Chapter 5

Urban Human Dynamics

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Abstract Urban areas are places where people concentrate in a relatively high density built environment to carry out a wide range of activities. Each urban area should provide adequate infrastructure and services to support the needs of its population. Since various resources, services, and facilities are at different locations, urban areas manifest a complex system of flows of people, goods, and information to support the economic, social, cultural, and political systems in human society. These activities, flows, and systems are driven by various processes and exhibit various spatiotemporal patterns that are the outcomes of human dynamics. However, how we investigate the various dynamic processes and complex systems in urban areas has been and continues to be a challenging research topic. Urban human dynamics cover multiple aspects and can be studied from different perspectives. This chapter discusses urban dynamics and human dynamics in terms of their respective approaches and methods, along with some selected examples. It then connects urban human dynamics research with urban informatics to highlight their relationships and how together they could lead to urban areas that can better serve human needs and improve the quality of life.

5.1 Introduction

Urban areas are places where people concentrate in a relatively high density built environment to carry out a wide range of activities. The terms urban area and city are often used interchangeably. The National Geographic Society, for example, indicates that “An urban area is the region surrounding a city” (<https://www.nationalgeographic.org/encyclopedia/urban-area/>). Each urban area requires adequate infrastructure and services such as electricity, water, sewer, transportation, schools, hospitals, shops, and parks to support the needs of its population. Since various resources, services, and facilities are at different locations, urban areas therefore have a complex system of flows of people, goods, and information to support their economic, social, cultural,

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and political systems. These activities, flows, and systems are driven by various processes and exhibit various spatiotemporal patterns that are the outcomes of urban human dynamics. It should be noted that urban human dynamics also constantly evolve across space and over time with changing technologies, environmental issues, and social values.

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO, https://www.unesco.org/education/tlsf/mods/theme_c/popups/mod13t01s009.html) and Our World in Data (<https://ourworldindata.org/urbanization>), the trend to global urbanization has dramatically accelerated in the past several decades. Approximately 30% of world population lived in urban areas in 1950 and around 55% in 2019. This urbanization trend is expected to continue, and it is estimated that close to 70% of the world's population are likely to live in urban areas by 2050. With this trend, many existing cities must grow bigger to accommodate the increasing population. Given the fact that many big cities already face significant challenges with respect to their current population size, how to accommodate a continuously increasing urban population without sacrificing our general quality of life has become an important and urgent research topic.

Urban areas have long been considered to be dynamic and complex in nature (Crosby 1983; Batty 2003). Batty (2005) suggested that the emphasis of urban models is no longer on spatial interaction but on development dynamics and local movement. However, how to investigate the various dynamic processes and complex systems in urban areas has been and remains a challenging research topic. Urban human dynamics cover multiple aspects and can be studied with different perspectives. In general, we can divide research in urban human dynamics into two major types, urban dynamics research, and human dynamics research. Urban dynamics research tends to focus on the evolution of an urban area in terms of its growth, change, and decline. In this case, the focus is mainly on the urban area itself, and human activities often are considered implicitly through the outcomes of human activities such as land-use types. For example, we can study how a city evolves spatially through its land-use change patterns over time in terms of its growth, change, and decline. Urban dynamics research also can investigate the dynamics among a system of urban areas such as studying various types of flows among a set of cities. In this case, the focus is mainly on the interactions between cities. Human dynamics research, on the other hand, has a focus on humans per se and studies the dynamics of human activities and interactions that lead to various flows and patterns in an urban area or between urban areas. Although urban dynamics and human dynamics are closely related to each other and should not be treated as two independent types of dynamics in urban areas, this chapter discusses each of these two types of urban human dynamics separately since they tend to use different research approaches and research methods.

5.2 Urban Dynamics

One way of studying complex and dynamic urban areas is to employ general systems theory (von Bertalanffy 1968; Straussfogel 1991; Alfeld 1995; Xie 1996). General systems theory considers a system comprising of a set of interdependent subsystems. A system, which can be more than the sum of its parts, exhibits emerging patterns from the interactions of its parts. Changes in one subsystem can affect other subsystems as well as the system as a whole. Forrester (1969), who is considered the founder of system dynamics, published a book titled *Urban Dynamics* in 1969. He states that “In this book, the nature of the urban problem, its causes, and possible corrections are examined in terms of interactions between components of the urban system” (Forrester 1969, p. ix). Forrester uses computer simulations to study the life cycle of an urban area to reveal its dynamic characteristics. This was an early effort at studying urban dynamics with a computer simulation approach to systematically examine the structure, growth, stagnation, and revival of urban areas.

Due to the influence of Forrester’s approach in investigating urban dynamics, two volumes of *Readings in Urban Dynamics* were subsequently published in 1974 and 1975, respectively (Mass 1974; Schroeder et al. 1975). These two volumes include articles that cover conceptual issues, models, and applications of various aspects of urban dynamics as well as responses to the criticisms of the approach presented in Forrester’s book. For example, Forrester uses a five-step process to reach his conclusions about the dynamics of a typical inner area of a US city, his example loosely related to Boston. The first step chooses certain basic variables to represent the social and economic composition of an urban area, followed by a second step of using specific equations to describe the development of an urban area. The third step introduces public policies to modify the development expressed in the equations, which then leads to the fourth step of deriving the development outcomes due to the public policies introduced into the equations. The fifth step compares the different development outcomes and recommends the public policy that would generate a desirable development outcome. Kadanoff (1971) pointed out several shortcomings of Forrester’s approach, which includes (1) Forrester’s model fails to include city–suburban interactions, (2) migration is the only interaction between an urban area and the outside world in Forrester’s model, and (3) Forrester’s model focuses mainly on predictive methods and does not give sufficient attention to the goals behind the normative approach. Kadanoff (1971, p. 262) then concluded that “I would reject the conclusions, but accept the model as an appropriate basis for further work.”

In response to these criticisms, Forrester (1974, p. vii) wrote: “With the publication of *Readings in Urban Dynamics*, it seems important to emphasize that the original *Urban Dynamics* model represented more a viewpoint and a methodology for analyzing urban behavior than a single, finished model. *Urban Dynamics* was a first step in a continuously evolving set of ideas about social systems. The urban dynamics approach has several major distinguishing features. First, it focuses primarily upon the *interrelationships* between economic, political, psychological, and sociological

variables rather than analyzing in detail any one subsystem of the urban environment. Second, it deals with the long-term evolution of an urban area; it treats the positive feedback processes that lead to urban growth as well as the nonlinearities and negative feedback processes that arise to limit growth. Finally, it provides a formal means for testing the implications of our collective assumptions about urban behavior.” The above statements provide a clear picture of Jay Forrester’s approach to studying urban dynamics; it is associated with general systems theory and uses computer simulations to examine the interrelationships among different subsystems of an urban area. More importantly, the computer simulation approach suggested by Forrester has been pursued by many other researchers in their investigation of urban dynamics, although different simulation models have been used in various studies.

5.2.1 *Cellular Automata for Urban Dynamics Research*

Cellular automata (CA), which were developed in the 1940s by Ulam (1950) and von Neumann (1966), are frequently used to model and simulate urban dynamics. Following these ideas, Tobler (1979) proposed a cellular geography that uses cellular spaces in geographic modeling. A cellular space can be considered as a two-dimensional grid, and each cell in the grid has a *state* that is determined by the states of its neighboring cells. The *neighbor* of a given cell can be defined in different ways, by either the four cells sharing a common side (known as von Neumann neighborhood) or the eight cells that share a common side or a common corner of a given cell (known as the Moore neighborhood). A *transition rule* then determines how the state of a cell changes into a different state from time t to time $t + 1$ based on the specific configurations of the states of its neighboring cells. For example, a transition rule could convert a given cell from the state of non-residential at time t to residential at time $t + 1$ if three of its four neighboring cells have a state of residential at time t . Cells, states, neighbors, and transition rules therefore serve as the foundation of cellular automata models.

There are two characteristics of cellular automata that are attractive to geographical problems (White and Engelen 1993). First, cellular automata divide a study area into a grid that is intrinsically spatial. Second, cellular automata can generate very complex forms from very simple rules that are useful to study complex spatial phenomena. In other words, simple local changes due to interactions among the neighboring cells in a CA model could lead to complex emergent global patterns (Wolfram 1983, 1984). CA models therefore can reflect micro–macro interactions in a simple and direct way, and the key contribution of CA models is to provide insights into how urban systems work rather than offer a simulation tool of urban dynamics (Couclelis 1985). This presents a way of linking the processes operating at different scales to tackle a major research challenge in many fields that attempt to link forms to processes and address local to global structures (Batty and Xie 1994; Emmeche 1994). In fact, Jacobs (1961) suggested that the observed disorders in urban areas

could be viewed as organized complexity due to a deeper order reflecting their diversity. Cellular automata models enable us to investigate urban dynamics from local processes in order to understand global complex patterns and to gain insights into the evolution of various aspects of urban dynamics.

Chapin and Weiss (1968) first applied the concepts of cellular automata to an urban land development model, and Tobler (1970) employed the idea of cellular space to simulate urban growth in the Detroit region, although both studies did not use the term cellular automata. Tobler (1970, p. 234) suggested that “the utmost effort must be exercised to avoid writing a complicated model. ... Because a process appears complicated is also no reason to assume that it is the result of complicated rules.” White and Engelen (1993) argued that most geographic theories, such as central place theory and urban economic models as embodied in the Alonso-Muth land-use theory, are static in nature and assume a state of stable equilibrium, which is contrary to our common sense and experience that all urban areas are undergoing continual growth, change, decline, and restructuring. White and Engelen (1993) consequently developed a CA model that generates fractal patterns of land use from relatively simple rules of spatial behavior in order to address the issue of complexity in urban structure. The objective of this study is to gain insight into the underlying reasons behind the evolution of land-use structures and to demonstrate the existence of a complex fractal order of land-use patterns. Their findings suggest that complexity is a necessary feature of cities. When cities are too simple in their structure, they probably will not evolve successfully and could cease to function effectively. This study is a good example of using a CA model to assess the complexity of urban structure and to establish general guidelines for planning policy.

Couclelis (1985) pointed out that the standard cell-space model has many limitations to its usefulness for tackling real-world geographic problems. These limitations include the infinite plane, neighborhood stationarity, spatial homogeneity, spatial and temporal invariance of transition rules, and closure to external events that are directly related to the basic assumptions of cell-space models. Batty and Xie (1994, p. S46) also suggested that a major problem of applying CA models to urban systems is that “It is most unlikely that urban systems can be simulated entirely at the local scale, but the value of this approach lies in focusing our attention on this scale and the extent to which a hierarchy of processes and scales is essential to understanding how cities work.” Xie (1996) discussed improvements to CA models over the years and proposed a generalized model for cellular urban dynamics, named dynamic urban evolutionary modeling (DUEM), to demonstrate the theoretical integrity and technical merit of the CA approach for urban dynamic applications. One major contribution of DUEM is to adopt a hierarchical system of CA spaces consisting of neighborhood, field, and region that can be used to simulate interactions between cell space, model space, and geographic space to overcome some limitations of the conventional cell-space models. DUEM further connects with a geographic information system (GIS) to benefit from GIS data, analysis, and visualization capabilities.

Anthony Yeh, Xia Li and their collaborators have used cellular automata models extensively to study urban dynamics. Li and Yeh (2000) developed a constrained CA model within a raster GIS that includes local, regional, and global constraints

to regulate cellular space and defines gray cells as representing the percentages of urban land development at any iteration of the CA model. Yeh and Li (2001) further used a constrained CA model and a raster GIS to simulate seven different types of urban forms and developments ranging from compact-monocentric to very highly dispersed development patterns. Their model considers various criteria such as urban forms, environmental suitability, and land consumption for the purpose of planning sustainable cities. They also combined CA models with computational intelligence methods such as neural networks (Li and Yeh 2001), ant colony optimization (Liu et al. 2008), and artificial immune systems (Liu et al. 2010) to investigate complex urban systems. Santé et al. (2010) offered a helpful review of urban cellular automata models applied to the simulation of real-world urban processes with respect to their capabilities and limitations. They also conclude that the widespread use of CA models is due to their simplicity. In the meantime, the simplicity of CA models is also the main weakness that limits their ability to represent real-world phenomena. Another major shortcoming is the lack of a standard method for the definition of transition rules in urban CA models which represent the complexity of the processes.

5.2.2 *Other Urban Dynamics Approaches*

Batty (2008) indicated that traditional urban models treated cities as aggregate equilibrium systems and mainly used spatial interaction. The approach changed in the late twentieth century to consider urban dynamics more as evolving complex systems whose structure emerges from the bottom-up. In his book *Cities and Complexity: Understanding Cities with Cellular Automata, Agent-Based Models, and Fractals*, Batty (2007) presented agent-based models as another useful approach to study complex urban dynamics as urban planning moves from a top-down centralized perspective to a bottom-up decentralized perspective. An agent-based model (ABM) consists of autonomous agents, which can be either individual or collective entities, with defined behaviors to simulate the effects on emerging system patterns from the actions and interactions of the autonomous agents. One key difference between cellular automata models and agent-based models is that agents in ABM are free to move and interact with each other and the environment. The goal of agent-based models is mainly to gain insights into the collective behavior of agents that follow simple behavioral rules. Huang et al. (2014) reviewed 51 agent-based residential choice models in three research domains, which are (1) urban land-use models based on classical theories, (2) different stages of the urbanization process, and (3) integrated agent-based and microsimulation models, to offer a retrospective on developments in agent-based models (ABMs) of urban residential choices. This review paid special attention to the progress of the representation of agent heterogeneity, the extent of land-market representation, and the method of measuring the extensive model outputs. They concluded that “Urban land-use models can benefit from agent-based modeling by incorporating heterogeneous intelligent agents and

explicit modeling of an institution that stands behind land exchange” (Huang et al. 2014, p. 681).

Xie et al. (2007) applied agent-based modeling to study the development of desakota, which is a mixed urban-rural space adjacent to a metropolitan area, in the Suzhou-Wuxian region in China for the period of 1990–2000. They developed an ABM that links local household reform to global urban reform in order to examine processes of local land developments that are moderated by the higher-level macroeconomy. Benenson et al. (2008), on the other hand, developed an agent-based model to study the complex self-organizing dynamics of parking patterns in a non-homogeneous road space by examining the distributions of search time, walking distance, and parking costs of different driver groups. Hosseinali et al. (2013) introduced an agent-based model with new methods of modeling agent movements and competition among agents to simulate urban land-use development in Qazvin, Iran. After the model is calibrated with existing data, it is used to predict land-use developments under four scenarios of development policies.

There are also studies of urban dynamics of a system of urban areas. For example, Batty (2003) presented an approach to urban dynamics that generalized Zipf’s rank-size model to investigate the changing rank-size relationships among cities through time. He used data of the 100 largest towns and cities from 1790 to 2000 at a ten-year interval to examine the volatility of the distributions of individual cities within the rank-size distributions with a measure of the half life of cities. He found that there is considerable volatility in the rank-size relationships which change almost entirely over a 200 year period. This study illustrates the dynamics of how an individual city rises, falls, or holds its position in a system of cities. In addition, Batty’s (2013a) book *The New Science of Cities*, which suggested that we must view cities not only as places in space but also as systems of networks and flows, further indicated the need for looking into the connections and interactions both within an individual city and among a system of cities to better understand various aspects of urban dynamics.

5.3 Human Dynamics

Human dynamics are the foundation of human society. All economic, social, cultural, and political systems and all built environments are developed to serve human needs that are dynamic in nature. The focus of human dynamics research therefore is on the dynamics of disaggregate individual behaviors as well as aggregate group behaviors (Shaw et al. 2016; Shaw and Sui 2018a, b, c). Human dynamics has been a research topic in many disciplines ranging from business, geography, planning, psychology, and sociology to physics. A recent surge of research interests in human dynamics is partially due to the work of Albert-László Barabási and his associates on scale-free networks and heavy-tailed distributions of human behavior. Barabási and Bonabeau (2003) suggested that many complex systems share an important characteristic of some nodes having a large number of connections to other nodes in a network while most nodes have just a handful connections. In other words, these networks appear

to have no scale or are scale-free. Barabási (2005) further indicated that individuals often execute tasks with bursts of rapidly executed tasks separated by long periods of inactivity that results in heavy-tailed distributions. This line of research identifies some general laws of human dynamics from the perspective of statistical physics.

From an urban planning perspective, we need to go beyond the general laws of human behaviors and gain further insights into human dynamics to facilitate policy making and planning practices. Human dynamics evolve with the changing environment, technology, and society (Shaw and Sui 2018b). The ways that people carried out their activities and interacted with other people and the environment 50 years ago are very different from human dynamics today. It is therefore important to gain a better understanding of evolving human dynamics in order to design and develop smarter cities to better serve human needs in the next 10–20 years, if not longer.

5.3.1 *Effects of Information and Communications Technologies on Human Dynamics*

Information and communications technologies (ICT) such as the Internet and mobile phones have significantly influenced the ways that people carry out their activities and interactions. The Internet allows us to access a huge amount of information and a wide range of services online through a global system of interconnected computer networks. With Wi-Fi technology, we can connect to the Internet from any locations that have a wireless local area network. Mobile phones and tablets which are equipped with increasingly powerful computing power further free us from the fixed landline phones and bulky computers, to stay connected almost anywhere and at any time. It is now feasible to find a journal article when a library is closed, purchase an item without a physical visit to a store, and stay in touch with friends almost all of the time. In other words, modern technologies have removed many spatial and temporal constraints on human activities and interactions to extend our activity space (Janelle 1973). Human activities and interactions therefore have become more flexible and spontaneous which in turn can change the nature and spatiotemporal patterns of human dynamics.

There have been many studies of the effects of ICT on travel and human activity patterns (e.g., Salomon 1986; Salomon and Koppelman 1988; Mokhtarian and Meenakshisundaram 1999; Townsend 2000; Hjorthol 2002; Ben-Elia et al. 2014). Mokhtarian (2003) suggested that there exist four types of relationships between telecommunications and travel. The first type of relationship is *substitution* such as teleconferencing or e-shopping, where an online activity substitutes for a trip in physical space. The second type of relationship is *complementarity*, which suggests that the use of ICT will increase activities in physical space. For example, sales messages pushed to smart phones could attract more people to visit stores in physical space. The third type of relationship is *modification*, such as when information obtained

from an online real-time traffic information service changes the route that a traveler takes to make a trip. This simply modifies a trip pattern in physical space without adding or reducing the number of trips in physical space. The last type of relationship is *neutrality*, which means that an activity using ICT has no effect on activities in physical space. This study illustrates the challenge of identifying specific effects of ICT on human dynamics.

Humans must move between different locations in physical space to carry out their activities (e.g., work, school, shopping, social, recreation). Transportation provides the means for people to move from a location to another location in physical space. Since physical movements take time, humans have to trade time to overcome spatial separation. As transportation technologies improve over time, we can overcome the same distance over a shorter time period, which is known as time-space convergence (Janelle 1968, 1969). With the rapid growth and widespread use of ICT in today's world, an increasing number of human activities and interactions are carried out in virtual space using ICT devices to navigate among different places in virtual space. For example, many people stay in touch with their friends via online social network apps and shop online with their smart phone or computer. These activities in virtual space can have major implications for the activities in physical space. For instance, an online order at Amazon.com triggers a shipment from a distribution center to the customer's location via a courier delivery service (e.g., FedEx or UPS). This delivery replaces a personal trip to a store. When there are many people who engage online shopping, a large number of personal trips are replaced by a few delivery truck trips that normally take different routes and occur at different times from those of personal shopping trips. We therefore need to consider human activities and interactions in both physical and virtual spaces, in order to study their interactions and gain a better understanding of human dynamics in the modern world (Shaw and Yu 2009).

5.3.2 Time Geography

Time geography, which was developed by Torsten Hägerstrand (1970), presents a useful framework for studying individual activities in a space-time context. A well-known time-geographic concept is the space-time path that tracks the movements of an individual across space and over time. When there are multiple space-time paths for a group of people, we can analyze their spatiotemporal relationships (Parkes and Thrift 1980; Golledge and Stimson 1997; Janelle 2004; Shaw and Yu 2009). For example, when two or more individuals are at the same location during the same time period, they have a *co-existence* relationship. If two or more individuals visit the same location at different times, they have a *co-location in space* relationship. If two or more people communicate with each other at different locations during the same time period (e.g., online chat), then they have a *co-location in time* relationship. When two or more people interact asynchronously in both space and time (e.g.,

email communications), it does not require co-existence, co-location in space, or co-location in time. These relationships make it feasible to study human activity patterns at the individual level to understand human dynamics in a space-time context.

Time geography also covers many other useful concepts for human dynamics research. Time geography assumes that every individual faces three types of constraints on their activities. Capability constraints are related to an individual's biological system and ability for utilizing tools. For example, all people must sleep and eat, which take time at certain locations. Also, a person who can drive a car can reach more distant locations than people who do not drive. Coupling constraints require that an individual be coupled with other people or entities to carry out particular activities. For example, a class lecture requires an instructor, and the students to be present at the same location during the same time period. Authority constraints are imposed by a domain. An example is that an individual cannot access a grocery store when it is closed. Our daily activities and interactions are conditioned by these three types of constraints, which in turn influence spatiotemporal human dynamics. Another useful time-geographic concept is the space-time prism, which allows us to identify the maximum feasible space-time extent that an individual could reach under given constraints. A space-time prism can help us understand why an individual exhibits certain space-time activity patterns. Diorama is another critical concept. Hägerstrand puts various time-geographic concepts together in a diorama to emphasize the presence of an individual in an immersive environment, such that the individual appreciates how situations evolve as an aggregate outcome while considering various constraints and situations to achieve the goal of a project (Hägerstrand 1982). In fact, Hägerstrand (1982, p. 338) stated that “without a diorama approach, the revealing power of time geography cannot be fully explored.”

Although time geography offers a useful framework for human dynamics research, it has not been widely used in empirical studies, due mainly to two limitations (Shaw 2012). First, time geography requires detailed spatial movement data over time at the individual level that is costly and time-consuming to collect. Most previous time geography studies used data collected from surveys or interviews that had a relatively small sample size. Second, even though many studies collected data of large sample size, it was challenging to conduct time-geographic analyses using a space-time path and a space-time prism due to a lack of computational tools to process, analyze, and visualize the data. These limitations have been overcome to some extent in the big data era, along with the advances in space-time-geographic information systems (GIS).

5.3.3 Big Data and Space-Time GIS for Human Dynamics Research

With advances in sensing, mobile, and information and communications technologies in recent decades, it has become far easier and much cheaper to collect individual

data. Mobile phones can constantly track our locations across space and over time at unprecedented spatial and temporal granularity using built-in global positioning system (GPS) capability. Phone companies have records of our phone communications including phone calls, text messages, and websites accessed. Credit card companies know where, when, and what we purchased, and how much we paid for each purchased item. Smart cards used in many cities for public transit know where and when we used public transit, which transit routes we used, and how often we used them. Search engine service providers such as Google know when we have searched online, which websites we visited, and how long we browsed a particular website. Online social network service providers like Facebook, Twitter, Flickr, and LinkedIn know who our friends and connections are, how frequently we communicated with each other, and what we discussed with each other. These tracking data cover not only human activities in physical space but also human activities and interactions in virtual space. They provide extremely useful data sources to conduct empirical studies of human dynamics, although the research community needs to pay close attention to the ethical and privacy issues of using such data (see Chap. 32).

In the meantime, the large amount of data available for human dynamics research demand adequate tools to process, manage, analyze, and visualize the data. GIS was designed to handle spatial data, yet they were not adequate to dealing with space-time data. Efforts extending the conventional GIS to space-time GIS started in the 1990s by developing functions in GIS that support time-geographic concepts. Miller (1991) first implemented the space-time prism concept in GIS to study individual accessibility, followed by many other efforts at expanding time-geographic functions in GIS (e.g., Kwan 2000a, b; Buliung and Kanaroglou 2006; Yu 2006; Chen et al. 2011; Scott and He 2012). One of the major challenges of applying time geography to human dynamics research is that most time-geographic concepts are based on human activities in physical space. Since many human activities and interactions today are taking place in virtual space, it is critical to extend the conventional time-geographic concepts to cover human dynamics in both physical and virtual spaces. Yu and Shaw (2008) developed a space-time GIS that extends the conventional space-time prism concept to support analysis of potential human activities and interactions in both physical and virtual spaces. Shaw and Yu (2009) further extended the time-geographic concepts of space-time path, station, bundle, activity, event, and project into a hybrid physical–virtual space and implement them in a space-time GIS. Yin and Shaw (2015) then developed a method for creating social closeness of space-time paths in a GIS environment, such that we can assess the relationships between any pair of individuals in both physical space and social closeness space. These efforts make it feasible to study human dynamics in a hybrid physical–virtual space based on time-geographic concepts, although many research challenges remain to be addressed.

5.3.4 Some Other Examples Human Dynamics Studies

In addition to human dynamics research based on time-geographic concepts, there exist a large volume of studies investigating human dynamics using a wide range of individual data collected in the Big Data era. Candia et al. (2008) used mobile phone data to study the mean collective behavior and identify the rise, clustering, and decay of anomalous events that can be useful in real-time detection of emergency situations. They also examined calling activities at the individual level and found that they follow a heavy-tailed distribution. Vazquez-Prokopec et al. (2013) employed GPS tracking of residents in Iquitos, Peru to study mobility patterns, infer mobility networks, and model infectious disease transmission within an Iquitos neighborhood. This study demonstrated how to use data collected from location-aware technology to characterize complex social systems in a developing country and then use the identified mobility patterns and networks to address an important health issue of infectious disease dynamics in an urban environment. Zhong et al. (2014) applied methods in network science to identify the spatial structure of city hubs using smartcard transit data collected in Singapore. They illustrated the evolving roles and influences of local areas in the overall spatial structure of urban movements and indicated that collective movement can shape local communities similar to what happens in social networks. Xu et al. (2016), on the other hand, used mobile phone data collected in Shenzhen and Shanghai, China, to compare their human dynamics patterns based on the number of major activity points, activity range, and frequency of movements (for further examples of this kind of research see Chaps. 28 and 29).

Liu et al. (2015) proposed a concept of social sensing, in contrast to remote sensing, to characterize the research that employs individual level Big Geospatial Data to study socioeconomic aspects of human dynamics. They also considered each individual person as a sensor that helps contribute data to human dynamics research. The concept of social sensing is clearly related to human dynamics research. Due to an explosion of research related to urban human dynamics in recent years using crowdsourcing data and other big data, it is not an intention of this chapter to provide a comprehensive review. Instead, readers can find various examples in other chapters of this book.

5.4 Urban Human Dynamics and Urban Informatics

With this brief review of urban human dynamics research, it is important to connect urban human dynamics to the theme of this book: urban informatics. Urban informatics, which is a relatively new field, takes a data-driven approach enabled by modern sensing, mobile, and information and communications technologies to gain insights into how people function in an urban area and how various systems and services operate in an urban area (Kontokosta 2018). Foth et al. (2011, p. 4) define urban informatics as “the study, design, and practice of urban experiences across

different urban contexts that are created by new opportunities for real-time, ubiquitous technology, and the augmentation that mediate the physical and digital layers of people networks and urban infrastructures.” This definition links place, technology, and people together in an urban environment.

As urban areas continue to grow in their geographic size and population density in order to accommodate the ever-increasing urban population, there is an urgent need for improving our understanding of how urban areas function, what causes urban problems, and how we can address these urban problems in smart and sustainable ways. These challenges are not new at all, and they have been studied for many decades. Unfortunately, it appears that we have not been able to reign in these urban problems, and many urban areas are experiencing worse traffic congestion, air pollution, heat-island effects, housing issues, job mismatches, etc., than ever before. If we accept that human dynamics are the fundamental driving forces of the economic, social, cultural, political, and other systems in urban areas, we must better understand human needs and how they interact with other people and the environment under various constraints imposed by the environment, society, and technology. When infrastructure and services in an urban area cannot adequately accommodate human needs, we run into problems. Since human needs emerge at different locations and different times, they present a challenge of matching supply and demand spatially and temporally. From an urban planning perspective, our goal is to design urban areas that can best meet human needs and improve the quality of life. This is a significant challenge, as evidenced by a wide range of problems facing most urban areas today.

In his article “big data, smart cities, and city planning,” Batty (2013b, p. 274) stated that “the growth of big data is shifting the emphasis from longer term strategic planning to short-term thinking about how cities function and can be managed; although with the possibility that over much longer periods of time, this kind of big data will become a source for information about every time horizon.” Batty (2013b, p. 276) further indicated that “There is, however, a coincidence between what are now being called smart cities and big data, with smartness in cities pertaining primarily to the ways in which sensors can generate new data streams in real time with precise geo-positioning; of course, it is often pointed out that cities only become smart when people are smart, and this is *sine qua non* of our argument here.” Technologies clearly play an important role in urban informatics and smart cities. However, we must keep in mind that urban informatics and smart cities are developed to better serve human needs and improve quality of life. Whether or not a city or a particular system in a city is smart should be assessed by how well it serves the needs of various population groups to improve the quality of life (Shaw and Sui 2019).

Shared bicycles experienced an amazing rapid growth in many Chinese cities a few years ago and this created a motive for reviving bicycles as a popular travel alternative in Chinese cities. However, the entire business collapsed quickly. As indicated by Huang (2018), “Bike-sharing apps seemed poised to be the solution—and millions of bikes were poured into China’s streets by the private sector in the last three years. But today, as the companies fail, unused units pile up in bicycle graveyards, and queues of angry users demand their deposits back, it is obvious just how doomed the

idea was from the start.” The bike-sharing apps were smart in the sense that users could unlock and lock bicycles and pay rent by smart phones anywhere in a city. Yet, it is not clear to what extent the shared bicycles fit well with human needs with respect to various constraints people face in urban areas to carry out their dynamic activity patterns. This example reminds us that it is critical to keep human dynamics in mind when we pursue urban informatics. In conclusion, it is beneficial to combine urban informatics with urban human dynamics research to better understand human activities and interactions in an increasingly hybrid physical–virtual space; yet we must remember that various systems and services in urban areas are created to better serve and meet the human needs in order to improve the quality of life.

References

- Alfeld LE (1995) Urban dynamics—the first fifty years. *Syst Dyn Rev* 11(3):199–217
- Barabási AL (2005) The origin of bursts and heavy tails in human dynamics. *Nature* 435(7039):207–211
- Barabási AL, Bonabeau E (2003) Scale-free networks. *Sci Am* 288(5):50–59
- Batty M (2003) The emergence of cities: complexity and urban dynamics. Center for advanced spatial analysis working paper series, paper 64. University College London
- Batty M (2005) Agents, cells, and cities: new representational models for simulating multiscale urban dynamics. *Environ Plan A* 37(8):1373–1394
- Batty M (2007) Cities and complexity: understanding cities with cellular automata, agent-based models, and fractals. MIT Press, Cambridge, MA
- Batty M (2008) Cities as complex systems: scaling, interactions, networks, dynamics and urban morphologies. Centre for advanced spatial analysis working paper series, paper 131. University College London
- Batty M (2013a) The new science of cities. MIT Press, Cambridge, MA
- Batty M (2013b) Big data, smart cities and city planning. *Dialogues Hum Geogr* 3(3):274–279
- Batty M, Xie Y (1994) From cells to cities. *Environ Plann B Plann Des* 21(7):S31–S48
- Ben-Elia E, Alexander B, Hubers C, Ettema D (2014) Activity fragmentation, ICT and travel: an exploratory path analysis of spatiotemporal interrelationships. *Transp Res Part A Policy Pract* 68:56–74
- Benenson I, Martens K, Birfir S (2008) PARKAGENT: an agent-based model of parking in the city. *Comput Environ Urban Syst* 32(6):431–439
- Buliung R, Kanaroglou P (2006) A GIS toolkit for exploring geographies of household activity/travel behavior. *J Transp Geogr* 14(1):35–51
- Candia J, González MC, Wang P, Schoenharl T, Madey G, Barabási AL (2008) Uncovering individual and collective human dynamics from mobile phone records. *J Phys A Math Theor* 41(22):1–11
- Chapin FS, Weiss SF (1968) A probabilistic model for residential growth. *Transp Res* 2:375–390
- Chen J, Shaw SL, Yu H, Lu F, Chai Y, Jia Q (2011) Exploratory data analysis of activity diary data: a space-time GIS approach. *J Transp Geogr* 19(3):394–404
- Couclelis H (1985) Cellular worlds: a framework for modeling micro-macro dynamics. *Environ Plan A* 17(5):585–596
- Crosby RW (1983) Introduction and asking better questions. In: Crosby RW (ed) *Cities and regions as nonlinear decision systems*. Westview Press, Boulder, CO, pp 1–28
- Emmeche C (1994) *The garden in the machine: the emerging science of artificial life*. Princeton University Press, Princeton
- Forrester JW (1969) *Urban dynamics*. MIT Press, Cambridge, MA

- Forrester JW (1974) Preface. In: Mass NJ (ed) *Readings in urban dynamics*, vol 1. Wright-Allen Press, Cambridge, MA, pp vii–viii
- Foth M, Choi JH, Satchell C (2011) Urban informatics. In: *Proceedings of the ACM 2011 conference on computer supported cooperative work*, Hangzhou, pp 1–8
- Golledge R, Stimson R (1997) *Spatial behavior: a geographic perspective*. Guilford Press, New York, NY
- Hägerstrand T (1970) What about people in regional science? *Pap Reg Sci Assoc* 24(1):7–21
- Hägerstrand T (1982) Diorama, path and project. *Tijdschr Voor Econ Soc Geogr* 73(6):323–339
- Hjorthol RJ (2002) The relation between daily travel and use of the home computer. *Transp Res A* 36(5):437–452
- Hosseinali F, Alesheikh AA, Nourian F (2013) Agent-based modeling of urban land-use development, case study: simulating future scenarios of Qazvin city. *Cities* 31:105–113
- Huang F (2018) The rise and fall of China's cycling empires. *Foreign Policy*, 31 Dec. <https://foreignpolicy.com/2018/12/31/a-billion-bicyclists-can-be-wrong-china-business-bikeshare/>
- Huang Q, Parker DC, Filatova T, Sun S (2014) A review of urban residential choice models using agent-based modeling. *Environ Plann B Plann Des* 41(4):661–689
- Jacobs J (1961) *The death and life of great American cities*. Vintage Books, New York, NY
- Janelle DG (1968) Central place development in a time-space framework. *Prof Geogr* 20(1):5–10
- Janelle DG (1969) Spatial organization: a model and concept. *Ann Assoc Am Geogr* 59(2):348–364
- Janelle DG (1973) Measuring human extensibility in a shrinking world. *J Geogr* 72(5):8–15
- Janelle D (2004) Impact of information technologies. In: Hanson S, Giuliano G (eds) *The geography of urban transportation*, 3rd edn. Guilford Press, New York, NY, pp 86–112
- Kadanoff LP (1971) From simulation model to public policy: an examination of Forrester's "Urban Dynamics." *Simulation* 16(6):261–268
- Kontokosta CE (2018) Urban informatics in the science and practice of planning. *J Plan Educ Res* 1–14. <https://doi.org/10.1177/0739456X18793716>
- Kwan MP (2000a) Human extensibility and individual hybrid-accessibility in space-time: a multi-scale representation using GIS. In: Janelle D, Hodge D (eds) *Information, place, and cyberspace issues in accessibility*. Springer, Berlin, pp 241–256
- Kwan MP (2000b) Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. *Transp Res C* 8:185–203
- Li X, Yeh AG (2000) Modelling sustainable urban development by the integration of constrained cellular automata and GIS. *Int J Geogr Inf Sci* 14(2):131–152
- Li X, Yeh AG (2001) Calibration of cellular automata by using neural networks for the simulation of complex urban systems. *Environ Plan A Econ Space* 33(8):1145–1162
- Liu X, Li X, Liu L, He J, Ai B (2008) A bottom-up approach to discover transition rules of cellular automata using ant intelligence. *Int J Geogr Inf Sci* 22(11–12):1247–1269
- Liu X, Li X, Shi X, Zhang X, Chen Y (2010) Simulating land-use dynamics under planning policies by integrating artificial immune systems with cellular automata. *Int J Geogr Inf Sci* 24(5):783–802
- Liu Y, Liu X, Gao S, Gong L, Kang C, Zhi Y, Chi G, Shi L (2015) Social sensing: a new approach to understanding our socioeconomic environments. *Ann Assoc Am Geogr* 105(3):512–530
- Mass NJ (ed) (1974) *Readings in urban dynamics*, vol 1. Wright-Allen Press, Cambridge, MA
- Miller H (1991) Modelling accessibility using space-time prism concepts within geographical information systems. *Int J Geogr Inf Syst* 5(3):287–301
- Mokhtarian PL (2003) Telecommunications and travel: the case for complementarity. *J Ind Ecol* 6(2):43–57
- Mokhtarian PL, Meenakshisundaram R (1999) Beyond tele-substitution: disaggregate longitudinal structural equations modeling of communication impacts. *Transp Res C* 7(1):33–52
- Parkes D, Thrift N (1980) *Times, spaces, and places: a chronogeographic perspective*. Wiley, New York
- Salomon I (1986) Telecommunications and travel relationships: a review. *Transp Res A* 20(3):223–238

- Salomon I, Koppelman FS (1988) A framework for studying teleshopping versus store shopping. *Transp Res A* 22(4):247–255
- Santé I, García AM, Miranda D, Crecente R (2010) Cellular automata models for the simulation of real-world urban processes: a review and analysis. *Landsc Urban Plan* 96(2):108–122
- Schroeder III WW, Sweeney RE, Alfeld LE (eds) (1975) *Readings in urban dynamics*, vol 2. Wright-Allen Press, Cambridge
- Scott D, He S (2012) Modeling constrained destination choice for shopping: a GIS based time-geographic approach. *J Transp Geogr* 23:60–71
- Shaw SL (2012) Guest editorial introduction: time geography—its past, present and future. *J Transp Geogr* 23:1–4
- Shaw SL, Sui D (eds) (2018a) *Human dynamics research in smart and connected communities*. Springer International Publishing AG, Cham, Switzerland
- Shaw SL, Sui D (2018b) Introduction: human dynamics in perspective. In: Shaw SL, Sui D (eds) *Human dynamics research in smart and connected communities*. Springer International Publishing AG, Cham, Switzerland, pp 1–11
- Shaw SL, Sui D (2018c) GIScience for human dynamics research in a changing world. *Trans GIS* 22(4):891–899
- Shaw SL, Sui D (2019) Understanding the new human dynamics in smart spaces and places: towards a spatial framework. *Ann Am Assoc Geogr*. <https://doi.org/10.1080/24694452.2019.1631145>
- Shaw SL, Yu H (2009) A GIS-based time-geographic approach of studying individual activities and interactions in a hybrid physical-virtual space. *J Transp Geogr* 17(2):141–149
- Shaw SL, Tsou MH, Ye X (2016) Editorial: Human dynamics in the mobile and Big Data era. *Int J Geogr Inf Sci* 30(9):1687–1693
- Straussfogel D (1991) Modeling suburbanization as an evolutionary system dynamic. *Geogr Anal* 23:1–24
- Tobler WR (1970) A computer movie simulating urban growth in the Detroit region. *Econ Geogr* 46:234–240
- Tobler WR (1979) Cellular geography. In: Gale S, Olsson G (eds) *Philosophy in geography*. D. Reidel Publishing Company, Dordrecht, Netherlands, pp 379–386
- Townsend A (2000) Life in the real-time city: mobile telephones and urban metabolism. *J Urban Technol* 7(2):85–104
- Ulam S (1950) Random processes and transformations. In: *Proceedings of the international congress on mathematics*, Cambridge, 30 Aug–6 Sept 1950, pp 264–275
- Vazquez-Prokopec GM, Bisanzio D, Stoddard ST, Paz-Soldan V, Morrison AC, Elder JP, Ramirez-Paredes J, Halsey ES, Kochel TJ, Scott TW, Kitron U (2013) Using GPS technology to quantify human mobility, dynamic contacts and infectious disease dynamics in a resource-poor urban environment. *PLoS ONE* 8(4):e58802
- von Bertalanffy L (1968) *General system theory: foundations, development, applications*. George Braziller, New York, NY
- von Neumann J (1966) Theory of self-reproducing automata. In: Burks A (ed). *University of Illinois Press*, Urbana, IL
- White R, Engelen G (1993) Cellular automata and fractal urban form: a cellular modelling approach to the evolution of urban land use patterns. *Environ Plan A* 25(8):1175–1199
- Wolfram S (1983) Statistical mechanics of cellular automata. *Rev Mod Phys* 55(3):601–644
- Wolfram S (1984) Universality and complexity in cellular automata. *Phys D* 10(1–2):1–35
- Xie Y (1996) A generalized model for cellular urban dynamics. *Geogr Anal* 28(4):350–373
- Xie Y, Batty M, Zhao K (2007) Simulating emergent urban form using agent-based modeling: desakota in the Suzhou-Wuxian region in China. *Ann Assoc Am Geogr* 97(3):477–495
- Xu Y, Shaw SL, Zhao Z, Yin L, Lu F, Chen J, Fang Z, Li Q (2016) Another tale of two cities—understanding human activity space using actively tracked cellphone location data. *Ann Assoc Am Geogr* 106(2):489–502
- Yeh AG, Li X (2001) A constrained CA model for the simulation and planning of sustainable urban forms by using GIS. *Environ Plann B Plann Des* 28(5):733–753

- Yin L, Shaw SL (2015) Exploring space-time paths in physical and social closeness spaces: a space-time GIS approach. *Int J Geogr Inf Sci* 22(4):409–430
- Yu H (2006) Spatio-temporal GIS design for exploring interactions of human activities. *Cartogr Geogr Inf Sci* 33:3–19
- Yu H, Shaw SL (2008) Exploring potential human interactions in physical and virtual spaces: a spatiotemporal GIS approach. *Int J Geogr Inf Sci* 22(4):409–430
- Zhong C, Arisona SM, Huang X, Batty M, Schmitt G (2014) Detecting the dynamics of urban structure through spatial network analysis. *Int J Geogr Inf Sci* 28(11):2178–2199

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