GEOVISUALIZING AND MODELING PHYSICAL AND INTERNET ACTIVITIES IN SPACE-TIME: TOWARD AN INTEGRATED ANALYSIS OF ACTIVITY PATTERNS IN THE INFORMATION AGE

DISSERTATION

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ABSTRACT

The widespread use of the Internet for conducting various types of activities may be leading to considerable change in people’s activity-travel patterns. Much research that focuses on the impact of the Internet on human activity-travel behavior has been conducted with various approaches. The results show that the impact of the Internet is highly complex, often involving substitution, generation, and modification. Although past studies have greatly enhanced our understanding of how the Internet plays a role in people’s daily life, limitations and challenges in the current literature reflect the need for further studies. This study aims to explore and model people’s hybrid activity-travel patterns (i.e. the patterns of people’s activities and/or travel in both the physical and virtual worlds) using an Internet-activity diary dataset collected in Columbus (Ohio, U.S.A.).

While GIS-based geovisualization techniques have been fruitfully employed in a wide range of fields, they have not been applied to explore human hybrid activity-travel patterns. This study develops two geovisualization approaches using 3D and 2D GIS techniques to address the difficulties faced by past studies. First, the notions of information cube and hybrid 3D space-time paths are developed to accommodate cyberspatial activities in exploratory data analysis. Second, a new representation of 2D space-time paths that incorporates parallel coordinate plots is developed for exploring
the multiple attributes of people’s Internet and physical activities. These two methods were implemented using ArcObjects and the Visual Basic for Applications environment in ArcGIS. The study shows that the 3D and 2D geovisualization methods developed allow us to uncover important patterns in hybrid human activity-travel behavior.

Based upon the geovisualization results and the previous research, this study further examines the complex interactions between different types of Internet and physical activities, with a special focus on gender differences and Internet maintenance and leisure activities. The results indicate that the impacts of Internet activities on people’s activity-travel patterns are significantly different across gender. In general, Internet use for maintenance purposes has a greater impact on women’s activity-travel in the physical world, while Internet use for leisure purposes affects men’s physical activities and travel to a greater extent. Further, breaking Internet activities down into different categories reveals some hidden patterns that would not have been detected if these different types of Internet activities were lumped together as a single category.

In general, this study reveals how the Internet changes human activity-travel processes and generates new activity-travel patterns. It shows that the impact of the Internet differs across different social groups and further discloses the gender role in mediating the impact of the Internet on activity-travel behavior.
DEDICATED TO MY PARENTS
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CHAPTER 1

INTRODUCTION

1.1 Introduction

Information and communication technologies (ICTs) have been rapidly spreading in the recent years. The Internet, one ICT, not only plays a critical role in both industry and business, but also greatly affects people’s daily lives because it provides a virtual space (cyberspace) where they can undertake many types of non-work-related activities. For example, according to the US quarterly retail sales records provided by the US Census Bureau, electronic commerce (E-commerce hereafter) sales have increased nearly 10 billion dollars from the first quarter of 2000 to the first quarter of 2004. The proportion of E-Commerce sales compared to total retail sales has also risen from about 8% to about 19%. Because of its tremendous influence, ICTs related research has drawn much attention lately and various studies of different scales with various focuses have been undertaken. Increasingly, studies focus on illustrating the impact of ICTs on people’s activity-travel patterns. This study will focus on the Internet, and its impact on people’s activity-travel patterns.
One important property of time is “zero-sum,” which implies that the time people spend on one activity takes away time spent on other activities if these activities are not performed at the same time. As such, Internet users will spend less time engaging in activities in the physical world (physical activities hereafter). The Internet activities, such as electronic shopping (E-shopping hereafter), can be undertaken at almost any time of day whereas local stores have specific business hours. Therefore, it could be expected that using the Internet allows people to flexibly schedule their daily activities. Furthermore, new information obtained from the Internet can generate new activities that require time to perform them. As a result, people reallocate their fixed usable time to various physical and Internet activities; when they do, their time-use patterns change as well.

Changes in time-use have geographic consequences in the physical world (Kwan, 2002). Unlike in physical space, people in cyberspace may not need any real physical travel to complete out-of-home activities if they have access to the Internet. In such cases, the necessary trips of the past are substituted for Internet use today. Likewise, the Internet also generates new trips as it may lead to new out-of-home activities. For example, shopping trips may result from sale information obtained from the Internet. Therefore, not only does the Internet affect the temporal pattern of human activity-travel behavior, but it also alters the spatial characteristics and spatial extents of people’s daily movement.
Additionally, people engage in different types of Internet activities for various purposes, indicating that the influence of these different Internet activities on human activity patterns might be different from each other. Thus, due to the complexity of human behavior and the power of the Internet, the impact of the Internet on activity-travel patterns could be multifaceted. In general, since people in the information age can conduct daily activities in both the physical world and over the Internet, the traditional activity-travel processes that only take place in the physical world has transformed into hybrid activity-travel processes in which the Internet plays a role in determining activity scheduling and travel decision. As a result, the hybrid activity-travel patterns are being formed.

To date, much research pertaining to ICTs and behavioral analysis has been conducted with various approaches. This research area has three prevailing foci. The first focus emphasizes extending existing theoretical frameworks or developing new ones to examine how the Internet alters people’s activity-travel processes and how people take advantage of advanced space-adjusting technologies to overcome distance barriers (Adams, 1995; Hanson, 2000; Kwan, 2001, Dijst, 2003; Couclelis, 2004). For example, drawing on time geography theory, relaxation of space-time constraints is one of the current frameworks used to study how the Internet modifies people’s activity-travel patterns by relaxing their spatio-temporal constraints, thereby providing them with more freedom in scheduling and arranging daily activities and travel.
Secondly, with the increasing availability of digital geographic databases of urban areas and georeferenced individual-level data, as well as improvement in the representational and geocomputational capabilities of Geographical Information Systems (GIS), geovisualization and geocomputational methods have widely been applied to explore and model complex activity-travel behaviors and to operationalize various accessibility measures that are closely related to activity-travel patterns (Miller, 1991, 1999; Kwan, 1998, 1999a; Weber and Kwan, 2002, 2003; Buliung and Kanaroglou, 2006). The-state-of-art GIS technology has proved to be a valuable tool for exploring and analyzing activity-travel processes.

Thirdly, activity-based modeling has replaced traditional trip-based modeling and it has become a more feasible framework for examining and simulating individual behaviors because it can better address the complexity of activity-travel behaviors (Recker et al., 1986; Kitamura, 1988; Kitamura et al. 1996; Golob and McNally, 1997a; Miller, 1997; Golob, 1998, 2000; Lu and Pas, 1998; Bhat and Koppelman, 1999; Kwan, 1999b; Goulias, 2002; Pendyala and Goulias, 2002; Arentze and Timmermans, 2000, 2003). Drawing on the activity-based framework, interrelations between ICTs use and activity-travel patterns have been partially revealed. The inconclusive empirical results indicate that the interrelation between the use of ICTs and activity-travel patterns are comprehensive, often involving substitution (replacement of traditional activities with corresponding activities conducted with ICTs), generation (newly generated activity-travel by the use of the ICTs), and modification (changes in activity-travel patterns such as timing) (Mokhtarian and

Although past studies have greatly enhanced our understanding of how ICTs plays a role in people’s daily life, research about the impact of ICTs on activity-travel patterns is incomplete. Limitations and challenges in the current literature reflect the need for further studies. For example, unlike spatial interaction in the physical world, cyberspatial activities (Internet activities) or “traveling” in cyberspace depends much less on the physical distance between an individual and a particular location. Therefore, traditional geographic frameworks, concepts, notions, and measures that explain interactions in the physical world are not appropriate. How to effectively represent and measure non-distance-dependent interactions remains unknown. Furthermore, it is quite challenging to effectively manage, represent, and analyze multi-dimensional travel diary and Internet use data, which are spatial, temporal, and descriptive. In order to gain insight into the impact of ICTs, effective data management and analytical tools are required for compiling knowledge from the rich data depository.

An important aspect of research on ICT’s that has not received enough attention in the current literature is how gender relations function in ICTs. The literature on gender and technology argues that the social relations of technology have historically subordinated or constrained women (Cockburn, 1983; 1985; Cowan, 1989; Wajcman, 1991). For instance, domestic technologies such as the home washing machine,
dishwasher or vacuum cleaner actually reinforced existing gender relations and the
gender division of domestic labor (Light, 1995). Therefore, it is necessary to
investigate whether ICTs function in a similar fashion. In fact, the gender relations of
ICTs can be revealed by analyzing how ICTs change people’s daily engagement in
different types of activities. Will ICTs, especially the Internet, allow men to undertake
more housework or will the Internet just change the traditional way woman perform
household related activities? This issue, which is important for a thorough
understanding of the impact of the Internet on people’s activity-travel patterns, has not
yet been fully studied.

1.2 Research Objectives
The objective of this research is to explore and analyze impact of the Internet on
human activity-travel patterns. Underlying this overall objective are two related issues:
the processes under which the Internet alters human activity-travel processes and the
outcomes as reflected by the changes in activity-travel patterns. Because gender
relation of technologies is an important dimension for understanding the impact of the
technologies on human and society as indicated by past studies, this study also takes
gender difference into account, which further enhance the complexity of the research.

Based on the previous findings of the literature, it can be expected that the Internet
intersects with the physical world through different channels since people can conduct
various activities over the Internet. The variety of activities in which individuals
participate over the Internet subsequently results in complex hybrid activity-travel
patterns. More importantly, the complexity of the mechanism with which the Internet influences activity-travel processes is also determined by the variety of circumstances in which the Internet is utilized. Put differently, the same Internet activities could change activity-travel processes in dissimilar ways when they are undertaken in different scenarios. For example, email could replace traditional communication means like mailing or calling, but it also could allow people to maintain contacts that they would not have been able to keep in the past. Therefore, it is reasonable to postulate that how the Internet modifies activity-travel processes is also dependent on the circumstances in which it is used.

Due to the nature of traditional gender roles, cyberspatial activity (activity conducted in cyberspace) patterns are expected to vary across gender after controlling other factors like employment status, age, and the skill of using the Internet. Therefore, changes in activity-travel patterns in the physical world will differ as well. However, it is not clear to what extent gender differences exists or what the impact of those differences in activity-travel patterns might be. Using activity-Internet diary data collected in the Columbus metropolitan area (OH), this study aims to enhance the current understanding of the gender relations on the Internet by analyzing how the Internet impacts individual activity-travel processes and outcomes. The results will be applicable when formulating social and transportation policies.
1.3 Organization of this Dissertation

A comprehensive literature review on activity-travel research and the impact of ICTs will be provided in Chapter Two and this study’s research questions will be introduced at the end of Chapter Two in response to discussions of the limitations of existing studies. Following the literature review, data and methodology will be introduced in Chapter Three. Chapter Four will focus on explaining the geovisualization approach developed in the study and discussing how the Internet affects human activity-travel processes in different circumstances. Chapter Four also discusses the cyberspatial activity patterns across different social groups. In this study, the samples are classified based on both gender and employment status. Besides the impact of the Internet on physical space, this study also looks into the potential effect of the geographic context on cyberspatial behaviors by examining the correlation between E-shopping patterns and geographic indicators of residential areas. Several regression models will be discussed in Chapter Five to reveal how the geographic indicators, including shop accessibility and residential characteristics, affect the E-shopping pattern. Based on the geovisualization results, several hypotheses regarding hybrid activity-travel patterns were made and two activity-based models were developed in Chapter Six. In doing so, Chapter Six aims to reveal how the impact of the Internet is mediated by gender and how the different types of Internet affect people’s activity-travel in the physical world. The structural equation modeling technique is used to investigate the complex relationships between different types of Internet uses (e.g. for maintenance purpose) and activity-travel patterns in the physical world. Further, multiple-group analysis is also applied in order to examine whether women and men are equally
affected by the Internet. Finally, Chapter Seven will summarize the results of this research and describe the direction future research will take.
CHAPTER 2

CYBERSPACE AND CYBERSPATIAL ACTIVITY

2.1 Introduction

This chapter will review major studies on ICTs and activity-travel research. In doing so, it attempts to identify the gaps that exist in the literature and identify the research questions for this study. The first part of the chapter will examine the unique characteristics of cyberspace and how the experience of conducting Internet activities differs from performing activities in the physical world. The newly developed lexicon, such as cyberspace and information superhighway, provides a good anchor for studying the characteristics of the Internet. By comparing cyberspace with physical space, we will be able to recognize how people behave on the Internet and how cyberspatial behavior differs from the behavior in the physical world.

Acknowledging the properties of the Internet, different theoretic frameworks of how the Internet influences human activity-travel processes will be introduced in detail. These include time geography, human extensibility, space-time displacement, and fragmentation of activity. These frameworks examine the impact of the Internet on
activity-travel behavior from different perspectives. Therefore, each of them has its own advantages and limitations. Although they cannot fully capture human hybrid activity-travel processes (activity-travel in both physical space and cyberspace), these various theoretic perspectives provide important conceptual frameworks for further analytical analysis of how the Internet interacts with physical space to change activity-travel patterns.

In addition to the theoretic research, there are many studies focusing on the development of analytical approaches seeking to uncover the impact of ICTs on human activity-travel behavior. Generally, there are two types of analytical approaches. The first one is exploratory analysis, which assists us in identifying hidden patterns embedded in the data. Geovisualization has been proved to be a powerful exploratory tool and it has been applied to studying activity-travel patterns in the past. In spite of some limitations in previous research, geo-visualizing activity-travel studies shed important light on people’s daily activity-travel behavior. The second commonly used method is activity-based modeling. This group of studies reveals significant insights on activity-travel processes by simulating household member decisions in space-time and discloses the complex interrelationships between ICTs, activity, and travel. However, due to the lack of the individual episode data on Internet activities, the impact of the Internet on activity-travel remains unexamined.

This chapter is organized as follows: the characteristics of cyberspace will be introduced in the next Section, followed by a review of the theoretic frameworks in
Section 2.3. Section 2.4 will focus on the geovisualization of hybrid activity-travel behavior, and the activity-based modeling approach will be detailed in Section 2.5. The limitations of previous studies will be discussed in each section. Based upon the gaps found in the literature, research questions will be raised in Section 2.6.

2.2 Cyberspace and Physical Space

In order gain insight into human’s cyberspatial activities and its impact on the physical world, it is necessary to firstly investigate cyberspace in which these cyberspatial activities take place, as people’s activity-travel behavior is highly contextual. For example, the traditional functions of banking that require physical travel to local banks now can be completed in a few minutes in cyberspace. Therefore, a thorough understanding of cyberspace will facilitate the examination of why people substitute traditional activities with cyberspatial activities, how they perform cyberspatial activities, and the impact of cyberspatial activities on their activity-travel patterns in the physical world. In this chapter, cyberspace specifically refers to the virtual space provided by the Internet.

The emerging new lexicon, such as cyberspace, information superhighway, and digital city, might provide the most straightforward description of characteristics of cyberspace as they directly connect and compare cyberspace with the physical world that people are mostly familiar with. Researchers have also gained much in-depth understanding of cyberspace by examining these place-based metaphors from different perspectives (e.g. Adams, 1997; Graham, 1998).
2.2.1 *Death of Distance?*

Unlike traditional physical space and transportation networks where materials composed of atoms are transported at limited speeds, the information superhighways in cyberspace form networks for coded information in bits that can be electronically transported much faster in optical fibers (Negroponte, 1995; Batty and Miller, 2000). For example, an Internet user in Columbus (U.S.) can read a Beijing (China) local newspaper Beijing Youth on the Internet by connecting to the webpage http://bjyouth.ynet.com (a few seconds), which would take several days (even longer) if the newspaper was physically delivered from Beijing to Columbus. Therefore, in the physical world, it is necessary to overcome the physical separations among locations as interactions occur from one location to another. Compared to physical space, however, interactions in cyberspace do not require conquering distance impedance, which implies that people will have dramatically different experience in cyberspace than in the physical world. Furthermore, space and time appear to converge in cyberspace from the viewpoint of time-distance, because the time needed to connect two locations approaches to zero.

Based upon the observation of space-time convergence, some technological determinists suggested the advent of the death of distance or end of geography in the information age (e.g. Mitchell, 1995; Cairncross, 2001). Although the ‘death of distance’ has long been questioned and it appears that physical space will still remain important in the future (Graham, 1997; 1998; Hanson, 1998; Gillespie and
Richardson, 2000), it is obvious that conventional geographic notions and geographic measures that are based on the principle of distance friction are not applicable to cyberspace. For example, although there is still no uniform definition on accessibility due to its complexity (Couclelis and Getis, 2000), measures of accessibility in the physical world, including both cumulative and space-time measures, are always distance relevant. In cyberspace, however, accessibility is more dependent on other factors than on distance. Dodge (2000) examined four key elements determining information accessibility within the global Internet and virtual space, which include network performance, size of the information space, information findability and persistence, and information structure, design and user behavior. Therefore, the characteristics of cyberspace call for the rethink on previous geographic frameworks and models.

2.2.2 Experiencing Cyberspace

Since the interactions in cyberspace have little to do with distance, people’s experience in cyberspace will also differ from that in the physical world. Firstly, the perception of cyber-environment is not directly relevant to the structure of cyberspace as the structure of hyperlinks seems to be invisible to the Internet users. Kwan (2001) summarized two major cognitive characteristics of searching for information in cyberspace. One is the lack of a sense of location. Unlike looking for a specific location in the physical world, distance and orientation are not necessary for searching for a virtual site in cyberspace. It is impossible and useless for them to know the location of each hyperlink host. The other characteristic is that cyberspace is its own
map, but people cannot locate targets on this map easily due to its complexity and large scale. These two distinctive properties mean that people hardly establish a mental map of cyberspace. Without such a mental map, people cannot make a journey in cyberspace in the same way as they move in the physical world, because people usually have knowledge about their local environment before they can get to their destinations physically.

In addition to the problem of disorientation in a hypermedia environment, the problem of information overload (Davenport, 1997; Sui 2000) also challenges ordinary people. In order to keep track of information needed and to find the appropriate information, a certain level of skills of using the Internet is required; otherwise people easily get lost in the vast number of hyperlinks to numerous information resources. Meanwhile, similar to the situation of traffic jam and rush hour that frequently happens in physical transportation networks, information superhighways have the same problem - latency. However, what is different between these two types of delay is that people have much less tolerance to the latency in cyberspace (Kwan, 2001), showing that Internet activities are much more subject to the performance of Internet networks. Even a minor difference in transferring speed, such as waiting for a web page to load for a few more minutes, will cause a person to give up an Internet activity. Past research has demonstrated that an individual with high education level, a long experience using the Internet, and a fast connection to the Internet, is more likely undertake Internet activities. However, the digital divide is being narrowed recently with the dropping price of ICT devices and services.
While people confront with new challenges in cyberspace, they also gain much benefit that they could not have before. Firstly, cyberspace greatly expands opportunities and information to which people can have access in their everyday lives. For instance, Internet users can read worldwide news online for free and borrow a book that is not available in the local library from an E-library. Therefore, not only can people perform various activities in cyberspace, but they could also complete these activities in more efficient and effective ways. Secondly, access to cyber-opportunities (resources available online) does not require any physical travel and these cyber-opportunities are usually available while physical opportunities are limited to business hours. Hence, space-time constraints that limit people’s actions in the physical world could be released to some extent and people will gain more freedom in selection of personal activities (Janelle, 1995; Black, 2001).

In summary, Internet users today engage in their daily activities in a hybrid environment that consists of physical space and cyberspace, implying that previous activity-travel frameworks and models that are based on distance friction function are not adequate for studying people’s hybrid activity-travel processes. In past decades, much attention has been paid to revealing the impact of ICTs on human activity-travel patterns. Drawing upon past activity-travel research, new analytical frameworks and more advanced technologies have been developed to integrate the impact of ICTs into activity-travel research. The next two sections will review the past studies on activity-
travel patterns and ICT use from two perspectives: analytical frameworks and analytical tools.

2.3 Theoretical Perspectives of Impact of ICTs on People’s Activity-Travel Patterns

The research on human activity-travel patterns has a long tradition in Geography. Among different perspectives that conceptualize human activity-travel processes, four theoretical frameworks have been extended to accommodate the impact of ICTs to study the hybrid activity-travel processes. They include time geography, human extensibility, space-time displacement, and fragmentation of activity. Each of the frameworks examines the impact of ICTs from a perspective and they are not exclusive to each other.

2.3.1 Relaxation of Space-Time Constraints

Time geography theory (Hägerstrand, 1970) has a significant influence on human activity-travel research because it integrates the temporal and spatial dimensions of human activity patterns into a single analytical framework. It conceives and represents an individual’s activities and travel in a 24-hour day as a continuous temporal sequence in geographical space. The trajectory that traces the activity sequence is represented by a space-time path in a 3D space-time “aquarium” that is composed by a geographic plane and time dimension as Z-axis. Using the space-time paths, Hägerstrand illustrated how a person navigates his or her way in a spatial-temporal environment and demonstrated that human spatial activities are often governed by
three types of constraints: capability, coupling, and authority. Capability constraints refer to the limitations on human movements due to physical or biological factors, for example, a person cannot be in two places at one time. A coupling constraint refers to the need to be in one particular place for a given length of time and the need to be in interaction with other people. This could mean anything from going to work to visiting a doctor. Lastly, an authority constraint refers to an area that is not accessible to particular individuals or groups.

According to the perspective of time-geography, a person’s activity participation and travel decisions are made based on different levels of constraints he/she experiences in his/her daily life. These constraints largely arise from the spatial or temporal rigidity associated with certain types of activities people undertake in their daily lives. These activities are called fixed activities because it is difficult to change the place or time to perform these fixed activities, and as a result they also tend to restrict a person’s freedom to undertake other spatially and temporally flexible activities. For example, the location and timing of chauffeuring a child daily may impose limits on a mother’s work hours (when) and job location (where). Therefore, this theoretic perspective takes interaction between the spatial and temporal dimensions into account to explain why individuals’ daily space-time trajectories are structured differently.

Based on the time-geographic framework, one approach to perceiving the impact of ICTs on human activity patterns is to view ICTs as relaxing individuals’ space-time constraints (Janelle, 1995; Black, 2001). Since having access to cyber-opportunities
does not require any physical travel and is less subject to keeping to business hours, space-time constraints that confine people’s freedom in choosing when and where to perform activities could be released to some extent. For example, an Internet user can conduct shopping activities online in the late evening when local stores are closed. Hence, more flexible spatial and temporal arrangements of personal activity-travel become possible through telecommunications (Kwan, 2002; Schwanen and Kwan, 2008).

However, the notion of the relaxation of space-time constraints does not infer that people can perform cyberspatial activities anytime and anywhere. It has been argued that three basic constraints still work for virtual activities, and people’s potential action space will continuously depend on their space-time constraints (Kwan, 2001; Dijst, 2003). For example, the space-time availability of access to devices or connecting services may affect the extent to which individuals can use ICTs, and restricted websites also limit the range of cyber-opportunities that a person could have access to in cyberspace. Therefore, ICTs can only partially release the space-time constraints that people experience in their everyday life. However, it is not clear yet to what extent ICTs could free space-time constraints and what consequences would occur as people have more freedom in scheduling and arranging their daily activities. Due to the lack of required data that contains the information about space-time constraints, very few studies have attempted to answer these questions explicitly.
2.3.2 **Human Extensibility**

An important extension of time geography theory is the notion of human extensibility that was firstly put forwarded by Janelle (1973). It refers to the ability of a person to take advantage of space-adjusting technologies, such as transportation, to overcome the barrier of distance. In the information age, the scope of space-adjusting technologies has been greatly broadened by advanced telecommunication technologies. Among these telecommuting technologies, the Internet might be the most powerful tool that can significantly enhance human extensibility by allowing interactions beyond a person’s physical presence.

The first attempt to extend human extensibility to study the impact of telecommunication technologies on people’s everyday life was made by Adams (1995). Drawing upon the approach of the space-time paths, a new space-time extensibility diagram was developed with a hypothesized example. A person’s daily activities and interactions with others were depicted by multiple and branching space-time paths in 3D space-time “aquarium”, which demonstrated how a person could extend into space-time with the aid of telecommunication technologies, and suggested that the person should be regarded as a spatially and temporally unbounded dynamic entity. Further, Adams (2000) constructed a CAD-based extensibility diagram to portray five people’s daily communications that were made at multiple spatial scales. Using the diagram, he pointed out that people should not be regarded as just “line-objects” as described in time geography theory, instead they should be perceived as “social agents or sensate beings with branches”. For instance, Internet users can
browse a website in cyberspace while they are performing physical activities, indicating that the capability constraint of “cannot be at two places at one time” is now relaxed. Therefore, the sequential and unbranching space-time paths in the space-time “aquarium” are not appropriate for representing actual human movements and accessibility in the information age.

Kwan (2000c) implemented the extensibility diagram as an analytical tool using three-dimensional geographical information systems (GIS). Compared with the extensibility diagram created by Adams (1995), her method accommodates multiple spatial scales at which cyberspatial activities are conducted in one framework. Using the navigational history of a person’s Web browser and data collected through personal interview, she developed a multi-scaled representation of space-time paths in a 3D GIS environment to reveal the temporal complexities (e.g., simultaneity and disjuncture) involved in individual activities in both the physical and virtual worlds.

### 2.3.3 Space-Time Displacement

One property of time is “zero-sum”; put differently, time spent on one activity takes time away from other activities, because the usable time in everyday is rather fixed. Hence, people might spend less time engaging in physical activities if they distribute more time to Internet activities. According to the “zero-sum” property of time, time-use research explores activity patterns through examining time allocation to different activities. Some time-use studies found that the Internet use, particularly home use of the Internet, would greatly decrease the time spent on social activities with family,
friends, and colleagues, and isolate frequent Internet home users from outside communities (Nie and Erbring, 2000; Nie et al., 2002). Opposed to the “displacement” observation, other studies suggested that the Internet seemed more like a “time-enhancer” and the Internet users did not give up other activities in order to accommodate it (Robinson et al., 1999, 2000, 2002). These conflicting empirical results indicate that variance in data collecting instruments and geographical contexts where these studies were conducted could have led to the disparity in results.

In addition to the temporal dimension, the spatial dimension is often ignored in time-use studies, which is actually very important for understanding the impact of ICTs on human space-travel patterns in space-time (Kwan, 2002). Changes in time-use caused by ICTs usually cause distinctive geographic consequences as reflected by the changes in the spatial characteristics of people’s daily activity-travel pattern. For instance, some physical trips to local shopping stores might be substituted by electronic shopping, and the time saved by the fast electronic transactions might be used for new trips for other purposes (Gould and Golob, 1997). Therefore, the usage of ICTs will not only cause time displacement, but also alter the geographic patterns of human activity. When there is considerable space-time displacement between people’s activities and new ICTs, significant changes in activity-travel patterns should be identified.

Drawing upon the time-space displacement framework, many researchers have built various activity-based models to examine the changes in individuals’ activity-travel
patterns as well as the relationship between cyberspatial activities and activities performed in the physical world (physical activities) in terms of time allocation and travel demand (see section 2.5). The main purpose of this group of studies is to identify the overall temporal and geographical outcome of the process of space-time displacement. However, since human activity behavior is highly complicated and there is a shortage of appropriate data, the impact of ICTs on activity-travel patterns was only partially revealed through these empirical studies. Therefore, a more close-to-reality activity model is needed in future research, which in turn requires a more complete conceptual framework for understanding hybrid activity-travel processes.

2.3.4 Fragmentation of Activity

Couclelis (2004a) recently proposed another new conceptual framework for examining human hybrid activity-travel processes. The hypothesis of this framework is “fragmentation of activity”, meaning that traditional connections between activities, physical locations, and time are loosened through interactions with ICTs. In the past, you could tell what a person was doing if you knew where he/she was and when the activity was being undertaken. Today, however, it is hard to predict what the person is doing with the information of location and timing because advanced ICTs allows people to conduct activities that are not associated with any particular place in the old fashion. For example, work activities can be undertaken at home through telecommuting and paying bills can be completed in the office through the Internet. Thus, the corresponding link between activity and place is weakened. Moreover, the Internet also makes it possible to request a book in the late evening through an online
service of a local library, suggesting that the association between timing and activity is also loosened.

Further, the way that activities are performed is changed in the age of ICTs, resulting in a redistribution of activity over space and time. For instance, shopping activity often includes different sub-tasks, such as searching for product information and completing transactions, and it is normally completed as single activity in the past. E-shoppers, however, could undertake these sub-tasks in different places and at separate periods of time: searching for product information online but buying the product locally or trying on clothes in a local store while buying it online. This theoretic perspective provides another explanation on the mechanism of how ICTs affect people’s activity-travel patterns. Obviously, ICTs become part of individual activity-travel processes by spatially and temporally fragmenting an activity and redistributing the sub-activities over space and time.

Although the hypothesis of “fragmentation of activity” appears very useful in illustrating the impact of ICTs on activity-travel processes, the empirical operationalization of this hypothesis has not been fully completed yet. To the author’s best knowledge, only Lenz and Nobis (2004) applied the cluster analysis method to study the fragmentation of behaviors, and they found that the behavior pattern of a small group of the population, called “Mobile Computer Fragmenters”, corroborated with this hypothesis. Unfortunately, this empirical study did not essentially
operationalize the hypothesis because individual spatial movements could not be detected with aggregate data.

Based on the fragmentation of activity hypothesis, Couclelis (2004b) argued that it is necessary to expand previous time-geographic view. The traditional space-time prism (Lenntorp, 1976), which is used to depict people’s space-time paths in the physical world, over-simplifies people’s activity-travel patterns by ignoring other dimensions associated with human spatial activity and by setting a rigid geometric formulation. Obviously, people engage in activities for particular purposes and the distance in cyberspace should not be measured by Euclidean distance. To overcome the limitations of the space-time prism, the new conceptual framework was designed based on the notion of the object of discourse and the analytic principle of semantic resolution. In addition to the space-time elements, information of a higher level (formal level, constitutive level, telic level and agentive level) is also included. In doing so, much semantic richness involved in activity-travel processes is maintained, which sheds light on the future activity-travel research in the aspect of revealing activity-travel patterns through multiple activity-travel attributes.

2.3.5 Summary of Theoretic Perspectives

In summary, these four analytical frameworks examine the impact of ICTs on activity-travel patterns from different perspectives. These frameworks are not exclusive to each other and are inherently linked. It is quite evident that the process of fragmenting and redistributing activities in space-time not only causes time-use changes, but also
leads to changes in geographic patterns of activity-travel. Therefore, the perspective of
space-time displacement links fragmentation of activity with the impact of ICTs on
activity-travel patterns. In the meantime, the activities/sub-activities assigned to
cyberspace might be less spatially and temporally restricted and therefore multiple
cyberspatial activities could be conducted simultaneously as the constraint of “cannot
be present at two locations” is relaxed. Further, the relaxation of space-time
constraints will allow people to choose their activities in space-time with more
freedom, which will result in the space-time displacement of activity-travel processes.

Therefore, examining the impact of ICTs from a single perspective is inappropriate in
that it will miss other important dimensions pertaining to the process of how ICTs
affect activity-travel patterns. Given the limitation of current conceptual frameworks,
a more comprehensive analytical framework for the relationship between the use of
ICTs and activity-travel patterns is required. In light of the complementarity of current
theoretic perspectives, the solution to the conceptual framework could be an
integration of these perspectives with a logical link. In doing so, the impact of the
ICTs on activity-travel processes could be revealed from various perspectives.

2.4 Geo-visualizing Human Hybrid Activity-Travel Behavior

Activity-travel research at the individual level is usually conducted with travel diary
datasets that contain a large volume of information, including spatial, temporal, and
multi-dimensional attribute data (e.g. Mokhtarian and Meenakshisundaram, 1999;
Senbil and Kitamura, 2003; Scrinivasan and Athuru, 2004; Kim and Goulias, 2004;
Choo and Mokhtarian, 2004). In order to gain more insight into people’s activity-travel patterns from such rich data repositories, a powerful data exploratory tool is needed. Due to the remarkable improvement in hardware and software for computer graphics and the increasing availability of geo-referenced data, geovisualization, which is evolved from traditional cartographic visualization, has been recognized as an effective exploratory approach to identifying hidden patterns and constructing new knowledge.

Maps can be considered as one kind of visualization in the sense that maps make the real world being visible. Therefore, maps were often the products of traditional cartographic visualization and they have traditionally been made using pen and paper. With the advent and spread of computers, however, not only has the way that maps are made been dramatically changed, new features have also been added to visualization environments to provide more perspectives on data. For example, representation of data today can be dynamic and three-dimensional, while paper maps only can represent spatial data for a specific moment. More importantly, in addition to seeing the data represented in a different way, map users, and scientific researchers in particular, are allowed to interactively explore the data and construct knowledge to support decision-making. Put differently, advanced technologies not only have changed tools that create map representations, but also have fundamentally altered the nature of how map users interact with those representations (MacEachren, 1994). Due to the radical change in the map-based visualization environment, cartography is evolving into a new paradigm of geovisualization.
Geovisualization was recently defined as a field that provides theories and techniques for visual exploration, analysis, synthesis, and presentation of geospatial data through an integration of traditional cartographic practice with exploratory data analysis (EDA), scientific and information visualization, geographic information science and image analysis (MacEachren and Kraak 2001). By utilizing the power of human vision, many studies to date have demonstrated the effectiveness of geovisualization in spatial data exploration, hypothesis generation, and knowledge construction (e.g., Gahegan and Brodaric, 2002; Koua and Kraak, 2004a,b; MacEachren, et al. 2004). As a result, geovisualization approach has been widely applied to study diverse location-dependent phenomena and fruitful research results have been obtained (e.g., MacEachren and Kraak, 1997; Mountain, 2005). Within the current paradigm of geovisualization laid out by MacEachren and Kraak (2001), this section reviews the major visualization issues and examples pertinent to the geovisualization of human activity-travel behavior.

### 2.4.1 Geo-visualizing Human Activity-Travel in Space-Time

One of the major tasks in geo-visualizing an individual’s daily activities is to represent his/her geographic locations and spatial movement throughout the day. Therefore, time is a critical element for understanding individual activity-travel patterns. To take into account the temporal dimension and to visualize dynamic geographic phenomena, animation approaches and interactive methods (temporal brushing and temporal focusing) are often applied (Monmonier, 1990; DiBiase et al., 1992; MacDougall,
The strategy used in these temporal mapping techniques is to visualize frames of animation sequentially. This, however, is a drawback for studying human activity-travel behavior since an individual frame is only a snapshot in time and connections between activities and travel are not explicit when using these methods. It is difficult to construct or interpret the entire activity-travel patterns of individuals. Similarly, using separate but linked views of the spatial and temporal dimensions (such as the space view and time view developed by Mountain (2005)) allows for an in-depth analysis of a particular dimension. But it does not allow for the entire pattern to be visualized.

In this regard, the time-geographic perspective provides an excellent framework in that it illustrates how a person navigates his/her environment in space-time (Hägerstrand, 1970). The earliest 3D method for the visualization of individual space-time paths is the space-time aquarium conceived by Hägerstrand (1970). In a schematic representation of the aquarium, the vertical axis is the time of day, and the boundary of the horizontal plane represents the spatial scope of the study area. Individual space-time paths are portrayed as trajectories in this three-dimensional aquarium.

The use of GIS-based 3D geovisualization in time-geographic research is a rather recent phenomenon. In most early studies, 2D maps and graphical methods were used to portray human space-time activities (e.g., Chapin, 1974; Tivers, 1985). Individual daily space-time paths were represented as lines connecting various destinations.
Using such kinds of 2D graphical methods, information about the timing, duration and sequence of activities and trips was lost. There has been, however, noticeable change in recent years. As more georeferenced activity-travel diary data become available, and as more GIS software has incorporated 3D capabilities, GIS-based 3D geovisualization has become a more feasible approach for time-geographic research (e.g. Kwan, 2000a,b; Kwan and Lee, 2004; Yu, 2004). For example, Kwan (2000b) and Kwan and Lee (2004) implemented the 3D geovisualization of space-time paths and aquariums using vector GIS methods and activity-travel diary data. These studies indicate that GIS-based geovisualization that draws upon time-geographic framework can be a fruitful method for activity-travel research as the spatial and temporal characteristics of human activity-travel are explicitly represented. However, it is difficult to represent other important attributes of people’s activity-travel behavior.

In addition, depicting a large number of individual space-time paths usually gives rise to a cluttered representation as the space-time paths may appear to be tangled up with one another. To overcome this problem, Forer and Huisman (2000) conceived the space-time “aquarium” with a 3D cellular framework. Deriving aggregate patterns of individual behavior in space-time and performing spatiotemporal queries about these patterns are greatly facilitated using Boolean operations on 3D cells.

2.4.2 Visualizing Multi-dimensional Activity-Travel Attributes

In addition to spatial and temporal information on activity-travel, travel diary data also contain multi-dimensional activity-travel attributes for a large number of individuals.
In order to maintain the semantic richness of the travel diary data and examine the relationships among high-dimensional activity-travel attributes, it is necessary to use existing or develop new multivariate visualization techniques in geo-visualizing human activity-travel patterns.

Multivariate representation and visualization has long been generated great interest in cartography. Considerable effort has been devoted to developing various approaches for representing multivariate data on a map. Slocum et al. (2004) provide a comprehensive introduction to bivariate and multivariate mapping techniques, such as using bivariate or trivariate choropleth maps, multivariate dot maps, and multivariate point symbol maps. In order to enhance the visual impression of correlation among attributes that are represented, conceptual issues related to symbolization and data classification should be taken into account. Bertin’s (1983) visual semantics for linking visual variables to data attributes has a profound influence in the field of cartography. Among the six retinal variables defined by Bertin (1983), color is perhaps the most universally used and powerful visual element for representing both qualitative and quantitative information. Understandably it has received much attention since the 1950s (e.g., Robinson, 1952; Olson, 1987; Levkowitz, 1991; Brewer, 1994; Healey, 1996; Rheingans, 1997). In particular, Brewer’s work (1994) links the categorization of data conceptualization with corresponding color schemes, which not only have important implications for bivariate and multivariate choropleth mapping but also extend previous work on color guidelines in a broad sense.
In addition to the bivariate and multivariate mapping methods in traditional cartography, a variety of multivariate visualization techniques have also been developed in the statistics and information visualization literature, including the scatter plot matrix (Andrews, 1972), parallel coordinates plot (Inselberg, 1985, 1989), multidimensional scaling (Kruskal and Wish, 1977; Young and Hamerm, 1987), grand tour (Asimov, 1985), star glyphs (Fienberg, 1979), and Chernoff faces (Chernoff, 1973). A more detailed review of multivariate visualization techniques and strategies can be found in Keim et al. (2005).

Among these multivariate visualization techniques, the parallel coordinates plot (PCP) has been recognized as a powerful technique for exploring spatial, temporal, and attribute-based relationships in the context of geographic visualization (Edsall, 2003). The PCP transforms a multi-dimensional information space into a 2D plane, with parallel axes representing different dimensions. When it is used as part of a geovisualization system, it is often interactively linked to maps and other statistical graphics by techniques like focusing, brushing, and strumming (Fairbairn et al., 2001). For instance, Edsall (2003) demonstrates the effectiveness of interactive features of a spatiotemporal PCP using two case studies in which an interactive PCP was applied to examine the output of a climate model and to explore multivariate health data. The results show that the interactive PCP greatly facilitated the detection of complex patterns and trends in spatiotemporal datasets.
To date, the interactive PCP has been implemented in several software packages, including cdv (Dykes, 1997, 1998), Descartes (Andrienko and Andrienko, 1999), GeoVISTA Studio (Gahegan et al., 2000), and GeoDa (Anselin et al., 2005).

Due to its usefulness, PCP was also utilized for visualizing high-dimensional activity-travel attributes (Couclelis, 2004b). An activity in a parallel coordinates plot is shown as a polyline connecting the corresponding vertices on the attribute axes. Although the multiple attributes of activity-travel behavior are maintained through the PCP technique, the geographic axes (X and Y) are rendered as two parallel axes, and the duration of each activity and people’s sequential movement cannot be directly visualized. Similarly, another visualization approach proposed by Adams (2000) has the same limitation of omitting geographic locations where activities took place. Using computer-aided design (CAD) software, Adams constructed a human extensibility diagram that incorporated semantic meanings of human communication including telecommunications. While detailed longitudinal and latitudinal information is not crucial for virtual activities, people’s activity-travel patterns cannot be meaningfully analyzed or understood without knowing the geographical context of their daily activities.

2.4.3 Summary of Geo-visualizing Activity-Travel Patterns

In general, geovisualization has been demonstrated to be a powerful tool for exploring activity-travel patterns and has been greatly improved upon using different methods in past studies. However, there are three main difficulties that hinder the use of
geovisualization for analyzing hybrid behavioral patterns. Firstly, people undertake their daily activities in both physical space and cyberspace, which calls for an integration of these two spaces in the analysis. Unlike spatial interaction in the physical world, however, performing cyberspatial activities or “traveling” in cyberspace depends much less on the physical distance between an individual and a particular location. Therefore, traditional frameworks that only deal with interactions in the physical world are not appropriate. Secondly, visualizing multi-dimensional travel diary and Internet use data, which are both spatial and temporal, is still difficult. Lastly, while various methods have been developed in past studies for identifying the behavioral patterns of different social groups, no statistical or visualization methods exist to date for identifying people’s Internet or hybrid activity patterns. In order to successfully explore human hybrid activity-travel patterns, it is necessary to tackle these challenging tasks in the future research.

2.5 Activity-Based Modeling

In addition to various exploratory studies on individual activity-travel processes as mentioned in last section, there is another group of research that focuses on examining human activity patterns using geocomputational and modeling approaches. Activity patterns are summary characterizations of all attributes of an individual’s daily activities and trips. These characteristics include the timing, duration, location, frequency and sequence of activities, and the travel time and distances of trips. Studies on human activity patterns normally also rely on data collected through the activity-travel diary, which provides a detailed record of a person’s activities and travel for
various periods of time (from one day to several weeks). Using these data, it is possible to gain significant insight about the everyday life of a person at a particular time and place, as well as the interaction between a person’s daily life and the local geographical and social context.

Modeling human activity patterns is a helpful approach that can discover the interconnectedness of a person’s daily activities with those undertaken by other persons within the household. One of the major advances made in this research area is the shift from trip-based modeling to activity-based modeling. (e.g., Golob and McNally, 1997; Kitamura, 1988; Golob, 1998, 2000; Bhat and Koppelman, 1999; Kwan, 1999; Lu and Pas, 1999; Goulias, 2002; Pendyala and Goulias, 2002). Activity-based modeling takes people’s daily activities and the associated trips as the fundamental analytical entities. It considers travel as a demand derived from the need to undertake activities at different locations. When compared with trip-based models, such as the four-step transportation model, activity-based models provide better frameworks for addressing the complexity of activity-travel behaviors as they consider a wider range of factors and interactions. For example, since an individual’s daily activity arrangement is often influenced by other household members, the effect of the decision-making of household members (especially the female and male heads) on both individual and joint activity-travel participation can be taken into account (e.g., Townsend, 1987; Van Wissen, 1989; Golob and McNally, 1997; Chandraskharan and Goulias, 1999; Fujii et al., 1999; Gliebe and Koppelman, 2002;). Results from previous research indicate that men and women tend to perform disproportionate
shares of particular household tasks, and that paid work and childcare responsibilities significantly affect the tradeoff between joint and individual activities.

Drawing upon the activity-based paradigm, different analytical techniques and tools were applied to study individual activity travel patterns as well as its interaction with urban and environment contexts. Microsimulation is a widely adopted strategy for modeling activity-travel process by simulating individual and household decisions through time and space (Miller, 1997), and various microsimulation models have been developed, such as Prism-Constrained Activity-Travel Simulator (Fujii and Kitamura, 1997; Kitamura and Fujii, 1997), Sequenced Activity-Mobility Simulator (Kitamura et al. 1996), Simulation of Travel Activity Responses to Complex Household Interactive Logistic Simulation (Recker et al., 1986), and A Learning Based Transportation Oriented Simulation System (Arentze and Timmermans, 2000, 2003). A detailed review on the applications of micro-analytical concepts to activity-travel research can be found in Buliung and Kanaroglou (2007).

Besides the microsimulation approach, statistical modeling techniques are also commonly used in activity-travel research, which aims to reveal complex interactions between activity scheduling, activity engagement, and travel demand during the individual and/or joint decision-making processes (Kitamura 1988; Golob 1998, 2000; Golob and McNally 1997a; Bhat and Koppelman 1999; Lu and Pas 1999; Kwan, 1999b; Goulias, 2002; Pendyala and Goulias, 2002).
Although these studies are not directly related to people’s Internet activities, they shed important light on conceptual and operational issues that need to be addressed. Further, based on past results, it can be expected that the Internet will not evenly affect activity-travel patterns across different social groups because the adoption of the Internet will be influenced by people’s individual, household, and socio-demographic attributes.

2.5.1 ICTs and Activity-Travel Patterns

To date, researchers have considered the impact of ICTs when investigating human activity patterns. Generally, existing studies can be classified into two groups. The first group concerns the interrelations between the general use of ICTs and activity-travel patterns. Empirical studies suggest that ICT use has a complex impact on activity-travel patterns. For instance, Mokhtarian and Meenakshisundaram (1999) conducted a longitudinal study to examine the relationships among different modes of communication over a six-month period. The study found a net generation of overall communication activities. Senbil and Kitamura (2003) found that telecommunication devices (such as home phones and cellular phones) affect different activities in different ways: substitution for work-related activities, complementation for discretionary activities, and neutrality for maintenance activities. Choo and Mokhtarian (2004) proposed a comprehensive model to simultaneously estimate the relationships among local phone calls, travel, infrastructure and cost, economic activities, and land use. The results indicate a complementary relationship between
local phone calls and travel. Another study conducted by Kim and Goulias (2004) suggested that the impact of ICTs is influenced by the locations where they were used.

2.5.2 Telecommuting and E-shopping

Compared to the first group of studies, the second group of studies focuses on the impact of some specific use of the Internet on travel behavior, such as telecommuting and E-shopping (Mokhtarian et al., 1995; Koenig et al., 1996; Bagley and Mokhtarian, 1997; Mokhtarian, 1997; Mokhtarian and Salomon, 1997; Gould and Golob, 1997; Balepur et al., 1998; Ferrell, 2004, 2005; Farag et al., 2005). The major research question is whether telecommuting/E-shopping can lead to a significant reduction in travel. Since telecommuting/E-shopping loosens the traditional association between space, time, and activities, people with the Internet access can rearrange their activities over space and time (Couclelis, 2004b) and consequently a more complex outcome than simply a reduction in travel will be generated. In the context of telecommuting, a study by Koenig et al. (1996) demonstrated that non-commute trip generation was a potential negative impact of home-based telecommuting. As for center-based telecommuting, Balepur et al. (1998) observed a slight increase in commute-related trips due to lunch-time trips made from home to telecenters and a significant shift in transportation modes from other modes to driving-alone.

Similarly, studies on E-shopping also suggest that the impact of home shopping is multifaceted. Gould and Golob (1997) suggested that teleshopping will lead to
complex interactions between people’s communication and transportation activities, and individuals who adopted telecommuting tend to engage in more shopping activities as their commute time saved through telecommuting is converted into new trips. Ferrell (2004) explored the impact of teleshopping on out-of-home shopping trips and travel distance. The study indicates that home shopping tends to increase shopping trips and the number of chained shopping trips with a reduction in total travel distance. In addition, Dijst (2003) hypothesized that the adoption of E-shopping might also cause the revaluation of motivations for shopping. In-store shopping could become a way to meet the need for social interactions or recreational activities.

In the context of E-shopping, some studies also paid attention to the factors affecting the adoption of E-shopping. In particular, research interest has expanded from studying the effect of socio-economic factors to the impact of geographic indictors. The first attempt to investigate the impact of spatial variables on E-shopping was undertaken by Farag et al. (2004a) for Utrecht in the Netherlands. Their results demonstrate that people with low accessibility to shops and people who live in non-urbanized areas conduct online buying more frequently, which indicates that people’s E-shopping behaviors in Utrecht is related to the spatial distribution of shopping opportunities and residential context. As urban and social structure and people’s behaviors are highly contextual and spatially contingent, it still remains unknown as to whether this finding holds in other socio-spatial contexts and what other insights we could obtain with a change in study setting.
2.5.3 **Summary of Activity-Based Modeling**

Although the interrelations between ICTs and activity-travel patterns have been examined in the past, some important issues still need to be addressed. Firstly, how the Internet alters human activity-travel patterns has not been fully revealed yet. Compared with other communication technologies, the Internet allows people to conduct a greater range of activities. As such, its influence would differ from other technologies. In order to fully study the impact of the Internet on people’s daily activities and travel, activity-travel diaries that collect detailed information about people’s physical and Internet activities are needed. Due to the lack of such required data, much of existing research either focuses on one type of Internet use (such as telecommuting) or fails to differentiate the Internet from other communication technologies. Therefore, the interaction between particular Internet activities and people’s activity-travel patterns in the physical world calls for more research.

Secondly, few of these studies to date specifically examine the role of gender in shaping a person’s activity-travel patterns. Often, gender is treated as an exogenous variable in existing models and does not play a role in determining the causal structure of the model. However, this approach is problematic because the causal mechanism being modeled may be different across gender groups and it is not appropriate to model using the same causal structure. Some of the literature on telecommuting and E-shopping already found significant gender differences in the adoption of telecommuting and E-shopping (e.g., Burns, 2000; Gould and Golob, 1997; Mokhatarian et al., 1998; Sell and Jacobs, 1984; Shamir and Salomon, 1985). Ren and
Kwan (2007) also observed gender differences in people’s Internet activities using a 3D geovisualization approach. They found that men participated in more Internet recreational activities when compared to women, and the temporal patterns of Internet activities differ considerably between women and men as well. Therefore, based upon these conceptual clarifications and empirical evidence, it is reasonable to hypothesize that there are significant gender differences in the impact of Internet activities on people’s activity-travel patterns in the physical world.

Thirdly, analytical methods used in past studies can be improved. Among various methods for modeling activity-travel patterns, structural equation modeling (SEM) was often used to investigate the complex relationships among people’s activity, travel, and ICT use (e.g., Fujii and Kitamura, 2000; Golob, 1998, 2002; Kitamura, 1997; Kuppam and Pendyala, 2001; Kwan, 1999; Lu and Pas, 1999; Pas, 1997; Senbil and Kitamura, 2003). Some important methodological issues pertaining to model robustness, however, did not receive adequate attention to date. For instance, SEM is a type of confirmatory analysis - which means that model specification should be built upon theory or empirical evidence. In practice, model structures sometimes need to be modified in order to improve model fitness, which may cause the issue of post hoc model fitting (the specification of the model is driven by a particular dataset). In the light of the fact that neither theory nor empirical evidence on the casual relations among people’s ICT use, activity, and travel is conclusive, model respecification is inevitable. However, model modification may be driven by the characteristics of a particular sample because the process of model respecification in SEM is a post hoc
analysis of covariance structure (Byrne, 2001). This important issue associated with post hoc model fitting was not addressed in past studies and hence calls for attention in future research.

### 2.6 Research Questions

Given the limitations in activity-travel research, this study aims to address three major issues related to hybrid activity-travel patterns: how the Internet changes human activity-travel processes, whether geographic context affect Internet use patterns, and the impact of the Internet on activity-travel patterns. To address the first issue, this study seeks to answer the following questions: (1) Why do people choose to utilize the Internet?; (2) How do cyberspatial activities alter the physical activity-travel processes across different social groups?; (3) What are cyberspatial activity patterns across different social groups? This collection of questions will be answered by visualizing the hybrid activity-travel patterns of a large number of individuals.

As for the second research subject, this study will pay special attention to E-shopping, as it might be mostly relevant to the geographic context of where people inhabit. In particular, the following questions will be answered in this study: 1) who are more likely to adopt E-shopping?; 2) Do shop accessibility and residential environment affect the adoption of E-shopping?; 3) What factors affect the frequency of online purchases and the amount of money spent on E-shopping?
For the last research focus, the following research issues will be addressed: 1) Does the impact of Internet activities on people’s activity-travel patterns differ across gender groups? 2) If yes, what kinds of gender differences can be observed? To answer these questions, multiple-group structure equation modeling was used to analyze an activity-Internet diary dataset. Further, a cross-validation strategy was also adopted to tackle the problem associated with post doc model fitting.
CHAPTER 3

DATA AND METHODOLOGY

3.1 Introduction

In order to explore and examine the hybrid activity-travel patterns, a wide range of datasets were used in this study, beginning with a highly detailed and disaggregate source of daily activity-Internet diary dataset collected in Columbus metropolitan area (OH). With the comprehensive episode data on activities and travel in both physical world and over the Internet, it is possible to investigate the cyberspatial activity patterns as well as the impact of the Internet on activity-travel processes and patterns. In addition to the individual activity-travel data, another three datasets that represent the geographic context of the study area were also applied, as human activity-travel behavior is highly contextually contingent.

Using these diverse datasets, integrated methods were applied to examine hybrid activity-travel patterns in space and time. Firstly, two new geovisualization approaches that combine 3D/2D GIS and parallel coordinate plot technique were developed. By geo-visualizing hybrid activity-travel patterns of a large number of
individuals, we are able to not only explore cyberspatial activity patterns but also investigate how the Internet changes activity-travel processes. Secondly, based on the geovisualization results, two activity-based hybrid activity-travel models (one for women and the other for men) were built and operationalized using structural equation modeling technique. In doing so, the complex interrelations between Internet uses and activity-travel patterns in the physical world can be revealed for women and men. Furthermore, the multiple-group analysis method was used to test the invariance across model structures of the two gender groups. By comparing women and men’s activity-travel models, we will be able to find out whether the Internet equally affects women and men and how the traditional gender role mediate the impact of the Internet on human activity-travel behavior.

This chapter is organized as follows: the study area and five sets of data will be introduced in Section 3.2. Methods applied in this study will be illustrated in Section 3.3, including travel distance and shop accessibility calculation, geovisualization approach, parallel coordinates plot, structural equation modeling, and multiple group analysis.

### 3.2 Study Area and Data

This study was conducted in the Columbus metropolitan area in Ohio (U.S.A.), which is a mid-sized metropolitan area with a population of about 1.62 million in 2000 (Figure 3.1). Columbus is especially suitable for undertaking the proposed research. Its social and economic characteristics have been representative of the national trend.
Figure 3.1: The study area of Franklin County (Ohio, U.S.A) and the distribution of households surveyed in the study so that it has been called the “average city” of the U.S. (England 1993). Over half of its population have computers and use the Internet - 57.1% have computers while 52.7% use the Internet in 1999. The digital divide in Ohio parallels national trends: African-Americans, poorer and less educated people have lower use of computers and the Internet. Columbus has a relatively flat physical landscape, dispersed urban development and a transportation system heavily influenced by several rivers running in the north-south direction. The inner city of Columbus is struggling to revitalize its landscape, while rapid suburbanization in the past three decades has led to considerable spatial expansion and problems associated with urban sprawl. While the
city has witnessed the continued importance of its tertiary sector, especially the finance and insurance industries, its major suburban centers are undermining the importance of the city center as the focus of employment.

### 3.2.1 *Internet-Activity Diary*

An activity-Internet diary survey dataset was used in this study. The dataset was collected in an NSF-funded project, in which Mei-Po Kwan was the Principal Investigator. The survey was conducted in two phases in 2003 and 2004 in Columbus, Franklin County, Ohio. The rich information contained in this dataset makes it suitable for this study. Firstly, it collected data about the respondent’s household, individual, and average Internet use patterns such as the time spent on various Internet activities in a typical week, frequency and amount of products purchased over the Internet, and the amount of money spent on E-shopping. These data on socio-demographic characteristics of participants and general Internet patterns allows the differentiation of subsamples in the following analyses.

In addition, a two-day activity-Internet diary was also included in the survey. The diary collected detailed data about participants’ physical and Internet activities for two consecutive survey days. Like traditional activity-travel diary data, the survey instrument collected standard activity-travel information (such as the activity purposes, activity location, activity time and duration, travel mode and time), which facilitates the exploration of spatial and temporal patterns of participants’ activity-travel in the daily life, including their activity patterns over the Internet. More
importantly, the diary data also contains the information about each Internet activity - for example, why an individual chose to use the Internet to complete the activity, how he/she would undertake the activity in the physical world if it was possible, and how long it would hypothetically take to complete the activity in the physical world. These attributes associated with each Internet activity make it possible to investigate why people use the Internet and how the Internet affects their physical activities and trips. By having episode data on both activities in the physical world and on the Internet, it also becomes feasible to build activity-based models to examine the relations between various types of activities.

Although this rich dataset contains the required information to study hybrid activity-travel patterns (activity patterns in both physical world and cyberspace), it has some limitations. For example, the data sample mainly comes from middle to high income households (42% of the households have annual income higher than $80,000, and only 14% of the households earn less than $40,000 per year), making it not representative of the population in the study area. Meanwhile, most of the participants are white (93%) and highly educated (80% are college or graduate degree holders). Therefore, the findings in this study are relevant largely to the white, middle-upper class population in the study area and should not be generalized to other social groups including minority or low-income groups.

Since the number of non-Internet users was very small in the final sample, this study only focuses on the behavior of Internet users, from whom a total of 420 usable
surveys were obtained. This subsample of Internet users includes 272 women and 148 men. Figure 3.1 shows the spatial distribution of home locations of the participants. It can be seen that the data samples are unevenly distributed and does not have a full coverage of the study region, which is a disadvantage for some spatial analyses such as point pattern analysis.

3.2.2 Data for Geographic Contexts

Besides the disaggregate diary data, another three datasets were used to represent different perspectives of the geographic contexts of the study region. More specifically, shop accessibility, residential characteristics, and street network were taken into account in this study.

According to our data sample, the products most frequently bought online are travel packages (air tickets and hotels), books, and clothes. Grocery is the least frequently bought product purchased online, implying that people in Columbus normally utilize the Internet to purchase non-daily goods. This E-shopping pattern is similar to those observed based on the sample in Utrecht (Farag et al. 2004a). In this study, shopping stores for non-daily goods will be used to calculate shop accessibility measures. This piece of information was extracted from a digital geographic dataset of Franklin County obtained from Franklin County Auditor’s Office. It contains detail information on all land parcels and their attributes. Basically, seven land-use categories were counted as non-daily shopping stores: small detached retail stores, discount stores and junior department stores, full line department stores, neighborhood shopping center,
Figure 3.2: The non-daily shopping opportunities in Franklin County extracted from parcel data. The density surface was generated using kernel density estimation with a search radius of 1 mile.

community shopping center, regional shopping center, and other retail structures. For detailed parcel coding information please refer to Appendix. There are 2902 parcels
counted as non-daily shopping opportunities. Figure 3.2 shows the non-daily shopping opportunities in Franklin County. The point pattern of shopping opportunities was obtained by extracting the centroids from land parcel data. The underlying background is the density map of non-daily shopping opportunities, which was generated from the shopping point pattern using kernel density estimation method. It can be seen that shopping opportunities are dispersed in northern and central Franklin County in which most of the participants of the study live.

Besides accessibility to local shops, the characteristics of people’s residential areas are also the major geographic indicators that could influence Internet use patterns, such as E-shopping patterns (Farag et al., 2004a). In this study, the 2000 U.S. Census data was applied at the Census block group scale. The residential area of a household is then evaluated by the demographic, social, and economic characteristics of the Census block group where the household resides. Basically, the following variables were selected to represent residential characteristics: percentage of population who are whites, population density, median household income, median contract rent, and percentage of population with a higher education degree.

The Last data source is a detailed digital street network of Franklin County provided by a commercial vendor. Household and activity locations collected in the activity-Internet data were geocoded on this street network for computing the integral accessibility measures and travel distances as described in Section 3.3.
3.3 Methods

Mixed methods were used in the study, mainly including geovisualization approach and structural equation modeling (SEM). In addition, logistic and linear regression methods were also used to examine E-shopping patterns. Since they are very basic statistic methods, they will not be repeated here. Before illustrating geovisualization and SEM methods, travel distance and shop accessibility calculation will be introduced.

3.3.1 Travel Distance and Accessibility Calculation

When geo-visualizing activity-travel patterns, it is necessary to generate travel distance between different locations where participants undertook their activities. Since the true routes that participants took were unknown, the shortest distance between two locations was used to represent the travel distances. Using the detailed street network data of the study area, network based shortest distances were calculated with the Avenue script developed using ArcView Network Analyst.

In addition, shop accessibility is also required for examining the geographic patterns of E-shopping activity in this study. It was evaluated by several cumulative-opportunity (CO) indices. In this study, CO indices were obtained by calculating the total number of and the sum of areas of shopping parcels that can be reached within specific travel times from respondents’ home locations. Since the parcel data is a polygon dataset, the centroid of each polygon was extracted in ArcGIS to represent the geographic location of each shopping opportunity. With geocoded households and

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shopping store points, all point-to-point distances on the street network were measured in travel times ranging from 6.25 minutes to 25 minutes. In order to generate more realistic representations of travel times, delay times for making turns or stopping for red lights were also added. Finally, an Avenue script was developed using ArcView Network Analyst to automatically compute the CO indices for each household.

3.3.2 Geo-visualizing Hybrid Activity-Travel Patterns

As described in Section 3.2.1, the activity-Internet diary dataset is a rich dataset, which contains multi-dimensional information on hybrid activity-travel patterns. In order to gain much insight from such a complex travel diary data, it is very important to have an effective exploratory tool to perform the first-step analysis, as it will provide necessary knowledge of the research domain for further studies.

Among various exploratory techniques, such as correlation matrices and cluster analysis, geovisualization approach was selected in this study to offer the gateway to a full understanding of hybrid activity-travel patterns. As indicated in Chapter 2, geovisualization has moved beyond the traditional cartographic visualization to become a powerful exploratory tool for spatial data exploration, hypothesis generation, and knowledge construction. It can greatly facilitate the detection of hidden patterns in the complex dataset by utilizing the strength of traditional cartographic practice, scientific and information visualization, geographic information science, statistical graphs and image analysis. Further, previous research on activity-travel behavior has already come up with a very useful theoretic framework and
different analytical approaches (see Chapter 2.4), which provides a solid base for more advanced studies. When compared to geovisualization approach, other methods would not enable us to identify the hidden activity-patterns by directly observing people’s movement in space-time and would not be able to explicitly maintain the spatio-temporal patterns of activity-travel. Therefore, geovisualization is a suitable approach for this study as it enables us to explore human hybrid activity-travel process from the complex activity-Internet diary data.

Drawing upon the time-geographic perspective, two new geovisualization methods were developed in this study for representing and exploring hybrid activity-travel behavior. First, the notion of information cube was developed to represent information space and adding information cubes onto the traditional space-time paths makes the traditional 3D space-time paths accommodate cyberspatial activities in exploratory data analysis. Second, a new representation of 2D space-time paths that incorporates parallel coordinate plots was developed for exploring the multiple attributes of people’s Internet and physical activities. These two methods were implemented using ArcObjects and the Visual Basic for Applications environment in ArcGIS. Chapter 4 provides a detailed elaboration on design and implementation of theses two geovisualization methods.

### 3.3.3 Parallel Coordinates Plot

In order to maintain multiple activity attributes when geo-visualizing hybrid activity-travel patterns, parallel coordinate plot technique was applied. In this approach, a point
in \( n \)-dimensional space is represented as a series of \( n-1 \) line segments (Inselberg, 1981, 1985) in a two dimensional space as illustrated in Figure 3.3. If the original data contains \( n \) dimensions, these dimensions can be represented with \( n \) mutually perpendicular and equally spaced axes in traditional Cartesian coordinates. For simplicity purpose, it is usually assumed that the distance between adjacent axes is 1. Any point \( p(x_1, x_2, ... x_n) \) in this \( n \) dimensional space is then drawn by locating the \( x_i \) along the \( i \)th axis. All the vertices on the parallel axes \((1,x_1), (2,x_2), ... (n,x_n)\) are then connected by a line with \( n-1 \) line segments. In doing so, the parallel coordinates plot transforms a high dimensional space into a 2D space.

![Figure 3.3: Parallel coordinates plot of a point in n-dimensional space](image)

If each line is thought of as a 'profile' of a given case, an entire \( n \)-dimensional dataset is the plot of all such profiles on the same graph. This is illustrated in Figure 3.4. This is a parallel coordinates plot that shows socio-economic characteristics of Franklin County. In this example, the entire dataset contains 883 “profiles”, each profile
standing for one census block groups, and it is a three dimensional dataset as there are three socio-economic variables associated with each census block groups. The appearance of the plot appears confusing, but can be used to highlight outliers. The real strength of the technique is to reveal the associations between different variables; especially, the associations can be easily found when subsets of the data are selected. For example, subsets of high-income areas that are selected in yellow (Figure 3.4) seem to be highly correlated with the areas that have higher proportion of high educated and white population.

![Parallel coordinates plot](image)

**Figure 3.4:** Parallel coordinates plot of socio-economic variables of census block groups in Franklin County, Ohio, U.S.A. Highlighted lines show the association between high income, high education level, and the percent of population that is white.
In light of the advantage of PCP in visualizing high dimensional dataset, it was adopted to maintain multiple activity attributes when geo-visualizing hybrid activity-travel patterns and to visualize the correlations between these activity attributes. Chapter 4 will specify the application of PCP in a 2D representation of hybrid space-time paths.

3.3.4 Structural Equation Modeling

Although geo-visualizing hybrid activity-travel patterns will enhance our standing why people choose to use the Internet and how the Internet affects activity-travel processes of different social groups, it cannot quantify how human activity-travel patterns has been changed by various Internet uses. Therefore, it is necessary to go beyond the exploratory analysis to investigate the interrelation between the Internet and activity-travel patterns. Structural equation modeling (SEM) was used in the study because it seeks to reveal the complex interrelationships between people’s activity-travel patterns and Internet use. The strength of SEM is its capability in simultaneously estimating the causal relationships among a set of observed variables based on a specified model (Bollen, 1989; Kaplan, 2000). In particular, decomposition of the total effect into direct and indirect effect allows us to gain important insight into the interrelations among the variables in the model. Since there are plenty of books and literature on this approach, this section does not intend to give a thorough introduction to this method. The basic idea and major issues of this approach will be reviewed below.
The goal of building a structural equation model (SEM) is to find a model that fits the data well enough to serve as a useful representation of reality and a reasonable explanation of the data. It can distinguish indirect and direct relationships between variables and can analyze relationships between latent variables without random error. It has been demonstrated to be a very useful to reveal hidden patterns embedded in the data. The general form of SEM usually contains two components: structural model (relationship among latent exogenous and endogenous variables) and measurement models (relationship between latent exogenous and endogenous variables and observed variables). Based upon this general form, there are some specific cases. For example, SEM with no measurement models is known as SEM with observed variables or simultaneous equations model, and SEM with one measurement model alone becomes confirmatory factor analysis. In the context of activity-travel research, SEM with observed variables is usually used. The equation for a SEM with observed variables is:

$$Y = BX + \Gamma X + \zeta$$

where

- $Y$ is a $p \times 1$ vector of $p$ observed endogenous (dependent) variables
- $X$ is a $q \times 1$ vector of $q$ observed exogenous (independent) variables
- $B$, $\Gamma$ are $p \times p$ and $p \times q$ coefficient matrices
- $\zeta$ is a $p \times 1$ vector of errors

Unlike multiple regressions, coefficients of SEM are estimated using covariance analysis. The underlying hypothesis of SEM is the covariance matrix implied by the model ($\Sigma(\theta)$) is equal to the covariance matrix obtained from the data ($\Sigma$). By
minimizing the difference between these two covariance matrices, the coefficients ($\theta$) can be solved. Several methods can be used to estimate the coefficients in SEM, such as maximum likelihood, least squares, and generalized least squares. These procedures are available in SEM software packages including LISREL and AMOS.

Normally, there are six steps in SEM approach: model specification, implied covariance matrix determination, model identification, model estimation, model evaluation, and model respecification. Among these procedures, model specification is the fundamental step because the following estimation and analysis are based on the model specified in the first step. Model specification is to construct the model structure by determining the path diagram (determine the causal relations) for the variables and identifying the correlation among the related variables. The researcher’s choice of variables and pathways represented will limit the structural equation model’s ability to recreate the sample covariance and variance patterns that have been observed in nature. Therefore, model construction theoretically should be based upon theories and empirical evidence.

In practice, however, SEM often combines exploratory purpose with confirmatory analysis, in that the model is often modified based upon modification indices suggested by the dataset used. The model respecification procedure enhances the risk that the model structure might be driven by the specific dataset, which is known as post hoc model fitting issue. One approach to solving this problem is to test the final model on the second independent sample. However, due to the difficulty of obtaining
the separate samples, it is feasible to cross-validate findings with two (or more) samples randomly selected from the original sample (Cudeck and Browne, 1983; Byrne, 2001). This approach will be used in this study to address post hoc model fitting issue.

Drawing upon the previous studies and geovisualization results in the exploratory analysis, SEM was applied to model hybrid activity-based patterns of women and men respectively. The two structural equation models with observed variables were built and estimated using AMOS 6.0, a SEM software from SPSS. In doing so, the complex impact of various Internet uses on activity-travel patterns for women and men groups can be uncovered. Further, multiple-group structural equation modeling was used in this study to test invariance in causal structure across gender.

3.3.5 Multiple-Group Structural Equation Modeling

Theoretically, group comparison is performed hierarchically with increasing constraints imposed on the model, varying from constraints on the same model structure across groups to constraints on the same model structure, parameters, residuals, and variance-covariance (Bollen, 1989). In this study, testing for invariance across groups was performed by using the built-in multiple-group analysis program in AMOS. Basically, three hierarchical models are used for testing invariance across groups when the baseline model does not have a measurement component. The lowest level of the hierarchy is used to enforce equality in structural weights, while the
highest level is used to enforce equality in structural weights, structural covariance, and structural residuals.

When conducting multiple-group analysis, samples sizes of different groups should be approximately equal to ensure stable parameter estimates. Since sample size of women group is approximately twice of that of men group in this study (256 women vs. 126 men), the women group was randomly split into calibration and validation samples. About half of the women in the original sample were randomly selected as the calibration sample, while the other half was the validation sample used to test invariance across the calibration and validation samples.

To perform multiple-group analysis in the study, two baseline models were first constructed for women and men respectively. The baseline model for women was estimated with calibration sample and then was validated with validation sample using the cross-validation strategy as introduced in Section 3.3.4. Only women group was cross-validated and the men group was not due to the small size of the latter group. Finally, multiple-group analysis based on the two baseline models was conducted to test invariance of causal structures across gender. The hypothesized models and testing results will be illustrated in Chapter 6.
CHAPTER 4

GEO-VISUALIZING PHYSICAL AND INTERNET ACTIVITIES IN SPACE-TIME

4.1 Introduction

This chapter will examine people’s physical and Internet activities using geovisualization approach. As discussed in Chapter 2, while GIS-based geovisualization techniques have been fruitfully employed in a wide range of fields, such as public health, environmental science, and crisis management (MacEachren and Kraak, 1997), they have not been applied to explore human hybrid activity-travel patterns. The most challenging task in geovisualizing human hybrid activity-travel patterns is to effectively organize and represent multi-dimensional information contained in travel diary data. The task becomes especially complicated when Internet activities are included. Although different approaches like multi-scale geovisualization representation and PCP have been explored, there are considerable room for further development when dealing with people’s Internet activities – especially in visualizing the interaction between people’s physical and cyberspatial activities. Furthermore, the task of integrating cyberspace and physical space into one geovisualization structure
has not been successfully solved. It is required to develop a strategy to overcome the limitations of traditional frameworks that take distance as a friction for interactions.

Drawing upon the time-geographic perspective, this study attempts to achieve the following objectives in the aspect of geo-visualizing hybrid activity-travel patterns: (1) sustaining spatial and temporal explicitness; (2) maintaining multiple activity attributes; (3) representing both Internet and physical activities in one geovisualization structure. To achieve the research goals, the notion of information cubes was constructed and the hybrid 3D and 2D space-time paths were implemented in the visualization environment of a GIS.

This chapter is organized as follows: 2D and 3D representations of hybrid space-time paths and implementation of the visualization approaches are illustrated in Section 4.2. Analysis of the results is elaborated in Section 4.3 and finally conclusions and implications for future research work are summarized in Section 4.5.

4.2 3D and 2D Space-Time Paths in the Geovisualization Structure

4.2.1 Hybrid 3D Space-Time Paths with Information Cubes

Conventional geographic concepts, including the construct of “space-time aquarium”, are based on distance in physical space. Compared with activities in the physical world, however, cyberspatial interactions differ considerably as they are much less affected by the physical separation among locations. In the physical world, greater
distance is often associated with higher cost in overcoming physical separation. In contrast, there is no need to overcome the impedance of distance in cyberspace, and distance is therefore not a useful notion for the study of activity behavior in cyberspace or “travel on the information superhighway.” Further, since people can visit multiple websites during a single web surfing session, the use of space-time paths that depicts an activity with a single line segment is not appropriate for portraying Internet activities. It is necessary to modify traditional space-time paths in order to accommodate Internet activities.

Drawing upon the concept of action space (Horton and Reynolds, 1971) and the conceptual model on individuals accessibility in cyberspace (Kwan, 2001), a person’s information space is defined in this study as the collection of cyber-opportunities he/she has access to or could interact with in his/her everyday life (or in one particular Internet session). Cyber-opportunities include a diverse range of information resources and activity possibilities in cyberspace (e.g., e-mailing, web surfing, e-banking, e-shopping, and blogging). Information space can be represented differently depending on the perspective one adopts. For instance, it can be represented as a graph composed of nodes (cyber-opportunities) and links (hyperlinks among websites) (Skupin and Buttenfield, 1996; Munzner, 1997). Although the network-based representation provides an objective information structure of cyberspace, it does not reflect the user’s perspective in that the structure of and relationships among opportunities in cyberspace are largely invisible to the user (Kwan, 2001). This study therefore adopts a user-based behavioral perspective and defines information space as the collection of
cyber-opportunities a person has knowledge of, has potential access to, can use to undertake activities, or could interact with (Gaines et al, 1997; Staple, 1995). In this respect, the space-time notion of individual accessibility sheds light on the representation of information space.

Past studies on individual space-time accessibility indicate that individual daily accessibility and activity space depend heavily on how far a person can travel and how many opportunities he/she have access to in a given amount of time (Kwan, 1998, 2004). Drawing upon this notion of space-time accessibility, the information space of an Internet user within one Internet session also depends on how much time he/she spends on the Internet, how quickly he/she can get to the intended websites, and how many cyber-opportunities he/she had access to.

Although it appears that distance and physical locations of information resources on the Internet are not crucial, this does not mean that people can have access to any intended websites without any barriers. Poor network performance, for instance, can increase the “friction” between Internet users and particular cyberspatial opportunities and may even prevent the successful launching of some websites. Internet connection speed is, in particular, one of the most important indicators of Internet network performance because Internet activities are sensitive to latency (Kwan, 2001). Controlling for other factors, high-speed Internet facilitates people to visit more websites and to obtain more diverse information, consequently increasing the size of the reachable information space. As such, Internet connection speed should be taken
as one essential measure for evaluating individual information space. Besides Internet connection speed, the amount of time spent on the Internet is also positively related to the size of a person’s information space.

Even with the same amount of time and same Internet connection speed, different individuals may have dissimilar information space because their Internet skills are different (e.g. searching for relevant information resources). Highly skilled Internet users, for instance, are more able to access cyber-opportunities than less skilled user, just as a long time resident of a city knows the location of local opportunities much better than a newcomer. Since Internet users only get access to intended cyber-opportunities by visiting the corresponding websites, the number of websites visited can therefore be used as an approximate indicator of the number of reachable cyber-opportunities for a particular person. As it is difficulty to evaluate the number of cyber-opportunities on each website, this study makes the simplifying assumption that every website provides the same amount of information resources. Alternatively, this can be conceived as assuming that the average numbers of opportunities for the websites visited by different persons are not significantly different - since some web sites have more cyber-opportunities while others have less, and the average number of cyber-opportunities for different persons may tend towards the mean over time. Based on these assumptions, all websites are equally weighted in this study and the more websites a person visits in a given amount of time, the greater his/her information space.
Based upon this conceptualization of the role of these three factors (duration, connection speed, and the number of websites visited), information cubes for a person’s space-time path are constructed as shown in Figure 4.1. Each information cube locates in a 3D information space with X axis representing Internet connection speed, Y axis representing the number of websites visited within a given duration, and Z axis representing the amount of time (duration) spent on the Internet in a particular online session. An information cube indicates the size of the information space that a person has access to during a specific amount of time, which is determined by the product of the three variables. The sum of the volume of all information cubes on a daily space-time path measures the entire size of information space a person has in a particular day, and it can also be used to assess this person’s accessibility over the Internet.

In order to accommodate cyberspatial activities in the representation of space-time paths, information space coordinate systems are superimposed onto space-time paths to replace the corresponding line segments in the space-time coordinate system for physical activities or travel (Figure 4.1). The origin of an information space coordinate system on a space-time path shows where an Internet activity or session was undertaken and when it began, and therefore indicates the spatial and temporal references of the activity in the physical world. Such representation of cyberspatial accessibility focuses mainly on the amount of potentially reachable cyber-opportunities for a person in a particular day, rather than the geographic locations of cyber-opportunities. The reason for doing so is that physical separation among cyber-
opportunities is not an obstacle to having access to them. Therefore, it is more meaningful to visualize where and when people engaged in cyberspatial activities (and therefore in the creation of their personal information space) and how large the information space was.

Figure 4.1: Modified 3D space-time paths

The 3D hybrid space-time paths, created by adding information cubes to conventional space-time paths, overcome the difficulty of representing non-distance based interactions in a distance-based analytical environment. The method provides an overview of what activities an individual engaged in and where and when he/she conducted these activities in a particular day. To visualize more detailed activity attributes, a 2D geovisualization structure is described as follows.
4.2.2 Hybrid 2D Space-Time Paths with Parallel Coordinates Plot

As shown in Figure 4.2, the 2D geovisualization structure consists of two coordinate systems that are linked together by sharing a common temporal axis Y: one representing physical space (on the right side) and the other cyberspace (on the left side). In the physical coordinate system, the X axis is the distance between a person’s home and his/her out-of-home activities, which depicts the spatial extent of people’s movement. Similar to the traditional 3D space-time paths, people’s daily activities including Internet activities are represented with different line symbols. In the cyberspatial coordinate system, the methodology of parallel coordinate plots (PCP) is employed since a PCP transforms a multi-dimensional space into a 2D space.

Figure 4.2: 2D space-time paths
In the 2D visualization structure (Figure 4.2), there are four parallel (vertical) axes in the cyberspatial reference system which represents different attributes of cyberspatial activities. The first one is Internet Use, which is represented by ten different categories: working, email, web surfing/gathering information, online purchasing, online banking/paying bills, online auction, borrowing books from library, maintaining personal blog/editing photos, and other Internet uses. The second axis (Reasons) pertains to the reasons that people choose to use the Internet instead of visiting a shop or facility in the physical world. It has five categories that include obtaining more information, saving time, saving money, eliminating travel, and other reasons. The third axis (Interaction) represents whether and how the cyberspatial activity in question can substitute for an activity in the physical world. Four types of physical-virtual interactions are considered in the visualization structure: (1) it cannot be performed in the physical world, indicating that the cyberspatial activity enhances an individual’s accessibility through providing new (virtual) opportunities; (2) it can be performed through using other media such as TV, magazines or fax, indicating the cyberspatial activity substitutes physical one-way communication; (3) it can be performed by traveling to a store or facility in the physical world, suggesting that the cyberspatial activity reduces some travel by the person in question; and (4) it can be performed through face-to-face meeting, implying that the Internet replaces physical two-way communication. The last parallel axis (Time Comparison) represents whether an Internet activity saves time if a similar or substitute activity can be performed in the physical world. This information is obtained by comparing the duration of the Internet activity with the amount of time needed if it was performed in the physical world.
By linking the attribute values on the parallel axes and the corresponding line segment in physical space (as shown in Figure 4.2), we will be able to know where and when an Internet activity took place, what type of Internet activity it was, why the individual preferred to use the Internet for performing the activity, what was its likely effect on the physical world (e.g. reducing travel or face-to-face meetings), and whether the Internet was a time-efficient tool for this particular activity. The hybrid 2D geovisualization framework, which includes activity-travel patterns in both physical space and cyberspace, therefore combines the illustrative power of conventional 2D space-time paths and the strengths of parallel coordinate plots (PCP). As detailed activity attributes is attached to particular points on the hybrid 2D space-time paths, the visualization method greatly enhance our understanding of people’s activity behaviors in both the physical and virtual worlds.

The geovisualization methods described in this section were implemented and explored with the activity-Internet diary survey on the ArcGIS platform. A custom geodatabase for representing and organizing the survey data was built using ArcObjects in ArcGIS. Since the proposed geovisualization system includes both 2D and 3D frameworks, 2D and 3D feature classes were created for representing physical activities, Internet activities, and trips. For instance, a 3D polyline feature class was created for representing 3D space-time paths and 2D polyline feature classes were created for representing physical or Internet activities in 2D space. To portray 3D information cubes in 3D space, a 3D multilayer feature class was used. Custom
interfaces for the geovisualization of hybrid 3D and 2D space-time paths were developed using Visual Basic for Applications (VBA) scripts in ArcScene and ArcMap.

4.3 Results

Before presenting the visualization results, a note on pattern detection and knowledge discovery using the methods developed in this study is warranted. The reader should note that figures presented in this section are static screen captures. Since the dynamic process of knowledge discovery through interactive 2D or 3D visualizations cannot be illustrated using static screen captures, the figures discussed in this section cannot convey the same amount and quality of information enabled by interactive visualizations. The reader may find it difficult to follow the discussion simply by looking at these figures because the text is based on observations enabled by the computer-aided interactive visualization environment created for the study. This environment allows the user to interactively zoom, pan, navigate, rotate, or modified the attributes of the objects or information displayed on screen, while such functionalities are not available to the reader. A color version of the figures will be available based upon request.
4.3.1 Hybrid 3D Space-Time Paths with Information Cubes

1) An Individual’s Hybrid 3D Space-Time Path

Figure 4.3 shows the custom toolbar for visualizing hybrid 3D space-time paths and the path of a selected woman. The toolbar has several customized functionalities for visualizing a hybrid 3D space-time path (e.g. loading data from the geodatabase). After selecting a particular survey participant, the system will ask for the day in which the data were collected and then display the person’s space-time path for the day. In addition, the system can display all the space-time paths and information cubes for a particular population subgroup, such as men working full time or women working part-time.

![3D space-time path of a selected woman](image)

Figure 4.3: The 3D space-time path of a selected woman
As shown in Figure 4.3, the color-coded 3D space-time path and information cubes convey useful information about where, when, and for what purpose an activity was undertaken and how large the information space was if it is an Internet session. The activity purposes in this study are classified into five categories: work or work related activities, household needs, personal needs, recreational needs, and social activities (the survey instrument allows the respondent to provide more than one purpose; the geovisualization reported here focuses only on the primary purpose). Meanwhile, 3D labels are attached to the space-time paths in order to identify the kind of places where an activity was performed. By viewing the hybrid 3D space-time path of the selected woman, we obtain a clear idea about her activities and travel on the day, which include working at the office, having lunch at Heavenly Ham, working at the Microsoft store, and running errands at Staples and Petsmart. In addition to these physical activities, there were four Internet activities: two of them (highlighted in red) were for work-related purposes and were performed in the morning and afternoon. Another one (in brown) was conducted for personal needs at the office at noon, and the last one (in green) was performed at home for household needs around 6 pm. Therefore, the 3D polylines and multpatches in the visualization environment are not merely geometric shapes; instead they carry the semantic meanings of what, when, and for what purpose people performed the activities.

2) Information Cubes of Subgroups by Gender

In addition to showing a person’s daily activity-travel behaviors, the hybrid 3D space-time paths also allow us to examine the Internet activity patterns of different
subgroups. According to past literature, gender and employment status play an important role in shaping people’s physical activity patterns (Kwan 1999). The data sample was classified by gender and employment status in order to examine their effects on people’s cyberspatial activity patterns.

Figures 4.4 and 4.5 show the information cubes of the men and women in the subsample for non-work purposes. Generally, both groups have larger information space for non-work activities in the evening as indicated by more and bigger information cubes for non-work activities in the evening. This is readily understandable since people tend have more free time in the evening; especially
working people are released from work responsibilities at night. Further, breaking down the information cubes into different categories will disclose more detailed Internet activity patterns.

A closer look at Figures 4.4 and 4.5 reveals that women have larger proportion of green information cubes than men, indicating that women conduct more household related activities in cyberspace. Further, performing household activities in cyberspace has a strong temporal pattern as most of the online household activities were undertaken in the evening. Since the two subgroups have different number of subjects,
we also created a normalized 2D aggregate graph as shown in Figure 4.6. The X axis in the graph represents time, with a 24-hour day starting from 3am, and the Y axis stands for the volume of household related information cubes normalized by the number of subjects in each gender group. The normalized graph confirms that traditional gender division of domestic labor still persists in cyberspace – that is, women’s tend to perform a larger share of household responsibilities than men.

Although women engage in more household-related activities online than men, Figure 4.4 suggests that the proportion of green information cubes is much smaller when compared to blue (recreation) and brown (personal needs) cubes. This suggests that women tend to use the Internet more for meeting personal and recreational needs than for undertaking household-related activities. This in turn may imply that household needs are more difficult to meet through the Internet and remain a small portion of women’s total cyberspatial activities when compared to personal and recreational activities. Another pattern evident in Figures 4.4 and 4.5 is that men have larger proportion of blue information cubes (recreation) than women, implying that men are more likely to use the Internet for recreational activities. The normalized aggregate results as shown in Figure 4.7 further supports this observation, especially given that men’s recreational information space peaks at about 9 am and 9:30 pm.
Figure 4.6: Information space of men and women for household related activities

Figure 4.7: Information space of men and women for recreational activities
3) **Information Cubes of Subgroups by Employment Status**

In addition to gender, past literature also suggests that the number of working hours per day plays an important role in determining people’s activities patterns since work-related activities constitute the most stringent space-time constraints in their daily lives (e.g. Pratt and Hanson, 1991; Kwan, 1999). Since the dataset does not have significant numbers of part-time employed and non-working men, we focus on the effect of employment status on the Internet behavior of the women in the subsample. As shown in Figures 4.8, 4.9 and 4.10, the cyberspatial activities of women with different employment status (in terms of working hours per week) have different temporal patterns. Non-working women tend to conduct online activities in the afternoon and in the evening because they experience less space-time constraints when compared to the other two groups of women. They have more free time to engage in Internet activities in both daytime and in the evening. Not surprisingly, the proportion of brown (personal needs) and blue (recreation) cubes in Figure 4.8 is the greatest when compared with those in Figures 4.9 and 4.10, indicating that non-working women pursue more Internet activities to meet their own personal needs. The normalized aggregate result also confirms this finding (which is not provided here).

In contrast, the cyberspatial activities of women working full time cluster mainly in the evening, indicating that they have to utilize their evening to conduct non-work Internet activities as their daytime are more occupied by their work obligations (Figure 4.9). Moreover, the proportion of green information cubes (household needs) found during evening hours of this group of women is greater when compared to the other
groups. This suggests that women working full time use more of their evening online time for meeting household needs since their space-time constraint in daytime is very tight. Moreover, it is worthy noticing that the Internet activity patterns of women working part time differ from those of the other two groups of women. Since part-time employed women experience moderate temporal constraints and their working hours may not be fixed, they can distribute their time in cyberspace throughout the day. This explains why information cubes in Figure 4.10 are temporally evenly distributed. In summary, examining the information cubes of different subgroups allows us to uncover hidden Internet activity patterns and enhances our understanding of how gender and employment status affect people’s activity behavior in cyberspace.

![Figure 4.8: Information cubes of non-employed women](image)

- **HH**
- **Personal Needs**
- **Recreation**
- **Social Needs**

Figure 4.8: Information cubes of non-employed women
Figure 4.9: Information cubes of full-time employed women

Figure 4.10: Information cubes of part-time employed women
4.3.2 Hybrid 2D Space-Time Paths with Parallel Coordinates Plot

1) An Individual’s 2D Space-Time Path

In order to visualize multiple activity attributes, hybrid 2D space-time paths with parallel coordinate plots (PCP) as described in Section 3.2 were also implemented in this study (Figure 4.11). There are four parallel axes in the cyberspace reference system (left in the plot): Internet use (e.g. email, web surfing, etc.), reasons for choosing the Internet instead of performing the activity in the physical world, the extent to which the activity in question can be performed in the physical world (Interaction), and whether using the Internet saves time for the activity in questions (Time Comparison). In the physical reference system (right in the plot), distance to home is calculated by the network-based shortest path method using a digital street network of the study area.

Similar to the toolbar for visualizing hybrid 3D space-time paths, a custom toolbar was also implemented in ArcMap platform to facilitate the exploration of the data. Besides displaying individual hybrid 2D space-time paths, it also displays the socioeconomic attributes of the selected person as shown in Figure 4.11. This greatly facilitates interpretation of individual paths as we have access to pertinent personal and household characteristics through the visualization interface.

For example, the person selected in Figure 4.11 is a 45-year old full-time working single mother with one child. She is a skillful Internet user with ten years of
experience in using the Internet and her average online time per week is four hours. On this diary day, she conducted one Internet activity in the morning at office and one in the evening at home. At the office, she went online for five minutes to check the balance of her bank account. Using the Internet saved her time and eliminated travel to the bank. If she performed this activity in the physical world, it would take her more time and, in this particular case, e-banking substituted for traveling to a bank. In the evening, the woman checked her email at home for about half an hour. She could perform this activity in the physical world with other means such as mailing, which would take longer time. The reason that she chose to use the Internet was because more information is available in cyberspace. In addition, the spatial extent of her movement in the physical world is rather small. She traveled less than five miles to her
office, and there were no recreational activities on that day. Therefore, the physical 2D space-time path shows that she was highly constrained by work and household responsibilities.

In general, hybrid 2D space-time paths reveal more details of the activity-travel processes. In addition to the time allocation to various daily activities and the spatial extent of people’s movement in the physical world, each Internet activity performed in the physical world is linked to the corresponding attributes represented with PCP, such as the reason why the Internet was utilized and how the Internet affected the physical world in this particular circumstance. In doing so, we can obtain a better understanding of how the Internet plays a role in altering activity-travel behavior. However, the geovisualization results could be more insightful if a person’s hybrid 2D space-time paths are linked to his/her 3D hybrid space-time paths, because an interactive and dynamic linkage between these two views will allow us to explore the activity-travel processes within an explicit geographic context.

2) 2D Space-Time Paths of Subgroups by Gender

Visualizing the 2D space-time paths of individuals belonging to particular social groups will help us identify the correlations between different attributes of Internet activities and the spatial patterns of different activities in the physical world. For PCP technique, the ordering and arrangement of the axes could greatly influence the effectiveness of the visualization because strong correlation between adjacent axes is much easier to perceive (Edsall, 2003). In order to provide clearer views of the
correlations between different attributes of Internet activities, the four groups of
attributes (Internet use, reason, interaction, and time comparison) are organized into
three pairs: Internet use and reason, Internet use and interaction, Internet uses and time
comparison (see Figures 4.12 and 4.13). The custom application allows the user to
select any one of these pairs of attributes to be explored together with the 2D space-
time paths. Further, different subgroups of individuals that meet specific criteria can
be selected for a particular analysis. As examples of this kind of visualization, Figures
4.12 and 4.13 show the hybrid 2D space-time paths of the full-time working men and
women who are between 35 and 55 in age and have good Internet skills in the sample.
The group of men has 44 individuals while the women group has 50 individuals.
These hybrid 2D space-time paths with parallel coordinate plots are useful for
visualizing the spatial patterns of daily movement of these two sub-samples in the
physical world.

The 2D physical space-time paths plotted in the physical reference system (on the
right) in Figures 4.12 and 4.13 show the spatial extents of different activities that these
two groups of men and women engaged in. Visualization of the paths reveals some
intriguing gender differences. When compared to the group of men, the length of
women’s commute trips (in red) tend to spread across a wider range from home, with
more commute trips within three miles and over 15 miles from home. On the other
hand, work hours of the group of women tend to be temporally restricted, while the
work hours of men tend to spread across a wider range (with several who work in the
evening and overnight). Further, the groups of men and women have evidently
hybrid 2D space-time paths of subgroup of full-time employed men

hybrid 2D space-time paths of subgroup of full-time employed women

Figure 4.12: Internet use and reasons of adopting the Internet
hybrid 2D space-time paths of subgroup of full-time employed men

hybrid 2D space-time paths of subgroup of full-time employed women

Figure 4.13: Internet use and how the Internet interacts with physical space
different non-employment activity-travel patterns. When compared to the men, women travel farther for household activities (in green) and take shorter trips for recreational activities (in blue) – some of the men’s recreational trips are more than 17 miles away from home, while no recreational trips in this range were made by the women. These observations corroborate the findings of previous studies (e.g., Kwan, 2000a), which suggest that women not only undertake more household activities but they also make longer trips for these activities. On the contrary, men spend more time on traveling to undertake recreational activities when compared to women. There can be considerable gender differences in space-time activity-travel patterns even for men and women of similar socio-demographic characteristics.

The plots in the cyberspace reference (on the left) in Figures 4.12 and 4.13 show the correlations between attributes of Internet activities (Internet use, reason, and interaction) for the selected groups of men and women. As indicated by the axis representing Internet use in Figures 4.12 and 4.13, it is clear that both groups utilize the Internet mainly for sending email, gathering information, and completing work-related tasks. When compared to the group of men, women are more likely to engage in online buying and banking/paying bills.

The cyberspace reference system in Figure 4.12 shows the association between different Internet uses and reasons why the Internet was adopted. While each type of Internet activities differs in the most important reason for its being conducted online, it appears that more information available online is the major reason for both groups of
men and women to conduct online activities. This result suggests that for certain products or services people can obtain much more information using the Internet for comparing products and prices than in local stores. For these products and services, the Internet becomes the preferred means for shopping when compared to local stores. Further, saving time is another important reason for undertaking Internet activities. In particular, it is the most significant reason for full-time employed women to perform online banking/paying bills, which might be due to their highly constrained time-budget. Theoretically, the Internet may benefit people through both eliminating travel and saving time. But the results suggest that eliminating travel is not as important as saving time in promoting Internet activities. This observation based on the visualization of the PCP is supported by results we obtained from the focus groups conducted shortly after the survey. They indicate that traveling in the physical world is often considered by the participants as a desirable process that involves exploration and pleasure. Further, the correlations between Internet use and time comparison (not shown here) also reveal that the Internet is used as a time-saving tool in most situations, because it takes people more time to perform certain activities in the physical world than via the Internet.

To further explore the interaction between Internet activities and physical activities, we use email as an example. As shown in the cyberspace reference system in Figure 4.13, three types of relationships between email activities and physical activities can be identified. The first group of email activities cannot be undertaken without the Internet (Only Way), indicating that the Internet enables people to communicate and
maintain contacts that otherwise could not have happened, and this tends to increase
the overall communication that people undertake. The second group of email activities
can also be completed by traveling in the physical world (Travel), implying that some
travel is substituted by email and the Internet reduces the need for people to travel for
these activities. The last group of email activities can be conducted in the physical
world by using other media (Other Media) such as mailing, meaning that the Internet
is used to substitute certain types of physical activities for saving time. This in turn
suggests that certain types of Internet activities (such as email) may impact upon
people’s activities or travel in the physical world in different ways, and that the
Internet could influence people’s behavior through different mechanisms in different
situations.

Further, the cyberspace reference systems of women’s and men’s hybrid space-time
paths in Figure 4.13 also show important gender differences. For each type of Internet
activities, women and men may have different reasons to utilize the Internet. For
instance, most of the men’s email activities cannot be undertaken without the Internet
(Only Way) when compared to the women, suggesting that men’s email activities help
them maintain contacts that otherwise could not have happened. On the other hand,
women tend to use the Internet for email activities to eliminate travel (Travel) in the
physical world, which might be due to their already heavy travel for non-employment
activities as discussed earlier. In general, gender differences like this highlight the fact
that Internet use may have different impacts on the activity-travel patterns of different
social groups.
4.4 Conclusion

This study develops and employs 2D and 3D geovisualization methods for exploring human hybrid activity-travel behavior. Extending the traditional time-geographic construct of space-time paths, information cubes were developed to represent people’s accessibility to cyberspatial opportunities and to replace pertinent line segments on traditional space-time representations. As distance is not an important determinant of accessibility in cyberspace, three new factors were used for measuring information space: time spent on using the Internet, connection speed, and the number of websites accessed. The hybrid 3D space-time paths reveal gender differences in cyberspatial activity patterns. Not only do men tend to have greater accessibility to cyberspatial opportunities, but they are also more likely to use the Internet for recreational activities. Women, on the other hand, seem to keep their traditional gender role even when undertaking activities in cyberspace, as they perform more household-related activities online. Employment status also has an important impact on women’s cyberspatial behavior. Compared with women employed part time and non-working women, women who work full time are less likely to engage in online non-work activities in the daytime due to their stringent space-time constraint. Rather, they shift their Internet activities to the evening and use more time in the evening to do household-related tasks in cyberspace.

Visualization performed with hybrid 2D space-time paths and parallel coordinate plots also reveal the spatial patterns of people’s activity-travel in the physical world and the
correlations between Internet activity attributes. The plots were effective for examining why and how the Internet is utilized in the daily lives of individuals who belong to different social subgroups. When compared to opportunities in physical space, cyberspatial opportunities offer much more information to assist people’s routine tasks and cyberspatial activities are less time consuming to perform. Further, gender difference was also identified using the hybrid space-time paths of selected groups of men and women from the sample. In the physical world, men and women seem to have different spatial extents for their non-employment activities, and in cyberspace they tend to undertake the same type of Internet activities for different reasons.

Corroborating the results of previous research, the study found that the patterns of physical-virtual interactions are highly complex. Using the 3D and 2D geovisualization methods developed allowed us to uncover important patterns in hybrid human activity-travel behavior. The study shows that the extension of tradition time-geographic framework and visualization approaches in this direction is a fruitful and useful project.
CHAPTER 5

DOES LOCATION AFFECT INTERNET USE?
A SPECIAL CASE ON E-SHOPPING

5.1 Introduction

How the Internet modifies the activity-travel processes across different subgroups has been explored in Chapter Four through geovisualization approach. However, whether the geographic world will affect cyberspace and to what extent the geographic environment would influence cyberspace still remains unclear. This issue can be addressed by exploring the spatial characteristics of cyberspatial activities, because any evident spatial patterns of Internet activities may indicate that the geographic context could play a role in influencing people’s cyberspatial activity behavior. One way to explore the geographic pattern is by visualizing it. For example, information cubes of a kind of Internet use (or all of them) can be projected onto X-Y plane. When the projected information cubes are linked to other geographic layers, it is possible to identify the geographic patterns of this particular type of Internet activities (or general Internet use patterns). Unfortunately, this method cannot be directly applied in this
study because the data sample used is not a spatial random sample from the study area, which will make the visualization result hard to interpret.

Instead, this study directly applied statistical models (logistic and linear regression models) to examine the correlation between the Internet uses and the geographic context. Since not all of types of Internet activities are equally dependent on location, it is necessary to differentiate Internet activities. This study focuses on E-shopping patterns because E-shopping might mostly relate to the geographic environment, especially accessibility to local shops. The first attempt to examine the impact of spatial variables on E-shopping was undertaken by Farag et al. (2004a). Their results demonstrate that people with low accessibility to shops and people who live in non-urbanized areas conduct online buying more frequently, which indicates that people’s E-shopping behaviors in Utrecht is related to the spatial distribution of shopping opportunities and residential context. As urban and social structure and people’s behaviors are highly contextual and spatially contingent, it still remains unknown whether this finding holds in other socio-spatial contexts and what other insights we could obtain due to the change of study setting.

Therefore, this chapter will compare our Columbus data with the Utrecht study (Farag et al., 2004a) in terms of how these two distinctive geographic environments influence E-shopping behavior. In addition, because the episode data on E-shopping activities contained in the activity-Internet diary is not enough for statistical modeling, general
E-shopping information was used, including whether participants adopt of E-shopping and their online buying patterns.

This chapter is organized as follows: Section 5.2 focuses on developing statistical models to study what socio-economic and geographic factors influence E-shopping patterns. Analysis results are illustrated in Section 5.3. Finally conclusion and future research work will be summarized in Section 5.4.

5.2 Modeling E-shopping Patterns

In order to investigate whether location affects E-shopping behavior, both logistic and linear regression models were developed. First, the factors that may determine whether a person is an E-shopper were examined by building a logistic regression model. An individual in this study is defined as an E-shopper if he/she spends time on E-shopping (including both buying online and searching online) in a typical week. The explanatory variables in the logistic regression model include four sets of indicators: personal information, household information, Internet use information, and accessibility to local shops (Table 5.1). The variables of the first three categories can be obtained directly from the survey and accessibility to shopping opportunities was calculated with the digital parcel data and the transportation network of Franklin County as described in Chapter 3.

Besides the logistic regression, the linear regression models on another three continuous dependent variables were also built on the following three dependent
variables: the number of purchases made in the past twelve months, the number of products bought online in the past twelve months, and the amount of money spent on E-shopping in the past twelve months. Similarly, the four types of explanatory

Table 5.1: Explanatory variables

<table>
<thead>
<tr>
<th>Socio-demographic variables</th>
<th>Ratio of Children to Adult Age Gender Household income Working hours per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet use variables</td>
<td>The history of using the Internet The ease of searching for information The ability of using the Internet The amount of time spent online per week The connection mode</td>
</tr>
<tr>
<td>Geographic context</td>
<td>The numbers of shopping opportunities within travel times of 6.25 minutes, 10 minutes, 12.5 minutes, 15 minutes, 20 minutes, and 25 minutes The areas of shopping opportunities within travel times of 6.25 minutes, 10 minutes, 12.5 minutes, 15 minutes, 20 minutes, and 25 minutes Percentage of white population Population density Median household income Median contract rent Percentage of population with a higher education degree.</td>
</tr>
</tbody>
</table>
variables in the logistic regression model were also applied in the linear regression models. However, before all the potential explanatory variables were included in the final logistic model, the correlation between independent variables was checked first in order to avoid the problem of collinearity. For example, different accessibility measures are significantly correlated and therefore only one of them can enter the model at a time. The analysis results will be elaborated on in the next section.

5.3 Analysis Results

5.3.1 E-shoppers’ Characteristics

The analysis results are summarized in Table 5.2 through Table 5.5 (only significant variables are listed in the tables). It seems that people who shop more in physical world are more likely to adopt E-shopping as well. For example, women in our data sample are more likely to become E-shoppers than men as shown in Table 5.2. This might be due to the gender role that women have in the daily life. The past literature already demonstrates that women undertake more household related responsibilities including shopping and therefore they experience greater spatio-temporal constraints (Kwan, 1999a, 1999b, 2000). Thus, the incentive to save time and to eliminate travel would make women more likely search or buy products over the Internet.

Similarly, people with longer working time per week are less likely to conduct shopping activities over the Internet as they normally spend less time on shopping in a household. Therefore, E-shopping appears to be a helpful means to complement the
traditional way of shopping for people with more shopping responsibilities, rather than an effective way to change the share of shopping tasks in a household. In addition to demographic factors, people’s Internet use pattern also matters. People who use the Internet intensively and have longer Internet use history tend to adopt E-shopping more easily as they are more familiar with the Internet and have better Internet skills.

\[
\begin{align*}
\text{Spend time on online shopping: 1} \\
\text{Not spend time on online shopping: 0} \\
\text{Number of obs } &= 392 \\
\text{Chi-square (8) } &= 67.613 \\
\text{Sig. } &= .000
\end{align*}
\]

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (women – 1; men – 0)</td>
<td>.866</td>
<td>.243</td>
<td>.000</td>
</tr>
<tr>
<td>Working hours per week</td>
<td>-.015</td>
<td>.006</td>
<td>.018</td>
</tr>
<tr>
<td>Months of using Internet</td>
<td>.009</td>
<td>.003</td>
<td>.010</td>
</tr>
<tr>
<td>Time spent online per week</td>
<td>.001</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>The area of oppt. within 6.25 minutes driving (^1)</td>
<td>-.002</td>
<td>.001</td>
<td>.060</td>
</tr>
<tr>
<td>Percent of white population</td>
<td>1.967</td>
<td>.902</td>
<td>.029</td>
</tr>
<tr>
<td>Constant</td>
<td>-2.860</td>
<td>.954</td>
<td>.003</td>
</tr>
</tbody>
</table>

\(^1\) The number of opportunities within 6.25 minutes driving is significant at P<0.1
\(^2\) The area of opportunities within 12.5 minutes driving is significant at P<0.1

\(^2\) The value is less than .001.

Table 5.2: Model 1 – logistic regression result

Once people adopt E-shopping, their E-shopping patterns over the Internet are closely related to their Internet use patterns instead of their demographic characteristic. For example, gender difference is not statistically significant among E-shoppers in terms of how many products purchased and how much spent on the Internet (Table 5.3
through Table 5.5). Instead, time spent on the Internet and the Internet connection mode appear to be significant variables in Model 2 through Model 4. This is understandable because whether or not to become an E-shopper is relevant to a person’s needs, while to what degree he/she can engage in E-shopping largely depends on how much time he/she can spend on E-shopping and how efficiently he/she can complete shopping tasks. Obviously, the more time an E-shopper can spend online, the more likely he/she will engage in online shopping activities. Better Internet network performance will also makes E-shoppers undertake more shopping activities over the Internet. Further, the amount of money that E-shoppers spend online is also affected by the household income. A person living in a wealthier household tends to spend more money online.

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>.821</td>
<td>.180</td>
<td>.000</td>
</tr>
<tr>
<td>Time spent online per week</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Internet connection mode</td>
<td>.376</td>
<td>.107</td>
<td>.001</td>
</tr>
<tr>
<td>Percent of white population</td>
<td>.682</td>
<td>.396</td>
<td>.086</td>
</tr>
</tbody>
</table>

Table 5.3: Model 2 – linear regression result on the number of purchases made online
Table 5.4: Model 3 – linear regression result on the number of product bought online

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>.489</td>
<td>.427</td>
<td>.253</td>
</tr>
<tr>
<td>Time spent online per week</td>
<td>.000</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td>Internet connection mode</td>
<td>.312</td>
<td>.124</td>
<td>.012</td>
</tr>
<tr>
<td>Percent of white population</td>
<td>.781</td>
<td>.456</td>
<td>.087</td>
</tr>
</tbody>
</table>

Table 5.5: Model 4 – linear regression result on the amount of money spent online

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.167</td>
<td>.285</td>
<td>.000</td>
</tr>
<tr>
<td>Time spent online per week</td>
<td>.001</td>
<td>.000³</td>
<td>.000</td>
</tr>
<tr>
<td>Internet connection mode</td>
<td>.281</td>
<td>.147</td>
<td>.057</td>
</tr>
<tr>
<td>Household Income (binary variable)¹</td>
<td>.376</td>
<td>.149</td>
<td>.012</td>
</tr>
<tr>
<td>The number of oppt. within 15 minutes driving ²</td>
<td>-.001</td>
<td>.000</td>
<td>.041</td>
</tr>
</tbody>
</table>

¹ The household income is classified as high-income households and others. According to the sample, high-income households are the ones that have annual income greater than or equal to $80,000.
² The area of opportunities within 15 minutes driving is significant at P<0.1
The area of opportunities within 20 minutes driving is significant at P<0.1
The number of opportunities within 20 minutes driving is significant at P<0.1
5.3.2 The Impact of Shop Accessibility on E-shopping

Two CO indices (the number of and the area of shopping parcels) were calculated for each participant at the following network-based travel times: 6.25 minutes, 10 minutes, 12.5 minutes, 15 minutes, 20 minutes, and 25 minutes. A total of twelve CO indices were obtained for each household location. The logistic regression result indicates that three shop accessibility measures significantly affect the adoption of E-shopping: the area of shopping opportunities within 6.25 minutes driving distance, the number of shopping opportunities within 6.25 minutes driving distance, and the area of shopping opportunities within 12.5 minutes driving distance. Controlling for other explanatory variables, people with low shop accessibility more likely adopt E-shopping, which corroborates with the finding from the Utrecht study (Farag et al. 2004a). This finding could be explained by the geovisualization results in Chapter Four. According the data, the Internet is often used as an efficient tool that could save people’s the time and travel required to complete tasks in the physical world. Therefore, E-shopping could become an efficient strategy for people who are lack of accessibility to local stores to complete shopping tasks in cyberspace.

Moreover, the results also demonstrate that accessibility measures at 15 minutes and 20 minutes travel times have negative relationships with the amount of money spent online (Table 5.5). Since such relationships do not hold for the number of purchases made online and the number of products bought online, it can be inferred that shop accessibility at longer travel times affects the purchase of more expensive
goods/services more than cheaper ones. This finding can be explained by the notion of perceived risk (Assael, 1998).

In the context of E-shopping, two types of perceived risk were identified (Bhatnagar, et al., 2000): product category risk and financial risk. Product category risk is associated with the uncertainty regarding whether the products would function as consumer expect. It arises when people purchase a product that is new, is technically complex, or has high price. The likelihood of adopting E-shopping will decrease with the increase of product category risk. Financial risk in an in-store purchase is related to the cost of product relative to consumers’ disposable income. In the case of E-shopping, it also includes the risk of credit card information being disclosed. It is quite evident that people will be more likely to conduct in-store shopping when financial risk they perceive in a purchase is high.

Hence, high price increases both product category risk and financial risk, which makes consumers more cautious before they spend a large amount of money to buy an expensive item. In such a situation, reducing perceived product category risk has a higher priority than eliminating travel. As such, consumers would rather travel long distance to personally check the products in local stores. Further, the potential insecurity of electronic transactions will also discourage people from spending a large amount of money at once over the Internet. Therefore, people tend to buy expensive products online only when they are not readily available within a considerable distance from their homes in the physical world.
5.3.3 The Impact of Residential Environment on E-shopping

Unlike European cities, racial composition is an important factor that determines the social structure in the U.S. context. Among the residential indicators, percentage of population who are whites significantly affects the adoption of E-shopping (as shown in Table 5.2). People who live in the neighborhood highly dominated by white people are more likely to conduct online shopping. Similar results are found in Model 2 and Model 3. Percentage of population who are whites also positively relates to the frequency of buying online and the number of products purchased online. This might be because the residential environment created by white residents is more favorable to the expansion of E-shopping. Generally, white people have better socio-economic status and education background when compared to other racial groups. Therefore, the new way of shopping would be easier to be accepted by the affluent white people in a community at the early stage and it then may spread out to the entire neighborhood through the process of spatial diffusion in which phenomena is spread from limited origins to a sustainable population over space and time. Thus, in addition to a person’s socio-economic characteristics, the residential environment where he/she inhabits may also affect his/her E-shopping behavior.
Figure 5.1: Percent of populations that is White for census block groups in Franklin County

When comparing the results with the empirical results obtained in Utrecht, some difference can also be identified. As shown in the choropleth map (Figure 5.1), the residential areas that are dominated by white people are mostly located in the periphery of the county, while the neighborhoods where the share of white population...
is low are located in the inner city of Columbus, particularly in the eastern part of the county. This area of Franklin County has a high concentration of low-income African Americans. Therefore, contrary to the study in Utrecht where affluent people live in downtown (Farag et al. 2004a), people in the inner city of Columbus are less likely to buy online, indicating that E-shopping patterns vary spatially when the corresponding socio-spatial context changes.

5.4 Conclusion

This chapter preliminarily examines the impact of location on Internet activities with a focus on E-shopping activities. The results show that both shop accessibility and residential context may play a role in shaping people’s E-shopping behaviors. Firstly, availability of shopping opportunities within short distances from one’s home tends to reduce the need for online shopping. Secondly, shopping accessibility at longer travel times from home more likely affects the purchase of expensive goods/service - in that expensive items are considered worthy of longer travel. In order to reduce the perceived risk in a purchase, people seem to be less likely to buy expensive products online even though such opportunities locate farther from home. Both of these findings indicate that the spatial distribution of shopping opportunities has an impact on E-shopping patterns. As shop accessibility decreases, E-shopping is more likely to be adopted since the Internet can enhance the efficiency of shopping by providing more product information and by removing the need for travel.
Besides accessibility to local shops, residential context matters as well. This empirical study suggests that racial composition is an important indicator of residential environment in Franklin County and percentage of population who are whites in residential areas significantly influences the adoption of E-shopping and the frequency of E-shopping. People who live in a white-dominated community are more likely to adopt E-shopping and tend to buy online more frequently. Further, the spatial distribution of white population shows that such white-dominated neighborhoods actually locate in the suburbs of Franklin County instead of the inner city or downtown, indicating that people who live in downtown are less likely to buy online than suburban people. This result is opposite to the finding in the Utrecht study, which implies that location affects E-shopping patterns but the impact varies in different socio-spatial contexts.

In addition, the analysis results also indicate that people who take more shopping responsibilities in their daily life are more likely to become E-shoppers. Women and people who work less are more likely engage in online shopping activities as E-shopping complements their in-store shopping. Therefore, the Internet does not seem to be able to alter the share of shopping responsibilities in a household. Further, compared with a person’s demographic characteristics, his/her Internet use patterns and the Internet connection mode have a greater influence on the frequency of buying online. When people spend more time on the Internet and the Internet network performance improves, the frequency of buying online will increase significantly.
However, the findings of this study may not be applicable to other social groups because they are based upon a group of research participants that largely comprises white Americans in Columbus who rely on their own cars for transportation. In addition, the specific socio-spatial context of Columbus also makes it inappropriate to generalize the results to other socio-spatial contexts.
CHAPTER 6

MODELING HYBRID ACTIVITY-TRAVEL PATTERNS

6.1 Introduction

The interactions between cyberspace and physical space have been explored in Chapter Four, through which we have gained much insight into how the Internet could affect activity-travel processes in the physical world. The geovisualization results suggest that the Internet changes human activity-travel processes in a very complicated fashion and cyberspatial activity patterns differ across gender. These findings shed important light on the hypotheses for modeling human hybrid activity-travel patterns. Because women and men tend to behave differently on the Internet, it is reasonable to presume that the generalized impact of the Internet may be different across gender. Further, the impact of different types of Internet activities may also vary across gender in that women and men tend to engage in different Internet activities for different purposes. Last, the impact of the Internet on activity-travel patterns is expected to be complicated, the reason being Internet change activity-travel processes in complex ways. For example, when the Internet eliminates the travel, physical trips will be substituted by the Internet counterpart. However, when the
Internet saves people’s time, new activities or travels might be generated in the physical world. Therefore, it is necessary to examining what the complex impact would be. To test these hypotheses, this chapter will focus on modeling hybrid activity-travel patterns. In doing so, the relationships among various physical and Internet activity-travel attributes will be revealed and whether these relationships significantly differ across different subgroups can also be tested.

With respect to modeling how ICTs affect people’s activity-travel patterns, significant progress has been made in this research area as reviewed in Chapter 2. However, the impact of the Internet, the most influential communication technology, on activity-travel patterns remains unclear to date. First, due to the lack of detailed episode data on both activities in the physical world and Internet activities, the majority of current studies either focus on the impact of specific Internet use (such as telecommuting or E-shopping) or do not distinguish the Internet from other communication technologies. As such, the role of the Internet in modifying human activity-travel patterns has not been fully revealed. Further, it is still not clear that whether the Internet equally changes activity-travel patterns across different social groups and, if yes, how the impact of the Internet varies across different groups. To fill in these gaps, structural equation modeling technique (SEM) will be used to model hybrid activity-travel patterns and multiple group analysis methods will be used to test gender difference.

This chapter is organized as follows: a conceptual activity-based model is introduced in Section 6.2, followed by hypothesized models in Section 6.3. Model evaluation and
modification are illustrated in Section 6.4 and analysis results will be discussed in Section 6.5. Finally, Section 6.6 summarizes the findings and points out future research directions.

6.2 Conceptual Activity-based Model

Most structural equation models can be graphically depicted with path diagrams, in which variables are connected by single-headed and double-headed arrows. The direction of the arrows indicates the causal relation between the variables. Therefore, path diagrams provide a straightforward expression of model structures. Path diagrams will be used in this study to present the model strictures.

As illustrated in Chapter 3, the model specification in SEM should be drawn upon theories and empirical evidence. In the context of travel behavior research, Golob (2000) proposed a conceptual activity-based model with three components and their causal relationships: (1) activity engagement generates travel demand; (2) travel demand leads to travel engagement; and (3) travel engagement in turn affects activity engagement as time spent on travel will compete for the time spent on activities (Figure 6.1). Since this is an activity-based model in which time is regarded as an entity, the activity engagement at the highest level in the hierarchical structure is measured by the time spent on activities. Travel demand is calculated by the number visits (out-of-activities) required by activity engagement, and travel engagement is again represented by time spent on travel.
Another conceptual model, developed by Lu and Pas (1999), also suggested that activity participation influences travel behavior. It, however, ignores the feedback loop between travel engagement and activity participation. Drawing upon Golob’s conceptual model, Senbil and Kitamura (2003) tested four model structures based on two different conceptual models to study the impact of telecommunication devices (telephones) on people’s activities. The first conceptual model was built on the assumption that people will firstly allocate time to different activities, while the second model assumes that people firstly determine activity locations and the amount of time spent on activities is conditioned on the number of activity location visited. Their empirical results showed that the first causal structure in which telecommunications affect activity duration (activity engagement) and activity duration influences the number of out-of-home visits (travel demand) fits the data best.
These two different conceptual models were also experimented with the dataset in this study. The results also showed that the causal relation of activity engagement influencing travel demand fits the data better. Thus, the three-component conceptual model, which is theoretically sound and supported by considerable empirical evidence, was adopted in this study to examine the impact of the Internet on people’s activity-travel patterns.

Before specifying the model structure, activities recorded in the survey were first classified using Reichmann’s (1976) scheme. Classification will be helpful in the analysis since different types of Internet activities may have dissimilar influences on different types of activities conducted in the physical world. Activities performed by the participants in the physical world (physical activities) and in cyberspace (Internet activities) were classified into three categories: subsistence or work-related activities, maintenance activities for pursuing household or personal physiological and biological needs, and leisure activities including social and recreational activities. Further, since there are very few telecommuters in our sample and very few participants worked online after work, online subsistence activities do not seem to play a significant role in affecting the participants’ activity-travel for non-employment purposes. This chapter will therefore focus on the impact of Internet maintenance and leisure activities in this study.

After preliminary examination of the correlations among the variables and checking for multicollinearity, the set of exogenous variables in the models include four
variables representing people’s demographic characteristics and Internet use patterns. They include: (a) child ratio in the household, which is the number of children divided by the number of adults 18 years of age or older in the household; (b) work hours per week; (c) Internet use history, which is the number of months a participant has used the Internet; and (d) Internet connection mode, which is evaluated by a dummy variable (cable and DSL are fast connections and telephone modem is slow connection). The effect of these exogenous variables on the endogenous variables will be discussed in Section 6.4. The following discussion focuses mainly on the hypothesized interrelationships among the endogenous variables.

6.3 Hypothesized Models with SEM

Since geovisualization results suggest that men and women have different cyberspatial activity patterns, it is anticipated that men and may have different hybrid activity-travel patterns. Therefore, two hypothesized models were constructed for women and men respectively and gender difference was further tested using multiple-group analysis method as described in Chapter 3.

6.3.1 Hypothesized Relations between Various Activities

Due to the “zero-sum” property of time, different activities will compete for the fixed amount of time available to a person. Casual relations in the model can thus be specified based upon the priority of different types of activities. Since subsistence or work-related activities are mandatory, they tend to have a negative impact on the other two types of activities. However, as preliminary data analysis indicates, the number of
online recreational activities that full-time employed men conducted peaks at 9am and 9pm, indicating that the number of work hours is not likely to reduce men’s online leisure activities significantly. Therefore, it is expected the path from work-related activities to Internet leisure activities would be insignificant for the men group. On the other hand, maintenance activities tend to have higher priority than leisure activities. It is thus expected that the time spent on maintenance activities will have a negative impact on leisure activities.

Further, due to women’s gender role, online maintenance activities are anticipated to substitute for women’s maintenance and leisure activities in the physical world, while women’s online leisure activities will only substitute for their leisure activities in the physical world. As for the impact of the Internet on men’s activity engagement, only online leisure activities are hypothesized to affect men’s physical activities since men engage in much less online maintenance activities than women as revealed in preliminary data analysis.

6.3.2 Hypothesized Relations between Activity Engagement and Travel Demand

The travel demand driven by a particular type of activity is measured by the number of out-of-home visits required to conduct that type of activity. As shown in past studies, a person’s activity engagement in the physical world tends to have a positive influence on the travel demand for the same type of activities and the relations between different travel demands are similar to those between different activities.
With regard to the impact of Internet activities on travel demand, it is anticipated that different patterns across gender as men and women tend to have different cyberspatial behavior. More specifically, Internet maintenance activities would have a greater impact on women’s travel demand and Internet leisure activities, while online leisure activities would influence men’s travel demand to a greater degree. However, the signs of the paths in the model cannot be clearly specified beforehand because Internet activities could either generate new trips or reduce the need to travel. These signs will only become apparent when the models are estimated.

6.3.3 Hypothesized Relations between Travel Demand, Travel Engagement and Activity Engagement

The third component of the conceptual model is travel engagement, which is generated by travel demand and measured by the amount of time spent on travel. An important relationship is that the amount of time spent on travel (travel engagement) will increase as levels of activity engagement and travel demand rises. Further, the time spent on travel will have a feedback effect on activity engagement as suggested by previous studies and indicated in Figure 6.1. It is therefore expected that long commuting time will reduce the time allocated to physical maintenance and leisure activities. As revealed by the preliminary analysis, direct paths from Internet activities to travel engagement are not postulated. However, indirect effect of Internet use on travel engagement is expected.
Figure 6.2: Final baseline model for women
Figure 6.3: Final baseline model for men
Generally, the hypothesized models modifies Golob’s activity-based conceptual model, to incorporate the Internet activities and its impacts on activity-travel patterns in the physical world. In particular, unlike the model structures in the previous studies, gender is not an exogenous variable; instead, women and men are expected to have different model structures and therefore they have their own hypothesized path diagrams.

6.4 Model Modification and Evaluation

6.4.1 Model Modification

Based on the hypothesized relations discussed above, the causal structures of two baseline models, one for the women group and the other for the men group, were specified and estimated with AMOS. Modifications of several Internet-related paths were made in these models in light of the modification indices generated by AMOS, the significance of the parameters, and substantive meanings of the paths. On one hand, two paths were added for the men group: one from Internet maintenance activities to physical leisure activities and the other one from Internet leisure activities to travel engagement for maintenance purposes. On the other hand, three paths were deleted: two from Internet leisure activities to physical leisure activities for both the women and men groups, and the other from subsistence activities to online leisure activities for the men group. The final baseline models are shown in Figures 6.2 and 6.3, and two charts that summarize the standardized total effects (STE) of online
maintenance and leisure activities are also provided in Figures 6.4 and 6.5 for the discussion in section 6.5.

6.4.2 Final Model Evaluation

The goodness-of-fit statistics of these models indicate that both models fit the data well (women: Probability of Chi-square (p) = 0.845, Goodness of Fit Index (GFI) = 0.955, Normed Fit Index (NFI) = 0.951, Incremental Fit Index (IFI) = 1.000; men: p = 0.523, GFI = 0.944, NFI = 0.917, IFI = 1.000). The standardized total effects between exogenous variables and endogenous variables are summarized in Tables 6.1 through 6.3, which indicate that most of the causal paths among physical activity-travel variables corroborate the findings of previous studies. This chapter will therefore focus largely on the impact of the Internet on physical activity-travel patterns below.

In addition to these two final baseline models, two multiple-group analyses were conducted: one is for testing invariance across the calibration sample and the validation sample in the women group, and the other is for testing invariance across gender. For testing invariance across the calibration group and the validation group, the women group in our subsample was randomly split into a two groups: 132 were in the calibration group and 124 were in the validation group. The calibration sample was used to estimate the final model for the women group, and the model was then tested using the validation sample as the baseline model. With structural weights, structural covariance, and structural residuals set to be equal across these two groups, the chi-square values of the three constrained models are not significant (p = 0.180, p = 0.221,
p = 0.128 respectively), which means that we cannot reject the hypothesis that model paths, residuals, and covariance are equal across the calibration and validation groups. This test increases the confidence in generalizing these findings to the entire group of women.

Multiple-group analysis for gender comparison was performed against the two baseline models. No matter which baseline model was used, the chi-square values are significant when structural weights are set to be equal across gender (p = 0.002 for women’s baseline model and p = 0.006 for men’s baseline model). This suggests that the hypothesis that the relationships between activity-travel patterns and Internet use for the women group and the men group can be modeled by the same causal structure should be rejected. Since significant variant model structures are found across gender, applying the same model to both gender groups cannot fully reveal how gender mediates the impact of the Internet on people’s activity-travel patterns.
<table>
<thead>
<tr>
<th></th>
<th>Baseline Model 1 (Women)</th>
<th></th>
<th>Baseline Model 2 (Men)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Child ratio</td>
<td>Work hours</td>
<td>Mode type</td>
</tr>
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<td>TimeWork</td>
<td>.005</td>
<td>.788</td>
<td>.000</td>
</tr>
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<td>TimeMaintenance</td>
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<td>-.662</td>
<td>-.018</td>
</tr>
<tr>
<td>TimeLeisure</td>
<td>-.112</td>
<td>-.460</td>
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</tr>
<tr>
<td>VisitWork</td>
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<td>.570</td>
<td>.000</td>
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<tr>
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<td>.019</td>
</tr>
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<td>VisitLeisure</td>
<td>.213</td>
<td>-.199</td>
<td>.000</td>
</tr>
<tr>
<td>IntMaintenance</td>
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<td>-.156</td>
<td>.116</td>
</tr>
<tr>
<td>IntLeisure</td>
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<td>-.132</td>
<td>-.026</td>
</tr>
<tr>
<td>TrvWork</td>
<td>.004</td>
<td>.609</td>
<td>.000</td>
</tr>
<tr>
<td>TrvMaintenance</td>
<td>.274</td>
<td>-.038</td>
<td>.015</td>
</tr>
<tr>
<td>TrvLeisure</td>
<td>.117</td>
<td>-.220</td>
<td>-.005</td>
</tr>
</tbody>
</table>

**Note:**
- Mode type – the Internet connection mode
- Int. history – the history of using the Internet
- TimeWork – time spent on work
- TimeMaintenance – time spent on physical maintenance activities
- TimeLeisure – time spent on physical leisure activities
- VisitWork – the number of visits for work
- VisitMaintenance – the number of visits for physical maintenance activities
- VisitLeisure – the number of visits for physical leisure activities
- IntMaintenance – the time spent on Internet maintenance activities
- IntLeisure – the time spent on Internet leisure activities
- TrvWork – the time spent on travel for work
- TrvMaintenance – the time spent on travel for physical maintenance activities
- TrvLeisure – the time spent on travel for physical leisure activities

Table 6.1: Standardized total effects of exogenous variables on endogenous variables defined in two baseline models
### Table 6.2: Standardized total effects between endogenous variables in women’s model

<table>
<thead>
<tr>
<th></th>
<th></th>
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<td>0</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
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<td>0</td>
<td>0.002</td>
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<td>-0.332</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>IntLeisure</td>
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<td>0</td>
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</tr>
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<td>0.222</td>
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<td>0.494</td>
<td>-0.04</td>
<td>0.067</td>
<td>0.784</td>
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<td>-0.06</td>
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### Table 6.3: Standardized total effects between endogenous variables in men’s mode

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<tr>
<th></th>
<th>TimeMaintenance</th>
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<td>-0.079</td>
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</tr>
</tbody>
</table>

Table 6.2: Standardized total effects between endogenous variables in women’s model

Table 6.3: Standardized total effects between endogenous variables in men’s mode
6.5 Results

6.5.1 Impact of exogenous variables on endogenous variables

Child ratio was used in this study as a surrogate measure for the amount of household tasks each adult within the household needs to perform. Previous studies have found that it is a superior measure of household responsibilities when compared to the number of children (e.g., Kwan, 1999). A person in a household with higher child ratio is expected to have higher level of household related activities and trips as more household tasks need to be performed. The model results support this anticipation in that women and men in households with higher child ratios spent more time on physical maintenance activities (Table 6.1). However, the magnitude of the two standardized total effects (STE) is quite different (STE for women is 0.111 and for men is 0.004). Hence, women seem to share a greater portion of domestic responsibilities associated with childcare. Further, men in households with higher child ratios tend to have lower levels of participation in maintenance travel, while child ratio have a positive impact on women’s travel associated with physical maintenance activities. This gender difference can be explained when the impact of child ratio on work hours is taken into account. As indicated in Table 6.1, men in households with higher levels of child ratio spent more time on work than women STE for women is 0.005 and for men is 0.074). This suggests that men tend to contribute to household labor through paid work while women tend to share a larger proportion of unpaid domestic responsibilities. This observation corroborates the results of some recent studies, which found that women’s Internet use tends to reinforce their
traditional gender roles and perpetuate existing gender division of household labor (Kwan, 2003; Schwanen and Kwan, 2008)

Further, although women’s in households with higher child ratios have higher levels of participation in physical maintenance activities and trips, both women and men in these households have lower levels of participation in online maintenance activities. This may be due to the difficulty (or impossibility) of performing most childcare-related tasks using the Internet (such as school drop-off and pick-up).

When compared to its effect on physical maintenance activities and trips, the effect of child ratio on physical leisure activities and trips is more complex. While reducing people’s time spent on physical leisure activities (STE for women is -0.112 and for men is -0.063), higher child ratios increase the number of out-of-home leisure activities and women performed more of these activities when compared to men (STE for women is 0.213 and for men is 0.015). This seems to suggest that many outdoor leisure activities of the participants are associated with the need of their children (e.g., sport games and outdoor playing).

Besides child ratio, employment status is also an important factor in people’s space-time constraints and activity-travel patterns. As expected, work hours per week has a negative impact on maintenance and leisure activities (and trips) in both the physical world and cyberspace, as work and work-related tasks are mandatory and they compete for usable time that can be used to perform other activities. Lastly, the
exogenous variables pertaining to people’s Internet use also affect the corresponding Internet activities. Participants with faster Internet connection and longer history of Internet use tend to perform more online maintenance and leisure activities.

6.5.2 Impact of the Internet use for maintenance

As shown in Figures 6.2 and 6.4, the effect of Internet (or online) maintenance activities on physical maintenance activities is different across gender. Online maintenance activities have a direct negative impact on women’s engagement in physical maintenance activities (path coefficient = -0.153). This negative path implies that, for the women group, maintenance activities that were undertaken using the Internet substitute some of the maintenance activities that were completed in the physical world before. However, the small path coefficient also suggests that most physical maintenance activities cannot be completed using the Internet (like cooking and eating). When compared to women, online maintenance activities do not have a direct effect on men’s engagement in physical maintenance activities. This may be due to the small amount of time men spent on online maintenance activities, and it also suggests that the maintenance activities that men usually conduct using the Internet would not have been undertaken without the Internet. Therefore, the Internet seems to complement men’s activity space in the physical world for maintenance purposes. This finding may be explained by the fact that men used to perform a smaller range of maintenance activities when compared to women, and this leaves them with more room for undertaking new maintenance activities as the Internet offer various opportunities for doing so.
However, the effect of online maintenance activities on physical leisure maintenance activities does not differ across gender. For both gender groups, Internet maintenance activities have a negative effect on leisure activity engagement (path coefficient for women = -0.287 and for men = -0.271). Further, travel demand for both gender groups declines as leisure activity engagement declines. However, since Internet maintenance activities reduce women’s participation in physical maintenance activities, which indirectly increase their engagement in physical leisure activities, the overall negative impact of online maintenance activities on women’s physical leisure activities is somewhat subdued, and that is why the negative impact of online maintenance activities on men’s leisure activity engagement and travel demand is greater (as shown in Figure 6.4).

Figure 6.4: Standardized total effects of online maintenance activities on physical activity-travel of different categories

Category 1: time spent on physical maintenance activities
Category 2: time spent on physical leisure activities
Category 3: number of visits for maintenance activities
Category 4: number of visits for leisure activities
Category 5: time spent on travel for maintenance activities
Category 6: time spent on travel for leisure activities
Further, the impact of Internet maintenance activities is quite complex even within the same gender group. On one hand, they reduce women’s engagement in physical maintenance activities. On the other hand, they have a direct positive effect on women’s travel demand for maintenance activities (path coefficient = 0.204) and the total effect is also positive (STE = 0.162) even taking into account the indirect negative impact mediated by physical maintenance activities. There are two possible explanations for these positive paths. When the Internet is used as a time-efficient tool, it will take less time to conduct an activity online than in the physical world. The time saved can then be used to conduct more out-of-home activities. Information obtained from the Internet may also generate new travel demand. Internet maintenance activities therefore tend to have a greater impact on women’s activity-travel patterns since women engage in more online maintenance activities than men.

6.5.3  Impact of the Internet use for leisure

Although Internet leisure activities do not have any significant impact on women’s activity-travel patterns (Figure 6.2), they have considerable effect on men’s activity-travel patterns. When compared to women, men’s Internet leisure activities reduces their engagement in physical maintenance activities (path coefficient = -0.184) and there is an indirect positive effect on their physical leisure activities (STE = 0.142). This observation implies that physical maintenance activities are less discretionary for women than for men as women’s maintenance activities are not directly affected. Further, Internet use for leisure activities does not directly affect the time spent on physical leisure activities for both women and men, which indicates that the Internet
may expand the leisure opportunities that people have access to instead of changing the way of performing the same activities.

![Figure 6.5: Standardized total effects of online leisure activities on physical activity-travel of different categories](image)

Similar to the complex impact of online maintenance activities on women’s physical activities, the impact of online leisure activities on men’s physical activities and travel is also complex. As indicated in Figure 6.5, men’s online leisure activities have direct impacts on their travel demand for maintenance and leisure, reducing their travel for leisure while increasing their travel for maintenance. After taking into account of both direct and indirect effects, these opposite effects of men’s online leisure activities on their maintenance and leisure travel remains similar (with small change in the
magnitude of the impacts). These opposite effects are understandable. Since a great variety of leisure activities can be performed with the Internet, men’s Internet leisure activities tend to substitute for their physical leisure activities and may therefore reduce their need to travel for leisure activities in the physical world. On the other hand, men’s Internet leisure activities seem to have a stimulating effect on their physical maintenance activities, as they may seek to meet their needs for being outsides and travel and undertake more maintenance trips.

Important insights into the impact of the Internet can be gained when the above findings related to online leisure activities are considered together with the results on online maintenance activities discussed in Section 6.5.2 above. First, it appears that men tend to use the Internet to expand their range of activities for both maintenance and leisure activities. The Internet therefore benefits men largely through providing more activity opportunities. Second, although the Internet has substitutive effects for both women’s and men’s activities and trips, they seem to stem from different processes. The substitution effect for the men group is largely due to time competition, where one type of Internet activities always reduces the time spent on the other type of physical activities. However, the substitution effect for the women group seems to involve replacing physical activities by Internet activities of the same type. Overall, the impacts of the Internet on people’s activity-travel patterns are highly multifaceted and gender plays an important role in mediating such impacts, rendering what are already complex effects even more confounding.
6.5.4 Impact of the Internet use for maintenance and leisure

After examining the impact of different types of Internet activities, we now turn to the total impact of both Internet maintenance and leisure activities. This was achieved by adding up Figures 6.4 and 6.5, and the result is shown in Figure 6.6, which reveals a

![Figure 6.6: Standardized total effects of online non-subsistence activities on physical activity-travel of different categories](image)

- Category 1: time spent on physical maintenance activities
- Category 2: time spent on physical leisure activities
- Category 3: number of visits for maintenance activities
- Category 4: number of visits for leisure activities
- Category 5: time spent on travel for maintenance activities
- Category 6: time spent on travel for leisure activities

Figure 6.6: Standardized total effects of online non-subsistence activities on physical activity-travel of different categories

...very intriguing pattern across gender: the gender differences identified above are no longer apparent when the two types of Internet activities (maintenance and leisure) are considered together. In general, Internet maintenance and leisure activities on the whole seem to consistently reduce people’s activity engagement in maintenance and leisure. But they have a more complex effect on travel demand and travel engagement:
they have a net positive impact on travel demand and engagement in maintenance activities, and a net negative impact on travel demand and engagement in leisure activities. Although gender differences are not apparent after combining different types of Internet activities, the underlying processes that generate the similar patterns are considerably different across gender as discussed earlier. Therefore, decomposition of Internet activities into different categories enables us to obtain better understanding of how different Internet uses lead to dissimilar activity-travel patterns across gender and how Internet activities generate similar overall activity-travel patterns across gender through different processes.

6.6 Conclusion

This chapter aims to examine the complex impacts of the Internet on human activity-travel patterns with a focus on gender differences. To achieve the research goal, multiple-group structural equation modeling was used to examine model invariance for two group structures. First, it was used to test model invariance across the calibration and validation samples within the women group in order to address the issue associated with post hoc model fitting. In doing so, the model constructed in the study is more robust and sound. Second, multiple-group analysis was conducted to test model invariance across the two gender groups in the subsample. The results indicate that the impacts of Internet activities on people’s activity-travel patterns are significantly different across gender. In general, Internet use for maintenance purposes has a greater impact on women’s activity-travel in the physical world, while Internet use for leisure purposes affects men’s physical activities and travel to a greater extent.
Further, breaking Internet activities down into different categories reveals some hidden patterns that would not have been detected if these different types of Internet activities were lumped together as a single category. This study, which focused particularly on Internet maintenance and leisure activities, yields the following results. First, the same type of Internet activities (e.g., maintenance) unequally influences activity-travel patterns across gender. For example, online maintenance activities substitute for women’s physical maintenance activities while complement men’s physical maintenance activities. When compared to women, men seem to take advantage of the Internet to perform more new activities. Second, the impact of the Internet is complex even within the same gender group. For instance, Internet use for maintenance activities boosts the number of women’s out-of-home maintenance activities while reducing the time they spent on physical maintenance activities. Similarly, Internet use for leisure purposes reduces men’s travel demand for leisure activities while increasing their travel demand for maintenance activities. Third, the same patterns across gender seem to have been generated by different processes. For example, substitution effect for men is largely due to time competition, while for women it is mainly a result of replacement of physical activities by similar Internet activities.

Because of its particular focus, this study has some limitations that should be addressed in future research. For example, some trip characteristics (such as trip-chaining) were not incorporated in the models. As a result of this, the impact of the
Internet on the sequencing of activities still remains unclear. Further, interactions between household members, which may play an important role in people’s activity scheduling and travel decision-making, were not considered. I plan to address these limitations in the future research.
CHAPTER 7

CONCLUSIONS

7.1 Introduction

The primary objective of this research is to examine the impact of the Internet on human activity-travel patterns with a special attention to gender difference. This research issue is important because the traditional geographic principles become improper to study human activity-travel behavior and other geographic phenomena that occur in cyberspace. In the physical world, distance is an important organizing principle of human spatial behavior and the city in that distance determines the cost to overcome the physical obstacle. However, there is no such a need to conquer the distance friction in cyberspace. Therefore, conventional geographic principles that based on distance impedance need to be expanded or modified in order to be able to accommodate the cyberspatial phenomena.

The research on modifying existing or creating new geographic frameworks to accommodate the impact of cyberspace has drawn much attentions and has been undertaken from different perspectives and at various scales. This research attempts to
move the inquiry further along by investigating people’s hybrid activity-travel patterns. In doing so, not only new geographies of everyday life can be revealed, but also it sheds lights on other related studies, such as research on transportation, urban travel demand and spatial structures, and gender relation. As a conclusion of this study, this chapter will mainly discuss the significance and key findings of the work and future research direction.

This chapter is organized as follows: the next section will generally discuss the relation between the Internet and activity-travel patterns as well as the gender relations of the technology. The implications of the study for other research areas will be summarized in Section 7.3. Finally, the limitation and future research direction will be pointed out.

7.2 The Internet, Activity-Travel Patterns, and Gender Relations

Extensive activity-based travel behavior research has been conducted since 1970’s due to the availability of new data collections and more advanced activity modeling approaches. These studies greatly enhance our standing of contemporary travel behavior and urban travel demand. However, human activity-travel processes are being changed today when more and more people adopt advanced telecommunication technologies, the Internet in particular, in their daily life. Unlike in the physical world where travel behavior and urban structures are formed by distance friction principle, the Internet provides a quite different environment where people can perform even more activities with much less space-time constraints. For example, the opportunities
over the Internet do not have business hours and no travel is required to have interaction with them. Unfortunately, human hybrid activity-travel behavior still remains unclear to date due to lack of proper analytical framework and the short of required data.

Given the limitations existing in the past studies, this work attempts to investigate the relation between the Internet and activity-travel behavior with two foci by using an activity-Internet diary data. The first focus is on exploring the interaction between geographic space and cyberspace from the perspective of individual activity-travel behavior. On the one hand, the Internet will affect geographic space through changing human activity-travel patterns in space and time. As a response to the modified activity-travel behavior in the physical world, city travel demand and the structure of urban opportunities might also be influenced as well. On the other hand, geographic space may also have impact on cyberspace by intervening people’s engagement in cyberspatial activities. The other focus of the study is on the quantifying the impact of the Internet on activity-travel patterns.

When addressing these two major issues, gender relation of technology should be taken into account, as it is an important dimension that will mediate the impact of technology. Past studies have argued that the social relations of technology have historically subordinated or constrained women (Cockburn, 1983, 1985; Cowan, 1989; Wajcman, 1991). They documented repeated instances of daily-use technologies intended to free women but actually confining them by reinforcing traditional gender
roles. For instance, domestic technologies such as the home washing machine, dishwasher or vacuum cleaner actually reinforced existing gender relations and the gender division of domestic labor (Light, 1995). Will women’s use of ICTs in the domestic context have the similar tendency to reinforce existing division of domestic labor? Or will the impact of increasing use of ICTs on women’s everyday lives be similar to transportation systems that restrict women’s mobility and exacerbate women’s confinement to the home and the immediate locality (Wajcman, 1991)?

The hybrid 3D space-time paths, an innovative geovisualization approach developed in this study, revealed gender differences in cyberspatial activity patterns. Not only do men tend to have greater accessibility to cyberspatial opportunities, but they are also more likely to use the Internet for recreational activities. Women, on the other hand, seem to keep their traditional gender role even when undertaking activities in cyberspace, as they perform more household-related activities online. Therefore, gender convergence theory (Bianchi et al., 2000; Presser, 1994) does not seem to readily examine the gender relation of the Internet.

Visualization performed with hybrid 2D space-time paths and parallel coordinate plots suggest that the way of the Internet intersects with geographic space is highly complex. For example, the same type of the use of the Internet can influence activity-travel processes through different ways, including expanding activity space, substituting physical travel, and modifying the traditional way of performing activities. The plots are also effective for examining why the Internet is utilized in the
daily lives of individuals who belong to different social subgroups. Gender difference was identified using the hybrid space-time paths of selected groups of men and women from the sample. In the physical world, men and women seem to have different spatial extents for their non-employment activities, and in cyberspace they tend to undertake the same type of Internet activities for different reasons.

While geographic space is under the impact of the Internet, it also alter cyberspace in return by intervening people’s use of the Internet. In this study, the effect of the geographic context on E-shopping activities was an example examined by geovisualization and statistic modeling approaches. The modeling results support the geovisualization observation that E-shopping is dependent on local environment. More specifically, shop accessibility and residential characteristics will influence the adoption of E-shopping and E-shopping patterns including the frequency of E-shopping and the amount of money spent on the Internet.

Therefore, cyberspace will by no means replace geographic space as argued by technologically determinists (e.g. Mitchell, 1995; Cairncross, 2001); instead, these two spaces interact with each other in a complicated fashion. In the meanwhile, new hybrid activity-travel patterns are being shaped as one of outcomes of such interactions. Generalizing such hybrid activity-travel patterns is the second major focus of the study. Collaborating with the results of previous research, this work finds out that the relationship between the Internet and physical activity-travel patterns are multifaceted
in that several effects coexist. For example, while the Internet substitutes activities in the physical world, it may also increase the travel demand to pursue other activities.

Complementing existing research, this study reveals more hidden hybrid activity-travel patterns by breaking down the Internet uses into different categories and by examining the gender difference in the impacts of these various Internet activities. The analysis results suggest that various types of Internet activities have significantly different impacts on women and men. In general, the Internet use for maintenance has a greater impact on women while the Internet use for leisure affects men to a greater extent. Another intriguing finding is that the impacts of the Internet on activity-travel patterns of women and men seem to be in a similar fashion when various Internet uses are mixed together, suggesting the similar pattern might be generated by different underlying processes. Therefore, it can be concluded that intervene of gender role makes the impact of the Internet even more complex and it is impossible to gain much insight into such complexity without differentiating the Internet activities.

In conclusion, the study developed new analytical approaches to overcome the difficulty of traditional activity-travel frameworks and collected a detailed activity-Internet diary dataset to facilitate modeling the relationship between the Internet, activity, and travel. It reveals how complex impacts of the Internet on activity-travel are mediated by gender, indicating that gender relations of the Internet is an important dimension for studying new geographies of everyday life.
7.3 Implications of Research on Hybrid Activity-Travel Patterns

Although activity-travel research is normally conducted with individual level data and emphasizes on individuals’ behaviors, it has significant implications for other related studies. The first research area that connects to individual activity-travel is transportation. The past literature already suggest that activity-based modeling approach can better forecasting urban travel demand since it consider a much wider range of factors to model relationship between individuals, household, and cities. However, with the involvement of space adjusting technologies, such as the Internet, travel demand is being altered. For example, in addition to office buildings, home could be the place where work activities occur through telecommuting today, showing that traditional spatial patterns of working activities are being rearranged and commuting travel demand are being reduced (Moss and Townshed, 2000a). Therefore, studying how individual adjust their travel demand in their daily life in the information age will have important implications for transportation policy and research.

Second, by revealing spatial patterns of activities and new geographies of a large number of individuals, we will be able to look into how the Internet could possibly reformulate urban spatial structures. For instance, shopping activities do not necessarily take place in shopping stores as they did in a traditional fashion. When E-shopping are widely adopted, this individual behavior will become more significant at the aggregate level, which will eventually result in geographic consequences at macro-level in the physical world, that is, urban opportunities will be redistributed and
rearranged. A local store may relocate to a remote area to save cost if local residents mainly purchase its goods via the Internet.

Besides geographical changes occurring in urban areas, ICTs is also creating other urban phenomena, such as information economy, information infrastructures, and virtual communities (Moss and Townshed, 2000b). All these new facts raise new questions to urban policy makers. To date, regional and urban studies have already recognized the limitations of previous urban planning models and have proposed to integrate ICTs into urban planning (Graham and Marvin, 1996; Grant and Berquist, 2000; Sanyal, 2000; Beyers, 2000). The common conclusion drawn from these studies is that new strategies are in demand in order to make a sustainable urban development plan that can accommodate telecommunication systems. In this sense, the insight gained from hybrid activity-travel research will enhance the understanding of how ICTs could transform urban phenomena through shaping new urban spatial activity patterns.

In the meantime, the study on hybrid activity-travel will also promote the research on accessibility. Accessibility has been one of the major subjects in geography for decades in that the formulation of urban spatial structure is inherently to maximize the accessibility of residents to different types of urban opportunities and urban infrastructures. From the perspective of recent space-time measures of accessibility (Miller 1991, 1999; Kwan 1998, 1999a; Weber and Kwan, 2002), individual accessibility is dependent upon personal activity scheduling decisions and the
accessible opportunities. When people can pursue activities over the Internet, the notion of “opportunities” should be expanded to accommodate the opportunities that exist in cyberspace, which implies that traditional accessibility should be extended to the notion of “hybrid-accessibility” (Shen, 2000; Kwan 2001; Dijst, 2003). Hybrid activity-travel pattern research to date has suggested the relaxation of space-time constraints and revealed people’s cyberspatial activity patterns and potential information space. These conceptual and empirical results considerably facilitate studying hybrid-accessibility.

Furthermore, the activity-travel pattern of an individual could also be a hint of his/her social status. A CEO’s daily activity pattern must differ from that of a blue-collar worker. Therefore, the investigation of impact of ICTs on people’s activity-travel patterns will also serve the study on social effects of ICT. The example of the wide adoption of private automobiles in the US has already demonstrated that an advanced technology could have two-side social effects (Shen, 2000). On the one hand, private automobiles greatly enhance mobility and accessibility of some subgroups that own private cars; but on the other hand, it becomes more difficult for subgroups that do not have private cars to have access to urban opportunities since these opportunities are dispersed to remote locations. Thus, automobiles to a great extent reinforce social inequity. In addition to the issue of social equity, Hanson (1996, 1998) also raised the questions about how the gender divisions of domestic labor might be changed as men spend more time at home by telecommuting, and whether ICTs would increase diversity of information exchanged and heterogeneity of social networks. To answer
those questions about social effects of ICT, such as social equality and the gender divisions of labor, one possible approach is to explore how people of different subgroups alter their economic activities as well as other activities with the help of ICT.

7.4 Future Research

Several topics can be identified as supplementing this study for further research. Because individual activity-travel patterns are often made through intro-household decision-making processes, it is important to include other household members’ activity scheduling and travel participation when analyzing an individual’s activity-travel patterns. This issue has been considered in conventional activity-travel research, but has not fully addressed in hybrid activity-travel studies. As a matter of fact, by studying the interactions between household members, especially the interactions between two household heads, we may gain more insight into how household members collaborates together to share household duties and meet their own needs through the use of the Internet. For example, when the Internet makes some daily tasks that were usually undertaken by women easier to complete, men might be more willing to participate in these activities since less efforts are required. In this situation, responsibility shift and changes in activity participation will occur for both household heads. Therefore, it is necessary to include interactions between household members when modeling hybrid activity-travel patterns. Further, some trip characteristics were not incorporated in this study, such as trip-chaining characteristics; as such, the impact of the Internet on frequency and sequence of activities still remains unclear. These trip
characteristics should be taken into account in future research in order to gain more insight.

An important research area for future is on spacing and timing of cyberspatial activities. Although cyberspatial activity patterns of different groups were identified in this study, it is not clear to date the rhythm of these activities. Drawing on the past activity duration studies, further research on Internet activity duration and location will add much value to the current literature.

Due to the data limitation, the samples in this study largely comprises white Americans in Columbus who rely on their own cars for transportation, which makes the findings of this study not be applicable to other social groups. In addition, the specific socio-spatial context of Columbus also makes it inappropriate to generalize the results to other socio-spatial contexts. Therefore, it is worth collecting data on other social groups in different study settings to examine whether the impact of the Internet remains similar. By comparing analysis results obtained from different datasets, we will be able to further examine the social effects of the Internet, such as the impact on social equity and social networks.
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### Appendix: Example of Franklin County Major Land Use and Codes

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<tr>
<td>401</td>
<td>Apartments: 4 To 19 Rental Units</td>
</tr>
<tr>
<td>402</td>
<td>Apartments: 20 To 39 Rental Units</td>
</tr>
<tr>
<td>403</td>
<td>Apartments: 40+ Rental Units</td>
</tr>
<tr>
<td>404</td>
<td>Apartments Over Retail (Walkup)</td>
</tr>
<tr>
<td>405</td>
<td>Office Over Retail (Walkup)</td>
</tr>
<tr>
<td>406</td>
<td>Storage Over Retail (Walkup)</td>
</tr>
<tr>
<td>407</td>
<td>Commercial Lawn/Garden Sales Or Other Commercial</td>
</tr>
<tr>
<td>408</td>
<td>Open Code Or Other Commercial</td>
</tr>
<tr>
<td>409</td>
<td>Housing - Elderly Or Other Commercial</td>
</tr>
<tr>
<td>410</td>
<td>Motel/Tourist Cabins</td>
</tr>
<tr>
<td>411</td>
<td>Hotel</td>
</tr>
<tr>
<td>412</td>
<td>Nursing Home - Full Service And Private Hospitals</td>
</tr>
<tr>
<td>413</td>
<td>Nursing Home - Custodial</td>
</tr>
<tr>
<td>414</td>
<td>Rooming Houses</td>
</tr>
<tr>
<td>415</td>
<td>Manufactured Home Park</td>
</tr>
<tr>
<td>416</td>
<td>Commercial Camp Ground</td>
</tr>
<tr>
<td>417</td>
<td>Day Care/Pre School</td>
</tr>
<tr>
<td>418</td>
<td>Fraternities/Sororities</td>
</tr>
<tr>
<td>419</td>
<td>Other Community Housing</td>
</tr>
<tr>
<td>420</td>
<td>Small Detached Retail Structures (Under 10,000 Square Feet)</td>
</tr>
<tr>
<td>421</td>
<td>Supermarkets</td>
</tr>
<tr>
<td>422</td>
<td>Discount Stores And Junior Department Stores</td>
</tr>
<tr>
<td>423</td>
<td>Catalog Showroom Sales</td>
</tr>
<tr>
<td>424</td>
<td>Full Line Department Store</td>
</tr>
<tr>
<td>425</td>
<td>Neighborhood Shopping Center</td>
</tr>
<tr>
<td>426</td>
<td>Community Shopping Center</td>
</tr>
<tr>
<td>427</td>
<td>Regional Shopping Center</td>
</tr>
<tr>
<td>428</td>
<td>Amusement Parks</td>
</tr>
<tr>
<td>429</td>
<td>Other Retail Structures</td>
</tr>
<tr>
<td>430</td>
<td>Restaurant, Cafeteria And/Or Bar</td>
</tr>
<tr>
<td>431</td>
<td>Apartments Over Office (Walkup)</td>
</tr>
<tr>
<td>432</td>
<td>Retail Over Office (Walkup)</td>
</tr>
<tr>
<td>433</td>
<td>Storage Over Office (Walkup)</td>
</tr>
<tr>
<td>434</td>
<td>Supper Club/Night Club</td>
</tr>
<tr>
<td>435</td>
<td>Drive-In Restaurant Or Food Service Facility</td>
</tr>
<tr>
<td>436</td>
<td>Family Restaurant/Dining Rooms, Cafe</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>-------------------------------------------------</td>
</tr>
<tr>
<td>437</td>
<td>Other Food Service Structure</td>
</tr>
<tr>
<td>438</td>
<td>Drive Through Carry Out</td>
</tr>
<tr>
<td>439</td>
<td>Convenience Food Stores Or Other Food Service Structure</td>
</tr>
<tr>
<td>440</td>
<td>Dry Cleaning Plants And Laundries</td>
</tr>
<tr>
<td>441</td>
<td>Funeral Homes</td>
</tr>
<tr>
<td>442</td>
<td>Medical Clinics And Offices</td>
</tr>
<tr>
<td>443</td>
<td>Carwash-Full Serve/Auto</td>
</tr>
<tr>
<td>444</td>
<td>Full Service Banks</td>
</tr>
<tr>
<td>445</td>
<td>Savings And Loans</td>
</tr>
<tr>
<td>446</td>
<td>Radio/Tv Stations</td>
</tr>
<tr>
<td>447</td>
<td>Office Building (1 And 2 Stories)</td>
</tr>
<tr>
<td>448</td>
<td>Walk-Up Office Building (3 Or More Stories)</td>
</tr>
<tr>
<td>449</td>
<td>Elevator Office Building (3 Or More Stories)</td>
</tr>
<tr>
<td>450</td>
<td>Condominium Office Building</td>
</tr>
<tr>
<td>451</td>
<td>Gas Station - No Bays</td>
</tr>
<tr>
<td>452</td>
<td>Automotive Service Stations</td>
</tr>
<tr>
<td>453</td>
<td>Car Wash-Self Serve</td>
</tr>
<tr>
<td>454</td>
<td>Automobile Sales And Services</td>
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<tr>
<td>455</td>
<td>Commercial Garage</td>
</tr>
<tr>
<td>456</td>
<td>Parking Garage, Structures And Lots</td>
</tr>
<tr>
<td>457</td>
<td>Parking Lot/Structure</td>
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<tr>
<td>458</td>
<td>Gas Station/Convenient Food Store</td>
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<tr>
<td>459</td>
<td>Gas Station/Car Wash</td>
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<tr>
<td>460</td>
<td>Theaters</td>
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<tr>
<td>461</td>
<td>Drive-In Theaters</td>
</tr>
<tr>
<td>462</td>
<td>Golf Driving Ranges And Miniature Golf Courses</td>
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<tr>
<td>463</td>
<td>Golf Courses</td>
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<tr>
<td>464</td>
<td>Bowling Alleys</td>
</tr>
<tr>
<td>465</td>
<td>Lodge Halls And Amusement Parks</td>
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<tr>
<td>466</td>
<td>Truck/Farm Equipment Sales &amp; Service</td>
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<tr>
<td>467</td>
<td>Used Car Sales Lot</td>
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<td>469</td>
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<tr>
<td>470</td>
<td>Single Family Dwelling, Converted To Office Use</td>
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<tr>
<td>471</td>
<td>Single Family Dwelling, Converted To Retail Use</td>
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<tr>
<td>472</td>
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<tr>
<td>475</td>
<td>Retail Condo</td>
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<td>478</td>
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<tr>
<td>479</td>
<td>Dog/Cat Kennels</td>
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<tr>
<td>480</td>
<td>Commercial Warehouses</td>
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<tr>
<td>481</td>
<td>Mini Warehouse</td>
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<tr>
<td>482</td>
<td>Commercial Truck Terminals</td>
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<td></td>
<td>Description</td>
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<tr>
<td>483</td>
<td>Bus Garages &amp; Terminals</td>
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<tr>
<td>484</td>
<td>Hospitals</td>
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<tr>
<td>489</td>
<td>Health Spas</td>
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<td>Marine Service Facilities</td>
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<td>491</td>
<td>Racquetball Courts</td>
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<td>492</td>
<td>Tennis Barns</td>
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<td>493</td>
<td>Swimming Club</td>
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<tr>
<td>495</td>
<td>Open Code Other Commercial</td>
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<tr>
<td>496</td>
<td>Marinas (Small Boats)</td>
</tr>
<tr>
<td>497</td>
<td>Auto Racetracks &amp; Horse Tracks</td>
</tr>
<tr>
<td>498</td>
<td>Skating Rinks</td>
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</tbody>
</table>