that can be reached given an individual's sequence of daily activities and under various spatiotemporal constraints. Since Hägerstrand's seminal work in 1970, many have developed space-time accessibility measures to analyze individual accessibility, for examples, see: (Delafontaine et al., 2011; Widener et al., 2015). Bo Lenntorp implemented concepts from time geography in his Program Evaluating the Set of Alternative Sample Path (PESASP) computational model that was used to examine the individual accessibility of households to different activities over time in the Vällingby-Bromma area in Sweden (Lenntorp, 1976). Harvey Miller explored how space-time prism constructs could be implemented in a GIS and then used to identify the potential locations available to an individual (i.e. their *choice set*) relative to various constraints on the individual's behavior (H. J. Miller, 1991). In a time when computational capabilities were relatively lacking, his work was one of the first to employ time geographic concepts into a GIS. Mei-Po Kwan further developed space-time accessibility measures in a GIS with her study of individual access to urban opportunities for 39 men and 48 women in Columbus, Ohio (Kwan, 1998). Drawing from two datasets, including 1) an activity-travel diary dataset detailing individual activity-travel characteristics, addresses of activity locations, and people's perceptions of their space and time constraints, and 2) a geographic database of the study area comprised of parcels, Kwan evaluated eighteen

different measures of gravity and cumulative opportunity variants and thirteen space-time measures using an algorithm developed in (Kwan & Hong, 1998). The results from her study revealed the differences in spatial patterns between men and women and also between space-time measures compared to conventional measures of gravity and cumulative opportunity. She argued that the conventional gravity-based and cumulative-opportunity measures, while useful as indicators of place accessibility, were comparatively poor in evaluating person-based accessibility, and from her results concluded that space-time measures were more capable of identifying interpersonal differences in accessibility, including along gender and ethnic divides. This is because space-time measures are more attune to individual life situations and social differences along axes of gender, race, class, age, etc. These different types of measures are sensitive and may reflect upon different aspects of accessibility. Thus, space-time measures may more accurately reveal accessibility for different people. Kwan's work brought to light the implications of using conventional measures of accessibility versus space-time approaches that, respectively, inform place-based and person-based accessibility.

These broader categories of measures reflect different ways of operationalizing availability and accessibility in the existing literature. Simple distance measures are concerned with the spatial separation of one location to another, and whereby accessibility is based on relations of distance and proximity—living close or nearby to a location with the desired service indicates greater accessibility. Cumulative opportunity measures assume only all locations within a particular distance or time threshold of an individual's location to be available and availability is assessed by the total number or proportion of opportunities within those thresholds; the more locations that can be reached, the greater one's access. In this sense, this provides the range of different opportunities that are available from one's location. Gravity based measures consider potential access as the opportunities available to an individual at a location but account also for the ways in which distance may affect the degree to which opportunities at different locations can be obtained. Utility based measures are based on utility theory and the assumption of utility maximization. But these geographic accessibility measures are sensitive to "the degree and type of disaggregation, the definition of origins and destinations, and the measurement of attractiveness and travel impedance" (Handy & Niemeier, 1997, p. 1178). These four separate but interrelated issues influence the results obtained in research on accessibility. For example, related research on geographic accessibility has found that the spatial unit of analysis can result in non-trivial errors because of issues such as the modifiable areal unit problem (MAUP) (Apparicio et al., 2008, 2017; Hewko et al., 2002) and edge effect (Chen, 2017). MAUP describes two separate but related issues in spatial analysis: 1) the choice of spatial unit can affect the organization of data and interpretation of results and 2) results can differ between different aggregations of spatial units (Openshaw & Taylor, 1979; O'Sullivan & Unwin, 2003). Relatedly, the edge effect describes how the use of an artificial boundary, as in the case of dividing and aggregating people into various spatial units, can affect the interpretation of those closer to the boundary or edge. Apparicio and colleagues compared the differences in results obtained based on the operational definition of geographical accessibility to health services and found that evaluating geographic access varies based on the accessibility measure, type of distance (Euclidean and Manhattan distances; shortest network time by walk, bike, public transit, and car), and method of aggregation (Apparicio et al., 2017). Further, simple distance, cumulative opportunity, and gravity based measures are without much theoretical bases, and while utility based measures have some theoretical foundation in random utility theory, the assumption is that accessibility is defined as a consumer surplus term (generally, the logsum

expected maximum utility measure) (E. J. Miller, 2018). This monetization of accessibility is certainly useful in various cases but if the goal is to assess access to human needs, economizing accessibility may place an overemphasis on money and less so on the actual characteristics of people's access. There is thus a profound lack of a theoretical foundation for measuring place accessibility to various human needs. These place-based measures too cannot be used to understand individual accessibility lest there be a case of ecological fallacy. Space-time measures are premised upon the time geographic framework and reconcile the issue of aggregation by enabling for investigation of individual-scale human behaviors over space and time; and moreover, they explicitly consider the temporal dimension but require extensive data and computational resources. They too do not fully capture the various dimensions of access.

Time Geography

The time geography framework is comprised of various concepts that can help researchers analyze phenomena across absolute space and time. A *space-time path* is comprised of an individual's movements and activities across space and over time. Hägerstrand referred to a path beginning from one's birth and ending with one's death in one of his earlier papers but, in an analytical framework, a space-time path can be of an interval based on one's question of interest. This realized path is one of many potential paths within a *space-time prism*, or the feasible areas that can be reached within a particular window of time and under different capability, coupling, and authoritative constraints. Projecting the space-time prism on to a planar geographic space (i.e. two-dimensional space) provides what is called the *potential path area* (Kwan, 2004; Lenntorp, 1976) *Capability constraints* refer to limitations imposed by the biological nature of humans (e.g. the necessity for rest, food, and water and the ability of the human body to traverse from one location to another.) *Coupling constraints* refer to limitations imposed by the requirement of other entities and/or beings to engage in an activity (e.g. a full-body checkup requires both the physician and patient to be in the same room). Similarly, *bundles* are groupings of different space-time paths which necessitate that there be multiple entities engaging in the same area. In other words, the actors in a bundle are engaging in the same areas at particular times. *Authoritative constraints* refer to the restrictions imposed by those with control, influence and/or power (e.g. a grocery store is only open according to the business hours of 7:00 AM to 11:00 PM.) As an extension of this concept, *fiats* or *domains* describe the areas under control by an authoritative entity. While Hägerstrand more clearly defines these concepts, he himself admits the fuzzy nature of projects and dioramas given the complexity of the world. Each individual/actor has their own *project* comprised of their chain of different activities across space and over time towards the completion of their goal(s). *Dioramas* embody the myriad projects of different actors/individuals and are inclusive of both biotic and abiotic elements in the environment, the heterogeneous nature of the system, and all the contexts in which actors/individuals are situated in. These concepts together form an ontological framework for which researchers across different disciplines can investigate people's access to various needs at a disaggregate and individual level.

Explicitly recognizing time in research on access is necessary as locational proximity and distance, while still very important, may not always capture the temporal variability of access for various needs and services experienced by individuals. A few research studies place similar emphasis on the relevance of time and the temporal dimension in food accessibility research (Widener, 2018; Widener & Shannon, 2014). They articulate the ways in which food access is premised beyond conventions of geographic distance and spatial proximity but is also shaped by

the temporality of the larger food system and mobile nature of individuals. Strictly exploring access as geographic accessibility overlooks other critical aspects, including time use and economic factors. This static approach can in turn obfuscate understanding of the relationship between the geography of healthy food opportunities and health outcomes related to dietary behaviors. Recognizing the importance of time in access, (Farber et al., 2014) use General Transit Feed Specification (GTFS) data from public transit agencies in the Cincinnati, Ohio area to examine the temporal variability of a weekday in public transit access to supermarkets for each census block. Echoing (Widener, 2018) and (Widener & Shannon, 2014)'s sentiments of the need to also include time in studies on access to food, Farber and colleagues found that accessibility to reachable destinations such as supermarkets via public transit drastically varies over time and few people have consistent access to supermarkets throughout a day. Thus, accessibility is not rooted just in space but as a function of space and time; [geographic] space-time accessibility describes the number of reachable destinations of various activities from origin locations over time. However, the classical time geographic framework is limited in its conceptualization of human behaviors that also take place in other conceptualizations of space. (Shaw & Yu, 2009; Yu & Shaw, 2008) extend the time geographic framework to develop equivalent concepts in virtual space and represent individual behavior in a hybrid physical-virtual world in a GIS.

Access in the digital age

With increasing developments in information and communication technology (ICT), time is more than ever integral in understanding access. Advancements in transportation and ICT have reduced the travel time necessary to reach a destination. Described as time-space convergence (Janelle, 1973), present society is being radically transformed in the ways in which it operates and functions and how people meet their needs. Prior to the Internet and digital revolution, most activities were carried out in person at a physical location, such as shopping for food at a grocery store, attending an appointment at a medical clinic, or working at an office. This meant that people's physical presence was required in specific locations during particular time periods. The environment in which these activities were and still are carried out can be understood as physical space. But in recent decades, the ways in which people are able to fulfill their needs have significantly changed. People increasingly carry out their daily lives in virtual space (Couclelis & Getis, 2000; Janelle & Hodge, 2000; S.-L. Shaw & Yu, 2009; Yu & S.-L. Shaw, 2008), enabled by ICT such as the Internet and other digital technologies. Essential and near-essential activities can be carried out with various digital technologies and media, such as mobile phone applications, online services, and interactive map platforms. This includes eat (e.g. Instacart and Amazon for grocery delivery), work (e.g. Zoom and Microsoft Teams for telework and teleconference), and move (e.g. Uber, Lyft for work commute and supply delivery). People today have the option to carry out the act of food shopping by themselves at a grocery store or place an order on a store's website or an online grocery service application for curbside pickup or home delivery. This affords significant time savings, reduces various constraints that would have been prohibitive to access to food, and additionally enables for options that otherwise would not have been within reach. In this regard, the virtual environment has become an integral part of human life and part and parcel with contemporary reality.

The Internet, computer, and spatial digital applications and platforms are radically restructuring human behaviors and interactions and how humans carry out different activities to fulfill their various needs across the interconnected physical-virtual world. Platforms founded on

spatial information such as Google Maps provide users with navigational information and curated results for people's destinations and local environments. In this regard, knowledge of a service and the ability for service providers such as grocery stores and hospitals to tailor their services to the needs of its customers and clients, may be influenced by virtual space. Online advertisements and communities on different websites enhance people's understanding of their local environments and the services that may be available to them. Such platforms also make available information about an establishment's services, inventory, amenities, safety measures, accessibility infrastructure for physically disabled persons, prices, contact details, and location. This can provide individuals a better understanding of how accommodating a grocery store, hospital, or other establishment may be to suit their needs. For example, Google Maps publishes details about the sanitary practices and social distancing measures for grocery stores. Users can see whether a store mandates mask wearing, and this in turn can either encourage or discourage an individual from patronizing the store based on their attitudes towards using protective equipment. As such, people can compare and weigh offerings between different establishments. Simultaneous to this is the increasing investment in technology and adoption of artificial intelligence (AI) across many industries to improve the effectiveness of their services which would theoretically increase their attractiveness to the broader population. A total of more than eighty-three billion USD was invested in healthcare technology between 2014 and 2018, primarily for patient engagement, data and analytics, and new care models (Singhal et al., 2020). AI can support improvements in healthcare systems to provide better and more appropriate care to people, increase the productivity and efficiency of care delivery, and improve the experience of healthcare practitioners (Spatharou et al., 2020). In the grocery retail space, more companies are integrating advanced analytics to monitor their supply chains, forecast consumer shopping behaviors, and optimize their inventory volumes (Chandra et al., 2020). Big players such as Amazon, Whole Foods, Kroger, Target, and Walmart are quickly accelerating their online services, offering grocery and delivery pickup services to customers at thousands of their locations. Other changes such as real-time order tracking and communications, expanding assortment in their online platforms (apps or websites), lowering fees for deliveries, and providing attractive subscription models and discounts seek to also improve the grocery shopping experience for people (Begley et al., 2020). Thus, the increasing pivot to digitalize various services may potentially expand the opportunity or activity space for different groups of people and increase their access. Whereas a store or medical service may have been physically unreachable due to the lack of grocery store or hospital nearby a community of people, delivery services offered online can thus make food and healthcare available and accessible for a larger population. The opportunity to price-match and compare prices online between different providers also changes the aspect of affordability as people can selectively curate the price and cost of various services before settling on one or more service providers or establishments. Online reviews detailing the experiences and attitudes by previous patronizers can shed light too on the acceptability, or practice and personal characteristics, of different establishments.

Concurrent to the expansion of the opportunities for people to fulfill their needs online, without their physical presence at a specific location during a particular time, and the increasing penetration of many industries online is the digital transformation underway across society. About half of fifty health care executives surveyed prior to the coronavirus pandemic on the potential impact of virtual health "thought at least a quarter of all outpatient care, preventive care, long-term care, and well-being services would move to virtual delivery" within the next two decades (Fera et al., 2020). The coronavirus disease 2019 (COVID19) pandemic has rapidly

prompted the adoption of new digital habits and intensified usage of online services. The recent stay-at-home orders, quarantine measures, and lockdowns throughout the world resulting from the widespread outbreak of COVID-19 stress the dire need to study newly evolving configurations of daily living and societal organization played out in a physical-virtual landscape. We are currently witnessing enormous social and cultural changes in how people fulfill their various needs and structure their daily lives. People are adopting new ways to fulfill their different needs and increasingly connecting to and carrying out their lives in the digital and virtual medium, resulting in a hybrid physical-virtual society. A survey in September 2020 by McKinsey found that the consumer base for online grocery shopping has grown at least 30% since the period right before the coronavirus situation started across the United States, United Kingdom, France, Germany, Spain, Italy, India, Japan and China, and that many people are expected to continue this behavior after the pandemic has subsided (Charm et al., 2020). Companies around the world are similarly migrating to digital technologies which will profoundly shape a new future of remote work and digitalization of different services across nearly all industries. In this sense, people's everyday lives are more and more "mediated, augmented, produced, and regulated by digital devices and networked systems powered by software" (Kitchin, 2017). There are new ways for people today to meet their various needs but it remains to be understood how the emergence of the virtual space has shaped access. Understanding access to human needs requires that the dynamic interplay of the physical and virtual be addressed.

COVID19 has especially heightened the necessity to understand the physical-virtual landscape and the digital divide. The digital divide was originally coined in the early 1990s to describe the disparity between those with and without Internet access. While still very important, the rate of telephone and broadband subscriptions have grown considerably, with a global average of less than 40 mobile telephone subscriptions per 100 people in 2005 to greater than 80 mobile subscriptions subscriptions per 100 people in 2018 (United Nations Conference on Trade and Development, 2019). Additionally, more than half (51.2%) of the global population, constituting 3.9 billion people, used the Internet in 2018 (ITU, 2018). Despite the significant growth in connectivity amongst the global population to the Internet and an increasingly inter-connected global economy, there still remains major concerns regarding the distribution of benefits from ICT. Today's digital divide is thus largely concerned not just with mere Internet connectivity but also with the knowledge and aptitude to efficiently use ICT. Economic, linguistic, economic, and generational barriers further contribute to inequalities between those who can and cannot effectively and efficiently use ICT. While at least 93% of adults in the United States today are using the Internet, there remain gaps by age, income, and education (Pew Research Center, 2021).

The digital divide in itself is an inequality that comes to bear also on another inequality: access to the virtual environments for grocery shopping, health and medical care, work, education, among many other facets of contemporary society. While the shift to virtual activities and services became the default during the COVID19 pandemic, the benefits accrued differ. A study of telemedicine visits between March 16 and May 11, 2020 found those who were older, Asian, did not speak English as their primary language, and on Medicaid were associated with fewer completed telemedicine visits (Eberly et al., 2020). Deloitte surveyed two-thousand adults between the ages of 18 and 70 in July 2020 on their fresh food purchases and found that those who used online delivery or pick up grocery services tended to be more affluent, younger,

resided in urban areas, and ethnically diverse (Renner et al., 2021). These two studies suggest a digital divide that manifests in access to food and healthcare. Distinct population groups have comparatively lower use of digital services and participation in the digital economy. Older individuals in particular suffer from comparatively diminished access in a world that is increasingly digital. However, there still remains much unknown about the factors that shape people's adoption of digital services and platforms to fulfill various activities. The former study largely focused on the demographic characteristics of patients while the latter study focused on consumer buying patterns for fresh food.

The new physical-virtual landscape in which activities are now carried out have not been adequately explored in existing studies. Technology has driven globalization and growth across the world but its development and increasing importance may consequently contribute to social inequalities. Some researchers have expanded traditional approaches to explicitly include the effects of various components of the virtual space. Shen proposed a composite measure of general accessibility to jobs based on the gravity measure by adding a variable that distinguishes telecommunication-based opportunities (i.e. telework jobs that are accessible to people who are connected to telecommunication networks and are adept at using ICT) (Shen, 1998). Doing this enables differentiation of the available job opportunities available to various sociospatial groups based not only on the available mode of transportation but also their technological connectivity. In other words, telecommunication is considered a means of spatial interaction. However, the virtual space extends beyond mere communication and is another environment in which humans carry out various activities in their daily lives. Beyond work, other essential activities such as to access food and medical care are increasingly mediated through digital applications and platforms. Thus, it is not enough to simply include the virtual environment as a single explanatory variable but to understand and model it as another realm in which life takes place. Recognizing the increasing prevalence of virtual space in human society, (S.-L. Shaw & Yu, 2009; Yu & S.-L. Shaw, 2008) developed a GIS-based approach to explicitly model activities and interactions in virtual space. While not directly created for the purpose of understanding accessibility and access, this approach is a useful guide for development of GIS premised beyond absolute space. However, other factors that may influence the opportunities accessible to people, such as time availability, workers' preference, and other aspatial factors, are not considered. This is similar to the critique of the classical time-geography framework such that it is based on concepts of absolute space and time and (1) inadequately captures how people are simultaneously situated with others in a network of relationships and (2) that it inadequately captures people's emotions, perceptions, and thoughts.

Human beings are social creatures that are influenced by their broader environments (e.g. laws and regulations, culture) as well as other people (i.e. their social networks.) Further, human cognition and mental capacities, including feelings, emotions, perceptions, and thoughts all shape what people perceive as acceptable and not acceptable, and whether something is or is not accessible. Notwithstanding, there exists no 'best' measure of access as each measure is only useful if it is consistent with how people perceive and understand their own situations (Handy & Niemeier, 1997). Understanding people's access cannot be understood simply by understanding the supply of and the distance or proximity to services and activities. There exist other aspects such as cost, cultural connotations, local context, social relationships and networks, and human perceptions, emotions, feelings, and cognition that are inadequately captured in much research emphasizing spatial accessibility.

The classical time geographic framework is limited in its conceptualization of human behaviors that also take place in other conceptualizations of space. Shih-Lung Shaw and Hongbo Yu extend the time geographic framework to develop equivalent concepts in virtual space and represent individual behavior in a hybrid physical-virtual world in a GIS (S.-L. Shaw & Yu, 2009; Yu & S.-L. Shaw, 2008). Even while individual behavior in physical-virtual space can be modeled and examined in a space-time GIS, there still remain many challenges left unaddressed. One such question is the capacity of a space-time GIS to also integrate human experiences and perceptions (Shaw, 2012). Humans experience and think about space differently, evocative of Immanuel Kant's metaphysical notion of space in which space is perceived and "is not something objective and real, nor a substance, nor an accident, nor a relation; instead, it is subjective and ideal, and originates from the mind's nature in accord with a stable law as a scheme, as it were, for coordinating everything sensed externally" (Kant, 1902 in Janiak, 2020). Relatedly, Yi-Fu Tuan's seminal paper on space from the humanistic perspective and his prescient thoughts that space is felt and perceived – "Visual perception, touch, movement, and thought combine to give us our characteristic sense of space… space is oriented by each centre of consciousness" (Tuan, 1979, p. 390). Clearly, there are different conceptualizations of space but one prevailing perspective connotes how humans mentally conceive of space. In this respect, (Shaw & Sui, 2019) adopts this perspective of human perception integral in shaping how people experience the world as *mental space*. People's thoughts, feelings, and senses matter too in determining the opportunities available to them and ultimately where they decide to go. (Egenhofer & Mark, 1995) similarly describe how people understand and perceive geographic space and time through intuitive spatio-temporal reasoning. To better represent and model the real world, and thus understand people's access to various human needs, in a GIS requires inclusion of human knowledge, perception, reasoning, and intuition.

Access along various concepts of space

The fetishization of physical and absolute space in most measures reify access as premised solely in absolute space, in the Newtonian fashion, i.e. an immovable and infinite entity implemented based on Euclidean geometry and the Cartesian coordinate system. But it is not just the question of 'where' but also 'who', 'what', 'when, and 'how' that is important in understanding access to any human need. The tradition in much research singularly adopts absolute space as the environment in which people access various locations and activities. However, there exist other concepts of space that reflect aspects relating to access beyond mere locations. The splatial framework proposed by (Shaw & Sui, 2019) describes multiple conceptualizations of space that can together complement and augment research in understanding human dynamics in the current era. They describe four concepts of space that ultimately emphasize the human experience:

- "*Absolute space* works with absolute locations in space and focuses on questions such as 'Where are the different objects?'
- *Relative space* works with relative locations to a fixed or moving object and focuses on questions such as 'What is around us?'
- *Relational space* works with relations to other objects and focuses on questions such as 'What is related to us?'
- *Mental space* works with the cognitive and mental aspects of space and focuses on questions such as 'What do people have in mind?'" (Shaw & Sui, 2019, p. 5).

These concepts of space are different interpretations of and describe different aspects related to how people experience, understand, and perceive space. The five dimensions of access

individually relate to either of or a combination of these four concepts. For example, while an individual may live two blocks from a grocery store, which explicitly inquires about absolute space: *where are the different objects?*, it might not necessarily be accessible because of a highway barrier that prohibits easy movement between the residence and the store. Situations like this illustrate the importance of considering relative space: *what is around us?* Further, their access may be further influenced by the people they know, or relational space: *what is related to us?*; if they have a friend employed at the store who shares insider knowledge about when the next shipment of fresh produce arrives, and can offer a discount, the individual may decide to shop there. This last part also reflects upon mental space: *what do people have in mind?* The explicit formalization of the four concepts of absolute space, relative space, relational space, and mental space augments extant research on the geography of access by considering the different ways that shape access because of physical location, context, relationships, and feelings/perceptions/thoughts.

An absolute space interpretation describes much of the research on spatial accessibility, with researchers often measuring access based upon the physical locations of residents and service providers. The number of grocery stores that can be reached or the potential interaction between a neighborhood and surrounding hospitals are measures based on absolute space. Including into consideration local context (e.g. time use) and situational characteristics, as is typical of space-time measures, additionally considers the context and the various space-time constraints that may come to influence one's access. Such measures can be thought of as a relative space interpretation of access. Meanwhile, a relational space approach to access considers the role of social relationships between people such as in (Nakamura et al., 2017). Mental space and how people perceive of their daily activity space and access to various services has been little explored but increasingly popular in recent years. While place-based measures capture accessibility of geographical areas, they are not able to capture differences at the individual level. And while person-based measures can be used to more accurately understand individual travel behaviors and their access, there are also questions regarding the completeness of both types of measures to capture how people perceive their access. As remarked by (Wong, 2018), oftentimes, space-time measures are based on hypothetical situations and don't always capture the actual travel behaviors of individuals and likely include activities and destinations that they do not want to travel to.

Nakamura and colleagues surveyed 102,869 Japanese seniors and inquired into their perceived food availability, relationships with neighbors and actual food intake. Perceived food availability was assessed with the question: "Are stores or facilities that sell fresh fruits and vegetables present within 1 km of your home?"; relationships with neighbors was assessed with the question "What kind of relations do you have with people in your neighborhood?"; and actual food intake was assessed with the question: "How often did you eat fruits and/or vegetables over the past month?" (Nakamura et al., 2017) They found that having low food access and a low level of relationships with neighbors was correlated with the infrequent consumption of fruits and vegetables. This study reflects an approach to integrating relational and mental space in understanding access. However, these different aspects were each only captured with a single question that did not take into consideration dimensions of affordability, accommodation, and acceptability, and inadequately captures the role of social relationships and mental perceptions, feelings, and thoughts.

Altogether, I propose that access and its five dimensions be explored further across various conceptualizations of space and time in an increasingly hybrid physical-virtual world. As a start, these are some of the relationships between availability, accessibility, affordability, accommodation, and acceptability with space and time in today's world expressed in a situation of food access:

Availability, "the relationship of the volume and type of existing services (and resources) to the clients' volume and types of needs" (Penchansky & Thomas, 1981, p. 128) of a service to an individual fluctuates over time based on the operational hours. The scheduling of supply chains and shipment of various items affects the volume and capacity of resources and services available at a service provider. For example, the delivery of dairy products to a grocery store may occur every few days which means that inventory fluctuates over a week as more consumers purchase these food items. Furthermore, seasonality and growing periods for different foods also affect the amount of available supply in each store and there may be different selections of various foods throughout a year. Thus, availability is also shaped by the rhythm of the seasons. Similarly, different points of the year feature various food themes which makes particular foods more abundantly available from the supplier, such as the association of cranberries, pumpkins, and green beans around the Thanksgiving holidays in the United States. The availability of health and medical services varies also with time. Parallel to the delivery of food items to grocery stores is the delivery of vaccines and medical supplies that are contingent upon the scheduling and shipment by producers and manufacturers. Seasonal allergies may influence the need for individuals to visit their primary physician for allergy medication or be hospitalized depending on the severity of their allergic reaction. The seasonality of various viruses and diseases (e.g. mosquito-borne diseases such as West Nile virus) can too influence people's needs for appropriate medical care. At a more granular scale, the availability of hospital beds fluctuates over time based on the number of hospitalizations and sick patients and thus shapes whether medical care is available or not. With the increasing prevalence of virtual space, various services such as telemedicine are increasingly available online. The supply of services and resources can also expand with online services. Digital services and applications such as grocery delivery services offer more supply options for individuals. For example, I've had orders on Costco delivered to my door using both Instacart and their direct website. If it wasn't for these services, I would not consider Costco to be available because I am physically unable to reach it. And from a multi-spatial conception, availability can also be conceived in the following ways:

- Physical Space: locations of food providers/suppliers remain fixed at a location (even though the number of 'available' options may increase)
- Mental Space: a person may identify a location as being available or not available based on their perceptions and feelings of the surrounding environment (and this relates to relative space as well.) If a grocery store is located in what one feels is an unsafe part of the area, they might choose not to patronize that location even though they may not live far away.

Time shapes the dimension of accessibility, "the relationship between the location of supply and the location of clients, taking account of client transportation resources and travel time, distance, and cost" (Penchansky & Thomas, 1981, p. 128) at multiple rhythms. People often consider the time needed to travel from one location to another when considering where to go and are also constrained by the scheduling of other activities throughout a day, such as work. Travel time varies based on external factors including but not limited to the traffic situation on

road networks, the weather condition, and the modes of transportation available to an individual. This speaks to the hetereogeneity of the human population and the necessity to look beyond purely spatial characteristics of the physical landscape people occupy. The emergence of a virtual space (e.g. in the form of grocery delivery services) has additionally reduced or eliminated the associated cost, travel time, or distance to be overcome for food shopping. Using a constraints-based approach from time geography also helps to better understand accessibility. For example, a coupling constraint occurs during grocery shopping at a physical branch which requires both the individual consumer and a store employee (e.g. checking out, assisting with finding various items). And from a multi-spatial conception, accessibility can also be conceived in the following ways:

- Physical Space: locations of food retailers and the locations of individuals (e.g. home, work) are fixed at a physical location at a given moment in time
- Relative Space: distance, cost, travel time, and proximity are relative based on one's physical location and how far they are from a food retailer/provider. Accessibility is more contingent upon the relative cost between locations than on the locations themselves. One respective location at the time of a need for food affects whether a food provider/supplier is available or not. While digital services for food are abundant in the digital marketplace today, their entry and use is not the same for different groups of people.
- Mental Space: cost can be measured as the perceived level of safety and/or the weighing of pros and cons with obtaining food (in a pandemic or when constrained with the need to carry out other activities)

While affordability is often based on one's financial situation, time geography can too be extended to understand this dimension to access. The three constraints can help better understand the relationship between the cost of a service or resource and an individual's ability to pay. Using food and grocery shopping again as an example, the price of food is often subjected to capability constraints. Shortages in the supply of food may occur due to the lack of capable and physically healthy farmworkers to grow and gather fresh produce. Additionally, an individual consumer either has enough or not enough money to acquire specific food items. Coupling constraints can also shape the affordability of various food items; buying groceries with other individuals at a big box food retailer or wholesale club may result in more overall savings and thus more affordable food. Benefits like Supplemental Nutrition Assistance Program (SNAP), Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) and Electronic Benefit Transfer (EBT) allocated by the Food and Drug Administration and other organizations and agencies can also enable for people to afford various items. Recipients of these programs however are selectively chosen by the organizations. This dynamic can be thought of as an authority constraint as it is upon the organizations and agencies to dictate who gets to have benefits. The growing prevalence of online grocery shopping has also significantly changed the affordance of various individuals to access food. Price matching, online coupons, discount codes, and comparing prices can easily be done online by pulling up the cost of various items in different food retailers. Additionally, online communities and forums are platforms for people to exchange about deals and sales at different stores throughout an area. Meanwhile, a consumer can also subscribe to a store's e-mail list for rewards, coupons, and sales, thereby potentially reducing the cost of food. The emergence of the virtual platform has arguably made food more affordable today for some people. From a multi-spatial conception, affordability can also be conceived in these ways:

- Relational Space: a consumer subscribes to a store's e-mail list for rewards, coupons, and sales; online communities such as Facebook groups for a local area are a platform in which individuals can share with each other about deals and sales.
- Mental Space: affordability is perceptually weighed by an individual by balancing the benefit and cost for obtaining food

Accommodation—how supply resources and services are tailored to people and their needs also matters in understanding access. Appointment systems, hours of operation, telephone services, and other similar features are contingent upon the temporal dimension. Being able to make appointments can minimize waiting and thus shorten the time needed to carry out an activity. With a scheduled appointment, people have the opportunity to chain together different activities in a trip that fits within an allotted window of time. Telephone services are often limited to the hours of operation and may require both the service provider and individual to connect at the same time. This too however can afford time savings as questions can be answered and orders placed even when both are in different locations. The amount of time people have to carry out various activities to meet their needs are limited with capacity constraints on scheduling imposed by various activities such as work. Their work situation in turn shapes their access to various needs, services, and amenities. An individual with a night-time shift may not have access to the aforementioned grocery stores if they are busy working at night and resting during store operation hours. The authoritative constraint imposed by a service provider's limited opening hours means that a service such as grocery shopping or medical care can only be obtained at select times throughout a day. For example, while grocery stores are usually open early in the morning to late at night, many are still closed in the late evening and early morning. Thus, that location is not available at particular times in the day. Because of the COVID19 situation, stores like Trader Joe's designate the first hour of operation for people over the age of 60 and with disabilities (Trader Joe's, 2021), making it impossible for people who don't fit either category to shop at their different branches. People's experience of space varies with time and are further limited by the biological need for rest (e.g. sleep) and food (e.g. cook). And the amount of time needed to carry out an activity can change based on the protocol by the service provider, such as a queue and limit to the number of the people that can enter the premises. While grocery shopping is increasingly made autonomous without the need for another individual to checkout, getting medical and health care often requires the need for an accompanying guardian if the patient is a child and also a skilled practitioner to carry out the service. Thus, there are also coupling constraints that affect the level of accommodation. However, the emergence of the Internet and the virtual platform has made it easier to obtain information about store practices and opening hours. People have an additional medium to connect beyond the telephone, and websites can make it easier to fulfill various tasks such as making appointments and scheduling. From a multi-spatial conception, accommodation can also be conceived in these ways:

- Absolute Space: Physical design of store layout, parking lot, wheelchair ramps, and etcetera
- Mental Space: Perceived safety of each store based on what the consumer deems is 'safe'; (e.g. while masks may be required, the store managers might not necessarily strictly enforce mask-wearing and there are dissenters who take off their mask)

People's attitudes about various characteristics of service providers and conversely service providers' attitudes towards potential clients shapes acceptability and can vary over time. The generation in which a person was born may shape their preferences and their beliefs about various service providers, such as preferences for particular store brands or primary care physicians. Further, the age of a consumer may inform whether the consumer has positive or negative associations with a service provider, especially during the COVID19 pandemic, food retailer that requires mask use or not. For example, Trader Joe's has a strictly enforced mask policy with stringent sanitizing measures and a security guard. A comparatively larger amount of older individuals may choose to shop at Trader Joe's because of these provider attributes. As expressed earlier, certain areas may be considered safe or attractive during the day but not during the night. Areas that observe more foot traffic and 'eyes on the street' are often considerably more attractive not the least because of its safety (Jacobs, 1961). The rise of social media and many digital services such as Google Maps and Yelp provides individuals to review and talk about specific locations which can be publicly read. Ratings, reviews, and knowledge about particular amenities, attributes, and offerings at a location all influence individual acceptance. From a multi-spatial conception, accommodation can also be conceived in these ways:

- Relational Space: supplier-consumer relations and dynamics (e.g. people generally have various impressions for different store brands.) Additionally, individuals may consider a location acceptable or not acceptable based on the feedback provided to them by their peers or others online (e.g. reviews online; blog posts about specific stores – Costco has a sterling reputation across many websites, blogs, and through word of mouth.)
- Mental Space: consumer attitudes towards the physical environment and services provided by a food retailer. Do they feel safe, respected, and welcomed; and how much do these aspects matter when choosing a place to shop at?

RESEARCH QUESTIONS

The central theme of my work is the development of a new framework for understanding the relationships between space, time, and access in an increasingly physical-virtual world. Tackling my research objectives to develop a new framework for the geography of access, identify useful data for the implementation of the newly proposed concepts, and implement these concepts with various methods, further requires a set of research questions. I will look to answer these questions that address my research objectives. These are:

1a. What are the relationships between different dimensions of access—availability, accessibility, affordability, accommodation, and acceptability—and various conceptions of space? How and to what extent are different dimensions of access changing in an increasingly physical-virtual world?

- (Example) Accessibility is no longer solely premised in the physical environment with the growing adoption of e-grocery services. Consumers do not necessarily need to step foot in a food store to acquire groceries as they can have them delivered to their doorsteps or picked up at a store's parking lot.

1b. How can Torsten Hägerstrand's time-geography framework be extended to different dimensions of access—availability, accessibility, affordability, accommodation, and acceptability—as understood with various conceptions of space (absolute, relative, relational, and mental space) in an increasingly hybrid physical-virtual society?

- (Example) A space-time path and prism describe, respectively, the realized trajectories and feasible areas that can be traversed under various constraints and an allotted amount of time. Such concepts can be extended beyond absolute space to also include how humans perceive, think, and feel. A mental space-time path could be used to describe how people

2a. What types of data can reflect upon people's mental perceptions, feelings, and emotions towards access?

- (Example) The big data era has brought about tremendous amounts of data such as online user-generated reviews for different POIs such as grocery stores and supermarkets. They presumably reflect an individual user's perception of that POI. Cell-phone traces are also increasingly ubiquitous in human dynamics research and can be integrated with online reviews to understand access to various human needs. Similarly, responses to long-form questions can also be extrapolated and analyzed to reflect upon individual participants' mental aspects towards their access.

2b. How can data sources reflecting upon people's subjective perceptions be integrated within a space-time GIS to understand access to various human needs?

- (Example) Currently, most space-time GIS are still largely, if not entirely, premised on the convention of absolute space. Inspired by the vector space in text analysis that encodes texts as vectors in a multi-dimensional space, a

shared perception space could be included in a GIS to accommodate mental space.

3a. What space-time GIS and other relevant methods are useful to explore people's physical, relative, relational, and mental aspects of their different dimensions of access to various human needs?

- (Example) A modified mental-physical space gravity-based measure for realized place-based access that includes in its formulation human perceptions of individual locations:

$$A_i = \sum_{k=1}^{N} \frac{P_{ik}}{\sum P_{ik}} * \frac{p1_k + p2_k + p3_k + p4_k + p5_k}{c_{ik}^{\beta}}$$

A_i = Accessibility of zone i
$p1_k$ = Polarity Score: Availability
$p2_k$ = Polarity Score: Accessibility
$p3_k$ = Polarity Score: Affordability
$p4_k$ = Polarity Score: Accommodation
$p5_k$ = Polarity Score: Acceptability

k = Facility 1, 2, .., N
P_{ik} = Number of people from zone i visiting facility k
$\sum P_{ik}$ = Total number of people from zone i visiting facilities k:N

c_{ik} = Cost Distance between zone i and facility k
β = Cost Distance decay function

  -

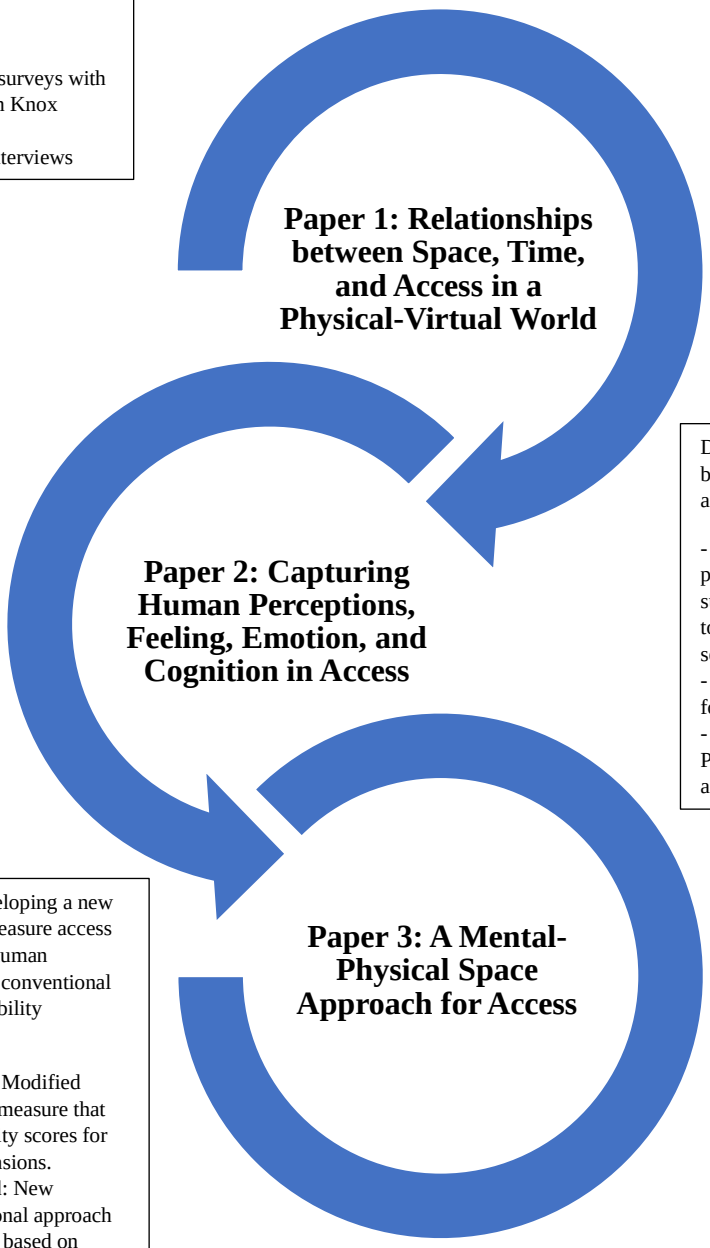
3b. What are the key differences in analysis and visualization functions between the conventional approach to studying access based on absolute space and a new framework that explores access comprised of various dimensions related to different concepts of space and time based on a case study of food access?

- (Example) Current analysis and visualization functions with the conventional approach to studying access based on absolute space often only captures the physical geographic space. The accompany analysis and visualization functions are similarly premised on absolute space in which physical locations are often the main subject. Human perceptions, feelings, and emotions can be captured in text communications but have not been widely explored in studying access. There will undoubtedly be differences in the analysis and visualization of an approach that incorporates the mental space relative to the conventional approach based on absolute space.

PROJECT DESCRIPTIONS

Developing a new theoretical framework of access by relating the different dimensions of access, space, and time in a physical-virtual world.

- Questionnaire surveys with local residents in Knox County.
- Focus group interviews



Data: Identifying small and big data sources useful for analyzing access.

- Crowdsourcing labeling process and applying supervised learning models to classify the semantic and sentiment of online reviews.
- Designing GIS environment for 'mental' space.
- Developing open-source Python environment for access research.

Analyze: Developing a new approach to measure access that includes human perceptions in conventional spatial accessibility measures.

- Place-based: Modified gravity-based measure that includes polarity scores for specific-dimensions.
- Person-based: New geocomputational approach to cull options based on survey and interview responses.

Paper 1: Relationships between Space, Time, and Access in a Physical-Virtual World

Introduction

Access is understood as having multiple dimensions beyond just accessibility, or the ease to which various opportunities and activities can be reached. The framework proposed by (Penchansky & Thomas, 1981), and comprised of availability, accessibility, affordability, accommodation, and acceptability, reflects different aspects that shape people's access to various human needs. As (Shaw & Sui, 2019) propose, understanding human dynamics requires explicit consideration of absolute location, context, relationships and networks, and human perception, feeling, emotion, and cognition. These are organized into four spaces—absolute, relative, relational, mental—which can be used to extend the framework by Penchansky and Thomas for more useful application. However, their framework of access is specific to medical care provision and in a time when various ICT (e.g. Internet, mobile phones, digital apps) were still not as fully developed nor pervasive as they are today. Today's world is markedly different than it was four decades ago. I will develop a questionnaire survey and carry out interviews with local residents of Knox County in order to better understand the relationships between various dimensions of access, space, and time and ultimately develop a theoretical framework for the geography of access.

Methods

I propose a conceptual model for access based on extensions of the framework of access by (Penchansky & Thomas, 1981) with (Shaw & Sui, 2019)'s splatial framework and (Hägerstrand, 1970, 1982)'s time-geographic framework in an increasingly physical-virtual world. Each of the five dimensions are revisited to contextualize them in the physical and virtual world, and then further extended to different conceptualizations of space and various concepts in the time-geographic framework. I will further explore the literature to identify particular aspects and specify relationships related to the different dimensions in my model. This includes a heightened focus on studies with qualitative approaches. Then, I will develop a questionnaire survey according to a Likert scale inquiring into various characteristics of people's actual and perceived behaviors for accessing food and their personal characteristics as a case study of the different factors that shape one's access, such as what grocery stores do they perceive as affordable or not affordable; what is their weekly budget for food; and etcetera.

I will consult city-wide agencies including the Community Health Council and Neighborhood Advisory Council in Knoxville, Tennessee. As I seek to obtain a sample that is representative of the demographic of the area, I will use a complex and multi-stage probabilistic sampling technique that first identifies all Census-defined census tracts and organizes them in descending order by median income. Afterwards, a systematic sampling procedure is carried out on the ranked list to identify census tracts at fixed intervals. Within each selected census tract, a number of households will be identified also with a systematic sampling procedure by consulting the appropriate city-wide agencies and neighborhood associations in these census tracts in Knoxville. I will attempt to reach out to these households via mail, phone, and e-mail. In addition, I plan to make available public advertisements in the aforementioned selected areas soliciting participation in my research study. This includes the use of paper advertisements (which I will seek approval for before posting and ensure that they are not prohibited) as well as posts in social media platforms (e.g. Twitter, Facebook, Reddit) online in which I will include information about the study and my contact should they be interested.

There will be Likert-type items/questions also relating to the influence of the local environment, social relationships, mental perceptions, and various constraints that may affect an individual's access. Multiple Likert scales, comprised of several Likert-type items, will be used to inquire into the relationships between different dimensions of access, space, and time in an increasingly physical-virtual world. For example, a Likert scale will be developed for each dimension, and they will each be comprised of multiple Likert-type items that asks individuals whether they agree that the dimensions are shaped by different concepts of space and time. The Likert-type items for each Likert scale can be grouped and summed or averaged to measure the degree to which the assessed dimension is related to various concepts of space and time. To date, I have already submitted an IRB proposal to survey around 400 that has been approved, but needs further revision to better reflect the data I need to answer my research questions. I will use confirmatory factory analysis to test my hypothesis about the relationships between access, space, and time in an increasingly physical-virtual world. Confirmatory factor analysis (CFA) is used to test whether the responses to the Likert-scale items are consistent with my hypothesized constructs (the relationships between access, space, and time in a physical-virtual world.) I expect that the responses to my Likert-scale items should be consistent with my hypothesized constructs as they are informed by relevant theory and research literature.

Classical multidimensional scaling (CMDS) is similarly another technique that could be used to assess the degree of dis(similarity) between the different dimensions reflected in the Likert-scales and items. The idea behind CMDS applied in this research is that it could help reveal the structure of the survey response data by plotting them in multiple dimensions in a spatial map; if Likert-scale items belonging to a Likert scale are close together in the spatial map, they are perceived to be more similar to each other and, conversely, if they are far apart, they are perceived to be more dissimilar to each other. Following that, if Likert scales are close together, they are also similar to each other and if they are not, they are dissimilar. In contrast to CFA, CMDS does not require assumptions of normality or linearity. In a CMDS analysis, the given dis(similarity) information is matched to the distances between points in this space. A correlation matrix of the Likert-scale items can be used as the input proximity matrix to derive the distances between the items. Larger distances between items and scales would thus indicate greater dissimilarity. Both the r-squared correlation coefficient between the distances and the data (i.e. the variance accounted for by the MDS procedure) as well as Kruskal's stress index are widely-used measures of goodness of fit of the CMDS solution and will be assessed to understand the fit of the model (Bartholomew et al., 2008). If the survey response data are normal-ish and linear-ish, I will pursue CFA; otherwise, I will pursue CMDS.

I may also consider to carry out multiple focus group interviews to collect similar information regarding people's perceptions of the various factors that shape their access to food. Groups of four to six participants conforming to a similar demographic profile will be asked in individual sessions similar survey questions but will be reworded to be more open-ended. It is the hope that there will be enough representation of the different demographic profiles that characterize Knox Country. I'll similarly consult various community health organizations to inquire about potential participants. Funding will be sought out to provide some incentives for people to come out and participate in my research study.

<u>Limitations and Uncertainties</u>

As the digital environment is still growing and as our world is still largely premised on in-person activities, both confirmatory factor analysis and multidimensional scaling of the

questionnaire survey might not pick up the difference between physical and virtual contexts of access. The questions/Likert-scale items may also not necessarily measure what I think it should. However, if my hypothesis is rejected such that access is shaped by a hybrid physical-virtual world, it may be instead that access is defined differently than I understand it to be or that I may not be asking questions that reflect what I think they should. In this instance, I may decide to instead pursue an exploratory factor analysis to identify the underlying factors that seem to emerge from participants' responses to the survey. This may better reflect how access as understood by individual participants. There is also the possibility of sampling bias in which the data obtained are only representative of that sample group and may not necessarily describe the broader population. But I believe that with my systematic sampling technique, I may be able to minimize the amount of bias that may arise.

Paper 2: Capturing Human Perceptions, Feeling, Emotion, and Cognition in Access

Introduction

Access may be influenced by physical location, context, relationships and social networks, and perception, feeling, emotion, and cognition. Spatial accessibility measures to understand the opportunities to various needs available to people are often premised on measurable and observable data such as the locations and socioeconomic characteristics of residents and activities. But it is understood that social networks and relationships (i.e. relational space) and perceptions, thoughts, feelings, and emotions (i.e. mental space) may also come to bear on an individual and a group's access to various human needs. While online reviews presumably describe an individual's perceived experience at a place, we still do not know what particular characteristics relating to access people describe about a grocery store or supermarket. Additionally, it is difficult to discern whether these users are local residents and who they are. Furthermore, the distribution of social media users is highly uneven by gender, geography, and race/ethnicity (Hecht & Stephens, 2014) and they may not necessarily be representative of the larger county population. Meanwhile, questionnaire surveys may provide another perspective on people's perceptions of their access to food but they require intensive efforts. How can these two different types of data sources reflect upon people's perceptions of their access and how can they be integrated into a space-time GIS?

Methods

To explore the relationships between access and mental behaviors, I will analyze online reviews for grocery stores and residents' responses to various questionnaire survey items to understand how people feel about the various options in their local food environments. I propose to extend the time-geographic framework to include human perceptions, emotions, and feelings and develop a mental GIS design to accommodate new constructs. To understand human perceptions from big data such as online reviews, I propose a general procedural workflow that can be used for many different purposes, not just to understand access for food. In addition, I explore the integration of residents' responses to various questionnaire survey reflecting various components of access into a space-time GIS design that focuses on the representation and analysis of people's mental and cognitive behaviors. In particular, I will design a space-time GIS to capture, model, represent, visualize, and analyze mental space. Residents' responses to various questionnaire survey items to understand how people feel about the various options in their local food environment can be represented in a multidimensional space inspired by vector space modelling from natural language processing. These various sources of data will be compared to understand the subjective perceptions of individuals from a 'big data' source and a 'small data' source.

Humans often verbalize their thoughts, feelings, and perceptions whether outwardly or internally. With respect to the 'big' review data, given a review, I want to understand which of the five dimensions are being described and then to further understand a reviewer's sentiment towards that dimension. To date, I have web-scraped locations and reviews for all grocery stores in and around Knox County (10 miles beyond to account for edge effect) in Google Maps. To understand the various aspects (e.g. dimensions of access) discussed in reviews by online users, I will crowdsource the annotation/labeling of a random sample of individual sentences from 10000 reviews according to the various dimensions of access and the polarity (i.e. how negative to positive) with Amazon's Mechanical Turk (MTurk). In brief, MTurk is a crowdsourcing website in which I can pay users and Amazon to perform various tasks such as annotating my reviews dataset with applicable and appropriate dimensions. I will apply for funding through various

opportunities including the Department of Geography's McCroskey Memorial Fund and Graduate Student Senate awards. If neither is sufficient, I will use my own money. With a training dataset, I will experiment with multiple supervised learning models to label reviews according to the various dimensions and also experiment with various lexicon-based and supervised learning sentiment analysis techniques to understand how positively or negatively a reviewer feels about that respective dimension. The Valence Aware Dictionary and sEntiment Reasoner (VADER) lexicon specifically constructed for analyzing social media posts could be useful to analyze the polarity of reviews.

And I draw inspiration from vector space modeling in natural language processing (NLP) in which text documents are encoded as vectors in a multidimensional space, and where each term is a dimension. This multidimensional space as the expanse of all words across all documents could understood as a *shared perception space*. Document similarity can be assessed with cosine similarity, or the difference in angles between two documents represented as vectors; the smaller the angle, the more similar two documents are. Documents may be novels, online reviews, or any collection of text by individuals. In essence, we can assess the similarity between people's mental perceptions by analyzing the cosine similarity of their verbal and textual communications. This could be used to extend the conventional space-time path (STP) premised in absolute space with different textual representations reflecting an individual's perceptions at different times. Cosine similarity would be a measure of shared perceptions between two individuals at a given time. A shared perception STP would be the movement trajectory of an individual's position within a shared perception space over time. While a longitudinal dataset of people's perceptions in the form of text would be required, I propose to also add two long-form questions in my questionnaire survey that inquires into how people perceived of their access according to the various dimensions pre-Covid and now. This data can be used as a prototype demonstration for how to integrate textual data reflecting on people's access in a space-time GIS. My next paper in which I propose a mental-physical space approach to access will build upon this work.

It will also be my goal to carry out all of the aforementioned process in an open-source GIS environment as part of a Python package I will develop. I propose to develop an open-source interactive three-dimensional GIS environment as a Python package that can support the concepts in my proposed framework and to ultimately help researchers process, manipulate, visualize, and analyze various data that could potentially reflect upon people's access. My work will build upon existing libraries such as GeoPandas to read in geographic data, MovingPandas to convert GeoPandas GeoDataFrames into Trajectories, ipyleaflet and folium to create interactive maps, and TextBlob, nltk, gensim to analyze and visualize text. I'll create new classes and functions to create an object-oriented library that can be used for both individual-level and aggregate-level analysis of access.

Limitations and Uncertainties

What people write about in reviews online may also not necessarily reflect the same semantics and sentiments of local residents; and they may only represent a particular subsample of the population (i.e. people who are more likely to post reviews have particular characteristics that may not be descriptive of everyone in the county.) And the outsourcing of the labeling task to online users on Amazon's MTurk platform may also be susceptible to various biases, and users who will be annotating the reviews may have preconceived notions of the world and interpret the reviews in ways that was different than what the original poster had in mind. There

would be no way to truly understand what the reviewer was thinking unless I actually asked them, and that is pretty much an infeasible task. Furthermore, this bias may be propagated in the supervised learning models for both classification of their various dimensions and opinion mining of their sentiments towards these dimensions. This means we have to carefully approach the obtained results such that it does not speak for the entire population and that this is just an attempt to model how humans think and perceive their local food access.

Paper 3: A Mental-Physical Space Approach for Access

Introduction

While there have been improvements to spatial accessibility measures to inform understanding of food access, many are still premised on the assumption that physical location is the most important determinant from both the supply and demand side. The fetishization of physical location may not accurately describe the situation of food access and omits critical aspects related to how residents in an area obtain food and perceive their access to affordable and healthy options. Understanding food access may be improved by not only looking at the quantity of grocery stores or the amount of time it takes to drive to a store but also by including human perceptions via online reviews and other types of information. People may have different ratings (sentiments) and priorities (weights) for different aspects (semantics) of their food situation. Furthermore, people do not necessarily patronize the closest option and instead may shop at locations seemingly far away from their home locations. With all this under consideration, this research explores the development of a multi-dimensional access measure to better understand access to affordable and healthy/nutritious food locations.

As (Caspi et al., 2012) found, while many research studies evaluated the food environment-diet relationship with Geographic Information Systems (GIS) based measures, few actually looked into dimensions of affordability, accommodation, and acceptability and were instead premised on either or both availability and accessibility, or *geographic accessibility*. Because of this finding, the authors recommend that there needs to be more standardized measures for assessing the food environment and ultimately to understand access to food and a heightened focus on other understudied dimensions. Studies on access to various health services can also be described the same, with the only difference lying in the ways in which geographic accessibility is operationalized and measured. Beyond the critique of existing research by Caspi and colleagues, the increasing adoption of digital applications to fulfill various human needs such as grocery shopping and more broadly the expansion of the Internet and digital communities means that access needs to be measured and analyzed in this new hybrid physical-virtual setting. What space-time GIS and other relevant methods are useful to explore people's physical, relative, relational, and mental aspects of their different dimensions of access to various human needs?

Methods

I propose to develop an approach to understand access that couples together human perceptions with conventional spatial accessibility measures including a place-based and person-based measure of access. Specifically, I will analyze online reviews for grocery stores and residents' responses to various questionnaire survey items to understand how people feel about the various options in their local food environments. These will be compared to understand the subjective perceptions of individuals from a 'big data' source and a 'small data' source which can each be, respectively, coupled with other sources of data including SafeGraphs Patterns and GPS traces, to understand access that integrates human perceptions at the individual and aggregate level.

With dimension-specific sentiment scores for grocery stores and supermarkets as described in the second paper, I can then develop a gravity-based measure that includes in its formulation the polarity scores of the different dimensions as an attractiveness factor coupled with travel time as the cost distance between an origin census block group and a destination grocery store. Both realized and potential access will be empirically derived, the former based on the observed

movement patterns from SafeGraph Patterns and the latter based on the assumption that all stores are within reach but that distance will be a limiting factor (i.e. the effect of distance decay). The impedance factor will be calibrated based upon the empirical trip distribution matrix (i.e. the flows of individuals from one census block group to the destination grocery store obtained from the SafeGraph Patterns dataset.) For each census block group, access from the centroid to all other opportunities can be measured. Gravity-based measures are measures of integral (place) accessibility and have been widely used to describe the spatial interactions and flows from one enumeration unit (e.g. census block group) to all possible grocery stores. This can be used to analyze and compare access at the census block group level. See the following figure for the mathematical notation:

$$A_i = \sum_{k=1}^{N} \frac{P_{ik}}{\sum P_{ik}} * \frac{p1_k + p2_k + p3_k + p4_k + p5_k}{c_{ik}^{\beta}}$$

A_i = Accessibility of zone i
$p1_k$ = Polarity Score: Availability
$p2_k$ = Polarity Score: Accessibility
$p3_k$ = Polarity Score: Affordability
$p4_k$ = Polarity Score: Accommodation
$p5_k$ = Polarity Score: Acceptability

k = Facility 1, 2, .., N
P_{ik} = Number of people from zone i visiting facility k
$\sum P_{ik}$ = Total number of people from zone i visiting facilities k:N

c_{ik} = Cost Distance between zone i and facility k
β = Cost Distance decay function

At the individual level, and as mentioned in the Methods section for Paper 1, I will be carrying out a questionnaire survey to inquire into their behaviors for accessing food in both the physical and virtual environments. This survey will also include (1) questions about participants' socioeconomic and personal characteristics and their perceived access to grocery stores and supermarkets and (2) a request for their GPS-tracked week-long location histories via Google Maps. As (Wolf et al., 2001) found, GPS data were found to either match or exceed the recollections of individuals' responses in travel diaries. Responses to questions in my survey can help to delineate an opportunity set specific to each individual, such as:

- "On average, how much time would you be willing to spend to reach a grocery store/supermarket?" [Perceived Accessibility]
- "Based on the following scale of $ = inexpensive, $$ = moderate, $$$ = expensive, and $$$$ = very expensive, how would you characterize your own food shopping budget for an average trip to the grocery store?" [Perceived Affordability]
- "Which of the following chain-brands (e.g. Kroger, Whole Foods, Publix, Walmart) do you shop at?" [Perceived Acceptability and Availability]
- "Which of the following accommodation practices (e.g. requiring masks) are important to you when choosing a grocery store or supermarket?" [Perceived Accommodation]
- "Do you shop for food online? If so, please provide the stores you shop at." [Perceived Accommodation, Availability]

In total, I hope to receive at least 400 responses. Responses to similar questions as described above can be used as criteria to identify feasible opportunities based on derivations of potential path areas (PPAs) from participants' GPS trajectories. PPAs are projections of space-time prisms (STPs) which represent all possible areas an individual can visit between two observed locations, such as home and then the workplace. Space-time prisms used in many space-time measures of access define the maximum extent of space that can be reached by an individual given various time constraints. However, not every service (e.g. grocery store) located within a prism is part of an individual's choice set. If a particular grocery store is not in a person's choice set, it cannot be accessed. A geocomputational approach to cull the options starts first with aggregating the PPAs and then limiting the choice set to only those stores within the PPA. Then, queries made with the responses to the questions related to access can further distinguish opportunities based on the examined individual's perceptions. This, in effect, is a perceived space-time measure of access. I will carry out an exploratory analysis based on surveyor's responses and their GIS tracks to understand access from both mental and absolute space.

Afterwards, I plan to carry out some spatial statistical tests such as Local Indicators of Spatial Association (LISA) to understand where there exists particular spatial regions that are found to have significantly lower access. I'll also carry out multivariate regreesion tests to further understand where population groups along class and other socioeconomic and demographic characteristics are similarly correlated with lower access.

Limitations and Uncertainties

As with any data source, the SafeGraph dataset does not reflect the dynamics of the entire population, although the company claims that the demographic of the population it collects data of is similar to the true makeup. Cell phone traces are used as a proxy of foot traffic but mobile phone ownership may be varied along different axes, including class. And as (Zhao et al., 2016) found, call detail records used in human mobility research tend to underestimate the total distance traveled and movement entropy. I must also be careful in how I interpret the results from my proposed approach to understand access. Furthermore, it will not be possible to explore place-based access at temporal scales smaller than a month with the SafeGraph data. There is a limitation too regarding the comprehensive nature of the data as not every store contains values for the visitor patterns field. Thus, the realized place-based access and derived impendance factor from the empirical trip distribution matrix will only reflect the CBG-store connections in which there are data available. I argue this approach is still very useful to understand place-based access as it takes into consideration actual flows and mental perceptions, in addition to the spatial characteristics often assumed in the existing literature. As physical distance and proximity are not necessarily the sole primary factors in access, especially with the advent of digital technologies such as e-grocery, a multi-spatial approach may perhaps better suited to explore the various absolute and mental aspects of people's access to food.

Obtaining a decently-sized sample of individuals to provide their week-long GPS histories may be challenging because many might be reluctant to give up such personal information. Constructing potential path areas for the space-time measure are highly contingent upon the sampled population, and with COVID19 currently ongoing, there may be little to no physical movement but doesn't necessarily reflect typical human behaviors. Of course, no single dataset can perfectly illuminate upon the real and daily lived situation experienced by every individual in society. There are limitations with each dataset but they can each be used to

ultimately provide a perspective on how people perceive their access to various human needs, such as to grocery stores.

EXPECTED OUTCOMES

I expect to publish at least three different articles from my proposed dissertation research as well as an open-source Python library for my proposed GIS environment used to inquire into access.

SCHEDULE

Goal	Date
Begin analysis for Chapter 2	Currently ongoing
Re-submit IRB proposal with updated goals and questionnaire survey	April/May 2021
Extract grocery store information from Google Maps and foot traffic data with origin CBGs to grocery store POIs from SafeGraph	Currently ongoing; done by April/May 2021
Obtain data: survey and GPS traces	May/June 2021
Apply for NSF DDRI	June/July 2021
Begin analysis for Chapter 1	June/July 2021
Submit Chapter 1 for Review	Late-Summer 2021
Begin analysis for Chapter 2	Fall 2021
Submit Chapter 2 for Review	Fall 2021
Begin analysis for Chapter 3	Late Fall 2021
Submit Chapter 3 for Review	Spring 2022
Graduate	Spring 2022

I understand that this proposed schedule may appear to be a bit over-ambitious but I feel confident in my abilities to execute in a timely fashion what I have proposed. Without any further anticipated coursework nor lead instruction responsibilities, I strongly believe that I will have adequate time to ultimately complete my stated research plan. However, in the case that I don't complete all my tasks by then, I have been approved for an additional year of funding by the Department of Geography contingent upon good standing and performance. In the worst case scenario, I hope that I will be done by the Winter of 2022, if not the Summer of 2022.

REFERENCES

Agency for Healthcare Research and Quality. (2018, June). *Elements of Access to Health Care: Timeliness*. Elements of Access to Health Care: Timeliness. https://www.ahrq.gov/research/findings/nhqrdr/chartbooks/access/elements3.html

Apparicio, P., Abdelmajid, M., Riva, M., & Shearmur, R. (2008). Comparing alternative approaches to measuring the geographical accessibility of urban health services: Distance types and aggregation-error issues. *International Journal of Health Geographics*, *7*(1), 7. https://doi.org/10.1186/1476-072X-7-7

Apparicio, P., Cloutier, M.-S., & Shearmur, R. (2007). The case of Montréal's missing food deserts: Evaluation of accessibility to food supermarkets. *International Journal of Health Geographics*, *6*(1), 4. https://doi.org/10.1186/1476-072X-6-4

Apparicio, P., Gelb, J., Dubé, A.-S., Kingham, S., Gauvin, L., & Robitaille, É. (2017). The approaches to measuring the potential spatial access to urban health services revisited: Distance types and aggregation-error issues. *International Journal of Health Geographics*, *16*(1), 32. https://doi.org/10.1186/s12942-017-0105-9

Bartholomew, D. J., Steele, F., Moustaki, I., & Galbraith, J. I. (2008). *Analysis of Multivariate Social Science Data* (Second). CRC Press.

Begley, S., Marohn, E., Mikha, S., & Rettaliata, A. (2020, February 14). *Digital disruption at the grocery store*. McKinsey. https://www.mckinsey.com/industries/retail/our-insights/digital-disruption-at-the-grocery-store

Ben-Akiva, M., & Lerman, S. R. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press.

Beyer, K. M. M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F. J., & Malecki, K. M. (2014). Exposure to Neighborhood Green Space and Mental Health: Evidence from the Survey of the Health of Wisconsin. *International Journal of Environmental Research and Public Health*, *11*(3), 3453–3472. https://doi.org/10.3390/ijerph110303453

Bocarejo S., J. P., & Oviedo H., D. R. (2012). Transport accessibility and social inequities: A tool for identification of mobility needs and evaluation of transport investments. *Journal of Transport Geography*, *24*, 142–154. https://doi.org/10.1016/j.jtrangeo.2011.12.004

Bosanac, E. M., Parkinson, R. C., & Hall, D. S. (1976). Geographic Access to Hospital Care: A 30-Minute Travel Time Standard. *Medical Care*, *14*(7), 616–623. https://journals.lww.com/lww-medicalcare/Abstract/1976/07000/Geographic_Access_to_Hospital_Care__A_30_Minute.6.aspx

Brown, E. J., Polsky, D., Barbu, C. M., Seymour, J. W., & Grande, D. (2016). Racial Disparities In Geographic Access To Primary Care In Philadelphia. *Health Affairs*, *35*(8), 1374–1381. https://doi.org/10.1377/hlthaff.2015.1612

Caspi, C. E., Sorensen, G., Subramanian, S. V., & Kawachi, I. (2012). The local food environment and diet: A systematic review. *Health & Place*, *18*(5), 1172–1187. https://doi.org/10.1016/j.healthplace.2012.05.006

Cha, A. E., Bernstein, L., Sellers, F. S., & Harris, S. (2020, March 31). Faced with a crush of patients, besieged NYC hospitals struggle with life-or-death decisions. *Washington Post*. https://www.washingtonpost.com/health/2020/03/31/new-york-city-hospitals-coronavirus/

Chandra, V., Gordusenko, O., Mutell, B., & Turco, A. (2020, September 2). *Beating the shrink on grocery shelves*. McKinsey. https://www.mckinsey.com/industries/retail/our-insights/beating-the-shrink-on-grocery-shelves

Charm, T., Grimmelt, A., Kim, H., Robinson, K., Lu, N., Mayank, Ortega, M., Staack, Y., & Yamakawa, N. (2020, October 26). *Consumer sentiment and behavior continue to reflect the uncertainty of the COVID-19 crisis*. McKinsey. https://www.mckinsey.com/business-functions/marketing-and-sales/our-insights/a-global-view-of-how-consumer-behavior-is-changing-amid-covid-19

Chen, X. (2017). Take the edge off: A hybrid geographic food access measure. *Applied Geography*, *87*, 149–159. https://doi.org/10.1016/j.apgeog.2017.07.013

Couclelis, H., & Getis, A. (2000). Conceptualizing and Measuring Accessibility within Physical and Virtual Spaces. In D. G. Janelle & D. C. Hodge (Eds.), *Information, Place, and Cyberspace: Issues in Accessibility* (pp. 15–20). Springer. https://doi.org/10.1007/978-3-662-04027-0_2

Dalvi, M. Q., & Martin, K. M. (1976). The measurement of accessibility: Some preliminary results. *Transportation*, *5*(1), 17–42. https://doi.org/10.1007/BF00165245

Delafontaine, M., Neutens, T., Schwanen, T., & Weghe, N. V. de. (2011). The impact of opening hours on the equity of individual space–time accessibility. *Computers, Environment and Urban Systems*, *35*(4), 276–288. https://doi.org/10.1016/j.compenvurbsys.2011.02.005

dos Anjos Luis, A., & Cabral, P. (2016). Geographic accessibility to primary healthcare centers in Mozambique. *International Journal for Equity in Health*, *15*(1), 173. https://doi.org/10.1186/s12939-016-0455-0

Drewnowski, A., Aggarwal, A., Hurvitz, P. M., Monsivais, P., & Moudon, A. V. (2012). Obesity and supermarket access: Proximity or price? *American Journal of Public Health*, *102*(8), e74-80. https://doi.org/10.2105/AJPH.2012.300660

Eberly, L. A., Kallan, M. J., Julien, H. M., Haynes, N., Khatana, S. A. M., Nathan, A. S., Snider, C., Chokshi, N. P., Eneanya, N. D., Takvorian, S. U., Anastos-Wallen, R., Chaiyachati, K., Ambrose, M., O'Quinn, R., Seigerman, M., Goldberg, L. R., Leri, D., Choi, K., Gitelman, Y., … Adusumalli, S. (2020). Patient Characteristics Associated With Telemedicine Access for Primary and Specialty Ambulatory Care During the COVID-19 Pandemic. *JAMA Network Open*, *3*(12), e2031640. https://doi.org/10.1001/jamanetworkopen.2020.31640

Egenhofer, M. J., & Mark, D. M. (1995). Naive Geography. In A. U. Frank & W. Kuhn (Eds.), *Spatial Information Theory A Theoretical Basis for GIS* (pp. 1–15). Springer. https://doi.org/10.1007/3-540-60392-1_1

El-Geneidy, A., Levinson, D., Diab, E., Boisjoly, G., Verbich, D., & Loong, C. (2016). The cost of equity: Assessing transit accessibility and social disparity using total travel cost. *Transportation Research Part A: Policy and Practice*, *91*, 302–316. https://doi.org/10.1016/j.tra.2016.07.003

Engemann, K., Pedersen, C. B., Arge, L., Tsirogiannis, C., Mortensen, P. B., & Svenning, J.-C. (2019). Residential green space in childhood is associated with lower risk of psychiatric disorders from adolescence into adulthood. *Proceedings of the National Academy of Sciences*, *116*(11), 5188–5193. https://doi.org/10.1073/pnas.1807504116

FAO, I. (2020). *The State of Food Security and Nutrition in the World 2020. Transforming food systems for affordable healthy diets*. FAO, IFAD, UNICEF, WFP and WHO.

https://doi.org/10.4060/ca9692enAlso Available in:Chinese Spanish Arabic French Russian
Farber, S., Morang, M. Z., & Widener, M. J. (2014). Temporal variability in transit-based accessibility to supermarkets. *Applied Geography*, *53*, 149–159. https://doi.org/10.1016/j.apgeog.2014.06.012
Fera, B., Korba, C., & Shukla, M. (2020, April 30). *The future of virtual health*. Deloitte Insights. https://www2.deloitte.com/us/en/insights/industry/health-care/future-of-virtual-health.html
Fieldhouse, E. A. (1999). Ethnic Minority Unemployment and Spatial Mismatch: The Case of London. *Urban Studies*, *36*(9), 1569–1596. https://www.jstor.org.proxy.lib.utk.edu:90/stable/43084524
Ford, A. C., Barr, S. L., Dawson, R. J., & James, P. (2015). Transport Accessibility Analysis Using GIS: Assessing Sustainable Transport in London. *ISPRS International Journal of Geo-Information*, *4*(1), 124–149. https://doi.org/10.3390/ijgi4010124
Gao, I., & Kolak, M. (2019). Healthy Access for Healthy Places: A Multidimensional Food Access Measure. *ArXiv*, 8. https://arxiv.org/ftp/arxiv/papers/1912/1912.11351.pdf
Glenza, J., Rao, A., & Villarreal, A. (2020, March 27). "It's what was happening in Italy": The hospital at the center of New York's Covid-19 crisis. *The Guardian*. https://www.theguardian.com/us-news/2020/mar/27/new-york-coronavirus-elmhurst-hospital
Gould, P. R. (1969). *Spatial Diffusion, Resource Paper No. 4*. https://eric.ed.gov/?id=ED120029
Hägerstrand, T. (1970). What about people in regional science? *Papers in Regional Science*, *24*(1), 6–21. https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1435-5597.1970.tb01464.x
Hägerstrand, T. (1982). Diorama, Path and Project. *Tijdschrift Voor Economische En Sociale Geografie*, *73*(6), 323–339. https://doi.org/10.1111/j.1467-9663.1982.tb01647.x
Haggerty, J. L., Lévesque, J.-F., Santor, D. A., Burge, F., Beaulieu, C., Bouharaoui, F., Beaulieu, M.-D., Pineault, R., & Gass, D. (2011). Accessibility from the Patient Perspective: Comparison of Primary Healthcare Evaluation Instruments. *Healthcare Policy*, *7*(Spec Issue), 94–107. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3399437/
Handy, S. L., & Niemeier, D. A. (1997). Measuring Accessibility: An Exploration of Issues and Alternatives. *Environment and Planning A: Economy and Space*, *29*(7), 1175–1194. https://doi.org/10.1068/a291175
Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, *25*(2), 73–76. https://doi.org/10.1080/01944365908978307
Hecht, B., & Stephens, M. (2014). A tale of cities: Urban biases in volunteered geographic information. *Proceedings of the 8th International Conference on Weblogs and Social Media, ICWSM 2014*, 197–205. https://experts.umn.edu/en/publications/a-tale-of-cities-urban-biases-in-volunteered-geographic-informati
Hellerstein, J. K., Neumark, D., & McInerney, M. (2008). Spatial mismatch or racial mismatch? *Journal of Urban Economics*, *64*(2), 464–479. https://doi.org/10.1016/j.jue.2008.04.003
Hewko, J., Smoyer-Tomic, K. E., & Hodgson, M. J. (2002). Measuring Neighbourhood Spatial Accessibility to Urban Amenities: Does Aggregation Error Matter? *Environment and Planning A: Economy and Space*, *34*(7), 1185–1206. https://doi.org/10.1068/a34171
Hilmers, A., Hilmers, D. C., & Dave, J. (2012). Neighborhood Disparities in Access to Healthy Foods and Their Effects on Environmental Justice. *American Journal of Public Health*, *102*(9), 1644–1654. https://doi.org/10.2105/AJPH.2012.300865

Hjortsberg, C. A., & Mwikisa, C. N. (2002). Cost of access to health services in Zambia. *Health Policy and Planning*, *17*(1), 71–77. https://doi.org/10.1093/heapol/17.1.71

Ingram, D. R. (1971). The concept of accessibility: A search for an operational form. *Regional Studies*, *5*(2), 101–107. https://doi.org/10.1080/09595237100185131

ITU. (2018). *ICTs, LDCs and the SDGs: Achieving Universal and Affordable Internet in the LDCs* (p. 128) [Thematic report]. https://www.itu.int/en/ITU-D/LDCs/Pages/Publications/LDCs/D-LDC-ICTLDC-2018-PDF-E.pdf

Janelle, D. G. (1973). Measuring Human Extensibility in a Shrinking World. *Journal of Geography*, *72*(5), 8–15. http://www.csiss.org/janelle/docs/Janelle-extensibility.pdf

Janelle, D. G., & Hodge, D. C. (2000). Information, Place, Cyberspace, and Accessibility. In D. G. Janelle & D. C. Hodge (Eds.), *Information, Place, and Cyberspace: Issues in Accessibility* (pp. 3–11). Springer. https://doi.org/10.1007/978-3-662-04027-0_1

Janiak, A. (2020). Kant's Views on Space and Time. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Spring 2020). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/spr2020/entries/kant-spacetime/

Khan, A. A., & Bhardwaj, S. M. (1994). Access to Health Care: A Conceptual Framework and its Relevance to Health Care Planning. *Evaluation & the Health Professions*, *17*(1), 60–76. https://doi.org/10.1177/016327879401700104

Kitchin, R. (2017). Thinking critically about and researching algorithms. *Information, Communication & Society*, *20*(1), 14–29. https://doi.org/10.1080/1369118X.2016.1154087

Knox, P. L. (1980). Measures of Accessibility as Social Indicators: A Note. *Social Indicators Research*, *7*(1/4), 367–377. https://www.jstor.org.proxy.lib.utk.edu:90/stable/27521950

Koenig, J. G. (1980). Indicators of urban accessibility: Theory and application. *Transportation*, *9*(2), 145–172. https://doi.org/10.1007/BF00167128

Kruk, M. E., Ataguba, J. E., & Akweongo, P. (2020). The universal health coverage ambition faces a critical test. *The Lancet*, *396*(10258), 1130–1131. https://doi.org/10.1016/S0140-6736(20)31795-5

Kwan, M.-P. (1998). Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using a Point-based Framework. *Geographical Analysis*, *30*(3), 191–216. https://doi.org/10.1111/j.1538-4632.1998.tb00396.x

Kwan, M.-P. (2004). GIS Methods in Time-Geographic Research: Geocomputation and Geovisualization of Human Activity Patterns. *Geografiska Annaler. Series B, Human Geography*, *86*(4), 267–280. https://www.jstor.org.proxy.lib.utk.edu:90/stable/3554351

Kwan, M.-P., & Hong, X. D. (1998). Network-based constraints-oriented choice set formation using GIS. *Geographical Systems*, *5*(1–2), 139–162. https://experts.illinois.edu/en/publications/network-based-constraints-oriented-choice-set-formation-using-gis

Laura Rocchio & Mike Carlowicz. (2019, July 17). *Green Space is Good for Mental Health*. NASA Earth Observatory; NASA Earth Observatory. https://earthobservatory.nasa.gov/images/145305/green-space-is-good-for-mental-health

Lenntorp, B. (1976). *Paths in space-time environments: A time-geographic study of movement possibilities of individuals*. Royal University of Lund, Deptof Geography.

Li, H., Campbell, H., & Fernandez, S. (2013). Residential Segregation, Spatial Mismatch and Economic Growth across US Metropolitan Areas. *Urban Studies*, *50*(13), 2642–2660. https://doi.org/10.1177/0042098013477697

Lin, Y., Wan, N., Sheets, S., Gong, X., & Davies, A. (2018). A multi-modal relative spatial access assessment approach to measure spatial accessibility to primary care providers. *International Journal of Health Geographics*, *17*(1), 33. https://doi.org/10.1186/s12942-018-0153-9

Liu, D., & Kwan, M.-P. (2020). Measuring Job Accessibility Through Integrating Travel Time, Transit Fare And Income: A Study Of The Chicago Metropolitan Area. *Tijdschrift Voor Economische En Sociale Geografie*, *111*(4), 671–685. https://doi.org/10.1111/tesg.12415

Luo, W. (2004). Using a GIS-based floating catchment method to assess areas with shortage of physicians. *Health & Place*, *10*(1), 1–11. https://doi.org/10.1016/S1353-8292(02)00067-9

Luo, W., & Wang, F. (2003). Measures of Spatial Accessibility to Health Care in a GIS Environment: Synthesis and a Case Study in the Chicago Region. *Environment and Planning B: Planning and Design*, *30*(6), 865–884. https://doi.org/10.1068/b29120

Luo, W., & Whippo, T. (2012). Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health & Place*, *18*(4), 789–795. https://doi.org/10.1016/j.healthplace.2012.04.002

McKinnon, R. A., Reedy, J., Morrissette, M. A., Lytle, L. A., & Yaroch, A. L. (2009). Measures of the Food Environment. *American Journal of Preventive Medicine*, *36*(4), S124–S133. https://doi.org/10.1016/j.amepre.2009.01.012

McLafferty, S., & Preston, V. (1992). Spatial Mismatch and Labor Market Segmentation for African-American and Latina Women. *Economic Geography*, *68*(4), 406–431. https://doi.org/10.2307/144026

McLafferty, S., & Preston, V. (1996). Spatial mismatch and employment in a decade of restructuring. *Professional Geographer*, *48*(4), 420. https://doi.org/10.1111/j.0033-0124.1996.00420.x

Miller, E. J. (2018). Accessibility: Measurement and application in transportation planning. *Transport Reviews*, *38*(5), 551–555. https://doi.org/10.1080/01441647.2018.1492778

Miller, H. J. (1991). Modelling accessibility using space-time prism concepts within geographical information systems. *International Journal of Geographical Information Systems*, *5*(3), 287–301. https://doi.org/10.1080/02693799108927856

Nakamura, H., Nakamura, M., Okada, E., Ojima, T., & Kondo, K. (2017). Association of food access and neighbor relationships with diet and underweight among community-dwelling older Japanese. *Journal of Epidemiology*, *27*(11), 546–551. https://doi.org/10.1016/j.je.2016.12.016

Nesbitt, L., Meitner, M. J., Girling, C., Sheppard, S. R. J., & Lu, Y. (2019). Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landscape and Urban Planning*, *181*, 51–79. https://doi.org/10.1016/j.landurbplan.2018.08.007

Neutens, T. (2015). Accessibility, equity and health care: Review and research directions for transport geographers. *Journal of Transport Geography*, *43*, 14–27. https://doi.org/10.1016/j.jtrangeo.2014.12.006

Office of Disease Prevention and Health Promotion. (2020, October 8). *Access to Health Services | Healthy People 2020*. U.S. Department of Health and Human Services. https://www.healthypeople.gov/2020/topics-objectives/topic/Access-to-Health-Services

Openshaw, S., & Taylor, P. (1979). A million or so correlation coefficients, three experiments on the modifiable areal unit problem. In N. Wrigley (Ed.), *Statistical applications in the*

spatial sciences (pp. 127–144). Pion. https://www-worldcat-org.proxy.lib.utk.edu/title/statistical-applications-in-the-spatial-sciences/oclc/8170391

O'Sullivan, D., & Unwin, D. J. (2003). *Geographic Information Analysis* (1st ed.). Wiley.

Penchansky, R., & Thomas, J. W. (1981). The Concept of Access: Definition and Relationship to Consumer Satisfaction. *Medical Care*, *19*(2), 127–140. https://www.jstor.org.proxy.lib.utk.edu:90/stable/3764310

Pew Research Center. (2021). *Internet/Broadband Fact Sheet* [Fact Sheet]. Pew Research Center. https://www.pewresearch.org/internet/fact-sheet/internet-broadband/

Ploeg, M. V., Breneman, V., Dutko, P., Williams, R., Snyder, S., Dicken, C., & Kaufman, P. (2012). *Access to Affordable and Nutritious Food: Updated Estimates of Distance to Supermarkets Using 2010 Data* [Report Summary]. United States Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/webdocs/publications/45032/33844_err143_summary.pdf?v=9280.8

Ploeg, M. V., Breneman, V., Farrigan, T., Hamrick, K., Hopkins, D., Kaufman, P., Lin, B.-H., Nord, M., Smith, T., Williams, R., Kinnison, K., Olander, C., Singh, A., Tuckermanty, E., Krantz-Kent, R., Polen, C., McGowan, H., & Kim, S. (2009). *Access to Affordable and Nutritious Food: Measuring and Understanding Food Deserts and Their Consequences* (pp. 1–160) [Report to Congress]. United States Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/webdocs/publications/42711/12716_ap036_1_.pdf?v=62.2

Pred, A. (1977). *City-systems in Advanced Economies: Past Growth, Present Processes and Future Development Options*. Routledge. https://www.routledge.com/City-systems-in-Advanced-Economies-Past-Growth-Present-Processes-and-Future/Pred/p/book/9781138102255

Renner, B., Baker, B., Cook, J., & Mellinger, J. (2021, Spring). The future of fresh. *Deloitte Insights*, *28*. https://www2.deloitte.com/us/en/insights/industry/retail-distribution/future-of-fresh-food-sales/pandemic-consumer-behavior-grocery-shopping.html

Rhone, A., Ver Ploeg, M., Dicken, C., Williams, R., & Brenemen, V. (2017). *Low-Income and Low-Supermarket-Access Census Tracts, 2010-2015* (EIB-165; pp. 1–21). U.S. Department of Agriculture, Economic Research Service. https://www.ers.usda.gov/webdocs/publications/82101/eib-165.pdf?v=42752

Rong, P., Zheng, Z., Kwan, M.-P., & Qin, Y. (2020). Evaluation of the spatial equity of medical facilities based on improved potential model and map service API: A case study in Zhengzhou, China. *Applied Geography*, *119*, 102192. https://doi.org/10.1016/j.apgeog.2020.102192

Saurman, E. (2015). Improving access: Modifying Penchansky and Thomas's Theory of Access. *Journal of Health Services Research & Policy*, *21*. https://doi.org/10.1177/1355819615600001

Shammas, B., Cha, A. E., Guarino, B., & Dupree, J. (2020, December 16). Record numbers of covid-19 patients push hospitals and staffs to the limit. *Washington Post*. https://www.washingtonpost.com/health/2020/12/16/hospitals-covid-overwhelmed/

Shaw, S.-L. (2012). Guest editorial introduction: Time geography – its past, present and future. *Journal of Transport Geography*, *23*, 1–4. https://doi.org/10.1016/j.jtrangeo.2012.04.007

Shaw, S.-L., & Sui, D. (2018). Editorial: GIScience for human dynamics research in a changing world. *Transactions in GIS*, *22*(4), 891–899. https://doi.org/10.1111/tgis.12474

Shaw, S.-L., & Sui, D. (2019). Understanding the New Human Dynamics in Smart Spaces and Places: Toward a Splatial Framework. *Annals of the American Association of Geographers*, *0*(0), 1–10. https://doi.org/10.1080/24694452.2019.1631145

Shaw, S.-L., & Yu, H. (2009). A GIS-based time-geographic approach of studying individual activities and interactions in a hybrid physical–virtual space. *Journal of Transport Geography*, *17*(2), 141–149. https://doi.org/10.1016/j.jtrangeo.2008.11.012

Shen, Q. (1998). Spatial technologies, accessibility, and the social construction of urban space. *Computers, Environment and Urban Systems*, *22*(5), 447–464. https://doi.org/10.1016/S0198-9715(98)00039-8

Shin, E. J. (2018). Disparities in access to opportunities across neighborhoods types: A case study from the Los Angeles region. *Transportation*, *47*(2), 475–501. https://doi.org/10.1007/s11116-018-9862-y

Singhal, S., Kayyali, B., Levin, R., & Greenburg, Z. (2020, June 23). *The next wave of healthcare innovation: The evolution of ecosystems*. McKinsey. https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/the-next-wave-of-healthcare-innovation-the-evolution-of-ecosystems

Slater, S. J. (2020). Recommendations for Keeping Parks and Green Space Accessible for Mental and Physical Health During COVID-19 and Other Pandemics. *Preventing Chronic Disease*, *17*. https://doi.org/10.5888/pcd17.200204

Spatharou, A., Hieronimus, S., & Jenkins, J. (2020, March 10). *Transforming healthcare with AI: The impact on the workforce and organizations*. McKinsey. https://www.mckinsey.com/industries/healthcare-systems-and-services/our-insights/transforming-healthcare-with-ai

Talen, E., & Anselin, L. (1998). Assessing Spatial Equity: An Evaluation of Measures of Accessibility to Public Playgrounds. *Environment and Planning A: Economy and Space*, *30*(4), 595–613. https://doi.org/10.1068/a300595

Tuan, Y.-F. (1979). Space and Place: Humanistic Perspective. In S. Gale & G. Olsson (Eds.), *Philosophy in Geography* (1st ed., pp. 387–427). Springer. http://www.cmecc.com/uploads/%E8%AF%BE%E6%9C%AC%E5%92%8C%E8%AE%BA%E6%96%87/[40][%E7%A9%BA%E9%97%B4%E7%A4%BE%E4%BC%9A%E6%96%87%E5%8C%96].Tuan.Yi-Fu.(2001).Space.and.place.pdf

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*, *166*, 628–637. https://doi.org/10.1016/j.envres.2018.06.030

United Nations. (2017). *Transforming Our World: The 2030 Agenda for Sustainable Development*. United Nations. https://doi.org/10.1891/9780826190123.ap02

United Nations. (2021). *About the Sustainable Development Goals*. United Nations Sustainable Development. https://www.un.org/sustainabledevelopment/sustainable-development-goals/

United Nations Conference on Trade and Development. (2019). *Digital Economy Report 2019: Value creation and capture: implications for developing countries*. United Nations. https://unctad.org/system/files/official-document/der2019_en.pdf

USDA Economic Research Service. (2019, October 31). *USDA ERS - Documentation*. Food Access Research Atlas: Documentation. https://www.ers.usda.gov/data-products/food-access-research-atlas/documentation/

Wachs, M., & Kumagai, T. G. (1973). Physical accessibility as a social indicator. *Socio-Economic Planning Sciences*, *7*(5), 437–456. https://econpapers.repec.org/article/eeesoceps/v_3a7_3ay_3a1973_3ai_3a5_3ap_3a437-456.htm

Wang, F. (2012). Measurement, Optimization, and Impact of Health Care Accessibility: A Methodological Review. *Annals of the Association of American Geographers*, *102*(5), 1104–1112. https://doi.org/10.1080/00045608.2012.657146

Weiss, D. J., Nelson, A., Gibson, H. S., Temperley, W., Peedell, S., Lieber, A., Hancher, M., Poyart, E., Belchior, S., Fullman, N., Mappin, B., Dalrymple, U., Rozier, J., Lucas, T. C. D., Howes, R. E., Tusting, L. S., Kang, S. Y., Cameron, E., Bisanzio, D., … Gething, P. W. (2018). A global map of travel time to cities to assess inequalities in accessibility in 2015. *Nature*, *553*(7688), 333–336. https://doi.org/10.1038/nature25181

Weiss, D. J., Nelson, A., Vargas-Ruiz, C. A., Gligorić, K., Bavadekar, S., Gabrilovich, E., Bertozzi-Villa, A., Rozier, J., Gibson, H. S., Shekel, T., Kamath, C., Lieber, A., Schulman, K., Shao, Y., Qarkaxhija, V., Nandi, A. K., Keddie, S. H., Rumisha, S., Amratia, P., … Gething, P. W. (2020). Global maps of travel time to healthcare facilities. *Nature Medicine*, *26*(12), 1835–1838. https://doi.org/10.1038/s41591-020-1059-1

Widener, M. J. (2018). Spatial access to food: Retiring the food desert metaphor. *Physiology & Behavior*, *193*, 257–260. https://doi.org/10.1016/j.physbeh.2018.02.032

Widener, M. J., Farber, S., Neutens, T., & Horner, M. (2015). Spatiotemporal accessibility to supermarkets using public transit: An interaction potential approach in Cincinnati, Ohio. *Journal of Transport Geography*, *42*, 72–83. https://doi.org/10.1016/j.jtrangeo.2014.11.004

Widener, M. J., & Shannon, J. (2014). When are food deserts? Integrating time into research on food accessibility. *Health & Place*, *30*, 1–3. https://doi.org/10.1016/j.healthplace.2014.07.011

Wolf, J., Guensler, R., & Bachman, W. (2001). Elimination of the Travel Diary: Experiment to Derive Trip Purpose from Global Positioning System Travel Data. *Transportation Research Record: Journal of the Transportation Research Board*, *1768*(1), 125–134. https://doi.org/10.3141/1768-15

Wong, S. (2018). The limitations of using activity space measurements for representing the mobilities of individuals with visual impairment: A mixed methods case study in the San Francisco Bay Area. *Journal of Transport Geography*, *66*, 300–308. https://doi.org/10.1016/j.jtrangeo.2017.12.004

World Health Organization. (2020, April 29). *Healthy diet*. https://www.who.int/news-room/fact-sheets/detail/healthy-diet

Yenerall, J., You, W., & Hill, J. (2017). Investigating the Spatial Dimension of Food Access. *International Journal of Environmental Research and Public Health*, *14*(8). https://doi.org/10.3390/ijerph14080866

Yin, C., He, Q., Liu, Y., Chen, W., & Gao, Y. (2018). Inequality of public health and its role in spatial accessibility to medical facilities in China. *Applied Geography*, *92*, 50–62. https://doi.org/10.1016/j.apgeog.2018.01.011

Yu, H., & Shaw, S.-L. (2008). Exploring potential human activities in physical and virtual spaces: A spatio-temporal GIS approach. *International Journal of Geographical Information Science*, *22*(4), 409–430. https://doi.org/10.1080/13658810701427569

Zhao, Z., Shaw, S.-L., Xu, Y., Lu, F., Chen, J., & Yin, L. (2016). Understanding the bias of call detail records in human mobility research. *International Journal of Geographical Information Science*, *30*(9), 1738–1762. https://doi.org/10.1080/13658816.2015.1137298