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Using Volunteer Tracking Information for Activity-Based Travel Demand Modeling and Finding Dynamic Interaction-Based Joint-Activity Opportunities

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I am submitting herewith a thesis written by Yitu Xu entitled "Using Volunteer Tracking Information for Activity-Based Travel Demand Modeling and Finding Dynamic Interaction-Based Joint-Activity Opportunities." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

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Using Volunteer Tracking Information for Activity-Based Travel Demand Modeling and Finding Dynamic Interaction-Based Joint-Activity Opportunities

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ABSTRACT

Technology used for real-time locating is being used to identify and track the movements of individuals in real time. With the increased use of mobile technology by individuals, we are now able to explore more potential interactions between people and their living environment using real-time tracking and communication technologies.

One of the potentials that has hardly been taken advantage of is to use cell phone tracking information for activity-based transportation study. Using GPS-embedded smart phones, it is convenient to continuously record our trajectories in a day with little information loss. As smart phones get cheaper and hence attract more users, the potential information source for self-tracking data is pervasive. This study provides a cell phone plus web method that collects volunteer cell phone tracking data and uses an algorithm to identify the allocation of activities and traveling in space and time. It also provides a step that incorporates user-participated prompted recall attribute identification (travel modes and activity types) which supplements the data preparation for activity-based travel demand modeling.

Besides volunteered geospatial information collection, cell phone users' real-time locations are often collected by service providers such as Apple, AT&T and many other third-party companies. This location data has been used in turn to boost new location-based services. However, few applications have been seen to address dynamic human interactions and spatio-temporal constraints of activities. This study sets up a framework for a new kind of location-based service that finds joint-activity opportunities for multiple individuals, and demonstrates its feasibility using a spatio-temporal GIS approach.

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CHAPTER 1: INTRODUCTION

People and objects are becoming increasingly "locatable" as location-aware technologies, such as Wi-Fi, cell phone signals, and Global Positioning System (GPS) proliferate. These technologies can now be featured by one-piece "wearable computers"—our cell phones—which have become important ubiquitous environmental sensors and information and communication endpoints. As a promoter of volunteered geographic information, Goodchild (http://www.esri.com/news/arcuser/0410/vgi.html) mentioned in an interview with an ESRI writer, "I think the most significant new opportunity lies in the fact that a substantial fraction of the human population now has access to mobile phones and, hence, to electronic networks." Information collected by different sensors, typically location sensors, on the cell phones can directly be posted to the Internet. This information is now used by service providers such as Navizon (http://www.navizon.com/), Xtify (http://www.xtify.com/), Skyhook (http://www.skyhookwireless.com/), and returned to users in the form of location-based applications on smart phones and personal computers. These applications cover many aspects of our daily life, such as engaging in social events, identifying local places of interest, turn by turn navigation, and location-based advertising, which go far beyond merely points of interest.

However, due to privacy concerns, real-time location-based applications have been limited to personal users and the data they use has been kept private. Recently, individuals have been more willing to share their personal information and locations with others. Many people, especially the young, tend to value their accessibility as a much

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more important aspect to their social lives than privacy. If we pay attention to the updated version of iPhone's privacy policy, the company added a paragraph noting that once users agree, Apple and unspecified partners and licensees may collect and store user location data. Agreements such as these are making many of our location tracking data sharing "voluntary".

Voluntary location tracking and sharing opens up new opportunities in gaining a variety of geographic information. Public domains such as OpenStreetMap (http://www.openstreetmap.org/) and Wikimapia (http://www.wikimapia.org) are established to support volunteer efforts in collecting geospatial data. Compared to perfecting our street maps, relatively few efforts have been made to use tracking data as a source for travel demand and activity-based travel studies. Yet, voluntary location sharing incubated platforms such as Google Latitude (https://www.google.com/latitude/) are ushering in a new era of Location-Based Services (LBS) for PC and mobile users. The tracking of friends, families, employees in real time is available with Google Latitude. Upon privacy agreement with cell phone service providers, personal location can go public within one's social network.

1.1 Tracking Data in Activity-Based Travel Demand Modeling

The origin of activity-based approach in modeling travel demand dates back to the 1970's. One of its supporting theories was Hagerstrand's time geography (1970), which believes human activities are confined by different constraints such as capacity, coupling, and authority constraints. Chapin (1974) built on Hagerstand's theories by emphasizing individuals' desires and characteristics behind their activities. From a transportation

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perspective, both theories attempted to illustrate that with given time and mobility, human travelling and activities are confined by limited opportunities and choices, which fundamentally shifted the travel demand study from the trip-based paradigm to a new approach known as activity-based travel demand modeling. Under this new approach, travel is deemed as a derived demand for participation in other activities. In the decades following, researchers have devoted much effort to this new approach of understanding travel demand as an outcome of human behaviors.

One of the problems with the activity-based approach is the increased cost and complexity on data collection. Besides the socio-demographics, respondents are usually asked to record all the detailed information of travel-related activity diary data for a 24-hour period in the form of paper surveys or phone interviews. It is not only a huge burden on the respondents, but the results can also be erroneous.

The wide use of GPS-equipped smart phones opens up a new opportunity for activity-based travel demand modeling. Carrying cell phones is considered as a common habit of a modern life style, therefore it is assumed that using cell phones in recording travel diary will impose little extra burden to people. Third party cell phone tracking applications have been developed for different purposes: tracking kids, recording biking or hiking trails, etc., which make tracking oneself extremely convenient. One of the applications chosen for this study is "Motion-X GPS Lite" (http://gps.motionx.com/iphone/). GPS Lite records GPS waypoints in every two or three seconds and supports running in the background of a smart phone's operating system. Users of GPS Lite can track themselves at a relatively high positional accuracy without

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interfering normal cell phone usage. When a 24-hour period tracking is finished, users only need to click one button to share their tracks on Twitter, Facebook, or desired emails addresses. Software like this has given us a chance to get high-quality tracking data without placing an excessive burden on the survey respondents.

With GPS-embedded smart phones, using a computer algorithm to automate the activity and travel identification process will also help simplify the survey process. It focuses on the pattern of recorded GPS waypoints. Through studying the waypoint pattern, this process can extract information regarding when each trip is made and where the origin and destination are. Built as a web-based prompted recall survey, respondents can respond to the surveys at anytime and are relieved from recalling detailed spatial and temporal information regarding each trip.

1.2 Tracking Data in Location-Based Services

Improvements in positioning accuracy have brought about a broadened range and better quality of location-based services. These improvements are most obviously embodied by turn-by-turn navigation, finding friends and places of interest, etc. With the availability of high level positional accuracy, current LBS are capable of making a tight and friendly connection between users and spatial surroundings.

However, as travel is usually perceived as a derived demand (Miller and Shaw, 2001), it is consumed as a means of fulfilling other activities. In other words, services, like navigation and POI picking, have been forged to facilitate travelling and finding desired destinations. They are not infused with "intelligence" to "recognize" on a user's behalf in terms of why (for what purpose or activity) the trips are made or "recommend"

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some places of interest (POIs) over others from a macroscopic perspective of time-use efficiency. This may result in two potential deficiencies for current LBS. First, there are always temporal constraints along with the spatial constraints. Overcoming spatial constraints alone is not a sufficient guarantee for carrying out a planned activity. Secondly, from the "travel as a derived demand" perspective, destinations and distances are essentially determined by where the activities take place, which are not always static. Especially in the age of ICT (Information and Communication Technology), an activity can involve dynamic interactions and decision making processes of multiple individuals.

As much as time is closely related to geographic information, it has not been well used in LBS applications. When considering an iPhone application that indicates London subway arrivals, if people miss a train, will the system transmit a warning that they may not arrive at the destination on time if they wait for the next train to arrive? If they are going to be late, will the tool suggest another route or another means of transportation that will still take them to the destination on time? The ability to answer those questions will make the application more useful to society.

Before the era of ICT, travel was seen as point-to-point behavior. This is changing as ICT has brought us the flexibility of coordination and decision-making process, and the ways that human activities are carried out are modified correspondingly. Many planned activities (with prearranged schedules and places) in the past are now subject to change. Travel behaviors are inclined to be more dynamic and ad hoc. Although travel may still happen in the "Origin-Destination" fashion, origins and destinations in the traditional sense may not adequately apply. Location is becoming more indeterminate

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since in many real life scenarios both origin and destination can change over time until

the event eventually occurs. The advent of Google Latitude may noticeably magnify this

effect. For instance, two individuals picked a Starbuck's to have a face to face meeting.

On their way, however, is a Dunkin' Donuts that is geographically closer for both of

them to reach. If neither of them is particularly picky on the flavor of coffee, then

Dunkin' Donuts may also be appropriate for their meeting purpose. Therefore, they can

just stop by at Dunkin' Donuts and avoid the rest of the travelling. If we put aside

personal preferences, Dunkin' Donuts, in this case, is a more time-efficient option, which

is neglected en route because Starbuck's was the prearranged destination. If they are

aware of the real-time locations of each other, either one of them noticing this Dunkin'

Donuts can contact the other so that both of them may redirect their routes in time.

1.3 Research Objectives

1. One of the objectives of this study is trying to collect the mobile tracking data for

    activity-based travel demand modeling.

    This study tries to propose a volunteered data collection method through an Internet-

    based approach. In practice, activity-travel information is usually collected by

    traditional time-use or travel surveys. Instead of using activity-travel or time-use

    surveys, we promote using GPS-embedded smart phones and a prompted recall web

    survey method to collect activity-travel data. To assist this process, an automatic trip-

    and-stop generation method needs to be developed to capture the space-time

    distribution of activity-travel patterns from the original tracking trajectory data.

2. The second objective of this study is to set up a LBS framework for finding joint-

activity opportunities as a demonstration for dynamic interaction-based LBS application.

Location-awareness is one of the popular topics in social networks and is anticipated to bring about more physical human interactions delimited by capability, authority and coupling constraints. Although the relationships between the constraints and human interactions have been analyzed in theoretical and empirical studies, they have not been applied in applications. The second objective of this study is to design a LBS that emphasizes the spatio-temporal constraints in human activities, especially those involving dynamic interactions.

1.4 Organization of the Thesis

This thesis is organized into five chapters. The next chapter reviews the literatures relevant to this study, including activity-based travel demand modeling, activity-travel data collection, ICT and human activity, location-based services, time geography, and spatio-temporal GIS. Chapter 3 is devoted to the design and implementation of a web application that supports collecting volunteered mobile trajectories. In this chapter, a data model is designed to accommodate the derived information from tracking trajectories. Then it introduces an algorithm that analyzes and automatically retrieves trip-and-stop information from trajectories. Finally, it briefly discusses the components of this application. Chapter 4 is devoted to design an application construct for interaction-based LBS using a spatio-temporal GIS approach. In this chapter, it analyzes three types of meeting opportunities: time spot, time interval, and prism meeting opportunities. The key measurement from time-geography—space-time prism—is used

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to calculate opportunities for joint activities. This chapter also simulates a meeting

scenario of two individuals in ArcGIS. Chapter 5 concludes this thesis with discussions

of these two potential applications and opportunities for future research.

CHAPTER 2: LITERATURE REVIEW

2.1 From Traditional Four-Step Approach to Activity-Based Approach

Transportation forecasting is the process of estimating the usage on the specific transportation facility in the future, such as vehicle number on a road, bridge, or ridership on a railway line. It is important because of its direct or indirect influences in transportation policy, planning, and engineering, such as how many lanes a bridge should have or how much financial aid should be allocated to build a new road.

Traditional transportation planning follows the four-step trip-based model or Urban Transportation Planning (UTP) procedure: trip generation, trip distribution, modal split, and traffic assignment. Although it has been used in transportation planning for decades, criticisms toward using four-step modeling have never ceased. Scholars such as McNally (2000), Davidson et al. (2007), and many others have pointed out the deficiencies of continuing to apply four-step model to today's world. A fundamental concept of trip-based approach is to use trips as the unit of analysis. Different models are established for different trips such as home-based and non-home based. Trips are seen as independent and non-sequential. As a result, the relationships among the trips are ignored. Trip-based planning also neglects the interactions among family members. Moreover, the duration and timing of trips are not strictly considered in the trip-based methodology.

These deficiencies of traditional four-step models switched the academic research focuses to the activity-based approach. The activity-based approach deems travel as a derived demand from pursuing participating activities (Jones, Koppleman, and Orfeuil,

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1990; Axhausen and Garling, 1992; Hanson, 1995). In this approach, human behaviors, instead of aggregated trips, became the objective of the study. Complex interactions between activities and traveling, including sequences of activities and trips and intra-household interactions, are considered within the same framework (Gliebe and Koppelman, 2002; Miller, Roorda and Carraso, 2005). With these emphases, it is expected that travel demand may better respond to different times (such as peak hour and off-peak hour) and policy changes (such as emission control).

To summarize, activity-based travel demand models rely on five changed paradigms: 1. Travel is derived demand from the activity participation. 2. Activity-travel sequences are important for the study. 3. An individual's activity-travel pattern should be studied together with intra-household interactions. 4. An individual's activity-travel behaviors happen in a continuous manner, they are connected with each other. 5. Choices of activity-travel are limited in space, time, and personal decisions.

2.2 GPS Data Collection for Activity-Based Travel Demand Study

2.2.1 Using GPS as Supplement for Activity-Travel Survey

The purpose of activity-based travel study is to find out and hence be able to predict individuals' activity-travel patterns. One of the most important aspects to consider is that individuals take part in different activities in the society. Two sets of information are needed to asses an individual's activity-travel pattern. The first is an individual's socio-demographic information such as income and working status. The second is the activity-travel behavior or time-use details over a continuous period of time, which usually is a

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24-hour period. Activity-based transportation models can also include land-use data to allow for more explanation.

Traditionally in the past, data for activity-based travel study is collected through surveys. Early surveys were conducted through paper-and-pencil interview (PAPI) methods in the form of mail-out and mail-back surveys. This method was gradually replaced by telephone interviews in the 1980's. In the 1990's, more and more data collection is conducted through computer-assisted telephone interview (CATI). More recently, computer-assisted-self-interview (CASI) allowed interviewees directly respond through computers. (Wolf, 2001)

GPS started to play an important role in travel diary surveys since the late 1990's. Using GPS as a data recording tool can be seen as revolutionary with the belief that it could supplement or even replace a travel diary. An overview of the capabilities of the GPS system for use in transportation can be found in Wolf (2004) and Stopher et al. (2006). At the beginning, GPS are used in conjunction with a traditional household travel survey. Typically, there are two ways of using GPS devices in a survey: passive data collection, where the GPS data are collected without additional input from the participants; or active collection, which often entails participants' additional inputs such as using voice recording or onboard computer logs.

Regardless of conducting the study in an active way or a passive way, the original purpose of such studies including GPS devices as data collection tools is to use GPS tracks to correct the survey content. Recorded GPS tracks are used as a supplement to compare with activity-travel survey log to improve accuracy. Some of the cross-sectional

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studies using active GPS recording are the Lexington study (1996), the Austin study (1997), the Pittsburg study (2001), the California Study (2002), and the Kansas City study (2004). Researchers found that activity-travel information recorded with GPS is much more accurate than using traditional mail-in survey, along with which is the long-existing issues of the under-reporting of trips with the mail-in surveys (Bricka and Bhat, 2006). Table 1 shows a summary of GPS-survey compared with activity-travel study. Almost all of the studies render a serious proportion of under-reporting of trips. These missed trips can lead to an underestimation of the regional level of vehicle miles traveled (VMT), particularly if the missed trips are complete round trips or multi-stop tours. Also, trips of short duration and of discretionary nature tend to be neglected. These short trips can play important roles in transportation study because of strong association with possible chaining—the decision to link individual trips together—in a tour (McGuckin, 1999; Levinson, 1997).

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Table 1: Summary of GPS surveys

Study	Year Conducted	GPS Firm †	# HH	# HH w/ GPS & CATI	% of total CATI surveyed HHs participating in GPS survey	Level of Trip Under-reporting	Reference
Lexington	1996	B	100	84	84.0%	NA	Battelle Memorial Institute (3)
Austin	1997	N	2,000	200	10.0%	31%/12%*	Casas & Arce (4)
California	2001	G	16,990	292	1.7%	23%	Zmud & Wolf (2)
Los Angeles	2001/2	B	23,302	293	1.3%	35%**	NuStats 2004a (5)
Pittsburgh	2001/2	G	2,554	46	1.8%	31%	NuStats 2002 (6)
St. Louis	2002	G	5,094	150	2.9%	11%	NuStats 2003b,c (7,8)
Ohio	2002	B	6,338	230	3.6%	30%**	Pierce et al. (9)
Laredo	2002	G	1,971	87	4.4%	81%***	Pearson 2005a,b (10,11)
Tyler/Longview	2003	G	2,336	249	10.7%	NA	Texas DOT (12)
Kansas City	2004	G	3,049	228	7.5%	10%	NuStats 2004b (13)

B—Battelle, N—NuStats, G—Geostats.

(Source: Bricka and Bhat, 2006)

2.2.2 Using Passive GPS Tracking as Replacement for Activity-Travel Surveys

In the past decade, there had been many efforts devoted to replace the household activity-travel survey with a GPS survey. The thought emerged out of the consideration of lowering the respondents' burden to the least level while promoting the quality of activity-travel information, especially in capturing the details of space-time distribution of activities and trips which most respondents had a hard time remembering or deliberately under-report (Murakami et al. 2003). Moreover, since exempting the respondents from keeping an activity-travel log can largely relieve the respondents' psychological burden, passive GPS tracking method also provides the possibility of carrying out multi-day surveys.

These reasons prompted some research attempts to replace and reconstruct activity-travel diaries using completely passive GPS data collection. One of the earliest attempts

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to replace the travel survey with passive data collection was conducted by Wolf et al. (2001) in Atlanta, Georgia. This study focused on deriving the purpose for each identified trip using underlying land use data. This study showed a decent percentage (around 78%) of matching on the activity types. Other studies include such as the study by Schönfelder et al. (2002), Axhausen et al (2004), as well as studies by Srinivasan et al. (2006), McGowen and McNally (2007), Huang et al. (2010). Most of these studies use underlying land-use information, and point-of-interest locations and socio-demographic variables to estimate activity types. There are also other studies such as Patterson et al (2003), Srinivasan et al. (2006) contributed to the automatic identification of travel modes.

The studies carried out above displayed a promising possibility that we might be able to use completely passive GPS data to replace activity-travel surveys. We can expect that the automated process can significantly reduce the onerous burden on the respondent side, which can in turn ease the survey process, and also provide the possibility of extending a multi-day survey. However, they all more or less share the common ground in terms of errors and limitations. For example, if an 18-year old girl goes to a mall for 5 hours, is she shopping or working? If a 28 year old male spend 8-9 hours on campus, is he working or schooling? The number of such examples is large. Moreover, incomplete, obsolete, or multi-functional land-use information will all result in the uncertainty of activity type at a stop. Lastly, passive data analyses ignore the important attributes of intra-household activity-travel behaviors, for example, a family going to a dinner together

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will be treated as separate trips. Therefore, it is important to incorporate respondents' participation in identifying certain activity-travel attributes.

2.2.3 Using GPS to Support Prompted Recall Activity-Travel Survey

Since passive GPS tracking data can be used to help deduce high-accuracy spatio-temporal attributes of trips, but not as effective in inferring associated attributes, a supplemental follow-up respondent survey process is opted in some GPS data collection studies. Such surveys are known as prompted recall surveys, where GPS trajectories are used to support the respondents to recall correct activity-travel information. Respondents are asked to provide additional information about the travel and activities, such as mode of travel and type of activities.

Some studies have been conducted using GPS data as supplement for prompted recall activity-travel surveys. The first prompted recall survey used in transportation study was conducted by Bachu et al. (2001), followed by Stopher et al. (2002), Wolf et al. (2004), etc. They were conducted using mailing back surveys. The transition from paper-based surveys to Internet-based prompted recall surveys was significant because it brought more interaction, timeliness, and freedom to the survey process. Stopher and Collins (2005), Lee-Gosselin et al. (2006), Li and Shalaby (2008), and Auld et al. (2009) have designed surveys over the Internet and extensively exhibited the potentials using Internet-based prompted recall surveys.

Results of these studies indicate that Internet-based prompted recall surveys fuse the merits inherited from passive GPS tracking data which identifies accurate activity-travel

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spatio-temporal distribution and the merits from respondent participated survey process which can provide related attributes to the activities and trips, such as activity type and travel modes. Also, Internet-based prompted recall surveys impose relatively low burden on the respondents,

For the research purpose of this study, we propose using GPS-embedded smart phones as opposed to standalone GPS transponders as data collection tool. Because cell phones are often carried with the individuals in everyday life, using GPS-embedded cell phones will impose little extra burden to the respondents. A computer-aided prompted recall web survey will be used as a supplement for data collection.

2.3 ICT and Human Interactions

Information and Communication Technology (ICT) has affected our lives in many ways. Today, more and more people can access to smart mobile phones, personal computers (PCs), personal digital assistants (PDAs). Large areas are covered by 3G network and Wi-Fi, making information-access almost ubiquitous. We acquire information from website and communicate with people with emails, instant messages, virtual social media, and phone calls. Many activities that have to be carried out in specific occasions in the past now can be accomplished through a smart phone that connects us to the vast information world. With today's highly developed ICT, constraints on people's activities in the physical world are mitigated.

Since ICT greatly boosted instant communication, many travel plans are no longer static agreements made ahead of travel schedules. Ling (2004) noted that clock-based activity planning is complemented with, and sometimes replaced by, phone-based

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scheduling. He further identified three ways of coordinating by mobile phones: (1) Midcourse adjustment is the redirection of trips that have already started and the rearrangement of the meeting details that have already been agreed upon. (2) Interaction-based coordination is interactive coordination, referring to the progressively exact arrangement of a meeting. (3) Schedule softening is the potential of mobile communications to increase scheduling flexibility as opposed to using more precise time-based arrangements (Ling and Yttri 2002, Kwan, 2007). Travel is likely to become more unpredictable as people increase their use of ICT to modify trips. Everyday life is more spatially-and-temporally complex in relation to physical mobility and daily travel patterns (Hjorthol, 2008).

One of the big changes in travel behavior brought about by the flexibility in planning can be featured as "fragmented". Fragmentation, as introduced by Couclelis (2000), means interrupting one activity by another and subsequently continuing the former activity by using ICT (Nobis and Lenz, 2006). Lenz and Nobis also elaborated on how activities are fragmented in space, time, and the manner how the activity is performed. Although this argument was originally made to epitomize the spatio-temporal pattern of how activities are carried out in the general sense, the change of travel pattern can be the most appropriate fit. Travelling, which used to take place in a more dedicated time window, is now fragmented in a more expanded span of discrete time slots. Spatially, the routing choice is more flexible and the origin-destination set is much larger. Moreover, travelling is constantly replaced, complemented, or generated by telecommunications. This concept was echoed by an empirical research about meeting

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and waiting behaviors conducted by Ohmori and his colleagues (2005). They found that comparing to the past, people are now less willing to fix an exact meeting place and time, and there is also more rescheduling.

As a particularly popular product in the age of ICT, rapidly growing social media like the Google community and Facebook have got millions of people's attention. Since Google Latitude and Facebook Place have now made themselves location-aware, it is easier than ever to identify the physical locations of one's friends through the virtual network. A key benefit of such social media has been the ability to bring people closer together in person, cultivating and strengthening online relationships through offline relationships and vice versa. ICT raises the propensity to get together and develops a strong sense of community surrounding the space (Ogneva, 2010). Some expect that with locations go transparent within the social media, more local offline interactions will occur among one's social network, such as parties and short face-to-face meetings. Although theoretical frameworks and empirical studies have been conducted to represent these newly emerged potential interactions, not many applications are available to quantify these fragmented and ad hoc interaction opportunities.

2.4 Location Based Services

Activities during mobility will often have embedded spatially-related actions resulting from user questions or desires (Steiniger, et al, 2006). Reichenbacher (2004) identified five elementary spatial actions (Table 2) regarding user needs for geographic information. The most obvious question to ask is where the user himself is with respect to somebody or something (locating). Users may search for persons, objects or events (searching); and

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they ask for the way to a location (navigating). Other users ask for properties of a

location (identifying), or they try to look for events at or nearby a certain location

(checking).

Table 2: User activities

	Action	Questions	Operations
	orientation & localisation locating	where am I? where is {person|object}?	positioning, geocoding, geodecoding
	navigation navigating through space, planning a route	how do I get to {place name| address| xy}?	positioning, geocoding, geodecoding routing
	search searching for people and objects	where is the {nearest | most relevant | &} {person | object}?	positioning, geocoding, calculating distance and area, finding relationships
	identification identifying and recognising persons or objects	{what | who | how much} is {here | there}?	directory, selection, thematic/ spatial, search
	event check checking for events; determining the state of objects	what happens {here | there}?	

(Source: Reichendacher, 2004)

To answer these questions and satisfy the desires, the term Location-Based Service

was created as a concept that denotes applications integrating geographic information

with the general purpose of services (Schiller & Voisard, 2004).

2.4.1 Interaction and Location-Based Media

For a long time, LBS were only geared to individuals' needs (Ratti et al, 2006) with most

research focusing on the interaction between humans and computers. In reality, many

activities are not solo but consist of more than one person; as a result, they will not occur without all participants present. Although Ratti speculated on the potentials when LBS are extended to the group users, no substantial progress was made in terms of LBS bridging the interaction among group users. Only recently have location-aware platforms of social media like Google Latitude, and Foursquare begun to emerge. Still, companies seem reluctant to enter the location segment in the traditional sense, which can be contributed to the initial perceptions that such platforms are simply "game platforms for geeks".

The location segment, however, is obviously more than just a game platform. With the introduction of Google Latitude and the most recent Facebook Places, an estimated 500 million potential users can make location-based status updates a mainstream concept. According to a Luth Research Survey (April, 2010), ten percent of the surveyed mobile users at least use LBS once in a week, and sixty-three percent of Apple iPhone owners use location services at least once a week. This amount of use almost guarantees the potential market for interaction and coordination based LBS.

2.4.2 Time and Location-Based Services

Time can be a precious commodity, and we often put great effort into deciding how best to spend it. It's not unreasonable to think that the technologies we use in our daily lives could help us make these decisions. However, time-related information and analysis is another void that LBS have yet to fill. Besides estimating travel time, functions for treating information with temporal dimension are seldom seen. Although LBS can be highly personalized by allowing users to specify physical and virtual space context and

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tasks, few applications are empowered with the capability of customizing temporal context and tasks. Raubal and his colleagues (2004) pointed out two limitations: (1) Current LBS capture the spatial properties of locations but neglect the temporal properties. (2) Current LBSs are unable to process chained activities. Instead, they tend to treat one query as an individual activity separated from others, not as a component in the schedule that is constrained by subsequent activities.

The first limitation has been a major challenge in the development of LBS. Those who drive daily are keenly aware that the optimal routes can change profoundly during commute hours. Traffic jams, road constructions, and inclement weather can all significantly affect the fastest routes. Meanwhile, shops' open hours, services' operating hours are also able to detour the planned trips. Most of these temporally associated variables, however, are not coded into current map database apriori. Time-critical applications heavily depend on the capability of database's capability of handling dynamic data and overriding existing information (Spiekermann, 2004). Many efforts are being devoted to this domain, and we have seen progress in modeling dynamic data.

The second limitation is closely related to the time-geography concepts. Carrying out activities is subject to the capability, authority, and coupling constraints. In theory, the measurement of these constraints is mature; but in reality, to implement these constraints in LBS applications, the precision is largely reliant on how well the first limitation is handled. With the improvements in dealing with real-time information, it is time to introduce scheduling and spatio-temporal constraints into LBS so that any one trip is no longer dissociated from the activity-chain and users can have better

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comprehension and control of time even though the activities are fragmented.

This section has reviewed two void aspects of interaction-based LBS, one is interaction, and the other is time. Time geography provides an effective framework to address these two aspects, and spatio-temporal GIS offers an operational solution to them. Relevant literatures are reviewed in the next section.

2.5 Time geography and Spatio-temporal GIS

Time geography was defined by Torsten Hägerstrand (1970), who first explored the temporal factor in spatial human activities. He introduced the notion of time as a third dimension, and constructed a 3D spatio-temporal environment. Examining discrete objects' motion in time with persistent identity, Hägerstrand (1970) designed the space-time path to conceptualize and illustrate an individual's movement in the spatial-temporal environment. A space-time path depicts a path that is taken by an individual in a continuous time window subject to capability, authority, and coupling constraints (Hägerstrand , 1970; Golledge and Stimson, 1997). The following is the description of each constraint:

- *Capability constraint* refers to the limitation on human movement due to physical or natural factors. For example, one must eat and sleep to maintain life, he/she cannot be simultaneously at two physical world locations; capability constraint also refers to the resource that one can access, such as vehicles, which closely related to a maximum distance that one can cover.

- *Authority constraint* refers to individuals' limited accessibility to certain places or

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domains due to institutional mechanisms, such as private properties or restricted

areas, by certain people or institutions. For example, one cannot take a bus at

midnight if the transit line does not operate overnight.

● *Coupling constraint* anchors an individual to a location while interacting with

other individuals or participating in other events. For example, a student needs

to be in class at a certain time, and a professor needs to be present at office

hours and/or faculty meetings. The space-time coincidence due to the coupling

constraint is described as a space-time bundle.

To better depict the possible space-time presence of a space-time path, Hägerstrand

(1970) constructed a continuous space in the three-dimensional orthogonal space-time

coordinate system called a space-time prism (Figure 1). The corresponding projection of

a space-time prism on the two-dimensional space is defined as potential path area.
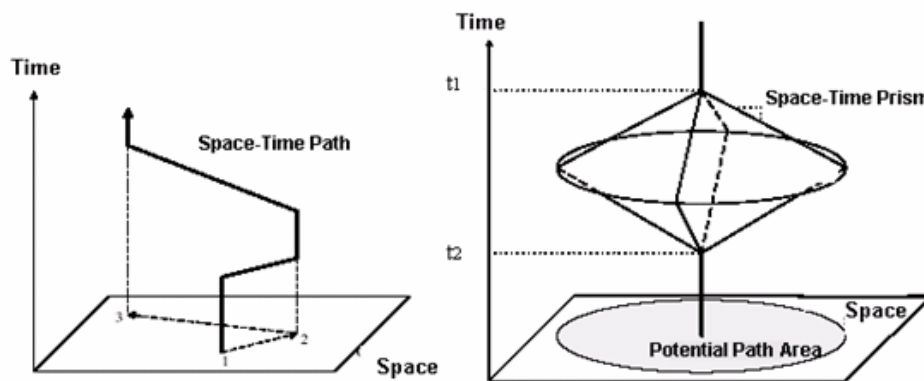
Figure 1: Space-time Path, Space-time Prism, and Potential Path Area
(Source: Miller 2005)

Concepts in time-geography are gradually operationalized in the past decades and

studies about implementing space-time GIS (ST-GIS) have also been conducted. For

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example, Miller (1991) quantified the network-based space–time prism and Kwan (1998) operationalized network-based accessibility measures using a geo-computational algorithm and digital geographic data of the transportation network. Accessibility and constraints have been extensively discussed by Miller and Wu (2000) and Kwan (2000a). Yu (2005, 2006) realized a three-dimensional representation of network prism (Figure 2).
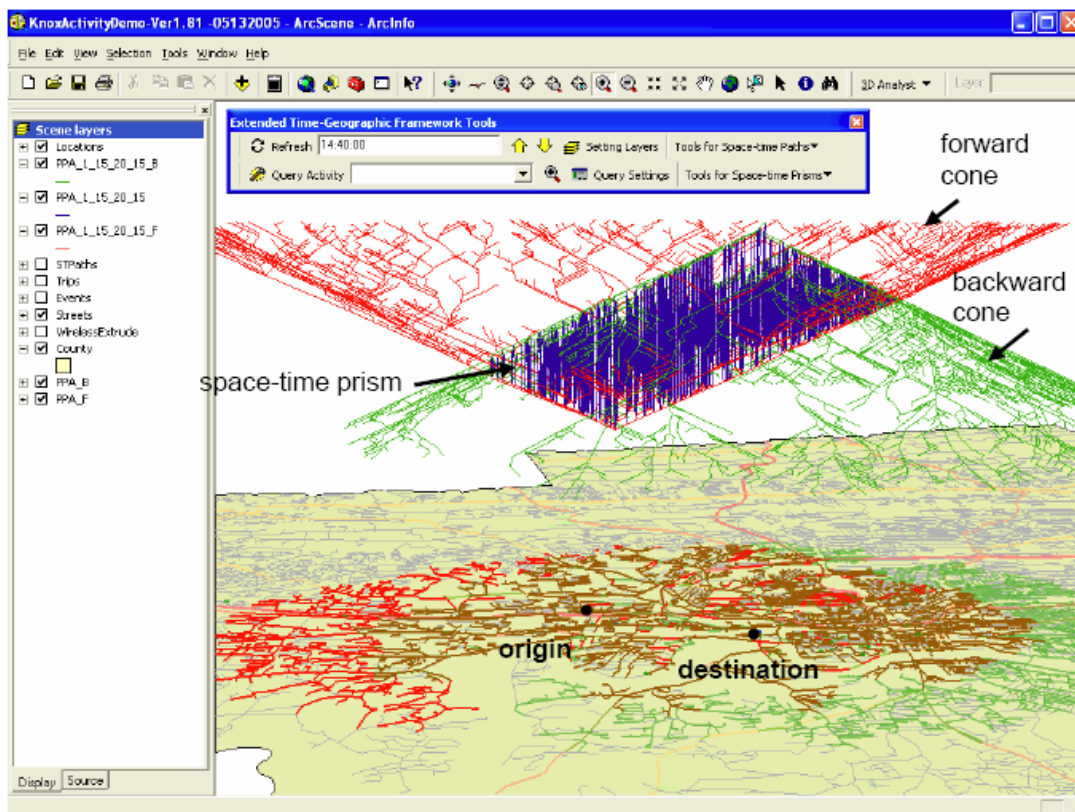
Figure 2:Space-time prism based on street network
(Source: Yu, 2005)

Yu and Shaw (2007) extended the time-geography framework to include virtual space. In 2009, Shaw and Yu also took on the challenge of designing a geospatial database to accommodate the spatiotemporal dynamics of individuals and joint activities. They implemented their extended framework in the ST-GIS approach to represent human

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activities in hybrid space. Their toolbox was also released to support computation of the relationships between space-time paths and activities, events, and projects with the key algorithm of temporal dynamic segmentation. All their proactive research provided an extensively evolved theoretical and technical guidance for detecting and measuring constraints and human interaction using time geography concepts. This guidance is extremely supportive for potential applications.

2.6 Summary

Conducting activity-based approach of travel demand modeling puts heavy requirements on the data collection. This chapter first reviewed the data collection methods for activity-based travel demand modeling and three GPS data collection methods are compared. The conclusion is that using GPS as supplement to support prompted recall activity-travel survey will impose comparatively low burden on the respondents while maintaining a good quality of collected data.

This study will adopt a prompted recall method for data collection and build a "proof-of-concept" volunteered tracking system. Instead of using standalone GPS devices, GPS-embedded smart phones will be used as data collection tools, which are considered to be pervasive but will only impose little burden to survey respondents.

This chapter also reviewed the human activities in the age of ICT. Human activities as well as interactions tend to be more dynamic and ad hoc. LBS sector, however, as one of the important sub-fields in modern ICT, is quite void in building services for dynamic human interactions. Time geography provides a useful framework for conducting analyses for human interactions in space and time.

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This study will devote to designing a LBS that stresses two limitations in current LBS: interaction and time. A space-time GIS approach will be used to demonstrate a two people face-to-face meeting scenario.

CHAPTER 3: VOLUNTEERED TRACKING SYSTEM FOR ACTIVITY-BASED MODELING DATA COLLECTION

One of the most promising potentials of using real-time tracking data is for activity-based transportation studies. Some pilot studies have demonstrated the feasibility of using tracking data to reconstruct daily activity trajectories, as opposed to using travel surveys. The tracking data was collected primarily by standalone GPS devices for a small population. In recent years, the increased use of GPS-embedded smart phones and simplified web access have made the collection of tracking data more convenient. This study attempts to advocate a web-based voluntary data collection method which applies a computer-aided activity-travel identification process.

3.1 Data Source Formats

Reading information from different de facto formats is the preliminary step to support different file uploading from a variety of devices and software. Smart phones and GPS devices record tracking points in XML schema or text, with four formats being most popular: GPX eXchange, KML, KMZ, and CSV formats.

GPX, KML, and KMZ files are well-structured XML schema data files whose data elements are strictly defined within standardized name tags, making accessing of the elements straightforward. These open and free formats are now supported by hundreds of software applications and websites, making them the de facto format for interchanging

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GPS data between GPS receivers, desktop and mobile software, and Web-based services. GPS waypoints in these data formats normally contain associated timestamps, which can together form a timeline. Serializing the collection of these waypoints along the timeline can form a trajectory of a tracked object or individual.

CSV file format is a set of file formats used to store tabular data in which numbers and text are stored in plain text form. Lines in the text file represent rows of a table, and commas in a line separate what are fields in the table row. The records in the same row are terminated by a new line. CSV files are more compact but less standardized. Data types and formats of CSV files can be arbitrary and device dependent. To avoid probable exception from reading arbitrarily defined CSV files, CSV files are not supported in this pilot design.

3.2 Data Model
3.2.1 Conceptual Data Model

For activity-based travel demand modeling, we are interested in the detailed information about the time-use information of individuals during the course of a period of time. The characterization of time-use during the surveyed period is usually accomplished at different levels corresponding to different emphases of various models, but generally entails the collection of data regarding all in-home, out-of-home activities and trips in between them. In addition to the travel-activity data, activity-based travel demand modeling also requires socio-demographic information of the individuals as necessary exogenous variables.

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Using tracking data as a replacement for conventional activity-travel survey requires a conceptual model that embodies accommodating raw tracking data as well as information described above. The model entails track information, stop information, trip information, and user socio-demographic information. With its original configuration, a track is recorded in GPX, KML, or KMZ files in the form of a collection of time-stamped waypoints. Each waypoint represents a smart phone user's location at a given moment. When the smart phone user is in motion, the waypoints are apart and easy to distinguish. These waypoints are recognized as an individual being in the course of traveling which generates trips (Figure 3, left). While the waypoints render a vibrating pattern around a static location along the timeline (Figure 3: right), the individual is considered to be in the middle of an activity. From the "travel as a derived demand" perspective, a trip happens when one needs to participate in an activity. An activity is the purpose of a trip (or multiple trips) that tries to fulfill. Both trip and stop information is essential to activity-based modeling and the target information we are trying to extract from the recorded tracks.
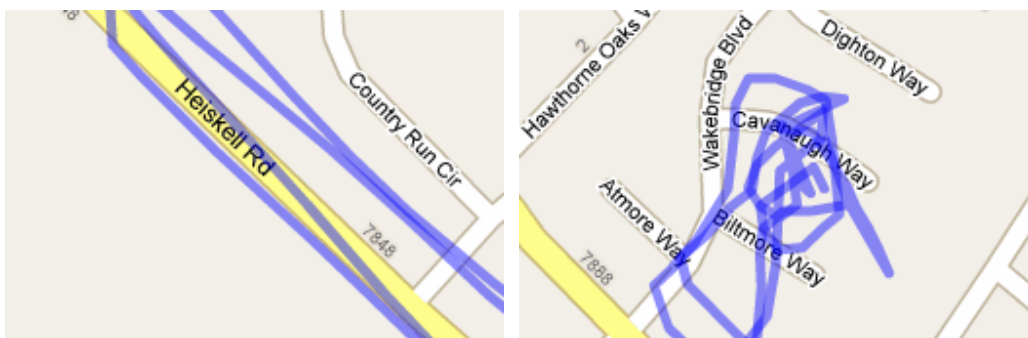
Figure 3: Individual in motion (left) and in activity (right)

Individuals' socio-demographic information is also important as it determines who makes the trips and who participates in the activities. This sample data is then used to make inferences about the behaviors of a population. For example, workers and non-workers could exhibit distinctively different activity-travel patterns due to the differences in temporal constraints.

3.2.2 Logical Data Model

Different activity-based models handle transportation problems in different perspectives and scales. Some models address these problems at a pattern-level, while others do so at a tour-level or stop-level. A pattern-level perspective describes an individual's tours in a day. For example, in the case of a full-time paid worker, a pattern-level perspective examines the number of tours before-work, work-based, and after-work, etc. A tour-level perspective focuses on more details of tour patterns and can include multiple trips ordered in a sequence. Each trip associates with a travel mode, an origin location, and a destination location. The tour-level perspective can also be sub-divided into periods of study time, such as before-work, work-based, or after-work for a full-time worker. The stop-level perspective examines the sequence of the stops an individual visits during the tracked period. Each stop has a specific location and is associated with a certain activity type. From the stop-level perspective, we are also interested in how long an individual spends at the stop, and how long the trip takes from the previous stop.

A data model (Figure 4) is needed to support views from these perspectives. Logically, individuals can have as many tracks as they make where each track corresponds to a designated tracking period. With computer-aided identification process,

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we can derive a collection of stop-level characteristics and trip-level characteristics from track information. Together with individual socio-demographic information, track information, stop information, and trip information, it is expected that we can provide effective pattern-level, stop-level, and tour-level queries.
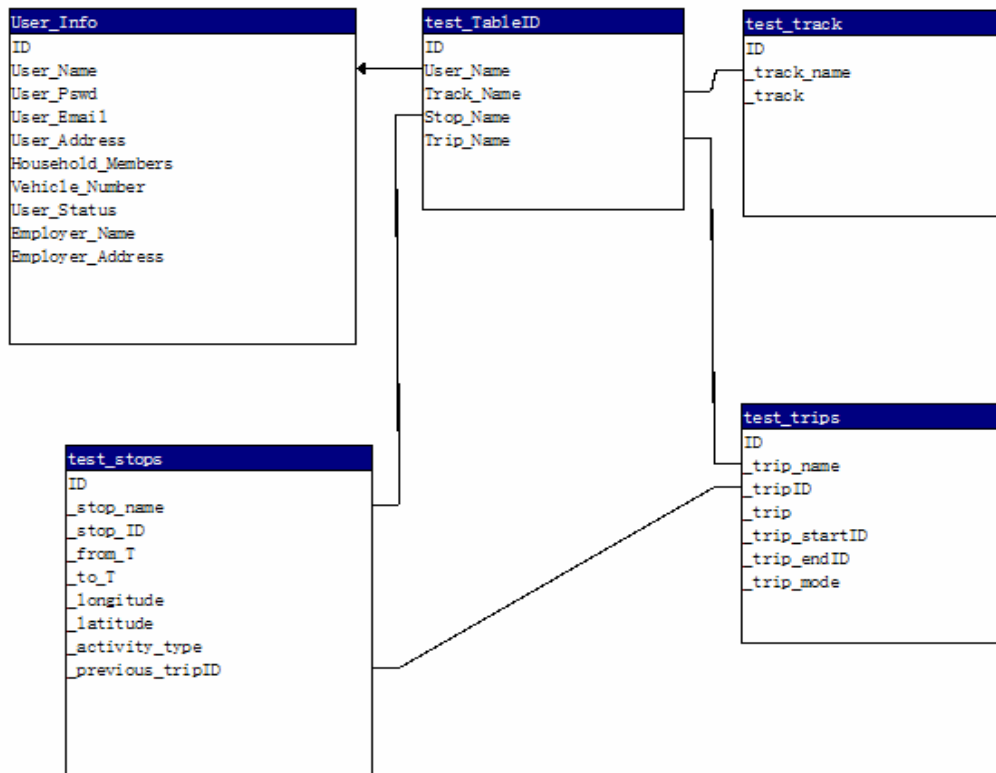
Figure 4: Logical Data Model

3.2.3 Physical Data Model

A physical data model must be implemented based on the needs of the logical model. As illustrated in the relationship diagram (Figure 4), track, stop, and trip information is managed through a table called TableID (Table 3). Each record in TableID is a reference

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between an individual and his/her track as well as the derived stop/trip information through a foreign key User_Name.

Table 3: TableID

Field Name	Data Type
ID	AutoNumber
User_Name	Text
Track_Name	Text
Stop_Name	Text
Trip_Name	Text

Table Track contains the information for raw tracking data. As shown in Table 4, Track has two fields. Field _track_name is used as a primary key to support querying for the track. _track is an OLE Object implemented as a Binary Large Object (BLOB). Within the BLOB, waypoints from different formats are tailored into a unified format as <timestamp, longitude, latitude> units, and serialized with timestamps.

Table 4: Track

Field Name	Data Type
ID	AutoNumber
_track_name	Text
_track	OLE Object

Table Trips (Table 5) records the attributes associated with all the trips an individual makes during a tracked period. Each trip is labeled with a unique tripID. Field _trip_name functions as _track_name, which is an indexed field. Trips are stored in the _trip field as a BLOB. _trip_startID and _trip_endID denote the stop IDs that this trip connects.

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Table 5: Trips

Field Name	Data Type
ID	AutoNumber
_trip_name	Text
_tripID	Number
_trip	OLE Object
_trip_startID	Number
_trip_endID	Number
_trip_mode	Text

Table Stops (Table 6) accommodates stops' attributes identified from a track. Each stop is represented with a unique stop ID (_stop_ID), a starting time (_from_T), an ending time (_to_T), and a location (_longitude and _latitude). _stop_name serves as an indexed field while _previous_tripID identifies the connecting trip to the stop.

Table 6: Stops

Field Name	Data Type
ID	AutoNumber
_stop_name	Text
_stop_ID	Number
_from_T	Number
_to_T	Number
_longitude	Number
_latitude	Number
_activity_type	Text
_previous_tripID	Number

Using this physical data model, we can effectively query information at different levels. From the pattern-level, the number of total trips during a tracked period is simply the count of trips recorded for the track. At a more detailed level, querying the number of before-work trips can be accomplished by finding the connecting trip to the work stop, and trace back the trip records in the Trips table.

A tour-level query, such as attributes associated with a commuting tour to work, can also be carried out by using Trips and Stops tables. In the Stop table, we can directly

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read number of stops an individual makes before the work stop. Each stop has a connected trip as indicated by _previous_tripID. Therefore, we are able to find the corresponding travel mode for the trip in the Trips table. Likewise, we can also find activity type, travel time from previous stop, stop location, activity duration for stop-level queries.

3.2.4 File System Design

Aside from a physical database model, this pilot design also creates an archive for raw tracking files. One advantage to this system is that archiving the original file facilitates restoring corrupted files and allows recovery from bad edits. Also, when we transfer XML schema data to the unified format database, we selectively extract time and location info. Yet, we purposely choose to overlook other information, such as real-time speed, direction, etc. Keeping a backup of original files provides a possibility of extending the current design to include additional data and features.

3.2.5 File Naming Policy

This pilot design applies a re-naming policy to the archived file as well as to the records in the database. Principles of the re-naming policy are: averting naming conflict and ensuring user-intuitiveness. Averting naming conflict refers to system needs to prevent duplicate file names. User-intuitiveness refers to the easiness for the users to find and retrieve the correct files and data records they look for. Users are able to upload multiple files and do the online survey at different times. Without a clear name to each file, it can be hard for users to retrieve the correct track for a specific day. This pilot design applies

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a quick scan of the track's starting time and ending time, and combines them into the string format as "year-month-day-hour-minute". The whole file is renamed as UserName_StartTime_EndTime. The same name will also be used to create a new data record in database: UserName_StartTime_EndTime for the track; UserName_StartTime_EndTime_Stop for the stops; and UserName_StartTime_EndTime_Trip for the trips.

3.3 Processing Raw Tracking Data

In this study, we collect tracking data using cell phone GPS applications. Raw tracking waypoints are densely recorded approximately every three seconds and each record includes a timestamp and coordinates. After transferring the track to our database, Track table will be populated with a BLOB record. However, trips and stops are not easily discerned from looking at the raw data. In this section, a computer-aided web survey method is proposed for helping volunteer users identify the details of stop and trip information.

The computer-aided web survey consists of two major processes: one is an automatic process; the other is a manual process which incorporates more user interactions. The automatic process identifies stops and trips mainly by analyzing the GPS waypoint patterns. These patterns include GPS waypoints' characteristics related to motion, station, and most importantly errors. Through analyzing these patterns, this study comes up with an algorithm that reveals most of the embedded trip and stop information. However, the automatic process cannot guarantee 100% accurate information retrieval,

and is not capable of dealing with GPS failure or malfunction. Therefore, as an alternative resolution, a manual process is necessary.

3.3.1 GPS Waypoints' Characteristics

This section first introduces the GPS signal, especially error characteristics. Based on these characteristics, an automatic identification process is introduced. In the end, it introduces a complementary manual identification process with user interactions.

GPS can provide location, altitude, and speed with near-pinpoint accuracy by transmitting signals trough two frequencies of low power radio signals known as L1 and L2. L1 frequency, which is at 1575.42 MHz in the UHF band, plays for civilian applications. The system has intrinsic error sources when a receiver reads the GPS signals from the constellation of satellites in orbit. The main GPS error source is due to inaccurate time-keeping by the receiver's clock. The built in clock of the GPS receiver is not as accurate as the atomic clocks of the satellites and the slight timing error can lead to corresponding errors in calculations. One of the most significant extrinsic sources is signal reflection. In urban areas, signals hitting objects such as buildings and walls can cause reflection, and consequently results in the delay of signal receiving. Both intrinsic and extrinsic errors are within small error range, especially when we are moving, which normally would not become a concern for our purpose. They exist in most circumstances and therefore cannot be used as significant indications of specific surroundings during the course of travel.

One characteristic of GPS is signal loss, which is a significant indicator of our physical surroundings. L1 frequency passes through clouds, glass, and light objects, but

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cannot penetrate solid objects such as buildings, thick walls, and mountains. Therefore, GPS signal reception can be blocked when we enter a building and resumed when we head out. Occasionally when our movements in the building get close to light objects such as windows, doors, balconies, or sun roofs, GPS signal may reappear. A closer look reveals that signal losses can also happen sometimes when GPS is well-exposed to signal reception yet under very static position for a period of time. This happens mostly according to how the GPS software is programmed, such as stop reception under a threshold velocity. As a result, a period of signal loss can mostly be seen as a hint of the individual being occupied with an in-door activity or at a static location.

Another interesting and indicative error phenomenon is GPS signal drifting when stationary or near-stationary. The explanation is that when an object is moving, the GPS signal becomes more identifiable because every position will be somewhere apart from a previous position. While stationary, GPS still assumes the object is moving and records hundreds of points at where it "thinks" the object could be. The GPS system has a 95% chance of recording the position within a certain radius of the true location, for example, 10 to 20 meters. Also, the stationary status enlarges the effect of signal reflection. Together, they create a 20 to 40 meter jumble around the true location of the object. A period of signal drifting can also be an important hint of GPS carrier being around a near-static position.

The raw tracking data will include these errors and signal losses because it is based on GPS units. Among these noises, some are negligible due to the small error range while others are important to understand the tracking data. For example, signal losses

and drifts create the most disturbances yet also provide significant features in identifying the activity stops.

3.3.2 Automatic Stop Identification

An understanding of the characteristics of GPS signals helps us to anticipate patterns of the trajectory during the tracked period. Although an algorithm can be developed out of these characteristics that would possibly deal with various stop types, a close examination to the overall track signal pattern, particularly the stop signal pattern, is very necessary. As a control, we compared GPS recorded tracks to accurate paper activity-travel diaries from my department colleagues and myself. The comparison reveals most of the signal patterns at stops.

Some stops are easy to identify, such as large buildings, which perfectly block the GPS signals. When these buildings are activity stops, in the perfect case, GPS signals disappear upon an individual entering the building and restore upon leaving. A stop like this anchored by the time of entering and leaving is recognizable.

However, most buildings are not sheer signal-proof. There are considerable chances that signals may re-appear from time to time when the person or object carrying the GPS is on the top floor, under the roof, or near a window. If the individual or object keeps exposed to the GPS signal receivable area in a stationary or low-speed-moving status for a period, the signals render a drifting pattern. Most stops are composed of spaced drifting patterns and signal missing patterns.

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There are also stops containing more than one actual location. These locations can be close enough to each other that they are normally considered as one stop. For example, an individual goes to a place close from office to have lunch, or the apartment laundry, or mail room near home. These locations are usually ancillary facilities within very short walking distance. GPS waypoints render a clean visible path during movements between the locations, yet we are not considering these paths to be trips.

Based on the properties of stop waypoints patterns, we developed an algorithm that automatically removes noise and identifies the activity stops. The automatic process starts off with the algorithm that identifies stops. Trips can be generated after stops are fixed.
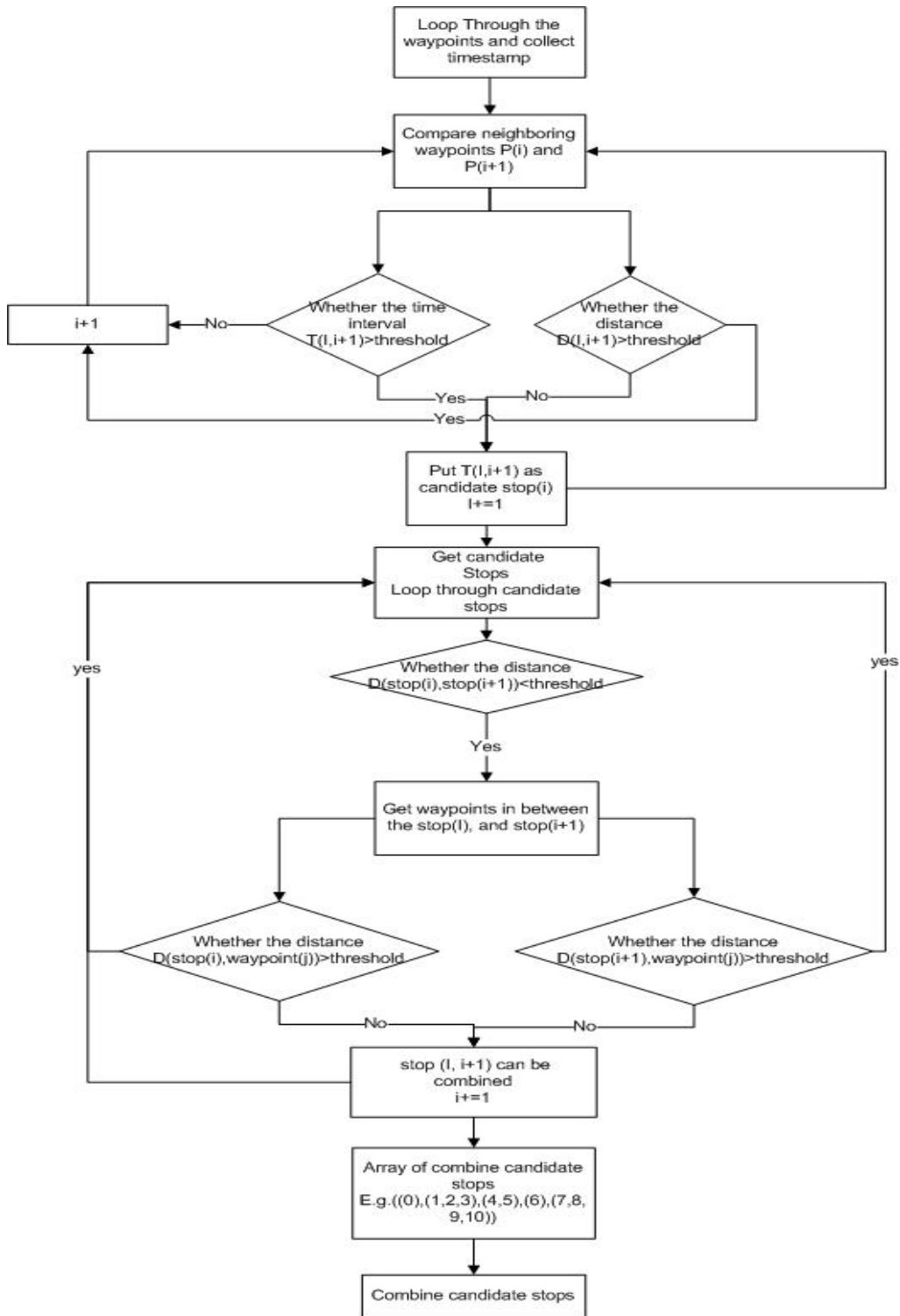
Figure 5: Flow Chart of Identifying Stops

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Figure 5 shows the flow of the algorithm. As discussed before, locations with signal losses can conditionally be seen as possible candidate stops. A candidate stop is characterized by neighboring waypoints with large time gap. It is also conditioned by the closeness of the neighboring waypoints. If the neighboring waypoints are distant, one possibility could be the individual is traveling by subway that signals are blocked during the whole course of travel; another more probable situation is GPS malfunction or powered off. In this first version of pilot design, the automatic process does not tackle with these cases.

A real stop can consist of multiple candidate stops which are close with each other. Candidate stops that fall in this category should be combined into one. This closeness not only has to be spatial, but also temporal. For example, a person goes out for an errand, assuming he/she makes no stop on the way, and comes back to the same office. Two stops (the office) almost have the identical spatial location, yet since there is a trip in between, they should not be combined as one.

On the other hand, candidate stops that are spatially close and temporally apart can also belong to the same real stop (see Figure 6). Most of stops belong to this category. Such cases exist when GPS reception is intermittent between the candidate stops, whereupon these intermediate GPS signal patterns become the only determinant of whether the candidate stops should be combined. If all the intermediate signals locate within a threshold distance to both sides of neighboring stops, it is reasonable to assume that all these signals are drifting waypoints inside one single major stop, and therefore the

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two neighboring stops should be combined. This rule applies to all the discrete candidate stops until they are grouped together to form new stops.

Figure 6: candidate stops (left) belong to one stop (right)

3.3.3 Cleaning Noise Waypoints

A potential use of the track is to display a clear individual activity-travel trajectory in a space-time GIS. The original track has bountiful sources of errors typically at the stop sites. Figure 7 shows a workflow cleaning up noise waypoints around the stop sites. The left-hand side branch illustrates clearing the noise waypoints inside a stop, and the right-hand side branch deals with the noise waypoints from outside of the stop's time window.

Clearing the inside-stop waypoints is easy, simply by deleting timestamp locateed inside the stops' time windows. Clearing outside-stop noises are a bit more complicated because they are recorded before entering or after leaving a stop where signals fade. These waypoints may present a dense low-speed moving pattern or drifting pattern, either of which creating a jumble around the stop. To remove such noise, we first enclose the noise jumble located around the stop. Among these enclosed waypoints, we try to remove those located within an empirical temporal threshold, for example, to remove the

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waypoints that are located within 100 meter from the stop with the condition that the time

intervals between these waypoints and the stop's time window are no larger than 2

minutes.

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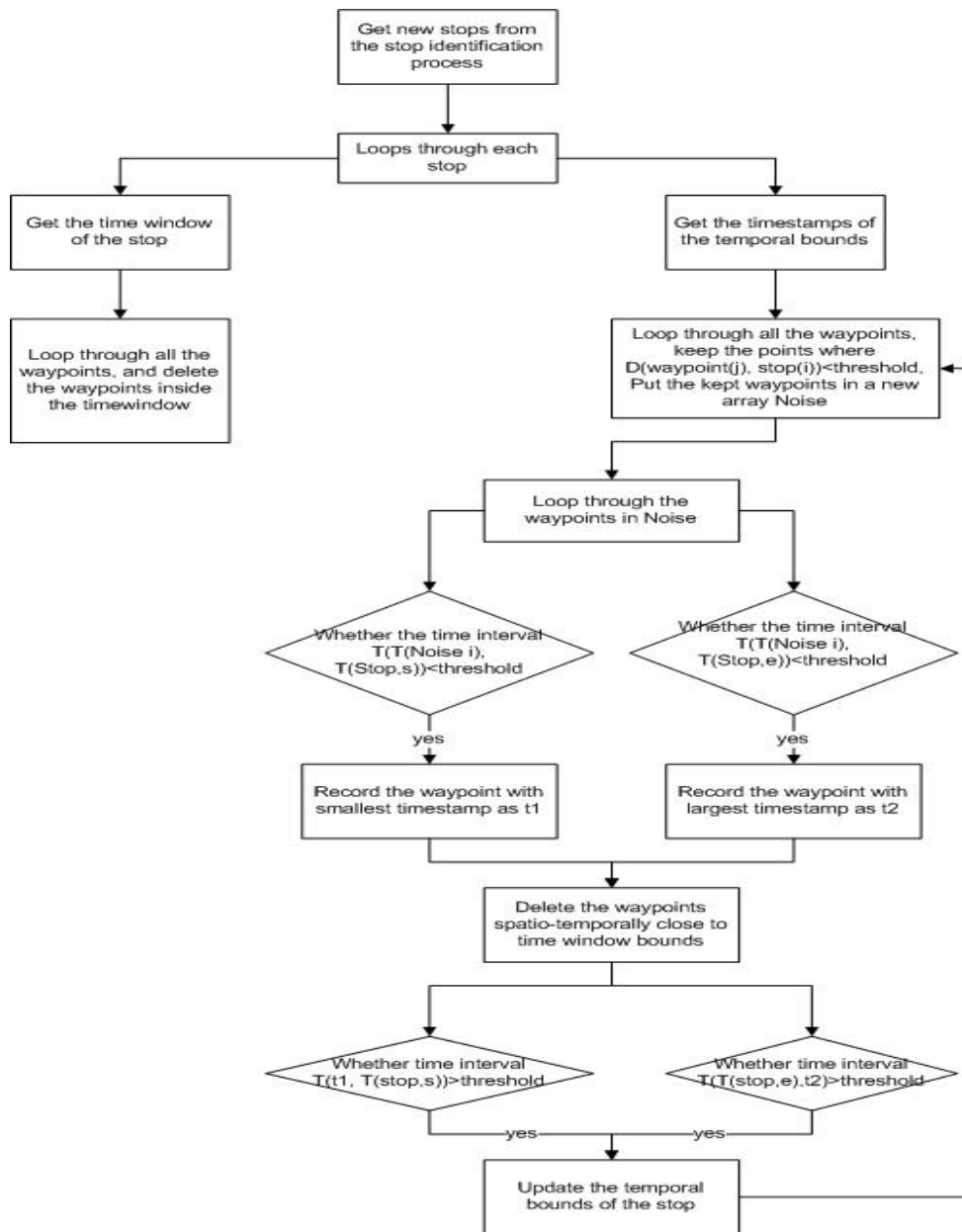
Figure 7: Flow Chart of Removing Noise Waypoints

(Note: "No" does nothing in the select case in this figure and takes it back to the loop of processing the next record)

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An improved version of cleaning outside-stop noises is to use a flexible temporal threshold, as indicated in the flowchart (Figure 8). While it still requires an arbitrary geographic threshold, the temporal threshold is replaced by an additional determinant. For example, as indicated in the flow chart, three consecutive waypoints are located outside the threshold. If we backtrack the waypoints before they enter a stop, assuming waypoint (i) is within the geographic threshold whereas its previous waypoints (i-1), (i-2), (i-3) are all outside the threshold, we can decide to keep those waypoints whose timestamp is smaller than waypoint (i), and determine those with larger timestamps to be the noise. The same rule can also apply to the upper-bound of the stop's time window.

Figure 8: Removing Noise Waypoints Improved

3.3.4 Generating Trips

Travel is composed of trips which are conducted to fulfill the needs for activities. A trip connects an origin stop and a destination stop, and is shaped by the waypoints in between. For example, a commuting trip starts when an individual leaves home, and ends upon arrival at workplace. With home stop and work stop identified, a commuting

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trip is anchored in space and time. Generating trips is a straightforward process which only entails segmenting a track at where stops are identified.

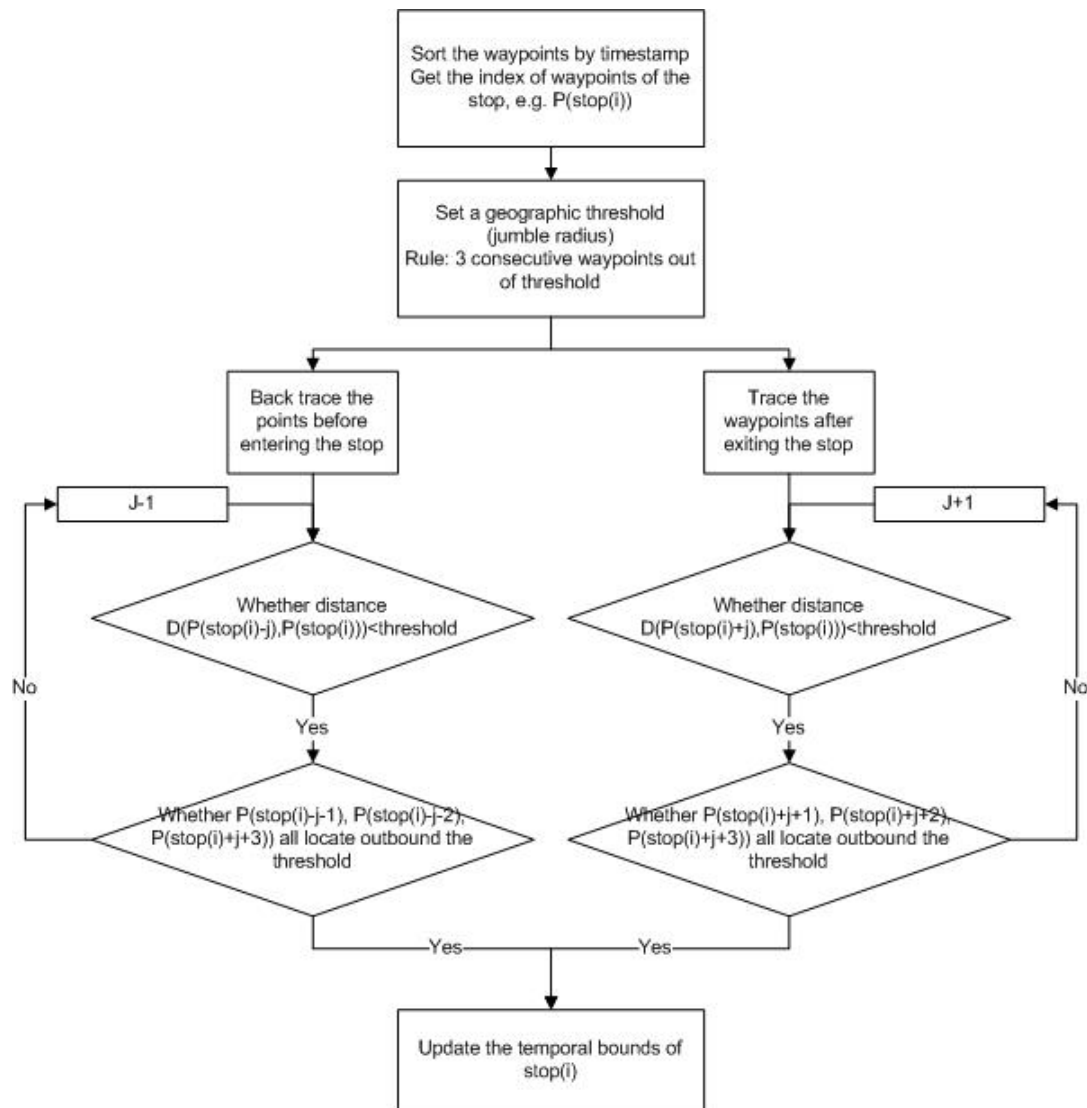In a nutshell, in the automatic process, a computer program captures the stop information from an individual's track based on the characteristics of GPS signal patterns. It also cleans up the noise waypoints inside and around the stops. Finally, it segments a track into trips based on the spatial-temporal distribution of stops.

3.4 Manual Process
3.4.1 Exceptions from the Automatic Process

Manual processing is a necessary supplement to the automatic identification process. Three major categories of unaddressed problems from the automatic process need to be treated with respondents' interactions. First, the automatic process may not be able to correctly recognize all the stops. The automatic process mainly depends on the processing of signal losses and drifting at the stops. Data processing is controlled by some empirical threshold values that applies to the whole track and determine the granularity of the measurement of stops. For example, if we try not to miss a 2-minute stop such as a drive-through or pick-up, we may end up obtaining some unnecessary stops during a traffic jam or extremely long red light. On the contrary, if we try to avoid having unnecessary small stops, we risk missing minor stops. Consequently, the automatic process may miss some stops or mistakenly identify excess stops. Manual identification is then needed to remove the incorrect stops and to add back the missed ones.

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Secondly, the automatic process may not be able to recognize unexpected signal patterns in cases involving certain outdoor activities. For example, GPS signals will record a moving pattern of a jogger around a standard 400 meter ground track in a stadium or a trail in a park. The stadium or park is usually considered as a stop, yet it is not identified because the signals should indicate the individual is under regular movements.

The third error category requires incorporating the manual identification process to address issues of GPS malfunction, software runtime error, cell phone power off, or traveling in regions with signal obstruction. These scenarios create errors that differ from the intrinsic or extrinsic signal errors, but are closer to mistakes than errors. There are several identified types of error representation. First, sporadic waypoints are misplaced far away from the real path during a runtime error or GPS malfunction. Second, GPS software, especially background-running cell phone based GPS software, can go dormant after a continuous period of signal reception failure. Sometimes, the background software is not awakened on time when the signal reception resumes. As a result, some important segments are missing. Third, GPS reception is simply cut off when the cell runs out of power or the individual travels in regions with signal obstruction, such as subways. The first type can be called as "waypoint-misplacement", and the latter two types can be generalized as "signal-loss". The automatic process will help detect where these errors occur, but cannot handle these exceptions.

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3.4.2 Manual Treatments for the Exceptions

Based on the three categories of unhandled exceptions, corresponding treatments are suggested. The first-category problems denote the need for removing excessive stops and adding identified stops. In practice, within an acceptable range we would rather identify more stops than to recall which ones are missed, because adding back a stop usually entails defining a time window that it occupies while removing a stop does not. Therefore, in the manual process, a stop-removing function is mostly needed for treating the first-category problems. The second-category problems describe the occasions that certain stops are overlooked in the automatic identification process. Therefore, to add back these stops, a manual stop-identification function is needed.

The first two categories of problems only pertain to the stop information. The third-category also relates to trips. For "single-waypoint misplacement" problems, a trip containing that waypoint is usually severely distorted (Figure 9, left: a waypoint was misplaced across the river.). To correct the route, a straightforward way is to delete the misplaced waypoint. "Signal-loss" (Figure 9, right: the entire track was lost, only the starting point and end point were recorded.) problems need additional analysis case by case. A low-ratio of signal-loss would not affect the usefulness of the track by much. An individual can manually identify the stops on the missed track and even restore the rough look of the route by interpolating waypoints. However, if there is a big proportion of missing track, the effectiveness of using this application will be questionable, because an individual will need to identify every single omitted stop just like responding to a paper survey.

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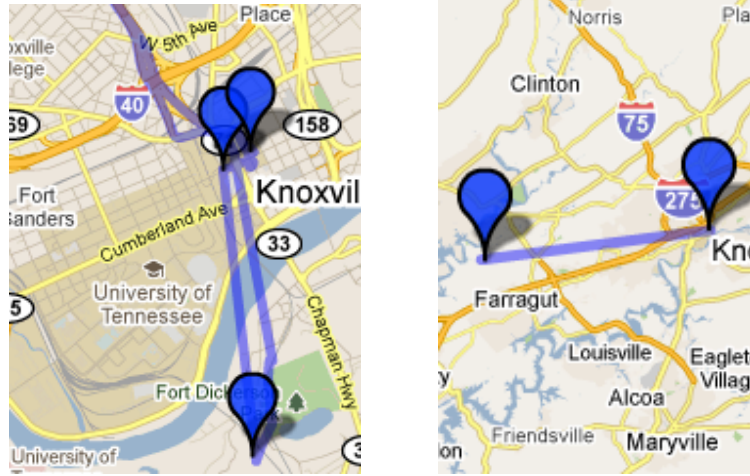
Figure 9: Waypoints-misplacement (left) and signal loss (right)

3.4.3 Activity Type and Travel Mode Survey

Automatic and manual identification processes are dedicated to capturing the allocation of stops and trips in space and time. Apart from the spatial and temporal characteristics of the stops and trips, activity-based travel studies also focus on the travel mode related to each trip and the activity type at each stop. Such information can be acquired through a prompted recall survey where the activity types and travel modes are classified as following:

Activity types are classified into 11 categories: 1. Activity at home; 2. Paid work; 3. School; 4. Volunteer work; 5. Pick up / drop-off person; 6. Social, recreation/church; 7. Catch a bus, train or airplane; 8. Shop; 9. Personal business (pay bills, doctor, dentist, etc.); 10. Eat meal; and 11. Others.

Mode choices are classified into 9 categories: 1. Driver of auto/truck/van; 2. Passenger of auto/truck/van; 3. Motorcycle, moped; 4. Bus; 5. School Bus; 6. Taxi/paid limo; 7. Walk; 8. Bicycle; and 9. Others.

To summarize, a manual process is needed when we try to identify additional stops or remove spurious stops as well as interpolate waypoints and remove occasional misplacements. This process is also necessary for collecting attributes such as travel modes and activity types that cannot be identified by the automatic process.

3.5 Implementing the web-based volunteered tracking survey system

The prototype of volunteered tracking survey system is implemented as a web application. Using the web as a dissemination medium for data and applications has proven effective for dealing with real-time maps, frequent updates of data and application, personalized map content, and most importantly, cheap and easy transfers of geodata across the Internet.

This prototype is composed of a server side implementation and a client side implementation. The server is built under Microsoft Internet Information Server (IIS). It is responsible for receiving the client side requests and forwarding them to asp dynamic resources for processing and delivers asp response content over the World Wide Web (www) using Hypertext Transfer Protocol (HTTP). A client side initiates communication by requesting a specific resource using HTTP and receives the content when the server responds. In the simplest setup, only a web-user agent is needed. This prototype client side is built as a Rich Internet Application (RIA) upon Adobe Flash Builder, which features ActionScript as the development language.

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3.5.1 Components

The application comprises three major components as illustrated in Figure 10: An embedded Google Map, an information datagrid (shown in the yellow box on the left), and an Application Control bar (shown on the top).
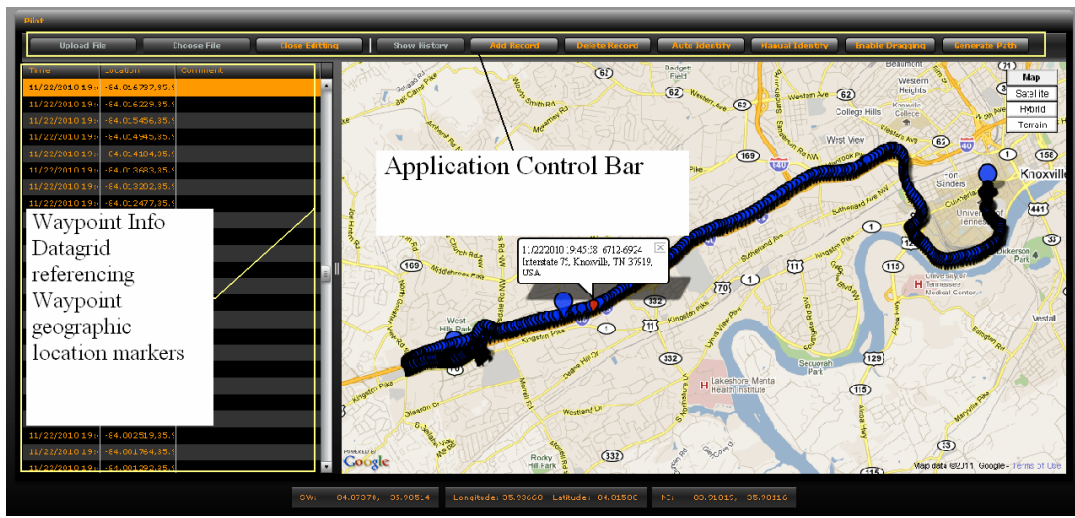
Figure 10: Voluntary Tracking System Main Interface

The Application Control Bar docks all the functions that this website supports. It contains a file operation function group, including file-uploading function, target-file-choosing function, and a data processing function group, including a one-click automatic processing function and functions for the manual process, such as editing waypoints and stops.

A Google Map is embedded for the purpose of displaying visual elements and to support the manual processing operations through a graphic interface using Google Map's APIs. The datagrid can switch between three modes: Waypoint Info mode, Stop Info mode, and Trip Info mode. In each mode, the datagrid displays detailed attributes

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regarding tracking waypoints (timestamp, coordinate), stops (time window, activity type, travel mode), and trips (time window, origin, destination, and travel mode). Data records in the datagrid are bi-directionally linked to visual objects on Google Map. Hovering over or clicking on objects on the Google Map flags the record in the data source and highlights the corresponding record in the datagrid, and vice versa.

3.5.2 Displaying a Track

Users have the ability to switch between a point mode and a line mode with this application. Figure 11 shows a waypoint mode of a GPS track. In a point mode, a track is shown in discrete waypoints, which provides convenient backtracking to exact locations at specific moments. Manual operations concerning waypoint information, such as interpolating waypoints and deleting misplaced waypoints, are only supported under a point mode. However, most waypoints do not have specific meanings. Since each waypoint takes an individual feature to represent on the embedded Google Map, loading up and refreshing graphics under a point mode takes a much larger browser cache, and thus much slower. Also, in areas possessing major stops, or constantly visited, or characterized with extreme low-speed traffic, densely scattered waypoints may block the display or conceal the real movement path. It is suggested to use a line mode for display unless there is a need to edit the waypoints.

Figure 12 shows the line mode of display which is the default mode for this application. A track displayed under the line mode comprises the stops and trips connecting them. In Figure 12, four large pushpins stand for four activity stops on the

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track.
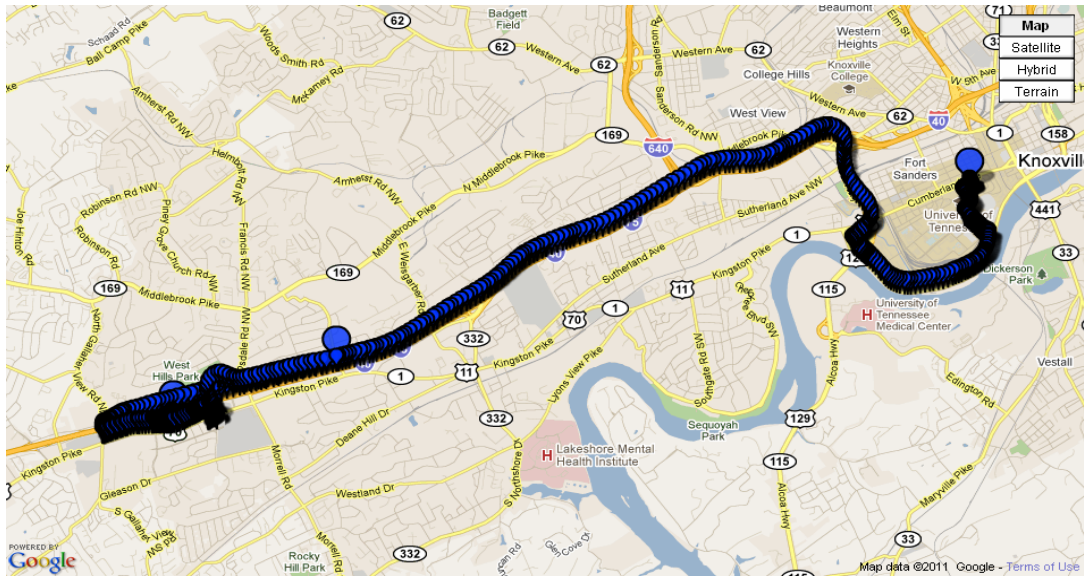
Figure 11: Waypoint Mode Display
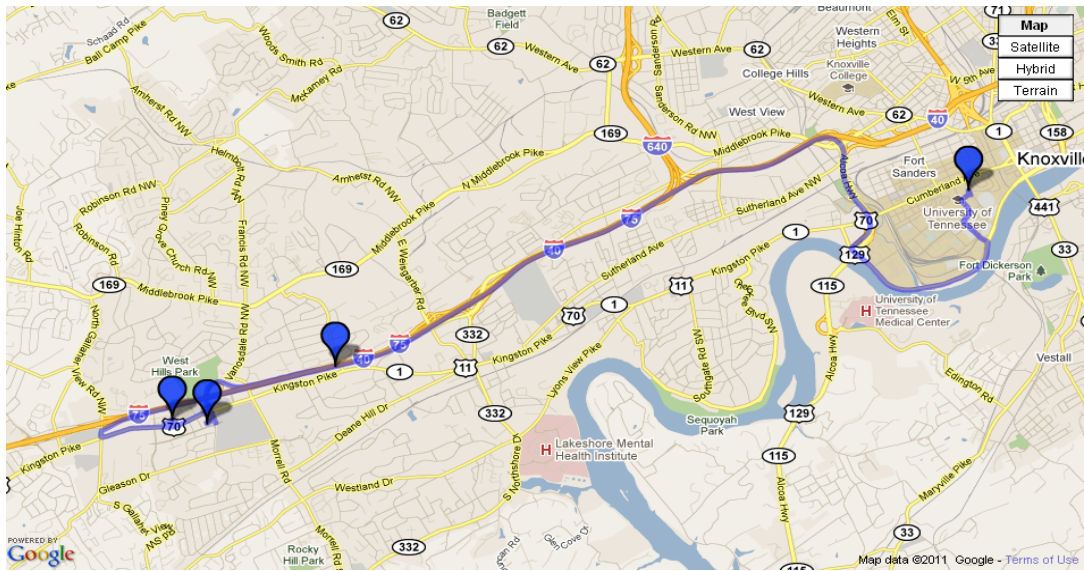
Figure 12: Line Mode Display

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3.5.3 Manual Stop Identification Component

The most important composition of the manual process is manual stop identification. An individual is asked to identify the stops he/she has made but were not captured by the automatic process because of unidentifiable signal patterns or signal losses. To ease this task, a manual identification component (see Figure 13) is developed, which features three ways for locating a stop in space and time: geocode locating, map locating, and geo-fence locating.

Figure 13: Manual Identify Form

Goecode locating pinpoints a stop by resorting to the Google Map's Geocoding services. To use geocode locating, a user needs the street address of a stop. A user can also directly locate the stop on the embedded Google Map using a map locating option. Besides location, both of them also need a user-input time window to fix the stop on timeline. When a user confirms a stop, the component creates it and removes the waypoints temporally inside its time window.

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Geo-fence locating (Figure 14) does not need the user effort in remembering a time window for the stop. It allows a user to identify a stop by drawing a geographical fence on the map. A user can draw a rectangular window on the map as an approximate boundary of the stop. Inside the fence, a waypoint with the smallest timestamp and one with the largest timestamp are selected as the starting point and the ending point of a stop. Waypoints that temporally locate in between the starting point and ending point are considered as noises, despite being geographically inside this fence or not.
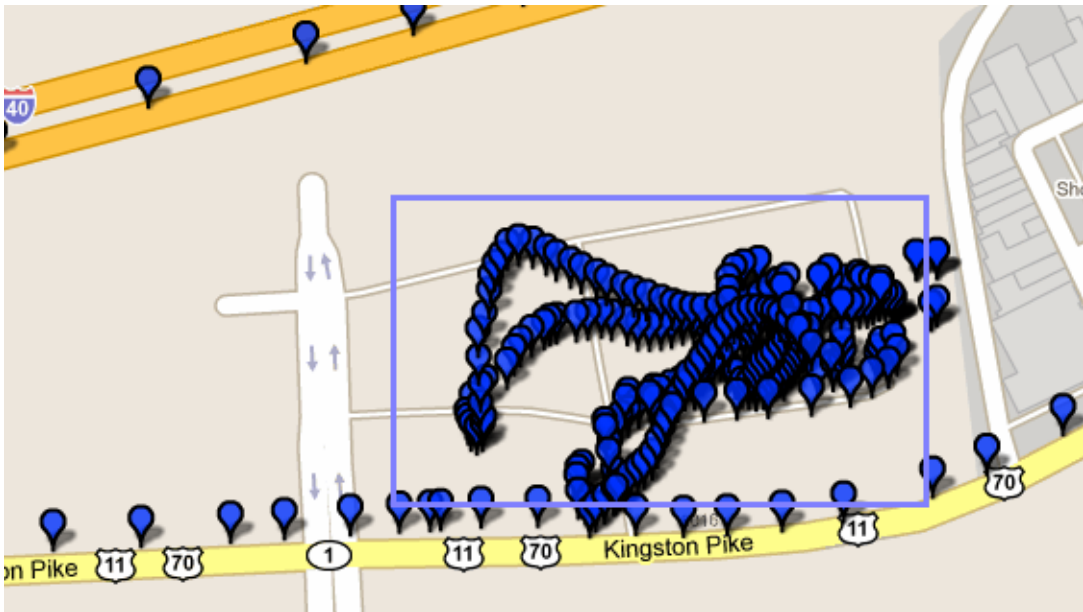
Figure 14: Geo-fence locating

Geo-fence locating is suitable for activity stops that are not repeatedly visited. However, when it comes to stops usually visited more than once in a day, the geo-fencing method no long applies. For example, a father drops off his children at a kindergarten in the morning and picks them up in the afternoon. There are two different stops at the same location (kindergarten) in a day, each creating a cluster of drifting points. Drawing

the window fence will enclose points from both stops, which automatically shrink the whole route by deleting all the stops in between.

3.5.4 Delete and Combine Stops

The automatic process may identify excessive stops so as not to miss minor stops. To remove the spurious stops, a user can select the stop and use the delete button on the main interface. Occasionally, one stop can be mistakenly split into two or more separate stops. If that happens, these stops need to be combined into one stop. Split occurs because signal misplacement not only happens during a trip but also happens inside a stop. Waypoints inside a stop misplaced as outside will deceive the program as if they were different intermediate trips between the candidate stops, therefore these stops should be combined into one. To allow for multiple-selection of stops, user needs to select the stops to be combined and run the combine function on the toolbar. The resulting stop updates its time window and removes the intermediate trip in between the candidate stops. The new combined stop is given a new location of averaged coordinates of the stops that comprise it.

3.5.5 Adjust Position

Adjust-position function is provided to fine-tune a stop's location. In the automatic process, the location of a stop is determined as the geometrical center of several candidate stops averaged by their Euclidean distance between each other. Automatically identified stops should locate in the proximity of true stops at most of the times. For example, when several candidate locations are identified in the same building, the true

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stop may still be in the building. However, it is also plausible that a person parks the car in the garage across the street from his/her workplace. The garage and the workplace may both be identified as candidate locations for the same stop, but their geometric center may sit in the middle of the street. In these occasions, we need to slightly adjust the location of the stop. In this application, users can enable adjust-position function on the main interface. Relocate a stop is simply dragging the place marker to a desired position on the map.

3.5.6 Editing Waypoints

Adding waypoints performs an interpolation to the existing route. It is useful for treating small portions of signal-miss on important road segments. When adding a point, a user has to identify two existing waypoints where the new point will be added in between. The location of the new point can be anywhere the user puts a new pushpin. Its timestamp is interpolated using the timestamps of the two identified endpoints and the Euclidian distance to each point.

Figure 15 illustrates two endpoints P1 and P2 recorded at "11/22/2010 19:48:27" and "11/22/2010 19:48:38". Signals are missing between them where there happens to be an important road segment on a merging lane, so we are to add in three waypoints to fill the gap. A new point PN can be interpolated as $T(PN) = T(P1) * (1 +/- (D(P1,PN) / (D(P1,PN) + D(P2,PN))))$. Figure 16 shows the signal missing section after being interpolated with three waypoints. Three interpolated points are time-stamped "11/22/2010 19:48:30", "11/22/2010 19:48:33", and "11/22/2010 19:48:35" successively.

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If a long section is missing and needs interpolation for displaying a rough shape, typically a crooked section, it is better to start interpolation from the middle or turning points of the route, and then interpolate the subdivisions respectively.

Figure 15: Before Waypoint Interpolation
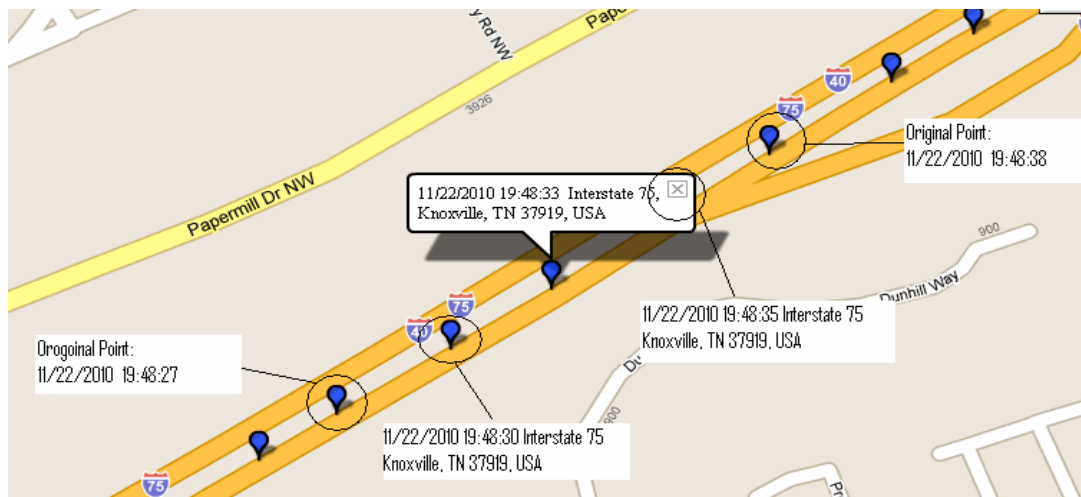
Figure 16: After Waypoint Interpolation

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The delete function that has been discussed can also be used to remove misplaced waypoint, where the user simply selects the target waypoint and delete.

3.5.7 Prompted recall Survey

Activity type and travel mode survey is the manual process of attaching activity types and travel modes to the trips and activities in addition to their spatial and temporal information. In the application (as shown in Figure 17), a user can specify his/her activity type in the stop info datagrid using the provided dropdown list. "Trip Mode" is an attribute associated with the trips. To simplify the survey, it is integrated into the Stop Info datagrid. There are two trips linked to each stop. In this application, "Trip Mode" denotes the travel mode used by the individual to get to that stop.

From	To	Activity Type	Trip Mode
2/10 6:32:0	2/10 6:32:0	Activity at home	Driver of auto/truck/van
2/10 7:59:4	2/10 8:8:32	School	Driver of auto/truck/van
2/10 8:44:21	2/10 17:41:32	Pick up/drop-off pers	Driver of auto/truck/van
2/10 18:20:54	2/11 7:48:5	Activity at home	Driver of auto/truck/van

Figure 17: Stop Info Datagrid

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CHAPTER 4: INTERACTION-BASED DYNAMIC JOINT-ACTIVITY OPPORTUNITY LOCATION-BASED SERVICE

Location-awareness is one of the most popular topics in social networks and is anticipated to make human interactions more dynamic. The effects discussed in section 2.1, such as coordination, could be even more enhanced because people now have better knowledge of each other through transparent locations. In time geography, although the relationships between capability, authority, and coupling constraints and human interactions have been analyzed in theoretical and empirical studies, they are rarely applied to interaction-based location-aware platforms. This section describes a LBS design that emphasizes the temporal factors in human activities, especially those involving interactions. The application is designed to have the following new characteristics:

1. To enable scheduling in LBS.

2. To use shared real-time tracking information as a source for interaction-based LBS.

3. To calculate the potential face-to-face meeting opportunities for the participants in a joint activity.

4.1 Location-Activated Scheduling

From old-fashioned written notes to printed agendas to digital gadgets like Google Calendar, tools for scheduling have evolved. With advances in scheduling programs such as Google Calendar, user can log in anytime, anywhere with mobile phones and access a

list of upcoming events with time information. Users can also receive reminders for scheduled activities and notifications of changes to the plans. Moreover, Google Calendar also enables sharing calendar with friends.

However, conventional scheduling does not take into account the spatial constraints of scheduled activities, whereas conventional location based services neglect the temporal constraints. Scheduling and LBS can complement each other. In this design, one of the tasks is to tie the scheduled activities with actual locations. As a result, a schedule not only denotes when an activity should happen, but also where it should happen. Instead of having "have lunch with Mr. John Doe at 11:30 am in Red Lobster's at downtown" in one's schedule, it is now "having lunch with Mr. John Doe at 11:30 am at the downtown Red Lobster's located at coordinates (-84.23432, 36.1312312)". A nominal activity place name related to the schedule is given an actual location with a geographic meaning.

In real life, individual schedules are generally composed of fixed and flexible events based on the degree of flexibility in space and time (Miller, 2005). Fixed activities refer to those activities with fixed locations and fixed time windows, whereas flexible activities usually can fit in between the fixed activities and yield to changes. However, sometimes the boundary between these two kinds of activities is vague, and many activities fall between the two categories.

In practice, human activities can be classified into many categories just by their spatial and temporal properties. Spatially, an activity can have a fixed location, an unfixed location, or a moving location. Temporally, an activity can have a fixed time

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window with start time and end time; only a fixed start time; only a fixed end time; a fixed duration; or totally unfixed. In tabulating all the possible combinations, fifteen subcategories result (Table 7).

Table 7: Types of Activities

	Fixed Location	Unfixed Location	Moving Location
Fixed Start & End	Fixed		
Fixed Start Time	Fixed-S		
Fixed End Time	Fixed-E		
Fixed Duration			
Unfixed			

However, in this design, among the various subcategories, only three subcategories are considered suitable to include in the schedule as fixed activities: activities with fixed time windows and fixed locations (Fixed), e.g., a regular class; activities with fixed locations and start times (Fixed-S), e.g., a basketball game starts at 7pm, but how long it takes depends on how the fouls interrupt the game and whether the game goes into over time; activities with fixed locations and fixed end times (Fixed-E), e.g., a student late for class sneaks into the classroom to sign the attendance sheet.

A fixed activity occurs at a fixed location with a temporal boundary. Outside the temporal boundary, flexible activities are allowed to occur. Unlike a fixed activity, a fixed-S or fixed-E activity is only temporally closed on one end, making the flexible time

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windows hard to estimate and apply in an application. This design suggests three ways of treating such activities:

1. To give a tentative end time for a fixed-S activity or a tentative start time for a fixed-E activity.

2. If a tentative start time or end time is not specified, then a fixed-S or fixed-E activity keeps one end of its time window open until it reaches the next fixed activity. For example, if the time window for a fixed-S activity A is (t1, unknown), and it is followed by a fixed activity B with closed time window (t2, t3), then the system neglects the flexible time window between A and B, and marks (t1, t2) as an activity time window.

3. A more viable way is to introduce a user-status sign, which is discussed in the next section.

4.2 User status

Used in many instant communication tools, a status sign can be very effective in showing other people the availability of the user. Typical instant-chatting tools, such as Windows Live Messenger, allow users to pick from any one of four statuses: available, busy, away, and offline. Such a mechanism can also be adopted in this meeting application design. With these statuses, problems such as the one-sided open-end time window described above, i.e. activities only has a starting time or an ending time, can be solved.

Since busy represents a user being not available, the status is automatically turned to "busy" if one is engaged in a fixed activity. For example, one has a class starting at 9am

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on the schedule, then the status turns to "busy" as soon as the clock reaches 9am. One can also manually turn the status to "busy" if not being available even if no activity is listed on a shared schedule. In a fixed-E activity, a user can turn on a "busy" status to signal the start time.

User status is automatically turned to "available" if the user is within a flexible time window. Also a user can turn the status to "available" if he/she is available to be met during fixed activities such as office hours. For a fixed-S activity with unbounded end time, a user can turn on the "available" status to signal the activity is finished.

A user can turn on an "away" status if not being physically around the device carrying this application, for example, when a user leaves for lunch without a mobile device. A user's "away" status also automatically overrides "available" when no-operation status lasts over a threshold time period, say 30 minutes. In that case, others who try to initiate a meeting with this user may need to call to confirm the meeting.

If one signs out of the application or chooses to appear as offline in the application to others, one's real-time location stops updating from where one logs off. Appointments can only be made through direct contacts in this case.

4.3 User specification of meeting request

Meetings, as with other activities, can occur as a prearranged appointment (e.g. one calls a friend, saying, "Let's meet at 3 pm tomorrow afternoon at the downtown Starbuck's and work on our final project for an hour."), or an unplanned occurrence (e.g. "Can you give me the midterm study guideline sometime tomorrow?"). A prearranged appointment

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can be treated as a fixed activity that one can put in the schedule, whereas an unplanned meeting can only happen when all the participants' accessibility overlap in space and time to create joint meeting opportunities. For an unplanned meeting, users should be able to specify their meeting requests such as meeting locations, when to start the meeting and how long the meeting should last.
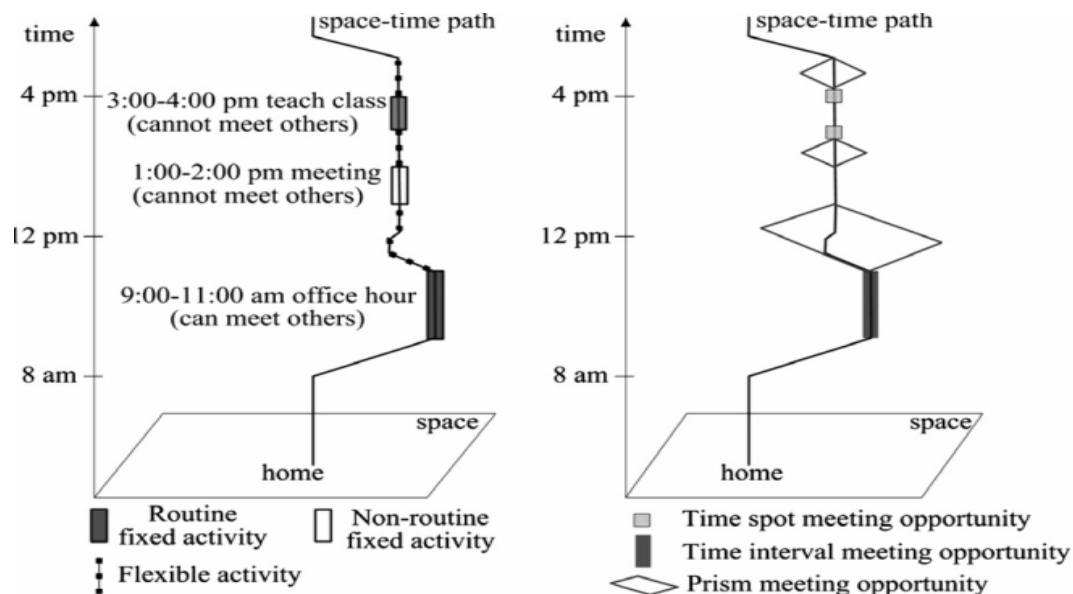
4.4 Calculate meeting opportunities
4.4.1 Types of face-to-face meeting opportunities

To conduct a face-to-face meeting, the meeting participants must be at the same location at the same time (synchronous presence). Meeting opportunities measure the potential space-time set for all of the meeting participants' possible synchronous presences.

For a two-person face-to-face meeting scenario, meeting opportunities can be calculated by comparing both-person's space-time paths and prisms. An individual's space-time path is composed of fixed activities, which are represented with fixed locations and time windows with flexible time windows in between. Flexible activities can be carried out within the flexible time windows but are spatially and temporally confined by the space-time prisms anchored by the end points of their previous fixed activities and the starting points of their next fixed activities. Within a space-time path, three types of meeting opportunities are identified: time-spot meeting opportunity, time-interval meeting opportunity, and prism-meeting opportunity (see Figure 18, Yin, Shaw,

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and Yu, 2010).

Figure 18: The three types of individual daily activities and the three types of potential face-to-face meeting opportunities

(Source: Yin, Shaw, and Yu, 2010)

Since a two-person face-to-face meeting requires synchronous presence, one user's space-time prism has to coincide or at least intersect with the other user's space-time prism somewhere at a moment in time. If two-people's space-time relationship is depicted in the 3D orthogonal space-time space, at least one of the following has to be satisfied:

1. Person A's time-spot meeting opportunity locates on person B's time-interval meeting opportunity or inside person B's prism meeting opportunity. In this case, the meeting opportunity is the time spot at person A's location at this time spot.

2. At least a portion of person A's time-interval meeting opportunity coincides with person B's time-interval meeting opportunity (see Figure 19: left), or intersects person

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B's prism meeting opportunity. In this case, the meeting opportunity is the overlap of A and B's time intervals or the section of A's time interval inside B's prism at A's location during the time interval. A spot meeting opportunity can be seen as a special case of interval meeting opportunity.

3. Person A's prism meeting opportunity intersects person B's prism meeting opportunity (see Figure 19: right). In this case, the overlapping volumes of the space-time prisms are considered as opportunities that are spatially and temporally feasible for both users.
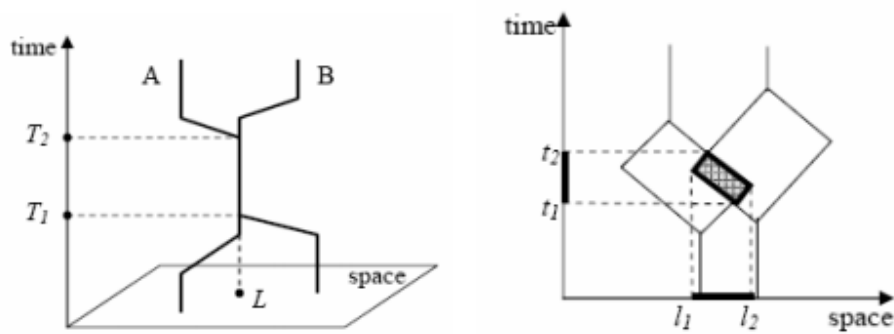
Figure 19: Interval meeting opportunity (left) and prism meeting opportunity (right)
(Source: Yu and Shaw, 2008)

4.4.2 Measure Meeting Opportunities with User Statuses

Based on the meeting opportunity types and user statuses, we tabulate (see Table 8) the types for a two-people meeting opportunities in this design.

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Table 8: Measurements for meeting opportunities

			Person A			
			Fixed		Flexible	
			Busy	Available	Busy	Available
Person B	Fixed	Busy	X	X	X	Point
		Available	X	X	X	Interval
	Flexible	Busy	X	X	X	X
		Available	Point	Interval	X	Prism

One can have fixed and flexible activities in the schedule. During a fixed or flexible activity, one can use a busy or available status to signal the availability for meeting with others. This allows each user to have four statuses: Fixed-Busy (FixB), Fixed-Available (FixA), Flexible-Busy (FleB), and Flexible-Available (FleA). We assume person A and person B are at different locations. Therefore, we can have the following conclusion:

1. During fixed activities, person A and person B will have no meeting opportunity.

2. If person B is busy, while person A is engaged in a fixed activity, they will have no meeting opportunity, and vice versa.

3. If person A and person B are both busy, they will have no meeting opportunity.

4. If person A is FixB and person B is FleA, they could have a time spot meeting opportunity, such as person B catches person A before or after the activity at the activity location.

5. If person A is FixA and person B is FleA, they could have a time interval meeting opportunity, such as person B finds person A during the fixed activity.

6. If person A is FleB and person B is FleA, they could not have meeting opportunity

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because person B's location is flexible and thus cannot be predicted.

7. If both person A and person B are FleA, they could have prism meeting opportunity.

Since person A and B are interchangeable, this table is symmetric on either side of the diagonal.

These measures can be extrapolated to multi-person scenarios. Since dimension of the opportunity decreases from prism to interval and to spot, to have a multi-individual conjunct prism meeting opportunity requires all the participants to be flexible as well as available (FleA). Any one of them being FixA or FixB will reduce a prism meeting opportunity to an interval or point meeting opportunity. If more than one person is occupied in a fixed activity, it will completely eliminate conjunct meeting opportunities, assuming all the participants are attending the meeting.

4.4.3 Calculate Meeting Opportunities

The last section identified three different types of meeting opportunities. To quantify these meeting opportunities, calculating the overlap of all participants' accessibility in the space-time orthogonal space is required. A prism meeting opportunity can be represented by a space-time prism, whereas an interval or point meeting opportunity can be seen as a special type of reduced-dimension space-time prism. To operationalize the concept in an urban transportation environment, Miller (1991) developed a Network Time Prism for implementing a network-based space-time prism. Network Time Prism calculates a prism upon a topological network with the transportation network's arcs and links. Each arc is weighed by link-based travel speed to simulate the real-world scenario.

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The key construct to carry a space-time prism is a Potential Path Tree, which is similar to the shortest path tree in Dijkstra's shortest path algorithm. A shortest path tree, in graph theory, is a sub-graph of a given graph constructed so that the distance between a selected root node and all other nodes is minimal. A Potential Path Tree is a sub-graph of links and nodes that can be accessed from a root location given a time budget. A Potential Path Tree can be obtained by clipping a shortest path tree with a time window.

As have been reviewed in Chapter 2, Yu (2005, Figure 2) implemented a 3D space-time prism based on the street network in Knoxville. To build the prism, he constructed a forward cone derived from the origin and a backward cone from the destination. A forward cone is built from a forward potential path tree and a backward cone from a backward path tree. With these two cones, every node visited within the time budget in the network gets a minimum travel time from the origin, known as earliest arrival time (At1) and minimum travel time to the destination, known as latest leaving time (Lt1). As long as the latest leaving time is greater than earliest arrival time (Lt1>At1), the node is within one person's access given the anchored origin, destination and time budget. The maximum duration that a person can stay at the node is $D1 = Lt1 - At1$.

In a two-people face-to-face meeting scenario, mutual meeting opportunities can be measured by adding a second person's (person B) prism meeting opportunity. Given B's anchored origin, destination, and time budget, B's prism meeting opportunity is the area where inside nodes satisfy the condition (Lt2>At2). At each node, D2 can be identified by Lt2-At2. As such, two prisms overlap at the locations where D1 and D2 overlap

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(At2<Lt1 or At1<Lt2). Projecting the prism overlap to the 2D produces the spatial meeting opportunities.

Extending a two-people meeting scenario to a multiple-people scenario at location X, we have the collection of n people's earliest arrival time $AC = \{At1, At2 \ldots Atn\}$; latest leaving time: $LC = \{Lt1, Lt2 \ldots Ltn\}$. If $Max\{AC\}<Min\{LC\}$, then X is qualified as a candidate for an N people meeting location.

Users can specify the meeting requirements by inputting the meeting duration, meeting start time, or meeting end time. These specifications can also be implemented into the design. Given:

x: a random location

$AC(x) = \{At1(x), At2(x) \ldots Atn(x)\}$: Collection of earliest arrival times

$LC(x) = \{Lt1(x), Lt2(x) \ldots Ltn(x)\}$: Collection of Latest leaving times

Ts : start time of a meeting

Te : end time of a meeting

D : duration of a meeting

For x to be a qualified meeting location candidate, the variables have to satisfy the following condition, where Ts, Te or D can be null if not specified in the request:

$Max\{Max\{AC(x)\},Ts\}+D < Min\{Min\{LC(x)\},Te\}$

4.4.4 Dynamic Measures of Accessibility and Meeting Opportunities

In reality, meeting opportunities are not static. Given the same capability constraints, four factors are identified as changing variables for people's accessibility and meeting opportunities.

First, schedules are usually more like guidelines than actual rules. Plans sometimes don't catch up with the changes. For example, a professor cancels a 10am-11am class on Friday morning because an important business trip creates a temporal conflict. For the students in the class, their constraint of being in the class between 10am and 11am is removed. Also, by dropping an intermediate anchor point, their accessibility is expanded. For example, some students may now plan a trip out of town on Friday. Assuming they abide by the disciplines, they have to show up in the class and can leave no earlier than the class ends, whereas if the class is cancelled, they could head out a lot earlier.

Second, a person's real-time location affects their potential meeting opportunities. For instance, a professor arriving at his/her office one hour earlier than usual office hours may give a student a prolonged time-interval meeting opportunity. A student deciding to stay at the library, doing homework during flexible time windows shrinks his/her prism meeting opportunities to time interval meeting opportunities by fixing his/her location.

Third, as time passes and real time locations change, an individual's accessibility will alter. Therefore, the meeting opportunities are also modified. A person's real time accessibility is depicted by a dynamic space-time prism which has two anchor points: the real-time location of the user, and the location of the following fixed activity. The time budget is the available time remaining until the next fixed activity.

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Fourth, an individual's status can be a varying factor to determine one's joint opportunities with others. For example, a professor engaged in a faculty meeting from 3pm to 4pm has a status of "busy" and is physically fixed at one location. Under such circumstances, he/she is exclusively occupied in one task and not available for students. In contrast, a professor doing research in the office has more freedom for multi-tasking, and therefore could put his/her status as available and be in the position of meeting students. Status can also be a common and realistic indication of emotional willingness of meeting. Just because a meeting is theoretically feasible does not mean it is an affirmative opportunity. Willingness to meet also adds dynamic uncertainty to meeting opportunities.

4.5 System Reminders

In a single-user scenario, this app design keeps track of a user's current location and dynamically calculates the user's space-time prism anchored by the next fixed activity. If the user gets to the prism's periphery, the system sends an out-of-time reminder. A user can then either choose to ignore the reminder or to change activities based on the schedule.

In a multiple-user scenario, individual updates to a schedule are synchronized to all the users whose agendas are displayed in the same view and notifications are dispatched in the meantime. Once a user sends a request to meet with someone else, the system then starts monitoring if the request is feasible to be fulfilled. Occasionally, one may change originally fixed activities, or may inadvertently travel into an "out-of-time" zone, causing the feasible meeting opportunities to change or disappear. Such circumstances result in

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wasting the uninformed participants' time. Although studies prove that timely mobile communication may relieve the early arrivers' waiting anxiety (Ohmori et al, 2005), effective avoidance of such waiting is almost always preferred. Consider this scenario: person A and person B are scheduled to meet at a downtown Starbucks at 3pm. However, on a short notice, B has to pick someone up at the airport, 40 minutes away from downtown, at 2:45pm, and forgets to cancel the appointment with A. As B drives away from downtown, meeting opportunities for A and B shrink. At the moment a threshold is triggered, for instance, when Starbucks is out of B's accessibility by 3 pm, both A and B should be informed to reschedule.

4.6 Determining Potential POI Set for Meeting

Meetings do not happen at random locations. Kwan and Hong (1998) defined a feasible opportunity set as available to an individual based on temporal and cognitive constraints, meaning aside from meeting spatial and temporal feasibility, personal preference is yet another important factor which determines whether a place is a potential meeting spot. In real life, most meetings only happen at specific places where people normally meet, such as restaurants, cafés, malls, whereas do not happen in the middle of a road, or in random crop land.

One of the most popular LBS applications is concierge services, such as Yellow Page, that help users locate businesses near a specified location. Concierge applications use business and landmark information that has been compiled into Points of Interest (POI) databases. In this design, after finding the feasible areas for meeting, we also want to identify the places where people can meet. People typically arrange the type of place

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to meet in advance such as picking restaurants for lunch or cafés for a short chat. These places have to be inside the participants' conjunct prism meeting opportunities. If such places exist and are found, detailed information such as name, street address, distance, phone number, and category can be sent to the user.

Occasionally, desired POIs requested by the users are not found. For example, two people intended to meet at a Starbucks, but unfortunately, no Starbucks was found to satisfy the spatial and temporal constraints based on two users' schedules. As an alternative, the system should identify the POI category of Starbucks, and search in the same area for other similar POIs. If similar POIs are found, it should return the users with a list of alternatives for a Starbucks.

4.7 Implementing a Prototype Client Side

In this study, we implemented a prototype user interface as a client side application. Due to the heavy reliance on the client-to-client, and client-to-server information delivery and handling, a real service is not built. Instead, we simulated the main procedure for finding two-people meeting opportunities using ArcGIS.

The prototype client interface is built on Flex Builder. It features the attributes that a user needs to customize to initiate a request and display the simulated responses. Eight components are constructed: Google Map plug-in, Status Control, Scheduling Grid, Buddy List, Message Stack, Place Window, Request Form, and Navigation Panel. These components will be introduced in the following section.
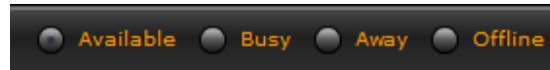
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4.7.1 Status Control

Figure 20: Status control bar

Status Control (Figure 20) is the component where a user can set his/ her status in this application. As discussed earlier in the chapter, when the interface is opened, a user can choose from four statuses: Available, Busy, Away, and Offline. On the map, where the users share their status and location, an available status is represented by a green glowing marker, busy by red, and away by brown. When user is offline, the marker grays out at where the user last appeared.

A user can switch among the statuses by choosing different radio buttons. By default setting, statuses automatically switch as discussed in section 4.2.

4.7.2 Buddy List

Figure 21: Buddy list

A Buddy List (Figure 21) shows all the friends that one has and the status of each friend. One can choose to share schedule with his/her friends by sending location-and-schedule-sharing requests to them. By sharing location and schedule information, they can see each other's real-time location as a glowing marker on Google map as well as reverse

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geocoded street address in "Location" column. A user can also visit a friend's most updated schedule with the pop-up InfoWindow (a GInfoWindow object) which is tied to the place marker.

4.7.3 Schedule Grid

The Schedule Grid is where one sets activity schedule. An activity schedule is composed of fixed-activities with four elements: starting time, ending time, location (either using street address or directly pointed out on the Google Map plug-in), and activity description. The specification of time and location together identifies the fixation of an activity. As discussed earlier, three types of activities can be seen as fixed: activities with fixed locations and closed time windows, and activities with fixed locations and semi-closed time windows. Each activity on the schedule is tied to a record on an activity marker on the Google Map.

4.7.4 Message Stack

Time	Message
8:34 AM	Sam has just changed his status to Busy
9:16 AM	Your next activity: 10:00, 1000 Phlip Fulmer Way, 37919, have class
9:18 AM	Sam has changed his schedule

Figure 22: Message stack

A Message Stack (Figure 22) caches the important short messages sent to a user. Several types of messages are cached in the stack: reminder of the user's own schedule. First, activity reminder: For example, the next activity for the user is to have a Class at 10am. The message pops up 15 minutes ahead of time. Second, schedule/status-change notice:

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If a friend changes his/her schedule or status, the system should automatically detect it and broadcast a notice to all the users that he/she shares information with. Third, out-of-time warning: Once one "travels" out of the space-time prism, he/she will get an out-of-time warning, suggesting the possibility of being late for the next activity. In a joint activity, a notice of one's possibly being late should also be forwarded to all the participants of the activity.

4.7.5 Request Form

A user wanting to initiate an individual activity alone or a joint activity with friends can specify the requirements through Request Form. Temporal parameters of the request include the minimum duration, a starting time, or an ending time. Type of POIs is the desired category of places where the activity is expected to occur. POIs include dining, coffee, nightlife, transit, parking, hotels, restrooms, Wi-Fi, gas station, on-going events, and so on. Transportation mode is by default set to travel by car.

In an individual activity request, one's requests are only constrained by one's own constraints. While in multiple-people joint activity requests, the requested opportunities are constrained by the constraints of all the participants. If none of the conditions are specified, all the POIs within the conjunct accessibility of all participants will be selected. POIs that meet the request will appear on the map, marked by balloons and a list of detailed information of all the POIs populates the Place Window.

4.7.6 Place Window

Name	Category	Price	Address	Duration
Little Italian Sub	Ethnic	Moderate	5102 Kingston P	19
Grill Express	American	Moderate	5103 Kingston P	19
Wok Hay Fresh /	Ethnic	Inexpensive	5018 Kingston P	19
Big Fatty's Cater	American	Moderate	5005 Kingston P	19
Geno's Pizza	Pizzeria	Moderate	7328 Middlebroc	7
Toddy's Back Do	American	Moderate	4951 Kingston P	19
S and S Cafeteri	American	Moderate	4808 Kingston P	19

Figure 23: Place window

The Place Window (Figure 23) is a populated data grid with a POI list returned from a
user meeting request. Each record in the Place Window contains typical information
such as name, category, price, address, contact info etc., while linking to a place marker
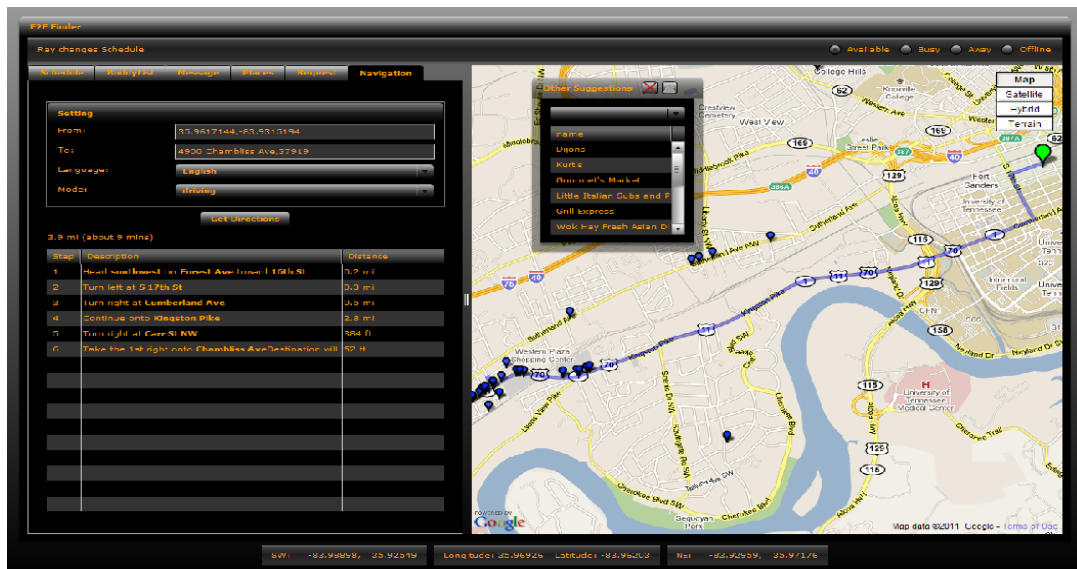on the map.

4.7.7 Navigation Panel

Figure 24: Navigation panel

The Navigation Panel (Figure 24) is an auxiliary tool that helps users navigate to the chosen POI. The system triggers a shortest path request through Google Map API once the meeting participants pick a place for rendezvous. A successful feedback returns a shortest path feature between the user's current location and the chosen POI as well as a descriptive turn by turn instruction.

The program also automatically finds other POIs of the same category in the vicinity of the chosen POI. These alternative choices are listed in a separate pop-up window on the upper-left side of the map as shown in Figure 24.

4.8 Server Side Simulation

The procedure of finding face-to-face meeting opportunity is simulated in ArcGIS using ArcOjects (AO) with the VBA language. The simulation uses two static datasets, a street network of Knox County and POI dataset in Knox County. The program also requires user schedules and "real-time" locations for the simulation. Figure 25 displays the workflow of the simulation which will be elaborated in the following sections.
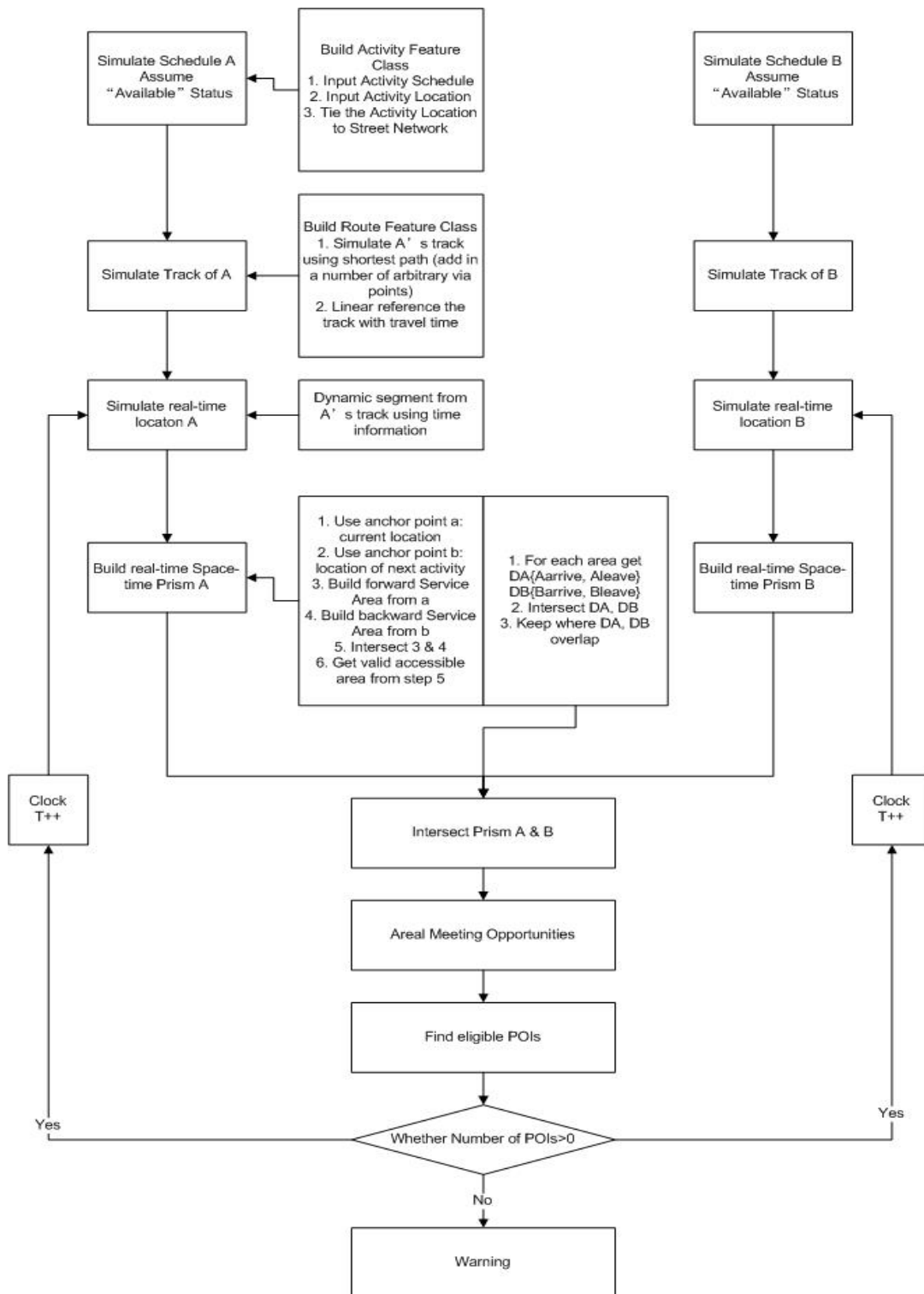
www.manaraa.com

Figure 25: Simulating Meeting Opportunities Flow Chart

4.8.1 Data Preparation

4.8.1.1 Street Network

To simulate the meeting scenario, we need to calculate people's accessibility under constraints. Network Time Prism is the key measurement to calculate. We set our simulation scenario in Knox County and built the street network dataset upon U.S. Census 2000 Knox County TIGER Line data. In TIGER Line data, street types are defined by CFCC codes. In this simulation, CFCC codes are divided into five groups: a. A10-A18 for Interstate, b. A20-A28 for U.S. and state highways, primary roads, c. A30-A38 for secondary roads, d. A40-A48 for local, neighborhood, rural, or city streets, and e. all other streets. Based on the classification of streets, speed limits are assigned to the road segments: 45 for interstates, or35 for secondary roads, 25 for local roads, and 15 f the rest. Travel time on each street segment is calculated by segment length divided by speed.

4.8.1.2 POI Dataset

For this study, we use the POI dataset collected by Ms. Kelly Sims, including 646 restaurants in Knox County. These POIs contain the detailed information typically found in a phone directory, Internet, and on-the-spot data collection. Information collected from multiple sources is merged to form a single, comprehensive data set. Detailed information of the POI dataset contains the name, category, price range, and street address of each restaurant. These POIs are then geocoded using the street addresses to add value to the map database's geographic content. Integrating the map database with

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the POI dataset creates a detailed, digital representation of the road network and business services available along it.

4.8.1.3 Geo-referenced Schedule

In this ArcObjects Macros, a schedule input form (Figure 26) is constructed to import the activity schedule with geo-referenced locations where these activities take place. Locations can be identified with directly clicking on the map and the program automatically snaps them to the nearest network segments around. For this demonstration, two activity schedules are fabricated, with activity locations randomly picked on the map.

Figure 26: User Schedule Input Form

4.8.4 Getting Real Time Location

A user's current location is where his/her cell/GPS signal is most recently detected. Current location is the key element to establishing a real-time environment and is essential to delimit a user's accessibility at a given moment. If one travels at 50 miles per hour and is 50 miles away from destination, given the current location and an hour time budget, one should probably stay on the shortest path; otherwise the user may run out of time. In practice, current location can be obtained from real-time tracking applications, such as Google Latitude, through RESTful APIs they provide. A typical trilateral authorization protocol implementing RESTful APIs between user, third-party application, and data provider (in this case, Google) is the OAuth framework. OAuth is an open protocol that allows users to share their private resources (e.g. photos, videos, contact lists) stored on one site with another site without having to hand out their username and password. A successful request through OAuth will be returned with a user's current location in JavaScript Object Notation (JSON) format, which can be easily parsed to get the coordinate, timestamp and travel speed.

In this simulated scenario in built in ArcGIS, we simulate "real-time" locations to create space-time prisms. Assuming the users do not have intermediate stops travelling between the scheduled activities, it is reasonable to make an assumption that they take the shortest path between different places. Or to make the routes more realistic, we can also add via-points in between the activity locations. Incorporating this in the scenario allows us to simulate a user's route either with a shortest path or a vehicle routing path.

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With a simulated route, using dynamic segmentation is especially useful in obtaining a user's location at a given moment. In ArcGIS, routes have a unique identifier and a common measurement system along the linear features—linear referencing—which is the idea of storing geographic locations by using relative positions along a measured linear feature. An obvious advantage of using shortest path as a route is that it can be linearly referenced with easy-to-get travel time on the route. With the route linearly referenced with travel time, we can simulate (dynamically segment) the location at any given moment by knowing its relative temporal lag from a known point in space and time.

4.8.5 Calculating Accessibility and Meeting Opportunity

Space-time prism is the fundamental time geographic measure of individual accessibility (Miller, 2005). Represented in the 3D space-time coordinate system, the prism is the volume contained in the space-time boundaries that an individual cannot go beyond under the given constraints. The projection of this volume to the 2D plane is the individual's spatial accessibility.

Resorting to ServiceArea functions in ArcObjects is a direct way of calculating spatial accessibility in 2D space. A network service area is a region that encompasses all accessible streets, that is, streets that lie within a specified impedance. For instance, a 10-minute service area for a facility includes all the streets that can be reached within ten minutes from that facility. Building a service area outward from the starting point assigns to each surrounding regions the smallest amount of time that it can be reached. Likewise, building a service area towards the end point assigns each surrounding region the smallest amount of time to travel to the destination. By building these two prisms,

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each region is assigned with an earliest arrival time (Ta) and latest departure (Td) time. Filtering out those regions where the Ta is larger than Td, we can get a user's space-time prism projected on the 2D space.

In a two people meeting scenario, each person's accessibility can be represented with a space-time prism. The overlapping volume of the prisms in the space-time coordinate system denotes the individuals' mutually shared spatio-temporally accessible region. In ArcMap, this process is conducted by intersecting two feature classes that store the "real-time" space-time prisms. Intersect creates joint attributes, including the earliest arrival (Ta1, Ta2) and the latest departure (Td1, Td2) for each person, in the intersected regions. A region is a feasible area for meeting when Td1>Ta2 or Td2>Ta1. Those designated POIs located in those feasible regions are candidate POIs for rendezvous.

Figure 27 shows a sample of thematic map meeting opportunity of person A (represented by the blue dot) and person B (represented by the green dot) at a given moment. The red regions in the middle indicate places with a large overlapping time window whereas the green regions on the periphery are places where A and B only share a tiny time window for the meeting that fits in each of their schedules.
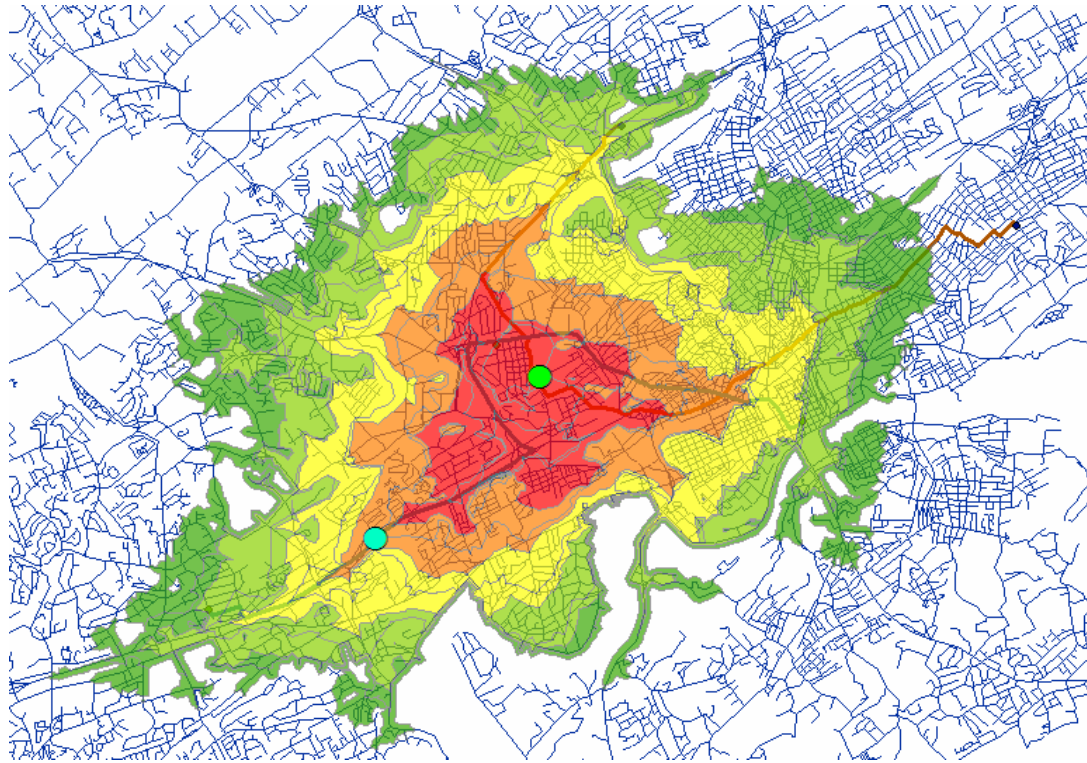
Figure 27: Meeting Opportunities Represented by Region

CHAPTER 5: CONCLUSION

5.1 Summary: Volunteer Tracking Information Collection

The transportation sector is increasingly interested in human behavior and specifically activity-based travel demand studies. Smart phones and ubiquitous computing have made large-scale detection of human-behavior possible. This pilot study uses smart phones as a trajectory recording tool to collect activity-travel data. The raw trajectory is parsed into stops and trips, and transferred to our data model. A prompted recall web application is then utilized to survey and validate attributes such as travel mode and activity type.

As the first stage of this pilot study, five users have participated in the test. A total of ten tracks were recorded. Most attention has been paid to extracting stop information. Out of the ten tracks, one track had a misplaced waypoint; another has a large segment of missing signal; seven tracks got 100% stop information from the automatic identification process; and only one track had an excessive stop identified which needed a manual fix. This indicates that automatic identification algorithm is effective. Moreover, with the aid of automatic identification process, some participants can easily recall the activity-travel details days after the tracks were recorded, which also indicates the benefits of this design.

However, significant issues still exist with automating the data extraction and identification for a volunteer tracking system, especially when it comes to reducing respondent burden to enable longer-term data recording.

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1. It is necessary to simplify the survey process for the respondents who volunteer to track themselves over a long period of time. Having a volunteer user input the activity type for each stop and travel mode for each trip everyday is a lot of burden. Stopher (1996) believes that most activity-travel behaviors are habitual and hence an individual's daily activity-travel patterns do not change drastically from day to day. With proper land-used and POI data, it is reasonable that we can "learn" travel mode and trip purposes at a high rate of accuracy (Auld et al., 2008, Stopher, 2010).

2. All tracking data is considered to be potentially useful, however, as a volunteered system, it is important to discern how different tracks can be used for different purposes. For example, among the voluntary tracks, there can be regular daily person-based tracks or vehicle-based tracks, or even wild tracks provided by world-travelers; some tracks are recorded at a standard 24-hour study period that can be directly applied for activity-based travel study, while others are only recorded during a certain period in a day which could still be useful, such as to identify the city's most-favored restaurant. These tracks are all considered to be valuable, but they require a better data model design and improved data mining methods to accommodate and recognize their detailed attributes.

3. Data collection, can potentially be used to improve survey design. If the timeframe of data collection is long enough, it is possible to speculate a person's cognitive map (Golledge and Garling, 2004) since it is likely that a significant portion of the common places in the person's mental map tend to be visited (Auld, 2008). Knowledge gained during these processes can be fed back to improve the survey

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design.

5.2 Summary: Interaction-Based LBS

People and objects are becoming increasingly "locatable" as location-aware technologies such as Wi-Fi, cell phones, and GPS positioning proliferate. Map databases are highly accurate and comprehensive while computational capability of LBS engines is growing, allowing LBS platforms to become more robust. The information sources being integrated into transportation studies and LBS application have become more extensive with improved information technology. These developments have improved in-depth human-behavior studies as well as provided highly personal information for LBS.

Time geography brings new thinking into the current LBS. Time geography stresses an emphatic notion of "constraints". Given a transportation mode and a limited time budget, a person's accessibility in real world is bounded. Under such constraints, satisfying a person's preferences and their required activities is the ideas addressed in "user-centered LBS" (Raubal et al, 2004). Interaction is another thread emphasized in this study. In real life, joint activities incorporate the participation of multiple individuals. How those activities should proceed is dependent on the constraints of each participant. These characteristics of human activities are driving this study, and an application embodies these characteristics is designed.

However, to build an integrated and usable web application, besides technical details in protecting information security, and implementing Internet communication, there are some other major and realistic concerns that should be addressed.

1. Most importantly, modeling travel time in a real world transportation network in real-

time is crucial for the accuracy of the service. When we travel from one place to another, especially when it entails multiple transportation means, the estimation of travel time can be very difficult. For example, traveling with multiple public transit lines could include walking to the transit station, waiting for the transit to come, traveling on the transit, stopping at the transit stations, waiting to make transfers, possible traffic jams, as well as traffic lights. This process comprises various aspects of transportation modeling and uncertainty, which by no means can be simplified as traveling with a constant speed on a road segment.

2. For a real-time service, the response time of a LBS engine determines its practicability. Based on an accurate real-time network travel time model, building dynamic space-time prisms can be time consuming, especially when a server receives request from multiple users. Efficient heuristics and path finding algorithms can greatly reduce the computational time, and therefore improve the usefulness of this application.

This study provides a preliminary construct. To build a usable application, it is imperative to carry out additional research.

5.3 Future Research Directions

In this study, two separate application designs are introduced. To build on this research, we are interested how human activities are constrained by habitual behaviors and personal preferences, together with constraints imposed by capability, coupling, and authorities. Moreover, as information becomes more and more ubiquitous and transparent, how individuals' activity-travel related behaviors can be dynamically

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influenced and changed by knowing those of others', for example, the real-time customer flow of the restaurants or traffic flow on the streets. This information could be potentially used by policy-makers to understand individual behavior.

Tracking data has contained a great amount of hidden information of how people behave in the society, which in turn can be used to reconstruct the dynamics of our world. Today, massive amount of tracking data is readily available from service providers such as Google, AT&T, and even third parties such as research institutions. Algorithms for location retrieval, spatial search, routing, mapping, etc. are packaged into APIs and made easy to exploit new applications. It is believed by the author that a great added value of our current transportation system, land use, and location-based services will be derived from a better comprehension of time and human behavior. And with this knowledge, it is hoped that we can better assist people to navigate their world.

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