A Visual Time-Geographic Approach to Crime Mapping

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A VISUAL TIME-GEOGRAPHIC APPROACH TO CRIME MAPPING

By

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ABSTRACT

When time geography was first proposed in the 1970s, it was considered quite innovative and on the frontiers of commonly practiced methods of geographic research. Some thirty years later it seems that time geography remains on the research frontiers. And while the use of time geography to visualize movements has been proposed in many potential applications, it continues to pose a number of operational barriers— one of which is in the area of usability. Equally relevant to question of usability of time-geographic tools are considerations of usefulness.

The research objectives of this dissertation cut across studies of mobility, cartographic visualization and time geography. The outcome of these objectives is a practical assessment of the cartographic usability of time-geographic maps within the context of crime mapping. At the core of this dissertation is a test of the usability (and usefulness) of time-geographic maps. A semi-structured interview process was conducted, wherein respondents were led on a cognitive walkthrough of five map iterations of a crime scenario. And while the results are largely qualitative, a breadth of feedback is useful for considering both the usability and usefulness of time geography within a crime mapping context.

A key factor in testing the usability of the maps within this project was the determination of whether the 3D time-geographic approach could reveal patterns where traditional 2D GIS methods usually could not. The results of the usability studies conducted in this dissertation have revealed certain potentials benefits and challenges for the application of time-geographic tools. The implications of these results can be contrasted with previous results from similar usability inspection projects, as well as data from future tests, to develop practical tools for representing and analyzing movement through space and time, whether of crime or other activities.
CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

The use of mapping for exploring and analyzing the spaces of crime has grown considerably in recent years. Uncovering hotspots, criminal networks, flows, and investigative leads have become common goals in the application of crime mapping by both researchers and practitioners. While some crimes have proven easily represented by conventional methods of mapping crime, other crimes have proven quite difficult to map. This dissertation contributes to the view that certain events, although still profoundly geographic, are not reducible to single points in space and time. Some crimes, such as identity theft, defy representation because of the fragmented nature in which the incident occurs across space and time (Hubers, Schwanen, & Dijst 2008). Other crimes, such as an incident of theft on a crowded public vehicle in transit, defy representation because of their intrinsic mobility. These types of crime events require a novel approach to mapping crime spaces.

Time geography (Hägerstrand 1970) offers a rich framework for representing movement across space and time (Kwan & Lee 2004; Miller 2005b; Pred 1977). The fundamental tenet underlying time geography is that all activities have both spatial and temporal dimensions and these cannot be meaningfully separated. These activities, viewed from the perspective of an individual’s mobility, are recognized as being bounded by defined constraints. Given these constraints, time geography utilizes visual semantic tools to explain individual movements in space and time. An extension of time geography to crime mapping, as proposed by this dissertation, requires an accounting for victim and offender mobility under event-related constraints (e.g. accessibility to a crime scene). While the usability of time geography for crime mapping has potential, operational and theoretical challenges remain and should be addressed.

1.2 RESEARCH OBJECTIVES

The research objectives of this dissertation cut across studies of mobility in crime mapping, cartographic visualization and time geography. The outcome of these objectives is a practical assessment of the cartographic usability and usefulness of time-geographic maps within
the context of crime mapping. The purpose of this research is to determine whether a time-geographic approach can be used to map crime events that otherwise cannot be represented meaningfully as a single point on a map. The key assumption of this research is that mobility, of both offenders and victims, makes certain types of crime events a challenge to map. In order to overcome these challenges, this dissertation seeks to operationalize the tools of time geography for geographic visualization of crime activity spaces. And by operationalizing the tools of time geography within a crime mapping context, we can then address the question of usefulness.

The research design for this dissertation centers on the application and assessment of time-geographic tools to the mapping of a crime event scenario. The scenario is chosen to illustrate the challenge of mobility in crime mapping and potential for time-geographic visual exploration. To carry out this research, I: (1) define a crime event scenario and analyze its time-geographic context; (2) create time-geographic crime maps based on the defined scenario; and (3) evaluate the usability and usefulness of these crime maps for practical and research purposes. To achieve these objectives this research strives to integrate three important fields of inquiry: the representation of time in crime mapping, time-geographic theory, and map usability.

1.3 RESEARCH RATIONALE

The intellectual merit of this research is in advancing the field of crime mapping by bringing it into the fold of emerging work by criminologists, human geographers and geographic information scientists (GIScientists) which recognizes the importance of both time and space for geographically exploring human activities. Specifically, a time-geographic approach to crime mapping places a rich theoretical body of work in time geography within a practical context: the mapping of crime. Both fields, geography and crime mapping studies, stand to benefit from the transformative potential of this research. When time geography was first proposed in the 1970s, it was considered quite innovative and on the frontiers of commonly practiced methods of geographic research. Indeed, it is often noted that the proposed methods of time geography preceded the technological capabilities to produce such maps (Kraak 2003). Although software did not yet exist to create such maps, the conceptual constructs of how to draw such 3D objects are grounded in descriptive geometry, a field that seeks to accurately represent objects (by means of drawing) and solve graphically all problems related to their form and position (Watts & Rule 1946).
Some thirty years later it seems that time geography remains on the research frontiers. And while the use of time geography to visualize movements has been proposed in many potential applications (Lentorp 2003; Moore et al. 2003), it continues to pose a number of operational barriers (Kwan 2000) - most notably in the areas of measurement and usability. Kwan (2000) describes one of the primary operational challenges of space-time accessibility measurements as being overcome by advances in GIS-based geocomputation and geovisualization (geographic visualization) methods. The measurement challenges of the time geographic approach have largely been taken up by Miller (1991), who has focused on the more analytically rigorous capacity of time geography. Miller’s work, combined with the work of others, demonstrates an increasingly overlapping interest between computer and geographic scientists who are concerned with the operational aspects of time geography (see Hariharan & Hornsby 2000; Pfoser & Jensen 1999).

A second operational challenge of time geography, and the focus of this dissertation, is in putting time geography into a usable and applied mapping context. With advances in computing and graphics technologies, the time-geographic framework has become a more feasible tool for analysis. However, the difficulties in cartographically representing human activities in time and space in a manner that is easily comprehended by map users may explain part of why time geography has seen little adoption in mainstream GIS software applications. This difficulty runs contrary to the intended goals of time geography which is, first and foremost, to be a simple approach (Thrift 1977). As a move away from statistical aggregation, time geography’s early literature focuses on the individual. In the words of Hägerstrand (1970), the time geography approach seeks to find its place “where the fundamental notion is that people retain their identity over time, where the life of an individual is his foremost project, and where aggregate cannot escape these facts” (p. 9). The position in this dissertation is that the time geography framework holds great potential in a geographic visualization environment for exploring complex space-time activities such as the mobility of crime events, but this dissertation also questions whether this potential can ever be realized because of usability problems.

### 1.4 OVERVIEW OF DISSERTATION

The remainder of this dissertation is divided into five chapters. Chapter 2 consists of a review of the relevant crime mapping literature, with a particular focus on map usability, and the
potential of the visual tools of time geography to assist in crime mapping in dealing with the
collapse of mobility. Chapter 3 focuses on the practical (technical and theoretical) aspects of
building time-geographic crime maps. Chapter 4 situates a hypothetical crime event into the
time-geographic framework which assists in contextualizing the time-geographic crime maps
created in this dissertation. Chapter 5 describes the process and results of time-geographic crime
map usability tests that were conducted with both practitioners and scholars of crime mapping.
A summary of the research conclusion and implication is presented in Chapter 6, as well as
discussion of future work in applying the time-geographic framework to the mapping of crime.
CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Literature cutting across both the crime mapping and cartography communities is relevant to this dissertation. The three predominant theories of crime mapping today are rational choice, routine activities and crime pattern theory. These theories help to explain when and where crime occurs. However, a specific challenge of mobility in crime mapping occurs because offenders and victims move in and out of the spaces of crime. Time geography offers a novel approach to representing individual accessibility moving across space and time. Placed within a crime mapping context time geography has the potential to aid crime mapping, especially for investigative purposes. However, a key operational challenge for time-geographic mapping is in the area of usability. Therefore, this chapter reviews three literatures that inform the dissertation research question: the literatures on crime mapping (with a focus on the problems encountered when one attempts to map a mobile crime), time geography, and map usability.

2.2 THE CHALLENGE OF MOBILITY IN CRIME MAPPING

The cartographic representation of crime faces an ongoing challenge from mobility. The practice of mapping a crime is traditionally realized by highlighting a single point, or an aggregated single point, which can be aligned with the convergence of the elements of the crime triangle (offender, opportunity and victim). However, the reduction of a crime event to a single point may not effectively serve the investigative process. Due to their inherent mobility certain crime events (such as an incident of theft on a crowded public vehicle in transit) defy cartographic representation, at least by conventional cartographic means.

Existing literature recognizes the challenge of mobility in crime mapping by providing theories of explanation as both offender and victims continually move in and out of the spaces of crime. Routine activities theory starts with a crime incident being necessitated by the convergence in space and time of a victim, offender, and opportunity. However, the term target is often used in place of victim because it is recognized that the victim is sometimes absent from the actual crime incident location (Felson & Clarke 1998). Here it is useful to consider the
categorical difference between burglary and robbery as it relates to property crimes. A burglary is often defined as a crime event where an offender steals a victim’s property while the victim is not present. However, a robbery is defined as a case where the offender and victim come in contact during the opportunity for crime. In the case of a robbery the offender, victim and opportunity do come together in space and time. However, during a burglary the offender and victim only meet in space but not time. Accordingly, journey-to-crime studies seek to explain how the victims and offenders move into immediacy of the crime (Brantingham & Brantingham 1984). Crime pattern theory attempts to contextualize this journey with factors, such as urban form, to explain crime patterns and occurrence.

2.2.1 The Social Production of Crime Data

Early usage of maps by law enforcement agencies were basically wall maps with pins placed in the locations of particular crimes. The investigators would then set about attempting to find some pattern or try to use spatial information to solve the crime. This is of course the predecessor of what has become known as crime mapping. The use of GIS (Geographic Information Systems) and cartographic visualization has become the modern equivalent of poster maps with pins in them. Police departments collect specific information about when and where crimes occur within their own jurisdictions. In order for computerized pin maps to be generated, the location of each crime incident must be geocoded, or assigned coordinates, so that it may be placed on a map (Lersch, 2004). Geocoding consists of giving the objects that one is mapping (points, lines or polygons) specific locations in Cartesian space. This Cartesian space is most easily conceptualized as the x-y coordinate system typically used in geometric theory.

The spatial nuances of certain types of crime are more complex, and require representation beyond a single point on a map to be of practical value. The problems of overly simplifying the spatial aspects of crime are often compounded by the necessity for tidy “record keeping”. This need is in turn driven by policy makers and mandated records retention procedures that require law enforcement agencies to be able to supply data on the crime incidents within their respective jurisdictions. In the United States, the primary reporting mechanism at the jurisdictional law enforcement organizational level has been the UCR (Uniform Crime Reports), a process started by the FBI (Federal Bureau of Investigation) in the 1930s for collecting crime statistics across U.S. jurisdictions. Therefore, UCR data has become the standard aggregated
approach to reporting crimes by police jurisdictions. A newer, since the 1980’s, reporting method of reporting crime called NIBRS (National Incident-Based Reporting System) has been created by the FBI in which each line of data represents a separate crime (Maltz et al. 1991). However, a 2002 study by the Arizona Criminal Justice Commission reports that the NIBRS method of crime reporting is only slowly being adopted by police agencies which have already built their processes around the UCR method.

It is instructive to consider how law enforcement agencies with local mandates collect and report crime data. For instance, Comaroff & Comaroff’s (2006) work on the social influences (construction) of gang related crime data in South Africa supports other work that suggests that police record-keeping practices regularly yield unreliable data. Compounding this problem, crime data is often put through automated data-entry programs that generate tabular presentations. The database interface with its associated drop-down and check-box interfaces has increasingly become the way in which crime is recorded and reported up through organizational channels. In the process the crime incident is often geocoded to one precise location, typically either the location of the crime, the victim address or the offender address.

Cartographic representation and the geocoding of the crime event as a tool for illustrating the location of the crime event are pivotal for the utilization of crime mapping. However, the complex modes in which a crime can possibly be carried out challenge both spatial and temporal cartographic representation. Consider, for instance, an armed robbery that occurs on a street corner where the offender escapes on foot. In this case the time and location of the incidence of crime is easily recounted by the victim. A point on a map, at the street corner, is a sufficient static representation of this crime event (Newton, 2004). In this case, the point as a representation tells us where the victim and offender came together in time and space. However, a second example such as a house being burglarized while the owners are away during a weekend is not so easily represented by a point (Ratcliffe, 2005). In this case a point on a map, at the location of the burglarized house only tells us where the victim and offender came together in space.

2.2.2 Activities, Patterns and Choices

Linking crime with place has been the objective of crime mapping since the nineteenth century, when French cartographers developed choropleth maps (thematic boundary maps
shaded with color) depicting property crimes against persons (LaVigne, Fleury, & Szakas 2000). The study of the factors that contribute to crime has become a common focus for researchers considering the spatiality of crime. These studies attempt to discover the environmental, or situational, factors that contribute to different rates of crime in different spaces and times. An approach that views the criminal event as the end point in a *rational decision process* (Brantingham & Brantingham 1993; Clarke & Felson 1993) takes cognizance of the activities leading up to the incident. Routine activities theory, as such an approach, views the crime event as the outcome of an opportunity that is precipitated by the convergence in space and time of three elements: the target (or victim), a motivated offender, and the absence of a “capable guardian” (e.g. a police officer) (Cohen & Felson 1979; Wilcox, Land, & Hunt 2003) (Figure 1a). Routine activities theory has become a powerful theory in considering the spatiality and context of crime events. In this context, crimes are conceived of as more than points on a map, but also as events leading up to the occurrence of a crime.

![Figure 2.1a: The Crime Triangle](image1.png)

Further, routine activities theory considers the rational criminal as a member of society who, in his or her daily activities, seeks or discovers opportunities for crime. The two key concepts here are that the criminal, like any other rational member of society seeking to
maximize reward and minimize cost, develops both awareness and action spaces in his or her daily activities. The concepts of awareness and action spaces adopted in crime mapping literature draws from economic geographers, who, in turn, borrow the concept from an earlier generation of geographers who were informed by social psychology (Wolpert 1965). Essentially, the spaces of action, or spatial behavior, for an individual are connected to the expected return, or utility for moving into those spaces. Although these early studies were considering empirical work and the decision to migrate from one locale to another, they fit well with theories of a rational criminal operating with routine activities. In this context, the action space that can be conceptualized is the collection of all urban locations about which the individual (potential offender) has information and the subjective utility or preference he associates with these locations (Horton & Reynolds 1971). Individuals making movement decisions based on awareness do so either from first-hand knowledge obtained from prior experience in those spaces or second-hand knowledge obtained through other channels such as acquaintances' experiences and mass media (Brown & Moore 1970). Thus a combination of routine activities and rational choice theories can be used to help us explain why crimes occur where they do, an analytical perspective that is embodied in crime pattern theory (Ratcliffe & Chainey 2005). Clarke & Felson (1997) define a pattern as a recognizable interconnectedness of objects, process, and idea. Further, they argue that crimes are patterned; decisions to commit crimes are patterned; and the process of committing a crime is patterned. Thus, by understanding the rational choices made by criminals and how those are made amidst certain activity patterns, crime patterns can be detected that, in turn, can guide searches for offenders and the prevention of future crimes. Crime patterns occur spatially in clusters, which Eck et al. (2005) calls hot spots, areas that have a greater than average number of criminal or disorder events, or areas where people have a higher than average risk of victimization. On a more practical level, crime pattern theory empirically depends on mathematical methods combined with visual/cartographic interpretation for discovery of clusters in a given dataset (Grubesic 2006).

Because it is often the case that pattern discovery is based on the necessary transformation of a given dataset for analysis, it is important to understand the basis of these methods. Interpolation methods represent a set of approaches that seeks to make a best guess at unknown data points based on known data points. The rationale behind spatial interpolation is the observation that points close together in space are more likely to have similar values than
points far apart. This rationale is based on Tobler’s (1970) first law of geography which says that “everything is related to everything else, but near things are more related than distant things” (p. 3). The interpolated surface is typically generated by applying a statistical algorithm to a given data surface. The applications of these algorithms are either global or local (Goodchild & Kemp 1990). Global interpolations determine a single function which is mapped across the whole region while, local interpolations apply an algorithm repeatedly to a small portion of the total set of points.

Miller (2004) directly links Tobler's first law of geography by describing a technique known as kriging. Kriging, Miller explains, treats the spatial variable being interpolated as regionalized, meaning that it varies continuously across space according to some spatial lag or distance in a partly random and partly deterministic manner. The basis of this technique is the rate at which the variance between points changes over space (Haithcoat 2010). The application of deterministic interpolation methods means that the same surface should be computed every time the algorithm is applied to the map. Given a set of input crime locations, the same output hot spots will be generated. This can be contrasted to other interpolation techniques that are stochastic, which incorporate the concept of randomness.

Interpolation is an increasingly popular method for visualizing the distribution of crime and identifying hot spots (Eck et al 2005). Another popular interpolation method, a transformation technique in the development of crime patterns, is called density estimation. The cartographic output of density estimation, called smoothing, produces aesthetically pleasing maps that make use of color transition between class breaks. Density estimation takes a set of data points and transforms them into a continuous surface based on a predefined spatial resolution called the kernel function (often symbolized as $k$). Eck et al. (2005) describe the creation of the kernel density method in three steps:

1. A fine grid is generated over the point distribution. In most cases, the user has the option to specify the grid cell size.
2. A moving three-dimensional function of a specified radius visits each cell and calculates weights for each point within the kernel’s radius. Points closer to the center receive a higher weight and therefore contribute more to the cell’s total density value.
3. Final grid cell values are calculated by summing the values of all circle surfaces for each location.
More often the kernel density function is expressed as mathematical notation. For instance, the standard formula for the $k$-means spatial interpolation approach, as formulated in Grubesic (2006), is given as follows:

$i$ = index of operations;

$a_i$ = attribute weight of observation $i$ (e.g. number of crimes at a given location);

$k$ = index of clusters;

$d_{ik}$ = distance between observation $i$ and cluster $k$;

$y_{ik} = \begin{cases} 1 & \text{if observation } i \text{ is assigned in cluster } k \\ 0 & \text{otherwise} \end{cases}$

K-means

$$\text{Minimize } Z = \sum_i \sum_k a_i d_{ik}^2 y_{ik} \quad (1)$$

Subject to

$$\sum_k y_{ik} = 1 \quad (2)$$

$$y_{ik} = (0,1) \quad (3)$$

The objective (1) of the k-means model is to minimize the total weighted squared difference in cluster group membership. Constraints (2) ensure that each observation is assigned to a cluster group. Constraints (3) impose integer restrictions on decision variables.

The choice of transformation method is often determined by the type of data, as different types of data are associated with a view of space as either a continuous surface or an empty field. One dataset might represent individual object entities, such as neighborhood locations which are at specific points in space, while another dataset might represent continuous variables such as crime locations which could occur anywhere in space. Likewise, Grubesic (2006) elucidates that because crime densities are measured over a continuous area, the actual boundaries separating hot-spots from areas with lower crime densities are largely perceptual constructs. And as a perceptual construct it may be further explained by its surrounding environment. For instance, in an urban environment these areas consist of such spaces as streets, neighborhoods, parking lots and downtown districts.
2.2.3 The Spaces of Crime: Nodes, Paths and Edges

Because crime mapping is based on the understanding of routine activities, the urban environment through which criminals and victims move is particularly relevant to understanding crime and location. Modern crime mapping has roots in what is often termed the “ecological approach”. This descriptive spatial approach pioneered by the University of Chicago’s school of Sociology (Shaw & McKay 1942) takes cognizance of site and situational factors associated with a criminal area (where crime occurred) and an area of delinquent residence, which may or may not coincide. With a particular focus on social disorganization, the ecological approach makes use of choropleth and dot mapping to analyze such factors as delinquency in relation to other variables such as infant mortality rates. By the 1990s a particular focus on the influence of the urban physical form for revealing geographic patterns of crime, known as environmental criminology (Brantingham & Brantingham 1993), had become the basis for modern crime pattern theory. Based on notions of nodes and pathways, environmental criminology drew heavily on work by architect Kevin Lynch (1960). Lynch was aware of how such structural forms influence behavioral patterns, of both perception and movement. Lynch's (1960) typology of city elements consists of the following:

- **Paths** are channels along which the observer customarily, occasionally or potentially moves.
- **Edges** are the linear elements not used or considered as paths by the observer.
- **Districts** are the medium-to-large sections of the city, conceived of as having two-dimensional extent, which the observer mentally enters “inside of,” and which are recognizable as having some common, identifying character.
- **Nodes** are the points, the strategic spots in a city into which an observer can enter, and which are the intensive foci to and from which he is traveling.
- **Landmarks** are another type of point-reference, but in this case the observer does not enter within them, they are external.

From this, ideas of how the urban environment influences crime patterns became rooted in a geometric descriptive framework. The uniqueness of this approach sets it apart from an analysis of spaces that does not consider the complex mosaic of the urban form. Indeed, empirical work has shown that the structural layout of the city does effect and influence people’s perceptions.
Brantingham & Brantingham (1991) point out that one of the most striking things about criminals, often forgotten, is that most of them behave as ordinary people most of the time. This means that they have jobs, appointments and other social activities to keep up. They are – to borrow from the two main theories that inform conventional crime mapping – rational actors who carry out routine activities. However, as they are carrying out these activities and are aware of their environment, the opportunity for crime is influenced by their surroundings. In their book *Environmental Criminology (1991)* the Brantinghams describe empirical work that supports the idea that the environment influences the spaces of crime, including Dufala’s (1976) study of robberies occurring within a particular geographic cluster at convenience stores near major roads with no surrounding evening business activity. The fact that these convenience store locations are more vulnerable due to their location is space is part and parcel to conceptualizing the significance of the spaces of crime.

### 2.2.4 Conceptualizing the Journey-to-Crime

The inherent limits of conventional crime mapping techniques manifest themselves when one considers how such maps encompass the fact that individuals move in and out of crime spaces. Mobility in crime mapping most often has been conceptualized as the journey-to-crime: a method to account for the distance travelled by an offender to commit a crime (Brantingham & Brantingham 1984). Journey-to-crime has been used to explore the spatial aspects of varying types of crime, from locating chop shops (where vehicles are dismantled and parts sold) based on recovery points (LaVigne et. al 2000), to identifying the activity spaces of drug dealers based on cellular phone tracking (Schmitz 2007). The cartographic symbol of an arrow, on a 2D map space, is typically how journey-to-crime is represented.

While conceptualizing the journey-to-crime is useful for knowing how victims and offenders move to the site of the crime, its application is limited greatly when the site of the actual offense is unknown or indeterminate. While some work in this area has considered the victim’s travel to the crime site, journey-to-victimization (Leipnik & Albert, 2003), other work has considered movement after the crime and has been conceptualized as journey-after-crime (Lu 2003). These approaches to mobility and crime utilize the theories of distance decay and routine activities for predicting and explaining the spaces of crime. Mobility triangles (Figure 1b) are used to combine these approaches by visualizing the spatial relationship between the victim’s
home address, the offender’s home address, and the site of the crime (Groff & McEwen 2006 & 2007). Both victims and offenders can be mobile and thus move in and out of spaces of crime. This approach represents a more sophisticated visual mapping of mobility, over the traditional methods of solely point-based crime mapping. However, the construction of these maps still depends on having specific spatial information on all of the elements of the crime triangle (target, offender, and opportunity). Therefore, when one of these elements is missing, often due to mobility, the ability to construct mobility triangles is significantly limited.

2.2.5 Addressing Non-Static and Unspecified Crime Events
Conventional crime mapping as a tool for exploring the spaces of crime is severely limited without the ability to place a point on a map and say that this is the location at which the crime occurred. Recent crime mapping literature addressing the challenge of mobility has incorporated time into the cartographic representation of crime (Brunsdon, Corcoran, & Higgs 2005; Liu & Eck 2008). For instance, the element of time has been used in crime maps as height bars representing the time of day in which the event occurred (Lodha & Verma 1999). While having slight similarities to time geography, this approach does not attempt to cartographically represent individuals’ mobility. Another approach incorporating time into the spatial analysis of crime is that of near repeat analysis. This approach comes from epidemiology where it is utilized to analyze the spread of diseases (Knox 1964). This approach focuses on determining the likelihood that a crime will occur within a certain amount of time of another crime and within a certain distance of that crime. More specifically, this method utilizes a null hypothesis to test whether a random occurrence of crime is just as likely in space and time. In other words, the focus of near repeat analysis is on spatial and temporal crime clusters, and how crime varies simultaneously in these two dimensions (Johnson et al. 2007). Ratcliffe and Rengert (2007) give a detailed account of the usage of near repeat analysis including a contextual explanation of why certain crime types are likely to occur near to one another. Despite this technique’s apparent attentiveness to temporality, the perspective still aims to represent a crime-event as occurring at a singular point on a map. In this sense, the element of time still is not symbolized in the resulting crime map.

Another use of time, as an additional criterion toward the locating of crime events, can be seen in the application of aoristic analysis (Gill 2007; Grubesic & Mack 2008; Ratcliffe 2000,
The results of aoristic analysis are essentially measures of uncertainty used to locate a temporally unspecified crime event. Aoristic analysis is useful for estimating a probable incident at a known location and an unknown time. Aoristic analysis has been proposed to have utility in the analysis of non-static and unspecified criminal events (Newton 2004; Andresen & Jenion 2004). Scenarios presented in the aoristic analysis literature address the probability of an incident occurring across specific times, such as a burglary while the victim is on vacation on a given weekend, or locating an occurrence of pick pocketing on a train somewhere between boarding and departure points. The outcome of this analysis (the assignment of various probability weights of likelihood) distinguishes the inherent uncertainty of crime events in which particular space-time factors are unknown.

The crime triangle conceptualizes the necessary occurrence of a crime event as the converging in space and time of a victim, offender and opportunity (Groff & McEwen 2007). Using these conceptual requirements as a departure point, a point as representation of a crime event is particularly challenged when it is impossible to place one of the elements of the crime triangle. A most basic obstacle occurs if the exact location of the crime incident is unknown. In this case we may have a victim but the opportunity connecting the offender and victim are unknown. Therefore we cannot symbolize a crime on a map. It should become obvious that if any one element of the crime triangle is unknown or unspecified the ability to meaningfully represent the crime is challenged. The crime triangle really breaks down when one considers a non-static crime such as the case of a robbery on a moving train as depicted by Newton (2004). In this case the victim and offender do meet in time and space, but the exact time and location is unknown for use in a crime map. As noted by aoristic analysis, including the temporal dimension is important in the mapping of non-static, mobility-based types of crime. However, the crime mapping literature, to date, has not focused on incorporation of time as a visual variable along with space. And so it remains a challenge to map crime incidents where the exact locations of the incident are unknown. It is for this reason that we turn to the time-geographic approach, which offers a framework for integrating time and space into the same map interface.

### 2.3 TIME GEOGRAPHY

Hägerstrand (1970) introduced the time-geographic framework at a time when regional science was increasingly focused on aggregated spatial analysis. Hägerstrand’s central position
revolved around the concept that just as important to where things occurred (spatial) was when they occurred (temporal), particularly when mapping human events. Hägerstrand’s approach, with a particular focus on the individual, asked “what it means for a location to have not only space coordinates but also time coordinates” (p. 10). So along with proposing novel methods for incorporating time, visually, into maps he offered a theoretical explanation for how spatial events are constrained. Central to Hägerstrand’s approach were contextualizing the conditions influencing human activity such as the consumption of time by movement in space, the fact that situations are always rooted in past situations, and limited human ability (Unwin 1992). Coincidently these conditions are relevant to the challenge of mobility in crime mapping. A crime cannot occur without the ability for an offender to be at the location of the crime when it is determined to have occurred. Therefore, if the actual location, or time, of a crime incident is unknown, then a mapping of known victim, or offender activity may reveal certain knowledge about where, and when, the crime was likely to have occurred.

2.3.1 Barriers to the Development of Effective Time-Geographic Maps

Time geography (Hägerstrand 1970) offers a rich framework for representing individual space-time paths in this increasingly mobile world (Kwan & Lee 2004; Miller 2005b; Parkes & Thrift 1980; Pred 1977). The time-geographic approach rests firmly on a micro-level knowledge of individual mobility across space and time. This approach requires us to go beyond, or come back down from, a certain level of map abstraction where we seek to represent events with a single point. Time geography represents a contextual, instead of compositional, approach (Pred 1984). This means that instead of dividing systemic wholes into their component parts, which are then joined back to form a whole, the contextual approach asks about the specific situations in which an individual is likely to be found and what connections exist between the individual’s characteristics and behaviors in these situations or contexts. From a time-geographic perspective it is problematic to ignore the context in which phenomena locally develop, connect and survive (Lenntorp 2003). Practically, time geography offers the addition of time as a cartographic variable, as described by MacEachren (1994).

The time-geographic approach largely depends on graphical geometric representations within a 3D (three-dimensional) environment. The 3D environment can be juxtaposed to the 2D environment where representation takes place along only two dimensional axes. The 3D
environment adds an additional dimension for cartographic representation. Therefore, instead of locating a point with two coordinate values you now need three. The idea of an additional dimension represented as time has its roots in the great mathematical thinkers: namely Minkowski followed by Einstein (Galison 1985). The mathematics of conic sections (Stewart 2003) such as the ellipse, cone and prism play prominent roles as the analytical tools of time geography. And while these geometric objects are built using defined maximum velocities and straight line distance, it is recognized that alternative measurements such as Manhattan metrics or network segments are possible (Miller & Wentz 2003).

A significant barrier to overcome for creating effective time geographic maps, and the focus of this dissertation, is in putting time geography into a usable and applied mapping context. With advances in computing and graphics technologies, the time-geographic framework has become a more feasible tool for analysis. However, the difficulties in cartographically representing human activities in time and space in a manner that is easily comprehended by map users may explain part of why time geography has seen little adoption in mainstream GIS applications and methods. Partly as a move away from spatial statistical aggregation, time geography’s early literature focuses on the individual (Unwin 1992). In the words of Hägerstrand (1970), the time geography approach seeks to find its place “where the fundamental notion is that people retain their identity over time, where the life of an individual is his foremost project, and where aggregate cannot escape these facts” (p. 9). The position in this dissertation is that the time geography framework holds great potential in a geovisualization environment for exploring complex space-time activities such as the mobility of crime events, but that the challenge of usability must be approached directly.

2.3.2 The Visual Semantic Tools of Time Geography

The ability of maps to visually explain and communicate complex spatial information in an uncomplicated way is a fundamental goal of map making. The three key attributes of maps are projection, scale, and symbolization (Monmonier 1996). And while scale and projection are technical necessities of map making, symbolization is often a cognitive/aesthetic choice. Mainstream GIS software environments can be used to handle the functional aspects of projection and scale for 2D maps. The visual semantic tools of time geography might be described as fitting within the cognitive/aesthetic category of symbolization. However, when
combined with the explanatory properties of the geometric symbols used in time geography (e.g. cones and prisms), time geography offers useful tools for both the analysis and visualization of mobility. For instance, the ellipse can be used to mathematically calculate an individual’s possible movements across space. Or, the slope of a cone can be used to illustrate maximum possible velocity, indicating the trading of space for time (Miller et al. 2004). Making extensive use of these geometric objects, the three primary visual semantic tools of time geography are: the space-time path, prism, and cube. A description of these tools will introduce the key concepts of time geography.

Space-time path: Although focused on human activities, it is noted that anything having spatial and temporal extents can be said to have a path - including inanimate things (Hägerstrand 1970; Thrift 1977). This can be translated into practical terms to mean a vehicle or electronic device such as a mobile phone or anything to which we can assign a space-time value. Visually, the space-time path (sometimes called the geospatial lifeline) is symbolized as a line.

Along with the space-time path, we can introduce the concept of the space-time station. The station recognizes stationary activity spaces such as time spent shopping, at work, or at school. Inherent within the idea of the station is the idea that although a person may not move in space, he or she is always moving forward in time. When two or more space-time paths come together for a certain amount of time, the station is termed a bundle. Both stations and bundles are dependent on defined map resolution. Visually, the space-time station and bundle is symbolized as a tube wrapped around the space-time path.

Space-time prism: Hägerstrand (1970) introduces this multifaceted concept by simply observing that the possibilities of reach for a given space-time path results in a prism. A space-time prism gathers all the potential space-time paths that an individual might have visited during a specific time range. Visually the space-time prism is the intersection of two geometric cones. The limitations of the space-time paths are the boundaries of the cones which delimit the potential paths space, termed PPS. The projection of the PPS onto a two-dimensional (2D) map surface creates an ellipse which represents the potential path area, termed PPA.

Space-time cube: Originally termed the ‘aquarium’ by Hägerstrand (1970), the more commonly called space-time cube represents a bounded approach to conceptualizing a given time-geographic representation. These boundaries can range from the size of a soccer field to national boundaries, but they ultimately depend on the entities being mapped. The cube is used
as a tool to represent the spatial 2D axis, \( x \) and \( y \), along with a third temporal axis, \( z \). Researchers have theorized that there are cognitive benefits to a space-time cube approach for data visualization. Indeed, there is even empirical evidence suggesting that the space-time cube representation is advantageous in conveying complex spatiotemporal data to users (Kristensson et al. 2008). The space-time cube is capable of representing, simultaneously, the whole space-time continuum and the position of events in this continuum (Gatalsky et al. 2004).

Although the early work of Hägerstrand’s time-geographic approach was utilized primarily for planning applications at the regional level, it also has been noted as having great potential in a number of different application areas. For instance, scholars studying tourist mobility have proposed an analysis of the dynamic aspects of tourist patterns by application of the tools of time geography (Zillinger 2005). Another example of the adoption of the Hägerstrand’s approach is Miller’s (1991) work in applied in the area of transportation geography. And while time geography continues to show promise in new application areas, such as crime mapping (Ratcliffe 2006), certain criticisms of the approach seem to continue to prevent its adoption. This dissertation focuses in particular, on one of these criticisms - that the maps are typically difficult for lay persons to navigate.

2.4 MAP USABILITY

In 2000, The International Cartographic Association took up as a key agenda item usability and cognition issues in geovisualization. The discussion of how to best build usable geovisualization tools continues in organizations such as the International Cartographic Association. Consideration of human-technology interfaces and the associated cognitive processing involved has been led from a variety of disciplines. Indeed human-factors engineering and usability inspection has been led by engineers (Bennett et al. 1989), cartographers (Bertin 1967), and more recently computer scientists (Nielsen 1993) focused on the interface between humans and technology.

2.4.1 Geographic Visualization

The conceptual constructs of how to draw such 3D objects are grounded in descriptive geometry, a technique that seeks to accurately represent objects (by means of drawing) and solve graphically all problems related to their form and position (Watts & Rule 1946).
Geovisualization is the use of maps for cognitive (or perceptive) purposes. Geovisualization is often linked in the literature to broader efforts by the scientific community to explore scientific visualization through computing (McCormick et al. 1987). A more functional definition for cartographic visualization, equating it with data exploration, is that it is a private activity in which unknowns are revealed in a highly interactive environment (Slocum et al. 2005).

Visualization complements other components of GIS, such as that of analysis through textual or numeric means. Geovisualization has been criticized as a method of exploration because it typically requires that one make a priori assumptions about the data, thereby compromising the researcher’s objectivity (Hallisey 2005). Defenders respond, however, that maps are models, or representations, and are understood to contain a certain level of uncertainty (Slocum et al. 2005; Yuan & Albrecht 1995), and that visualization as a mechanism for harnessing powerful human information-processing associated with vision can greatly assist in spatial knowledge discovery (MacEachren 1992). More to the point, geovisualization is considered an exploratory approach to hypothesis generation which makes specific use of the cognitive tools of human perception.

An important function of geovisualization is the representation of Cartesian space. Cartesian space is most easily conceptualized and modeled as the x-y coordinate system typically used in geometric theory. Much recent work in the cartographic visualization literature has focused on ways of extending this space to incorporate the element of time (Worboys 1998 et al.). Traditional approaches to depicting time, change, or movement in maps have involved either manipulating symbology, such as line width (Tufte 1990), or sequencing a set of static maps, also known as chess maps (Monmonier 1990). More recent work that combines cartographic methods for conceptualizing individual movement in time and space is of particular relevance to this dissertation (Kwan & Lee 2004; Miller 2005). Technical limitations, such as rendering speeds, that hindered visualization, are largely being overcome by advances in personal computing technologies (Gahegan 1999). Further, recent developments in graphical modeling software tools such as the Open Scene Graph (OSG), IBM’s OpenDX, Virtual Reality Modeling Language (VRML), DirectX (for PCs) and Google’s SketchUp offer up rich functionality for creating three-dimensional (3D) visualizations. Further, GIS software tools, which historically have been limited to operators with specialized knowledge, are becoming widely available through new technologies such as Microsoft’s Virtual Earth and Google’s Earth products. Work taking advantage of these new software tools, combining traditional GIS methods with 3D
visualization, is seen in a variety of applications in the literature, from the simulation of urban planning activities (Lloret et al. 2008; Riedijk & van de Velde 2006) to the visualization of spatio-temporal crime activities (Lodha & Verma 1999). More often than not, what is required to develop cartographic visualizations is the use of multiple software tools and environments. This hybrid software approach represents a bridge between the development of artistic, architectural and geographic representations. For instance Kwan (2000) utilized the GIS software ARC/INFO, ArcView, and ArcView 3D Analysts to create time-geographic maps of a 1995 dataset over a two-day period of 10,084 individuals’ travel diaries.

Through the use of multimodal interfaces accomplished via windows-icons-menus-pointing devices (WIMPs), novel approaches to map interaction have become possible (Oviatt 2003). Cartographic visualization uses these interface elements for representations of space. Visual techniques for highlighting certain portions of a dataset, such as focusing (highlighting an arbitrary set of spatial entities), querying (asking specific questions of the dataset), and brushing (highlighting a subset of numeric values) are examples of methods employed in cartographic exploration. And, because of the complexity of layered geographic data, certain visual filtering methods are necessary. These interactive methods have been used in visualization techniques such as animation (Moellering 1976; Tobler 1970), interactive filtering (Ahlberg, Williamson & Shneiderman 1992), and comaps (Cleveland 1993). While a comap makes use of small multiples of diagrams to allow visual comparisons, animation exploits the capability of the computer screen to rapidly update its contents (Andrienko, Andrienko, & Gatalsky 2002). A coupling between components of a display such as sliders, Boolean query and other manipulation devices becomes important in the exploratory process. With advances in technology, animated maps have moved from the passive presentation of spatial information to serving as interactive “thinking tools” for geographic research (Harrower 2004).

Map animation offers the ability to view dynamic events (across time and space) for visual discovery. Early work in geography on time comes from Isard (1970) who characterized four types of time: linear, cyclical, ordinal and relative. Still other complementary work by Frank (1994) describes four types of change in geography as: constants, trends, cycles and shift. Making use of variations on these concepts of time there are various methods of map animation. For instance in a fly-by animation, the user is given the feeling of flying over a 3D surface (Slocum et al. 2005).
Perhaps most relevant to this dissertation is the use of geovisualization techniques, such as animation and interaction, for storytelling (or retelling of events). While one purpose of map use is the visual retelling of what is known, another purpose can be for revealing unknowns (Slocum & McMaster 2005). An interactive map has the potential to enhance a map’s exploratory value. Empirical work by Monmonier and Gluck (1994) found that usability of animated maps was limited without the use of interactive tools, such as replay, stop and verbal script. Providing user interaction, as such, moves us closer to what has become known as virtual reality (VR) models. Although VR is commonly associated with the video gaming industry it also is being adopted in geovisualization methods. Brodlie et al. (2002) describe VR as a form of human-computer interface that is distinct from traditional cartographic transformations. This distinction, they argue, is apparent in the focus on the relationship between the representation (map) and user (map image). This focus is on the development of HCIs (human computer interfaces) as a usable method overlapping the user with the representation.

2.4.2 Overcoming Static Representation

Maps have traditionally been static representations of phenomena and the spatial relationships between them. This static representation was a necessity of paper mapmaking. A map represents a snap-shot in time of a space. But with advances in database and graphic technologies efforts to make maps more usable often incorporate dynamic and interactive techniques. Along with the development of computing technologies, geographic scholars and others have argued that more dynamic forms of representation are possible. Early work in this area utilized spatiotemporal patterns, such as Waldo Tobler’s 3-D portrayal of population growth models for the city of Detroit, Michigan (Slocum et al. 2005). A particular focus of dynamic map usability has been on structuring representation so as to consider both spatial and temporal (often termed spatio-temporal) characteristics of geographic phenomena. Towards this end, Peuquet (1994) has proposed a triad approach to asking spatio-temporal questions:

- **when + where = what**: Describe the objects or set of objects that are present at a given location or set of locations at a given time or set of times.
- **when + what = where**: Describe the location or set of locations occupied by a given object or set of objects at a given time or set of times.
• *where + what = when*: Describe the times or set of times that a given object or set of objects occupied a given location or set of locations.

Common in the literature addressing how to integrate time into spatial representation are the different ways of defining time. Hariharan (1999), in considering how to model geospatial lifelines (space-time paths), differentiates between continuous and cyclical point movements. Continuous point movements, such as movement of a person or vehicle, occur as uninterrupted from a beginning to ending point. Cyclical point movements, such as journey-to-work, occur with a regular or predictable frequency. The concepts of continuous and cyclical time can be tied to the broader geographic literature considering representations of space and time. However, the overall theme revolves around two essential concepts. Objects are either located within an unchanging geometry defined by a space-time matrix, or the focus is on the object in relation to other objects (Peuquet 2002). One way to consider this is that today is Tuesday, September 8, 2009. This date will never occur again in the ongoing absolute view. Or, in the relative view, next week Tuesday will occur yet again on a cycle of weekdays.

Finally, scale remains an important consideration when considering how to represent time and space in a dynamic map environment. Cartographic scale, also called representation fraction (RF), is defined traditionally for a map as the ratio between distance on the map and the corresponding distance on the ground or earth. Maps built for temporal querying can be built according to a linear or cyclical representation of time. A linear representation of time treats time as a sequence of moments, never repeating any particular moment (Andrienko et al. 2003). Cyclical as an alternative representation of time is where the level of temporal measure is on a cycle, and can be measured over the course of repeated events in space. Harrower et al. (2000) use a cyclical approach to scaling time for their querying technique called *temporal brushing*, which is used for choosing specific times of day (e.g. 6 p.m.) and studying what happens at this time over the course of multiple days.

**2.4.3 Map Usability**

From the study of color usage to the selection of symbols, cartographic scholars tend to define a “usable” map as one that easily conveys some meaning through a visual interface. Geovisualization, which relies on usable map interfaces, is the use of maps for cognitive (or
perceptive) purposes and is often linked in the literature to broader efforts by the scientific community to explore visualization through computing (McCormick et al. 1987). Visualization for exploration is typically supplemented with spatial statistical techniques to confirm the significance of correlations and trends that are indicated by a visual presentation of the data (O’Sullivan & Unwin 2003). Usability engineering methods have been developed to test the design of new interfaces in everything from software to mobile phones. The three common usability evaluation methods that arise from the literature are cognitive walkthrough, heuristic evaluation, and usability testing. During cognitive walkthrough, experts simulate users walking through the interface to carry out typical task. During heuristic evaluation, expert reviewers critique an interface to determine conformance with a short list of design measurements (Plaisant 2004). Usability testing is when the interface is studied under real-world or controlled conditions, with evaluators gathering data on problems that arise during its use (Jeffries et al. 1991).

Usability studies have become a rich body of work that cuts across many disciplines but is rooted in human factors engineering, more recently termed ergonomics. In this work, pioneered by Chapanis (1965), who initially focused on mechanical interfaces such as aircraft controls, engineers developed a number of principles of motion economy, arrangement of work, and work design. Earlier still, Taylor (1947) studied scaffold design to optimize bricklaying. Taylor’s work enabled bricklayers to increase the number of bricks that they could lay, from 120 to 350 per man per hour (Chapanis 1965). More recently usability testing has been adopted for graphical interface design purposes ranging from web pages to portable electronic devices.

Rubin (1994) identifies three goals of usability testing: exploration, assessment and validation. Exploratory tests are conducted quite early in a development cycle, after development of the user profile and the usage (or task) model which is to be evaluated. Validation takes place near the end of the development cycle and refers to usability testing as a process that employs participants who are representative of the target population to evaluate the degree to which a product meets specific usability criteria. Assessment testing is the most common and is normally conducted midway through development to verify design.

An important part of the usability engineering process is the test plan. It is important to note that testing is always an artificial situation that represents a depiction of the actual situation of usage and not the situation itself. The test plan is the foundation for the entire test of usability.
and includes problem statements and objectives, user profiles, and methods (test design). For instance walk-throughs are used to explore how a user might fare with a product by envisioning the user’s route through an early concept or prototype of the product. Also important is the test environment or lab. For instance the traveling or mobile lab has no room or rooms designated for testing; instead test equipment is carted to actual customer sites. In modern terms a mobile lab might consist of a portable laptop and audio recorder.

Usability engineers studying graphical and software interfaces, HCIs, have begun to apply these approaches to the assessment of map interfaces (Harrower et al. 2000; Nivala, Sarjakoski, & Sarjakoski 2007; Olson & Brewer 1997). A key feature of usability engineering is the testing with a group of potential users of a product in order to lead or inform the design process. Through usage assessment methods, a product, method or interface is evaluated.

### 2.4.4 Crime Map Usability

The investigative application of routine activities theory, popularly termed as geographic profiling in the crime mapping literature (Rossmo 2000), is utilized to identify patterns of offense and develop search strategies (LaVigne et al. 2000). Louisiana State University geographer Milton Newton largely laid the groundwork for what would become known as geographic profiling. Newton’s (1988) geoforensic analysis method was geared toward locating an offender’s base of operations, or haven, and his work influenced later developed methods of geographic profiling (Kent et al. 2007). Further, geographic profiling methods have become particularly targeted toward uncovering serial, or repeat, offenders. Search strategies are then used to define where investigative resources should be focused in locating offenders. As the investigation evolves, various sources of information are pursued (e.g. cell phone records). A primary assumption of a geographic profile is that the offender’s base of operations lies within the distribution of crime incident sites (Rossmo 2000). Combining the concept of anchor points with the crime triangle of routine activities theory, a crime event occurs when both the victim and offender are within proximity to the offender’s anchor point. Further placing these concepts within a time geography framework, an anchor point will lie within a given victim’s space-time prism (potential paths) along his or her space-time path (known paths). It is recognized that,
empirically, a search strategy would become more focused with successive crime event data (Newton 1988).

Software packages specifically implementing geographic profiling methods have been developed and are used by some law enforcement analysts and researchers (e.g. the CrimeStat, Rigel and Dragnet software packages). However, a debate is ongoing as to whether current geographic profiling software is practically useful for locating offenders (Snook et al. 2007). A parallel debate exists among the authors of the popular geographic profiling software tools as to which is most accurate (Paulsen 2006). This dialog, largely led by the developers of CrimeStat (Ned Levine) and Rigel (Kim Rossmo), has recently been stimulated by a roundtable panel organized by the National Institute of Justice (NIJ) to evaluate how accurately the current software tools predict “offenders’ base of operations.” This evaluation involved usability testing of the different software packages and evaluation of the outcomes. As the debate has continued, it has centered on the key challenges of mathematically deducing offender location for crimes given the limited availability of data sets. Methods such as the utilization of a distance decay function for travel demand modeling are mathematically complex. For instance widely used distance decay models place the variable of distance as an inverse function to some power such as 1 or 2 (de Smith, Goodchild & Longley 2009). Then, the value of some variable of interest, \( z_i \), as shown in equation (1) at location \( j, z_j \), might be modeled as some function, \( f() \), of attribute values, \( z_j \), associated with other locations, \( i \), weighted by the inverse of the distance separating locations \( i \) and \( j \), \( d_{ij} \) raised to a power, \( \beta \):

\[
    z_i = \frac{f(\{z_j\})}{d_{ij}^{\beta}}, \beta \geq 0 \quad (1)
\]

And while mathematical innovations in geographic profiling software are expected to increase in future versions, for instance through the incorporation of Bayesian approaches (Levine 2005), the usability of such systems for visual exploration of crime spaces will likely remain limited.

2.5 CONCLUSION
With the advancement of analytical and technical capabilities the crime mapping industry is embracing innovation. However, the mobility of crimes, criminals, and victims continues to
challenge the cartographic representation of crime. Time geography offers a novel approach to
dealing with the representation of mobility. However, the usability and operational utility of the
time-geographic approach remains a question. Map usability, a method of testing the geovisual
potential of maps interfaces, offers a useful metric for testing the operational potential of a time-
geographic approach to mapping crime events.
CHAPTER 3

TECHNICAL CONSIDERATIONS WHEN CREATING TIME-GEOGRAPHIC MAPS

3.1 INTRODUCTION

The time-geographic framework calls for a novel approach to mapping. This approach goes beyond traditional GIS methods by incorporating time as a visual variable. Further, the time-geographic framework takes place within a 3D (three-dimensional) map environment, where the third, vertical, dimension represents time. However, GIS as a software platform is commonly oriented towards creating 2D maps. Along with a discussion of the visual semantic tools of time geography this chapter discusses the necessity of adapting the traditional GIS software environment to a 3D geovisual environment.

3.1.1 Hybrid GIS-3D Modeling

Neutens et al. (2008) describe a narrowing gap in functional requirements between GIS and CAD (computer aided design) software. CAD technologies developed in the early 1980s to provide graphical tools for engineers, largely replacing the need for items such as pens, paper, slide rules and drawing boards. The tools are commonly used at the scale of specific objects such as automobiles or buildings. Though developed around the same period, GIS software has been primarily geared to providing tools for spatial analysis based on the concept of the map. Both software platforms, GIS and CAD, require a certain level of expertise while having different standards and workflows, leading to large gaps in practice and industry (Jukes 2007). These differences contribute to challenges in bridging the software paradigms and embracing a 3D GIS technique such as the one proposed by a time-geographic approach.

Often the functional requirements of a particular geographic visualization cut across the software features available in both GIS and CAD technologies. For this reason the geovisual framework of time geography requires a hybrid GIS-3D modeling software approach. Adams (2000), for example, used CAD along with GIS to map daily routines and illustrate two-way communications such as telephone conversations using a time-geographic framework. The principle advantage of bringing the visualization from a GIS into 3D modeling software is the ability to represent objects across dimensions (0D – 3D). Representation of objects across dimensions is required to construct such objects as space-time prisms, and GIS typically does not
provide this functionality. For example, the space-time prism utilizes the volume of a prism as a visual surrogate for accessibility (Lenntorp 1976; Neutens et al. 2008).

The maps created in this dissertation utilized a hybrid GIS-3D modeling software approach. What this means is that instead of relying on a traditional GIS software package, such as ESRI’s ArcMap, an alternative software package, Google SketchUp, was utilized. Although it is capable of creating images in 2D, SketchUp is particularly suited for creating 3D graphical models. Though often aligned with Google’s Earth product, the SketchUp product is more oriented towards architectural-scaled renderings. One way to consider the differences between GIS and CAD software is the extent to which they are often utilized to represent real world area or objects. GIS renderings are usually at the extent of cities or larger (e.g. countries). However, 3D modeling software such as SketchUp or CAD is principally utilized to create representations at much smaller geographic extents such as a particular building or street. Time geography, which has a particular focus on the micro-geographies of individuals, requires both the smaller extent functionality available in 3D modeling software and the larger extent functionality available in traditional GIS software packages.

### 3.2 THE SPACE-TIME CUBE

There is little discussion in the existing time geography literature on the mechanics of constructing the space-time cube. In fact the concept of the *space-time cube* is not even mentioned in Hägerstrand’s (1970) seminal paper introducing time geography. And while early time geography literature actually used the term “aquarium”, the concept has become more formally referred to as the space-time cube (Kwan 2000; Thrift 1977).

With the space-time cube, certain features become self evident when actually creating time-geographic maps. Consider that the horizontal face of the space-time cube represents the 2D geographic space while the third dimension of time is represented along one of the vertical edges of the cube, orthogonal to the 2D geographic space. The challenge of cartographically scaling the cube is served well by considering the mathematical properties of a cube. Geometrically, a cube is composed of six square faces (or planes) that meet each other at right angles and has eight vertices and 12 edges (Weisstein 2009). This particular feature of the space-time cube, that each of its edges is the same length and that each of its faces is a square, becomes particularly relevant in scaling (height and resolution) the temporal axis.
The space-time cube represents a bounded approach to conceptualizing a given time-geographic representation. These boundaries ultimately depend on the entities being mapped. The space-time cube is used as a tool to represent the spatial two-dimensional (2D) axes, \( x \) and \( y \), along with a third temporal axis, \( z \). Empirical evidence suggests that the space-time cube representation is advantageous in conveying complex spatiotemporal data to users (Kristensson et al. 2008). Further, the space-time cube is capable of representing, simultaneously, the whole space-time continuum and the position of events in this continuum (Gatalsky et al. 2004). However, there are particular challenges with utilizing the space-time cube for event visualization. Gatalsky et al. (2004) note that difficulties exist in selecting the appropriate temporal resolution for the space-time cube. The temporal resolution is a measure of granularity, which we can use to relate time to the \( z \)-axis (or temporal axis). This difficulty is not unlike the challenges presented by the modifiable areal unit problems of traditional cartography where selecting different levels of aggregation results in varied correlations amongst the data. Attention is required in selecting the appropriate time interval to represent events. Incorrect selection may produce sparse clusters or even false clusters. For example, if we are interested in mapping all of the burglaries that occurred within a given month, a temporal resolution of minutes may be too small, while days may prove too long.

### 3.2.1 Moving from 2D to 3D Representation of Space

GIS has been traditionally built around the concept of 2D representation of space. This 2D representation of space is grounded on the concept of a view from above, often referred to as the plan view. However, real objects have real surface volume, length, breadth and depth and hence are of three dimensions. When reducing real objects to a mapped 2D representation, such as a computer screen or paper map, it is necessary to distort the representation, resulting in what is referred to as projection. Distortion, as an inevitable product of flattening, constitutes a necessary representation compromise. In order to situate the map area within the Cartesian coordinate framework it is necessary to apply a projection so as to standardize the distortion. The choice of which projection is applied to a map impacts the appearance of items such as grid lines of latitude/longitude and mapped features (Slocum et al. 2001). For example, the benefits of this compromise were well understood by early seafaring navigators who relied on the Mercator projection because of its ability to provide a constant, straight-line bearing.
A good starting point for considering the concept of dimensionality as it relates to mapping is an explanation of basic elements of cartographic symbolization. These common elements of map design are used to represent geographic phenomena. And the distinction should be understood between the symbols used and the space in which they are represented. Typically these symbols are represented within either a 2D or 3D space. Slocum et al. (2005) describes the spatial extent of geographic phenomena and their perspective spatial dimensions:

- **Point**: is termed as zero-dimensional, and assumed to have no spatial extent. A point is defined as an $x$ and $y$ coordinate pair (add $z$ for 3D space).
- **Linear phenomena**: such as that of a road have a spatial extent of one-dimension defined as a series of $x$ and $y$ coordinates (add $z$ for 3D space).
- **Areal phenomena**: are two-dimensional in spatial extent. Areal phenomena are defined by a series of $x$ and $y$ coordinates that are closed, meaning the starting coordinate is the same as the ending coordinate.

Treatment of the third dimension for representing a phenomenon as having a single-valued function is called by some 2.5D, or quasi-3D (Turner 1997). A common example of 2.5D is the Digital Terrain Model (DTM) which represents elevation (or relief) of a geographic entity having elevation across one-to-many $X/Y$ points. Stated another way, for any given point on the $X/Y$ plane you can only have one elevation. Sometimes it is argued that a true 3D phenomenon is multi-valued having 4 coordinate values: an $X$ coordinate, a $Y$ coordinate, a $Z$ coordinate, and the value of the phenomenon (Slocum et al. 2005). Of consequence always is the scale at which one is mapping and how one defines geographic entities within that scale. For instance, nested polygons on the $X/Y$ plane to depict multiple elevation points along the $Z$ axis could be utilized to represent relief on a hill. Elevation in this sense cannot be used to represent surface area or volume but instead is used to represent a single value, in this case relief.

In time geography, time is modeled as an orthogonal $Z$ dimension. And though the concept of using a singled-value third axis is not unique, the assignment of time does present unique challenges. One attempt at addressing this challenge is the concept of a taxel, a specifically raster approach to the space-time cube introduced by Forer (1998). The concept of the taxel builds on the idea of voxels, a grid based method of representing a 3D value as tied to a 2D coordinate space (see Forer 1998). And again this may be considered only 2.5D because along a given space-time path there is only one $Z$ value for any given set of $X/Y$ values.
However, there are certain aspects of the time geography framework that extend themselves into true 3D. For instance the space-time prism is a true 3D object with multiple Z values for any given set of X/Y values. In other words the space-time prism is a true 3D object with volume. The fact of the matter is that the time-geographic framework combines both 2D and 3D visualizations. The base map, which is the bottom face of the cube, is often referred to as “area” while elements located along the 3D axis are referred to as “space”. Time geography combines a 2D map area within a 3D visual representation of space.

Although the space-time cube is situated within a 3D framework, the bottom face of the cube, the map area, actually remains a 2D representation. As the third axis, Z, is utilized to represent time it is no long available to represent geographic relief. Shepherd (1995) notes this particular drawback to the time-geographic approach as the z-axis is unavailable as a height variable and this is potentially limiting for cartographic representation. Further, “overloading” the z-axis so that it stands for both height and time it is not advisable as this would likely lead to difficulties in visual interpretation. A possible solution to the challenge of using the z-axis to represent both height and time, called stacking, is offered by Roth et al. (1995). The stacking method sets an artificial base at which the values along the z-axis stop representing height, and start representing time.

The extent of the map area must be selected with regard to the temporal data and purpose of the map. The extent is the area over which we have data or are seeking to observe (Newsome, Walcott & Smith 1998). It is important to note that the selected extent of a study area can affect the outcome of spatial analysis such as a nearest neighbor analysis that considers the distance between features. And while it is tempting to use an envelope approach for the extent, draping only over the data, it is recommend that one use the actual areal extent of the complete study area (Mitchell 2005). The extent of the study area becomes even more relevant in time geography as we are attempting to draw conclusions about the predicted movement in space based on known movements. To put this into a particular context, consider a map of crime patterns in a particular jurisdiction. The question of what extent to choose brings about the knowledge of a common problem, referred to as edge effects, occurring in selecting too narrow of an extent for spatial analysis. An example of the problem and how it is solved, albeit through arbitrary means, can be seen in the geographic profiling software Rigel. Rigel calculates the boundaries of an offender
search area by adding half the mean x and y inter-point distances to the most eastern and western, and northern and southern crime sites, respectively (Rossmo 2000).

A 3D visualization approach provides particular advantages and challenges for mapping. The 3D visual approach allows us to more fully consider the mapped phenomena within a certain context. By utilizing a compositional methodology, events and processes are broken down and studied in isolation of each other and events and processes are studied within their specific environment. To quote Parkes and Thrift (1980), “…it is only by inclusion of time that the geometric properties of relations among items (or events) become geographic” (p. 12). Within a 3D visualization it is possible to more fully represent mapped phenomena within context. For time geography this means representing individual mobility across both space and time. However, mapping in 3D is not without its challenges. Besides the obvious technical challenges to creating 3D visualizations there are specific cognitive challenges (Sebrechts et al. 1999). Google SketchUp provides a tool called the camera to position the view of the model. This tool allows us to pan and orbit around the model obtaining multiple perspectives. Therefore, while we remain in a top view we can move the camera around and obtain multiple perspectives. An interesting visual challenge occurs when we are in a top view, looking down from above, but the camera is slightly offset from the center of the screen.
Figure 3.1: A view from above the space-time path map

From this perspective it may appear that items in the 3D space are not directly over the 2D counterpart area (Figure 3.1). However, if we were to move the camera to the center of the screen we would see that the items do actually overlap. The challenge of map orientation within a virtual 3D environment is potentially one of the larger barriers to effective exploratory visualization in the geographic sciences (Gahegan 1999), and this is investigated in greater detail in the remainder of this dissertation.

3.2.2 Scaling the Temporal Axis

Scale is always an important consideration in accurate mapmaking. While scale in conventional 2D maps refers to the size of units across space, temporal scale refers to the size of time units (Montello 2002). At one scale a road may be represented as a 1D line, while at a larger scale it may be represented as a 2D polygon. On a 2D map, where the x and y-axes are coplanar
(on the same plane), an RF represents the comparison of distance on the map to, in the same units, on the ground. For instance an RF of 1:100 may be defined as 1 inch on the map equals 100 inches on the ground. In the same way a certain distance along the temporal axis can be defined to correspond to a particular measure of time units.

It is important to consider that every map is created for a specific purpose and it is this purpose that puts cartographic design within a particular context. Unwin (see Brodlie et al. 2002), in his forward to the book *Geographic Visualization*, makes the argument that context is as important as ever for map makers. For example if we are creating a map to show housing density across a small city we will be guided in choosing an appropriate scale. In this sense our map design, and specifically scale selection, is guided by the context for which we are making the map. The fundamental problem of putting a map in context can be understood by considering the type of geographic data that is to be represented by the map. The categories of geographic attribute data, as defined in common geographic texts, are (Slocum et al. 2001; Longley et al. 2001):

- **Nominal**: the root of the word nominal is “nom” which simply means “name.” These values serve only to distinguish one entity from another; level of measure involves grouping but not ordering (or ranking); examples include letters and even colors;
- **Ordinal**: the word ordinal comes from order and implies rank. These values have a natural order; level of measurement involves categorization plus an ordering (or ranking); examples include probability;
- **Interval**: differences between values make sense; level of measure involves ordering the data plus an explicit indication of numerical difference between two categories; arbitrary zero point; examples include temperature (Celsius or Fahrenheit scale) or elevation;
- **Ratio**: ratio between values make sense; non arbitrary zero point; examples include weight or temperature (Kelvin scale);
- **Cyclical**: level of measure is on a cycle; examples include degrees, minutes, and seconds (DMS), the time of day or angular measurement (360 degrees).

Decisions about scaling the temporal axis are not unlike the decision making process for the spatial axes of $x$ and $y$. The importance of context is further explored in the next two sections discussing the two common methods of categorizing objects mapped along a temporal scale.
3.3 SPACE-TIME POINT

There is very little mention of the space-time point as a construct in time-geographic literature. Instead the space-time point is often seen as a necessary element in the construction of the space-time path. Miller (2004) refers to them as control points and describes the space-time path as the linkage of a series of space-time points. However, in a case where we have no need, or are not interested in, particular path information the 0-dimensional space-time point is all that is required (Hendricks et al. 2003). Further, with the use of mathematical scaling as a method of sizing the area (or volume) of point symbols in direct proportion to the data, we can represent multiple occurrences at the same location (Andrienko et al. 2003). It is worth noting numerous studies which show that perceived size of proportional symbols does not correspond to their mathematical size and that people underestimate the size of larger symbols (Slocum et al. 2001). In these cases another technique called perceptual scaling is suggested.

3.3.1 Linear verses Cyclical Time Axes

Time geography’s use of the third axis for representing time is deceivingly simple. However, the variable of time, as it relates to space, can be conceptualized in different ways. Harower and Fabrikant (2008) point out that although no agreed upon method for representing geographic time exists, all include the concepts of linear and cyclical time. The linear view of time sees it as ongoing from one moment to the next, never repeating any particular moment (Figure 3.2). In this sense time is representative of a one-way arrow, or in time-geographic terms a single-value on the x-axis. Most of the literature discussing the time-geographic approach builds around the concept of a linear time axis. And most systems built for temporal querying are built according to a view of time as a linear sequence of moments (Andrienko et al. 2003).
Most work considering the use of the time-geographic framework assumes a linear approach to time. This may be attributable to the constructs of the *space-time path* and to the *space-time prism* requiring a linear approach to time. However, there are times when a cyclical view of time is more appropriate. For instance Harrower et al. (2000) use a technique called “temporal brushing” for choosing specific times of day (e.g. 6 p.m.) and studying what happens, particular events, at this time over the course of multiple days. An example of these two types of geographic time can be understood in common map symbols utilized to illustrate time. While an example of a linear time map might utilize a bar or line, a cyclical time map might utilize a circular clock symbol.
One application of the cyclical concept of time can be seen in the work of Andrienko et al. (2003), who build space-time cube representations of events occurring across a cyclical time axis (Figure 3.3). Their approach consists of placing graduated spheres along the time axis with sizes proportional to the number of events occurring in duplicate space-time points. Finally, the graduated spheres approach could be useful in cases where a large dataset of space-time information is available. From a visual perspective it may prove to complex too show many space-time objects constructed from space-time paths. Therefore, if you were to aggregate the space-time points you could reduce the visual complexity.

The decision of whether to use a linear or cyclical time axis approach when constructing a time-geographic map is dependent on the space-time point data availability and map purpose. The cyclical approach might be useful for crime maps where path information is not available, or informative, but temporal sequencing is. One of the fundamental challenges in crime mapping and analysis is pattern recognition (Grubesic 2006). “Hot spot” analysis, which is often used in
crime mapping, involves the use of clustering algorithms to categorize groupings of crime incidents in space. The cyclical time axis approach would be advantageous for developing clustering algorithms. By extending hot spot analysis into a time-geographic context we can begin to consider clusters in both time and space. An inherent disadvantage of the cyclical approach is that without path information it is not possible to build more advanced time-geographic constructs such as space-time prisms. The linear axis is more appropriate for when the focus of the map is on revealing unknown path information based on known path information. And with the path information the more advanced time-geographic constructs such as space-time prisms can be utilized to reveal potential paths. However, it is often difficult to obtain the space-time path data required of a linear time axis.

3.4 SPACE-TIME PATH
Hägerstrand (1970) grounds the idea of an individual’s path as the fundamental unit of time geography, describing it as a path that starts at the point of birth and ends at the point of death. Given this broad definition, it should be clear that issues of scale play a prominent role in making operational time-geographic maps (this was addressed earlier in my discussion of the space-time cube). An individual’s space-time path is constructed by drawing straight lines connecting known space-time points such as those provided by travel-diary survey data (see Kwan, 2000).

![Figure 3.4: Illustration of the space-time path and space-time station](image)

Figure 3.4: Illustration of the space-time path and space-time station
The maps developed in this dissertation employ Miller’s (2005a; 2005b) definition of a space–time path as consisting of two components: (1) a strictly ordered temporal list of measured control points, each consisting of an observed spatial location and a time stamp when that location was recorded; and (2) inferred path segments between temporally adjacent control points. The formula for control points is given as:

\[ C_i \equiv C(t_i) = x_i \]  

where \( x_i \) is a location in space and \( t_i \) is a moment or instant in time. The set of control points, \( C \), which determine the path is a finite list of space–time observations strictly ordered by time:

\[ C = \{(C_S, ..., C_i, ..., C_E) | t_S < ... < t_i < ... < t_E \} \]  

where \( t_S \), \( t_E \) are the start time and end time (respectively) for the path, that is, the first and last observed locations.

The visual aspect of the space-time path concept represents an individual’s known trajectory illustrated on a two-dimensional plane, with a third dimension as a vertical \( z \)-axis representing time (Figure 3.4). The concept of the space-time station can be introduced along with the space-time path. The space-time station represents stationary activity spaces such as time spent shopping, at work, or at school. Inherent within the idea of the station is the idea that although a person may not move in space, he or she is always moving forward in time.

When two or more space-time paths come together for a certain amount of time, the station is termed a bundle. Both stations and bundles are dependent on defined map resolution and thus scale. Visually, the space-time station is symbolized as a tube wrapped around the space-time path. In this sense the space-time station has a spatial extent (Thrift 1977). Figure 3.4 illustrates the coming together of two separate space-time paths for an amount of time such as a meeting or engagement of individuals.

### 3.5 SPACE-TIME PRISM

The space-time prism (Figure 3.5) leads to the idea of the time budget, in which a person can move away from the start location, limited only by the maximum travel velocity and the next known point (Tessmann 2006). A space-time prism gathers all space-time paths an individual might have drawn during a specific time budget and delimits the feasible set of opportunities within a person’s reach (Dijst & Vidakovic 2000; Forer 1998). In theory, the prism is the intersection of two cones, called beads by Hornsby and Egenhofer (2002) and Hariharan (2001).
The lower cone represents the possible paths, in space-time, of travel from a given starting control point, while the upper cone represents the same path possibilities, in space-time, approaching the destination control point.

Figure 3.5: Space-time prism or right bead

Figure 3.5 represents what Hornsby and Egenhofer (2002) and Hariharan (2001) formalized as a right bead (prism). In this formulation the bead consists of the intersection of two half cones. Conceptually building on the space-time path constructed from two space-time points \((x, y, t)\), Hariharan (2001) defines the apexes of a bead as either being collocated in space, but shifted in time \((x_0, y_0, t_0 \text{ and } x_0, y_0, t_1)\), or shifted by both space and time. If the two space-time points are separated only by time then a right bead is formed. In this case the two half cones form a circle located in the plane

\[
v(\text{maximum velocity}) = \frac{|s-t|}{x_1-x_1}
\]

around the center

\[
t = \frac{(t_0 + t_1)}{2}
\]
\[ (x_0, y_0, \frac{(t_0 + t_1)}{2}) \]  \hspace{1cm} (4)

with a radius of

\[ r = \frac{(t_1 - t_0)}{2} \tan \theta \]  \hspace{1cm} (5)

The projection of the right bead (prism) onto the 2D plane forms a circle. The other possibility, called an oblique bead (prism) is when the two space-time points are shifted by both space and time, or not spatially aligned. It is the projection of the oblique bead (prism) onto the 2D plane which forms an ellipse, or a PPA.

The slope of the cone shows a given possible maximum velocity for the represented individual from a known point in space, while the space-time path indicates an individual’s activities in both space and time. The mathematical formulation for velocity is given as:

\[ V_{ij} = \frac{||x_j - x_i||}{t_j - t_i} \]  \hspace{1cm} (6)

where \( || \) is the vector norm or distance between the locations. Placing Equation (6) within the context of the prism represented in Figure 3.5 we can see that this equation allows us to scroll through locations in the space–time path using time as an index.

Using the maximum velocity assumption we can then conceptualize how an offender’s potential path space (Wu & Miller 2001), represented by the interior of the cone, intersects with a crime incident site \( x_j \), by showing all of the locations in space and time that the offender could have occupied during the time budget interval \( (t_i, t_j) \). The range of offender travel capability then is constrained only by a defined maximum velocity, signified as \( v \). This velocity is, mathematically, the subtraction of a known time segment, \( t_j - t_i \), divided by the distance between known control points, \( x_j - x_i \). The concept of velocity, expressed as PPA, is integral to a time-geographic approach. Therefore a potential path representation is used to show the points in space and time that the person could occupy during this travel episode (Miller, 2005b).

### 3.6 POTENTIAL PATHS

Embedded within the idea of the prism are the ideas of potential path space (PPS) and potential path area (PPA). The PPA represents the individual’s ability to reach (be coincident with) locations in space and time given the location and duration of fixed activities (Miller,
The PPS, which is the ellipse created by the intersecting cones, depicts points in space and time that an individual could possibly have reached during a given time period. While visually both are symbolized as ellipses, the PPA sits on the 2D plane with no time variable, and the PPS lies at the interior of the prism and is elevated on the temporal z-axis (Figure 3.5). The PPA, termed the geo-ellipse by Miller (2007), is the 2D projection of the PPS and is defined by velocity and time budgets. These potential paths are realized as possible movements across an isotropic, or frictionless, surface in any direction constrained only by the defined maximum velocity and time budget. Armed with the maximum velocity, a time budget and two known points on the space-time path, the ellipse can be constructed utilizing mathematical principles (Figure 3.6).

This example illustrates two known control point points on a space-time path, P1 and P2, represented in 2D along the major axis of the ellipse. Based on Miller’s (2007) formulation of the PPA with the velocity we can predict the distance traveled in a straight line to get the vertex points. Finally, utilizing the mathematical formula for an ellipse:

\[
\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1 \tag{7}
\]

along with the Pythagorean theorem:

\[
b^2 + c^2 = a^2 \tag{8}
\]

the intersection with the minor axis can be found.

Placing equations (7) and (8) within the context of the prism represented in Figure 3.6 we can see how the major and minor axes of an ellipse are found. The dotted lines between the control points, P1 and P2, represent two different possible paths. The paths, occurring on a frictionless surface, are constrained only by a defined maximum velocity, \(v\), and a time budget, \(t_b\).
As an example, consider the two points depicted in Figure 3.7. If we know that the distance between the two control points, C₁ and C₂, is 1051.54 ft, we have a constant travel speed, and we know the actual times at C₁ and C₂, then we can determine the time left over in a time budget for discretionary travel. For instance, if the time to get from C₁ to C₂ is 5.97 minutes and 2.0253 minutes is left in the time budget, then the vertex of the ellipse is found to be 1229.77. From here we can find the Y-intercept by plugging the known values into the equation of the ellipse. The result is a visual representation of potential paths.
3.7 CONCLUSIONS

A basic assumption of time geography is the concept that *when* something occurs is equally important as *where* something occurs. For crime mapping, a particular challenge exists when attempting to uncover a pattern when singular points are not available, or representative, of a crime event. And even when the actual crime locations are known a point on a map may offer limited explanation of a crime event. The potential utility of the time geography approach in revealing likely victim/offender journeys, analogous to hypothesis generation, is worth exploring. For this reason the integration of a visual time-geographic approach into existing methods of crime mapping analysis, as proposed by this dissertation, seeks to add breadth to the tools available to crime mapping practitioners and researchers.
CHAPTER 4

PUTTING TIME GEOGRAPHY INTO CONTEXT

4.1 INTRODUCTION

This chapter addresses the explanatory tools of time geography. Along with introducing
the scenario which subsequently was used in carrying out the time geography usability test, the
associated maps are introduced and explained. Finally, possible criticisms of the time-
geographic approach are addressed.

4.2 CONSTRAINTS: THE EXPLANATORY TOOLS OF TIME GEOGRAPHY

Time geography proposes a certain focus on representing not only human activity, but
also possible actions under certain defined constraints and structures. Hägerstrand (1970)
categorizes the concept of constraints as fitting within one of three types: capability, authority,
and coupling. These three types of constraints are seen as being interrelated rather than additive,
and they manifest themselves by dictating the space-time control points between which activities
undertaken to achieve predetermined goals (i.e., projects) can take place (Carlstein 1978;
Neutens et al. 2007; Zillinger, 2005). A fundamental tenet underlying time geography is that
human activities have both spatial and temporal dimensions and these cannot be meaningfully
separated. Individual mobility in these dimensions is recognized as being bounded by certain
space and time constraints. While the visual semantic tools of time geography provide a means
of representing potential mobility, it is the concept of constraints that accounts for the limits of
movement. In a time-geographic approach, constraints, both physical and social, are utilized to
explain the limits of a given space-time path.

4.2.1 Capability Constraints

Hägerstrand (1970) described capability constraints as those which limit the activities of
the individual because of his biological construction and/or the tools he can command. Further,
capability constraints address the physical limitation of individuals, such as those imposed by the
need to eat or sleep. Suppose that a single offender were carrying out a succession of pickpocket
acts across a given shopping district area. Then a key assumption is that the offender has the
capability, on foot or otherwise, to reach the different criminal opportunity points. Though the
average human walking speed is between 2 and 3 miles per hour (Gross & She 2001), particular constraints, such as crowd density, may restrict speed. Therefore various assumptions about velocities of movement can be made depending on a given context.

4.2.2 Authority Constraints
Authority constraints reflect the influence of organizations external to the individual that control access to different places at different times (Ratcliffe 2006). Authority constraints refer specifically to levels of access at an individual level. As Hägerstrand (1970) notes, shops, banks, doctors, and barbers permit random access between given hours. The idea would then be that customers only have access to these locations and the resources within that location during operating hours. For the rationalizing criminal, such as described by Clarke and Felson (1993), authority constraints play a prominent role in the decision making process leading up to an act of offense. Along similar lines, Brown and Altman (1981) developed a conceptual model of the burglary process where a potential burglar uses a series of cues to make a judgment about the openness/closedness of a particular boundary. These cues include a determination of certain boundaries as having differing levels of accessibility. At a broader level this constraint describes a need for granted authority to domains that are space-time entities, such as a township, nation, company, or university controlled by an individual or a group (Hariharan 1999). Visually, authority constraints may be illustrated as cylinders; the insides of which are either not accessible at all, or are accessible only upon invitation or after some kind of payment, ceremony, or fit (Hägerstrand 1970).

4.2.3 Coupling Constraints
Coupling constraints are recognized as the necessity of certain activities to form production, consumption, social, and miscellaneous activity bundles (Pred 1977). Practically, coupling constraints are defined by socially accepted modes of behavior such as shop operating hours or bus departure times. In order for a certain exchange to take place between two people, they must come together in time and space (e.g. a waiter taking your order). The concept of coupling constraint fits well with Cohen and Felson’s (1979) routine activities theory. To commit a given crime implies the ability to take advantage of a given opportunity for that crime. In order
to steal a victim’s wallet, a pickpocket must be in the proximity, in both space and time, of the victim (e.g. on the same elevator or on the same street).

4.3 MAPPING VICTIM SPACE-TIME PATHS: STREET PICKPOCKET SCENARIO

The first part of the methodology of this dissertation consisted of: placing a crime scenario into a time-geographic framework by creating five different maps that increasingly incorporate time-geographic tools. Accompanying each map there is a discussion of the visual potential for revealing a crime event profile. The exact time and location of the crime incident are unknown, necessitating the need to develop a criminal event profile. The purpose of the crime event profile is to inform the development of a search strategy. Though the street network used in the maps is of a real location, the actual space-time data is fictional.

4.3.1 Locating pickpockets through victim space-time paths

Street robbery has been studied extensively in the crime mapping literature (Cornish & Clarke 1986; Groff & McEwen 2007; Walsh 1986). Further, empirical work has found that street robbery has certain associated activities, such as journey paths, which take on certain rhythms, timings, trends, and cycles (Cohen & Felson 1979; Georges-Abeyie & Harries 1980; Hawley 1950). Typically, pickpockets operate within crowded public places, where numerous individuals’ space-time paths converge. Pickpockets rely on distraction techniques that are assisted by victims’ attention being diverted. For instance, one news story reports of a string of pickpocket incidents where the victims were distracted while entering and exiting elevators (Siegel 2009). The crime scenario that is addressed in this dissertation, pickpocketing on the street, is described as follows:

- **Scenario description:** Incidents of pick pocketing are occurring while victims are moving through a crowded shopping district. The primary mode of movement in this district is walking. Each victim discovers that his/her personal property has been stolen at a certain point during the same shopping episode and is able to recount, or provide information on, known space-time points leading up to the discovery of the crime event.

The scenario is designed with the assumption that a single offender is carrying out the crime. However, all that we have is victim space-time data across a range of possible locations and times at which the incident occurred. Also, integral to this scenario is the assumption that the
victims and offender are both traveling on foot under similar velocity constraints. An offender moving at much greater velocities would draw attention to him or herself. Therefore, in selecting a maximum velocity, we are actually estimating the potential offender movements. The time budgets are developed by iterating through the known space-points, looking at each start and destination control point. Victims of pickpocketing generally become aware of the situation only when they realize that they have lost their personal property. But, by that time, the offender whereabouts are unknown as well as the stolen property. Data for the offender is not provided. Instead the space-time paths in this scenario are defined as the victims’ paths of movement leading up to the discovery of the crime incident. This approach is dependent on the fact that the offender and victim must meet at least one point in space and time (Cohen & Felson 1979). This path could be recounted by the victim, or it could be based on time/location information of retail transactional records while shopping or even security camera review, leading up to the discovery of the crime event.

The purpose of criminal event analysis, the identification of conditions immediate and relatively close to the actual act (Meier et al. 2001), is compatible with the contextual approach of time geography (Pred 1977). Because information as to when or where the actual pickpocket incident occurred is not known, a more encompassing event profile, rather than a specific incident documentation, must be developed. This approach considers the contexts within which criminal events occur. The purpose of the maps developed in this dissertation is to reveal an informed criminal event profile. This criminal event profile should inform a more focused search strategy by narrowing in on the likely incident location and time. The search area can be conceptualized as a base of operations for the pickpocket. Perhaps it is an area, such as a crowded street corner, which offers the greatest ability to distract potential victims and hence increased opportunity for offenders. Further, if the pickpocket is skillful in his or her job then the incident will remain unnoticed by the victim (Hentig 1943). The visual exploratory approach seeks to reveal unknowns about the spaces of crime through the use of known-event geospatial data. Peuquet’s (1994) triad of when + where \(\rightarrow\) what is particularly relevant here in revealing the interrelatedness of objects in space and time. The what, in this case, is the incidence of pickpocketing. The crime incident is necessitated by the offender’s mobility, requiring that ability to reach both victims. Therefore, in time-geographic terms a coupling constraint exists,
for both the victim and offender must have the ability to meet in space and time. However, we have *when* and *where* information only for the victims.

### 4.3.2 Model Data and Software

The time-geographic maps created in this dissertation were built using Google’s software package called SketchUp. SketchUp is a 3D modeling tool that uses surfaces (thin shells called faces) and edges (lines) for its geometry. Among the key features of SketchUp is the ability to situate 3D models within an interactive environment (e.g. pan, zoom, orbit, animation, and walkthrough) with relative ease. SketchUp also allows for integration with GIS-exported map graphics. An additional benefit of SketchUp is its robust object-oriented scripting language, Ruby, which allows for automation and customization of its environment. This scripting language was used to automate the constructions of the space-time paths. SketchUp allows the user to modify the view of the model through a device called the camera. With the camera, one can orbit (rotate around), pan (move vertically and horizontally), and zoom (move in and out). SketchUp also provides 6 standard views: Top, Bottom, Front, Right, Back, Left, and Isometric.

The geographic base layer for the maps in this dissertation is La Rambla, a popular tourist destination in Barcelona, Spain. La Rambla consists of a multi-block area dominated by pedestrian movement. As of 2009 this popular locale was cited as being the most likely place in the world to be pickpocketed (Adams 2009). The area of focus on the maps is about 1.37 acres. The characteristics of this area, being a popular tourist site open to the general public, make it suitable to the type of space in which a pickpocket is likely to operate. The base map layer itself was created using the software Adobe Photoshop. This map image was then imported into SketchUp and placed on the plane of the *x/y*-axis. Once the image was imported into the 3D software environment (SketchUp) it was scaled accordingly.

For the explanatory purposes of this article we will focus only on the basic elements of scale. The data (or spatial) resolution is a measure of granularity of the phenomenon that is being mapped (Slocum et al. 2005). For the maps in this dissertation the smallest distance units measured on the ground are in feet, and the smallest time units in minutes. Therefore, the *spatio-temporal resolution* of the temporal axis is set at 35.98 feet/minute.
4.3.3 Map Scale Considerations (Space and Time)

The victim space-time data is hypothetical. For a crowded tourist area (such as that used in this scenario) average walking velocities would be predicted. The maximum velocity for this map is set at 88 ft/min based on a leisurely pace in a crowded shopping district. Although this velocity is applied explicitly to the victim space-time path, it implicitly defines the offender potential space-time path as well. A key assumption for these maps is that all three individuals, the two victims and the single offender, are constrained by the same maximum velocity. The crime event, then, is necessitated by the victim and the offender coming together in space and time. Therefore, we can say something about the spatiality, and mobility, of the unknown offender, based on the known victim data. The victim space-time data utilized in the maps is listed in Table 4.1. The italicized rows indicate where the two victims’ known space-time points are at their closest location (in 2D excluding time). The bolded rows represent the locations at which the victims’ space-time points are at their closest in space-time (in 3D). Finally, it is important to note that no data on the offender or the actual location or time of the pickpocketing incidents is provided.

Table 4.1: The data used to build the usability scenario maps

<table>
<thead>
<tr>
<th>X Coordinate</th>
<th>Y Coordinate</th>
<th>Date</th>
<th>Time</th>
<th>Minutes Elapsed</th>
<th>Z Coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1043.0396</td>
<td>563.7279</td>
<td>4/4/2009</td>
<td>12:05</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>335.5859</td>
<td>1258.319</td>
<td>4/4/2009</td>
<td>12:20</td>
<td>15</td>
<td>539.75</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X Coordinate</th>
<th>Y Coordinate</th>
<th>Date</th>
<th>Time</th>
<th>Minutes Elapsed</th>
<th>Z Coordinate</th>
</tr>
</thead>
</table>

4.3.4 The Visual Potential of Time-Geographic Maps for Crime Event Profiling

The maps for this crime scenario represent victim movement and are built with the intention of revealing a specific search strategy for locating the offender and the likely locations, in space and time, at which the crime incidents occurred. In developing a geographic profile, an anchor point is the location that is definable from which an offender operates (Rossmo 2000).
For a pickpocket, this could be a crowded street corner or somewhere that maximizes the crime opportunity while minimizing the risk of being caught in the act (Hentig 1943). Combining the concept of anchor points with the crime triangle of routine activities theory, a crime event occurs when both the victim and offender are within proximity to the offender’s anchor point. Further placing these concepts within a time geography framework, an anchor point will lie within a given victim’s space-time prism (potential paths) along his or her space-time path (known paths). It is recognized that, empirically, a search strategy will become more focused with successive crime event data (Leitner et al. 2007). However, for the purposes of illustrating a specific visual approach, these scenario maps in this dissertation will consider only two victims’ data.

To illustrate the potential usage of time-geographic maps for geovisualization of crime spaces, this article will compare five different maps that increasingly incorporate time-geographic tools. The goal of the map is to reveal a crime event profile. A crime event profile, in turn, should lead to more certainty in developing a search strategy for offenders and locating, in space and time, where the incidents occurred. Because of the complexity of layered geographic data, certain visual data filtering methods become necessary. Visual techniques for highlighting certain portions of a dataset, such as focusing (narrowing the set objects displayed to a small subset that depicts entities having similar values on one variable), querying (asking specific questions of the dataset), and brushing (highlighting a subset of numeric values), are examples of filtering methods employed in cartographic exploration.

The maps in this dissertation represent an increasing use of time-geographic tools over the same crime scenario dataset. The five maps used are:

- **Point Map**
- **Flow Map**
- **Potential Path Area Map**
- **Space-Time Path Map**
- **Space-Time Prism Map**

### 4.4.1 Point Map

In the first map, the *Point Map*, a rudimentary depiction of the known victim data is represented (Figure 4.1). This depiction consists of the 2D control points across the offense time ranges. These points are based on the first two columns of Table 4.1, the $x$ and $y$-coordinate
points. Measures of distance decay could be used to test the degree to which the interaction between two locations declines as the distance between them increases. This line of reasoning also parallels the gravity approach, often referred to as the first law of geography, which proposes that objects that are near to each other are more likely to be related than distant objects (see Tobler 1970). Applying this line of reasoning, with the visual information available in the Point Map, the likely area that the offender might have operated out of would be the area where known victim control points appear at their closest. However, this map challenges the ability to say, with certainty, the location at which the two victims were at their closest. This challenge exists because control points alone do not indicate any level of spatial or temporal sequencing. Therefore, the ability to develop a search strategy for where the single offender may have operated out of is significantly challenged.
4.4.2 Flow Map

In the second map, the Flow Map, we consider the 2D flows of the two victims’ movements (Figure 4.2). To build the Flow Map, a series of control points and the order in which they occurred are needed. This approach, modeled after Tobler (1987), takes each of the known control points and draws a straight line along the given paths. Arrow symbols are provided to indicate direction of movement. This article will use the term flow path to refer to this 2D depiction of individual movement across space. This type of mapping has been used to develop mobility triangles examining victim/offender convergence illustrating movements between
respective places of residence and the location of the crime event (Groff & McEwen 2006). Since the location and time of the crime event are unknown, the approach taken here is to show movement of the two victims across 2D space. With this map, we can determine where the two victim movements are at their closest. Assuming a rational offender who seeks to minimize travel cost (distance decay) and maximize returns, nearer crime opportunities will be preferred over those further away (Felson & Cohen 1980). The type of analysis is similar to measures of distance decay utilizing simple distance metrics on the x and y-axes.

This map indicates some level of spatio-temporal sequencing. And although the two victims’ flow paths actually cross each other at a certain point, one cannot have much confidence that this was the likely location of the crime events, and that it represents the criminal’s base of operations. A notable limitation of the Flow Map for revealing an informed search strategy is the absence of any visual representation of time. By leaving time out of the visual representation of victim paths it cannot be determined with certainty at what time the paths are actually relative to each other.
4.4.3 Potential Path Area Map

The third map, the Potential Path Area Map, utilizes the 2D flow paths while adding PPA ellipses. The PPA ellipse represents all of the possible locations that the victim could have reached between two given known points. This map (Figure 4.3) introduces the temporal dimension as the PPA ellipses are built with particular knowledge of time budgets and velocity. The formula for the ellipse is given in chapter 3, section 3.6 as equation (7). Mathematically, an
ellipse is defined as the set of points in a plane, the sum of whose distances from two fixed points, in this case victim control points, is constant (Stewart 2003). The ellipse gets wider between control points when the time budget is greater or the distance between points is relatively shorter. Therefore, the ellipse offers a visually implicit representation of time.

Visually, the Potential Path Area Map shows that some locations have greater intersecting PPAs than others. One search strategy, then, considering these intersections, might be to target the area where the greatest amount of overlap between PPA ellipses occurs as an indicator of the most likely location at which the offender could have reached both victims with a minimum of effort.

Figure 4.3: The potential path area map
4.4.4 Space-Time Path Map

The fourth map, the *Space-Time Path Map*, adds the victim space-time paths to the 2D flows of movements (Figure 4.4). This space-time path map offers a visually explicit representation of time. Integrating these visualizations into a GIS-like environment involves situating spatial (2D) axes, \(x\) and \(y\), within a third temporal axis, \(z\). Therefore, this map introduces the use of the third temporal axis or \(z\)-axis, and thus the necessity for a 3D modeling environment. In a time-geographic approach, the third axis, \(z\), is defined as some constant interval of time across which are mapped \(x\) and \(y\) coordinates. Put into mathematical terms, we can say \(z = f(x, y)\) to make explicit the value taken on by \(f\) at the general point \((x, y)\). Therefore, the variables \(x\) and \(y\) are independent variables and \(z\) is the dependent variable (Stewart 2003). Essentially, if given a time (\(z\)-axis value), the
location (x/y-axis value) of an individual’s space-time path can always be determined. However, the opposite is not true: if given the location (x/y-axis value) of an individual’s space-time path, the time (z-axis value) cannot be determined. This is a key property of the relationship between time and space, which is that an individual cannot be in two places at the same time.

4.4.5 Space-Time Prism Map

The visual exploration of space-time paths reveals many locations on the map where the two different victims’ path could have crossed. Visually, map user cognition may be challenged in determining where an offender could have reached both victims. Multiple views produce different victim space-time path locations at which they are at their closest in both space and time. Corresponding to height along the z-axis, time variable values are labeled at each victim space-time point along his or her respective space-time path. The Space-Time Path Map reveals the necessity and potential benefits of map user interactivity. Computer-based maps offer many possibilities for improving geovisualization. At the map interface (the computer screen) the user benefits from being able to change perspectives (views) through interactive devices, like Google SketchUp’s camera tool. By orbiting, panning, and zooming around this map, one can gain different view perspectives on the dataset and thereby see the locations in space-time at which the two paths are at their closest.

A particular cognitive challenge with this map for users may be in conceptually connecting the 3D space-time paths to the potential 2D movement on the ground (the x/y-axis). These two paths represent the same movement. However, while the space-time path is situated in the 3D space-time context (x, y, and z-axis), movement on the ground is situated on the x/y plane. If the camera is oriented at a location close to directly above the map space it becomes more obvious that the flow paths correspond to the space-time paths. At this perspective the map user is looking down on the 3D map space from above. The ability to change perspectives is essential to the visualization of 3D objects on a 2D screen. However, depending on the position of the observer (the camera tool in SketchUp), different challenges are known to occur. This is not a new challenge for visualization of 3D illustrations. As early as the fourteenth century, artists had become aware that objects depicted on a canvas diminish in size as they move away from the
spectator, and that the parallel sides of a floor or a ceiling recede towards the end of a room as one looks at them (Pedoe 1983). These challenges of perspective remain on a 2D computer monitor. Therefore, while visual inspection of space-time paths can be used to reveal particular locations where the two victims are at their closest, alternative view perspectives could lead to different conclusions. And while this map may be able to reveal the locations at which the two victims on their respective space-time paths were at their closest, it is limited in revealing potential paths. Each victim’s space-time path represents a straight line distance, the shortest distance, between two known control points. However, it is more likely that the victim’s travel varied from their paths, as they meandered through the shopping district’s streets, sidewalks and corridors. Therefore, although the addition of space-time paths adds a visual cue of time, potential paths in space-time are still required to realize a more certain search strategy at which the victims were potentially at their closest in space and time.

The final map, the *Space-Time Prism Map*, combines the three primary visual tools of time geography discussed in this dissertation (Figure 4.5). The cognitive focus taken in this dissertation is on how the map has the potential to reveal a particular crime event profile through only the map’s visual interface. The realization of this event profile increases confidence in locating the likely incident place, time, and offender base of operations.

The visual exploratory approach views the map as a communication device (Andrienko et al. 2003; Kraak 2003). A specific usability difficulty of 3D modeling on a computer is the fact that we are working on a 2D screen (Chopra 2007). To overcome this challenge multiple perspectives are possible with interactive devices. This map makes full use of the 3D display environment. The prisms are constructed by iterating through a victim’s space-time control points, constructing the respective cones, and developing a 3D space-time prism. This prism is a true 3D object which has multiple z values for given x/y values. By orbiting around the space-time prisms we can visually explore potential paths.

The *Potential Path Area Map* is visually complex and likely would challenge map user cognition. One approach to filtering this map is to include only those PPA areas at which the two victims’ potential paths intersect (Figure 4.6). With this filter applied,
particular areas where the intersections are the greatest are potentially more apparent. At this point a map user might make an assumption that these are the areas at which the incident is most likely to have occurred. The greatest amount of intersection might be determined by the map user to be on Carrer de la Portaferrissa. However, as there are multiple intersections of the two victims’ PPAs it is impossible to say with certainty that a particular area, and time, is the prime location of pickpocket activity. Although the PPA ellipse shows potential paths on the ground, potential paths in space-time (PPS) are not represented, thereby limiting the development of a more informed search strategy. Finally, by making the flow paths and PPA ellipses the same color for each victim the map user should be more easily able to associate a given ellipse to its perspective path.

The PPS is introduced in this map as the ellipse connecting the upper and lower cones along each space-time path segment. This ellipse can be seen in the diagonal of each space-time
prism. The visual approach to developing a search strategy as proposed in this dissertation involves interactively searching for space-time nearness through exploration of the map interface. By zooming and orbiting around and through the space-time prisms, the location at which the victims were at their closest in space and time can be found. Once a potential search area is revealed a more confident event profile can be developed. An actual intersect of the two victim’s; space-time prisms can be verified by face/surface textures (e.g. to wireframe) to reveal true intersections (Figure 4.7).

Figure 4.6: The potential path area map (intersections only)
With the *Space-Time Prism Map* one can see the victims’ potential movements, which implies the offender’s potential movements in both space and time. An actual intersection of the two victims’ space-time prisms indicates a significant spatio-temporal relationship. The *alibi query* asks whether two moving objects, that are given by samples of time-space points and speed limitations, can have physically met (Hornsby & Egenhofer 2002; Othman & Kuijpers 2007). This query, while computationally intensive, offers a mathematical method for proof of space-time intersections. For this article, the SketchUp *Intersect with Mode* tool provides a sufficient method to verify that two graphical objects do in fact intersect. With this tool, two space-time prisms can be selected and tested for intersection.

![Figure 4.7: A view of the wireframe space-time prism intersection](image)

Finally, due to the combination of space and time objects within one map, methods of reducing visual complexity will likely become increasingly necessary. These methods can involve highlighting entities by selection and directing map user attention (see Monmonier 1990). For the *Space-Time Prism Map* a focus can be applied by zooming in on the specific space-time elements to draw attention to nearness or an intersection. Andrienko et al. (2003) caution that any map image focusing that results in conveying only partial information must be compensated by showing different aspects of data in multiple views. A final focus consists of removing all of the space-time prisms and leaving only the intersection; in this manner, a specific
search area is revealed. In this case, the intersection of the two space-time prisms produces a triangular shape. By projecting this triangle, which is situated in the 3D space, onto the 2D map space, we can locate it on the ground (Figure 4.8), which is the location at which the two victims were likely at their closest: the block area of Carrer de la Portaferrissa and Carrer del Duc de da Victoria. In criminal geographic profiling terms this area informs a likely anchor point for the offender. Furthermore, a space-time range between 12:20PM and 12:35 is indicated by both victims’ space-time paths at the intersection, indicating a time of likely criminal activity to pair with the likely place of criminal activity. With this search area, we then have a more focused search strategy for our serial pickpocket offender. This search area represents an optimal search strategy, based solely on the metric of distance, given limited information on the offender, location, and time of the incident.

![Figure 4.8: The area at which the victims were at their closest in space and time](image)

4.5 CONCLUSION AND POSSIBLE CRITICISMS

As human beings, we are, on the one hand, interwoven with the environment and processes that make up the world and, on the other, we step out of this unity to observe, experience, reflect on, and choose between possible ways of being in the world (Holt-Jensen 1999). Although time geography offers a novel approach to cartographically representing being
in the world, it has a number of possible shortcomings which become relevant when considering how it might be applied in a crime mapping context. A possible criticism of the time-geographic approach is that it fails to include an explicit representation of the motivation for individual movements (in our case offender and victim movements). However, an implicit explanation, such as the concept of offender awareness spaces as described by Brantingham and Brantingham (1991), correlates well with a consideration that current activities are directed towards the future and informed by the past (Heidegger 1927). For example a serial pickpocket develops awareness of which street corners, or corridors, are likely to increase his chances of being successful in carrying out his crime.

The frictionless surface approach is a limitation shared with contemporary geographic profiling applications, which rely on modeling offender travel behaviors with conventional straight-line (Euclidean) distance (Kent et al. 2006). This is a noted limitation for analysis, because practically speaking the urban mosaic such as streets and structures does not allow for this type of unimpeded movement. And significant work as been done towards situating spatial analysis within transportation networks (Downs & Horner 2007). However, with a well chosen maximum velocity, in certain map contexts, this limitation may be inconsequential. The presumption of a uniform travel velocity across space and time, in time geography, has recently been relaxed by Miller and Bridwell (2009) who utilize velocity fields to represent continuously varying velocities. This is an important contribution to time geography because crime events do not necessarily occur evenly across space and time.

Finally, a possible criticism of the time-geographic approach is its use of the z-axis for the variable of time. Because the third axis, z, is utilized to represent time, it is no longer available to represent geographic relief (Abdul-Rahman & Pilouk 2008). This would become increasingly relevant where geographic relief were needed in a representation of crime such as a mountainous area. However, this shortcoming may not be relevant for most crime mapping applications, which are often at the scale of street-level mapping.
CHAPTER 5

USABILITY TESTING OF TIME-GEOGRAPHIC MAPS

5.1 INTRODUCTION

Both time-geographic and crime mapping methods have been the subject of usability testing. Snook et al. (2007) and Paulsen (2006) have carried out map usability testing with police officers asking them to mark an ‘X’ on the map where they thought that a serial burglar lived based on a 2D crime map pattern. The Snook et al. (2007) test was based on research showing that people use simple cognitive heuristics, or mechanisms that allow decisions to be arrived at quickly and with little mental effort (Gigerenzer & Todd 1999). Kristensson et al. (2008) carried out testing comparing baseline 2D maps with 3D space-time cube maps. The Kristensson et al. (2008) test was conducted with an audience of novice users with the purpose of verifying the visual utility of the space-time cube. This dissertation combines the objectives of these two tests, assessing the usability of 3D space-time cube maps for representing crime patterns, and thereby testing the utility of the time-geographic framework for use exploring crime events that occur at unknown points in space and time. To this end this chapter discusses the usability test design, interview process, and results directed towards the research objective of assessing the practicality of using time geography within a crime mapping context.

5.2 OBJECTIVES GUIDING TEST DESIGN

This section discusses the objectives guiding the usability test design. The key objectives guiding the usability test design were adapted from Gatalsky et al. (2004):

1. Learnability: Assess the user’s ability to understand time-geographic tools and learn how to use them.

2. Applicability: Assess the level to which the visual tools of time geography can be used in a specific application of crime mapping. Specifically, this objective seeks to determine the potential utility (usefulness) of the visual tools of time geography for revealing geographic profiles.
3. *Satisfaction*: Assess the level to which the user develops a liking, or sees application for the tools.

A cognitive walkthrough processes was used as a means for assessing the usability of a visual time-geographic approach to crime mapping. Cognitive walkthrough is a usability inspection method that evaluates the design of a user interface for its ease of exploratory learning where the user has set goals, performs actions, and evaluates feedback (Polson et al. 1992). The methodology of a cognitive walkthrough was relevant to the test design because it is used to evaluate the ease with which users can perform a task with little or no formal instruction (Polson et al. 1992). In this sense the usability test participants could be considered domain specialists, individuals who have knowledge about the data and have both the motivation and qualifications to do proper interpretation of the analysis (Koua & Kraak 2004).

A key assumption about the participants was that they had familiarity or training in crime mapping techniques, particularly geographic profiling or crime pattern recognition. With this assumption the more novel tools of time geography were introduced and tested for usability within a particular scenario context. All of the participants agreed to have the interviews recorded for transcription. A cooperation fee of $100, which is appropriate for professionals (Denzin & Lincoln 1998), was used for recruiting. The one-on-one interviews conducted as cognitive walkthroughs provided qualitative depth by allowing interviewees to talk about the subject in terms of their own frames of reference.

Two groups of participants were defined as:

- **Crime mapping practitioners**: Most of the practitioners interviewed were crime analysts who work for, or consult to, police departments. The crime analyst is positioned at the intersection of street-level police work and back-office spatial analysis. Crime analysts frequently use maps to uncover hotspots, criminal networks, flows and investigative leads. Participants in this category are traditionally focused on 2D mapping for practical application and have likely had little to no exposure to alternative methods of cartography (e.g. spatio-temporal representations). Individual law enforcement agencies were contacted to set up interviews with their practicing crime analyst, and additional analysts were interviewed at the 2009 joint meeting of The International Association of Crime Analysts and the Arizona Association of Crime Analysts.
• *Crime mapping researchers*: The other group of participants had a specific research interest in crime mapping, the application of GIScience to crime mapping, and knowledge of geographic profiling methods. Participants in this category were more focused on theoretical applications and likely had previously been exposed to alternative methods of cartography and spatial analysis (e.g. spatio-temporal representations). These individuals were selected based on a review of publications and curriculum vitae. The primary source of interviews in this category came from the 2010 meeting of the American Association of Geographers.

Nine crime mapping researchers and ten practicing crime mapping analysts were interviewed from 2009-2010. The participants were selected based on their familiarity with commonly practiced crime mapping methods and research. Therefore, the participants can be categorized as advanced GIS users and domain experts. Each interview lasted approximately 45 minutes. A principle evaluation metric of the usability test was whether the participant’s answers (specifically with reference to their being able to locate the point at which the two victims’ paths were closest in time and space) became more certain with the addition of time-geographic tools. Also, questions eliciting perceptions of usefulness were included (e.g., even if the respondent could successfully use the map to identify where the victims’ paths intersected in time and space, would this be useful in making decisions regarding allocation of police resources and would this knowledge likely assist in apprehending the offender?). The metric of participant response time or length was not considered because the administration of the questions and tasks were not conducted in a timed manner. Instead, breadth of answer was elicited. Profiles for the participants are provided in APPENDIX I. These profiles are generalized so as to protect the privacy of the participants per the signed consent form. A copy of the verbal consent form is provided in APPENDIX II. Note that the description of the flow of the map usability test process in the consent form varies slightly from the actual implementation of the test because minor changes were made in the map usability test design following Institutional Review Board approval.
5.3 USABILITY INTERVIEW PROCESS

The usability interview process consisted of a pretest briefing and the actual interview. At each session, the participant was presented with the crime scenario described in chapter four where incidents of pickpocketing were occurring while victims were moving through a crowded shopping district.

5.3.1 Pretest Briefing

The pretest briefing was meant to set up the actual interview. See APPENDIX III for a copy of the pretest briefing form that was provided to participants during the interview. At the start of the interview the participant was categorized as a practitioner or researcher. Also, the participant was asked if he or she was familiar with the concepts of geographic profiling or crime pattern recognition. Next the participant was presented with some basic assumptions of the scenario or key facts of the case:

- The maximum velocity for each map is set at 88 ft/min based on a leisurely pace in a crowded shopping district.
- This area is approximately one half of a mile by one half of a mile wide.
- Though this velocity is applied to the victim space-time path, it is also assumed to apply to the offender.
- Therefore, a key assumption for these maps is that all three individuals -- the two victims and the single offender -- are traveling the same maximum velocity.

After the crime scenario and key facts were explained, the participant went through a semi-structured interview process conducted as a cognitive walkthrough. Each user was given a table of two known victim space-time points and a brief explanation of the visual tools of time geography to be utilized. Harrower et al. (2000), in conducting usability studies of cartographic interface tools, noted that novel interfaces may not result in improved performance unless sufficient training is provided in how to use them. For some of the participants, particularly in the practitioner category, the concept of 3D time-geographic maps would be a new concept. Therefore, care was taken in explaining the time-geographic concepts, e.g. space-time cube, space-time path and space-time prism.
5.3.2 Usability Test Protocol

The interview consisted of five map iterations based on the scenario context described in chapter four. Once the pretest briefing was complete each interview commenced with an introduction to the first map. At each interview session participants were presented with a crime scenario (pickpocketing in a crowded shopping district) which assumes a single offender acting on two victims within a given range of time. And while victim space and time paths were known and provided, no offender data was given other than the constraint of velocity. The concepts of time geography were explained at the start and again as they were introduced during the exercise.

With each map iteration the tools of time geography were further incorporated. Participants were asked questions throughout to test their understanding of the tools of time geography based on the visual representation of the map. See APPENDIX IV for a copy of the usability test questionnaire. During each map iteration participants were given both a paper color map and access to the computer-based map (laptop) with Google SketchUp. To structure the process the participants were asked to answer a set of questions and complete a specific task regarding each map as it was introduced.

The first map iteration utilized the 2D Flow Map containing point symbology at the known point locations for each victim along with directional flow arrow symbology indicators between known points (Figure 4.2).

**Question 1:** Can you tell me what is going on in this map?

**Question 2:** At what time do you think the two victims were at their closest?

**Task 1:** Please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

**Follow up question to Task 1:** How or why did you select this area?

**Question 1** in this iteration was designed to acclimatize the participant to the map interface and cognitively connect the content pretest briefing to the map interface. **Question 2** in this iteration was designed as a direct test of usability, but was not answerable by the map alone. **Task 1** in this iteration was meant to test both usability and usefulness.

Next the participant was provided with the Potential Path Area Map containing the potential paths for the victims between known points based on the assumptions of the scenario
(Figure 4.3). At this point the concept of PPA was again briefly explained. The participant was then asked to answer the following questions and complete the following task regarding the map:

**Question 1:** What does this map add to better identify a search strategy for the offender?

**Question 2:** At what time do you think the two victims were at their closest?

**Task 1:** Please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

*Follow up question to Task 1:* How or why did you select this area?

**Question 1** in this iteration was a question meant to illicit the participant’s perceptions of usefulness. **Question 2** in this iteration was a direct test of usability, but was still not answerable by the map alone. **Task 1** and its follow up question were meant as both a test of usability and usefulness. Next the participant was provided the same Potential Path Area Map with only the intersections of the two victims (Figure 4.6). This concept was briefly explained as a filtering, or a further illumination, of a certain aspect of the Potential Path Area Map. The participant was then asked to answer the following questions and complete the following task regarding the map:

**Task 2:** Please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

*Follow up question to Task 2:* How or why did you select this area?

Next the participant was provided the same Space-time Path Map incorporating the two victims’ paths in both space and time (Figure 4.4). The concepts of space-time paths and space-time cubes were reiterated. Also, the participant was directed to utilize the mouse and interactive features of the 3D map within the computer-based map. The participant was then asked to answer the following questions and complete the following task regarding the map:

**Question 1:** What does this map add to better identify a search strategy for the offender?

**Question 2:** At what time do you think the two victims were at their closest?

**Task 1:** Please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

*Follow up question to Task 1:* How or why did you select this area?
Question 1 in this iteration was a question meant to illicit the participant’s perceptions of usefulness. Question 2 in this iteration was designed as a direct test of usability, and was answerable, with some certainty, by interacting with the map interface. Task 1 and its follow up question in this iteration were meant to test both usability and usefulness.

Next the participant was provided the same Space-time Prism Map incorporating the two victims’ potential paths in both space and time (Figure 4.5). The concept of the space-time prism was reiterated. And again the participant was directed to utilize the mouse and interactive features of the 3D map within the computer-based map. The participant was then asked to answer the following questions and complete the following task regarding the map:

**Question 1:** What does this map add to better identify a search strategy for the offender?
**Question 2:** At what time do you think the two victims were at their closest?
**Task 1:** Please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

*Follow up question to Task 1:* How or why did you select this area?

Finally, the participant was asked an open ended question meant to assess satisfaction and potential utility (usefulness) of the tools of time geography:

**Final Question:** Are these types of tools practical in your job or research?

During this interview there were five map iterations, and with each map iteration the participant was asked to develop a search strategy to reveal the location of the offender. And though it is impossible to know for sure where the offender carried out the crime, a search strategy, it was explained, in this case represented a hypothesis of where the offender’s bases of operations are. To assist the participants when developing their search strategies, verbal cues
were given throughout that would assist the participant in connecting the exercise with practical
decision making that occurs when one is attempting to thwart or catch offenders, such as
selecting a location for police patrols or installation of security cameras. Thus each participant
generated five different search strategies, by circling areas on the map with each subsequent
search strategy being supplemented by utilization of the tools of time geography.

5.4 USABILITY RESULTS

5.4.1 Developing the Search Strategy
The time-geographic tools provided an ability to represent individual contextual factors
such as the victim speed constraints, while the street map itself represented environmental and
place-based context such as street layout and building locations. What could not be represented
by the maps was the unknown which was in this case the actual location of the crimes and the
offender. Conceptually this translates into two elements of the crime triangle being missing.
Therefore, it was left to the map user (interviewee) to draw conclusions about the unknown
(offender data) from the known (victim data). To frame the question in crime mapping
terminology participants were asked to develop a search strategy for a single offender by circling
an area on the map. Often the participants wanted to select multiple areas but they were
encouraged to try to limit their selection to a single best search strategy area. Equally relevant
were the reasons cited for making their search strategy selections. It is interesting to note that
most of the participant selections changed as a new map, and hence an additional time-
geographic tool, was introduced. However some participants felt strongly about their previous
choice and tried to stick as closely as possible to that choice, even when confronted with new
data.
The areas that participants selected have been generalized to areas indicated by capital letters on the map (Figure 5.1). The associated pie chart shows the percentage of participants who selected each area. For the first map, the Flow Map, participants were asked to explain what was going on in the map and then to develop a search strategy for a single offender. This initial question was asked to make sure that participants understood the map since it was the simplest representation used in the series. While most participants relied more on map symbology (the directional arrows) in reaching their conclusions some of the participants focused more on the environmental and situational context to develop their search strategies. For instance, four of the practitioner participants justified their search strategies by noting that a pickpocket would likely frequent a university or market area (areas D, C or E on Figure 5.1). One of these participants stated, “I am looking strongly at the built areas and the influence on the likelihood of the crime. For example the market area is likely to have a lot of opportunities for distraction.” However, as can be noted from the majority of participants selecting area A, the location where the two victims’ paths crossed was picked by a majority of participants (63%).

With the introduction of the PPAs to the map, participants became less certain that the area where the two victims’ paths crossed (area A) was the best place for a search strategy,
although it remained the predominant choice (Figure 5.2). Again, several of the participants, in particular those who were practitioners, cited environmental factors in selecting their search strategy. One participant, calling the PPA intersections “convergences,” commented, “Given the area of convergence I am thinking that [around] the Galleria area that is open and the offender could have had more opportunity. The offender could see more about where the victims were coming and going.” This trend might best be explained by specific knowledge gained from experience of seeing how crime is actually carried out within context. This same participant went on to comment about the limited way in which time was represented on this map: “Time and space are important in geographic profiling to locate the most likely area at which the victim and offender will meet with an opportunity. But, I don’t see time here as of yet.” The participant is correct to note that time had not yet been explicitly represented in the map. However, the PPAs themselves were explained as being based on the speed of travel and amount of time between two known points. The introduction of PPAs definitely gave the participants more to consider in developing their search strategies. Another participant noted that the PPAs told him more about where the victims might have spent time in a common area, or near each other. And, another participant commented “…the narrower the PPA there is likely to have been a choke point forcing them into a likely crowded area and increasing vulnerability to pick pocketing.”
One of the challenges with visually analyzing the PPA map is in discerning the different PPA intersections. One participant replied that he reached his [or her] search strategy choice “…by looking at the intersecting circles.” But he followed up this answer with, “Actually there are bunches of intersecting PPAs so this does get a little confusing. I was influenced by the original intersection [when I was viewing the Flow Map] but now I am reconsidering. Along the edges the offender would be able to isolate the victims. If I was going to allocate foot patrol officers I would consider that they get bored very easily patrolling in a small area. I would choose a larger area of intersection.” And another participant remarked, “I am still most certain about the crossing paths (area A) but with the intersecting PPAs. Also, I am considering this road [La Rambla] and am assuming it is a busy road with a lot of traffic.” These quotations reveal a desire to supplement incomplete (or, perhaps, confusingly presented) time-geographic information with contextual data.

Anticipating the challenge of discerning the different PPA intersections the next map iteration removed all of the PPA information except for the intersections. This map drew the
participants’ attention more toward the areas of densest PPA intersection such as areas A and E. Area E definitely seems to have the tightest intersections and some participants noted this. One participant remarked, “The areas with the tighter intersections (smaller) also become an area of interest.” But still other participants felt strongly persuaded by their original line of reasoning, with one saying “…with this one it is still close to the market but the intersections move me a little bit.”

![Figure 5.3: The search strategy areas selected by participants from the potential path area intersections map](image)

The next iteration, along with the addition of 3D, introduced explicit time data that had been noticeably missing from the previous maps (as one participant noted during the previous iteration, “If I knew a range of times then I could rule out places where they were too far apart”), and it was anticipated that this new data might lead to a radical shift in participants’ search strategies. Because of the addition of 3D, at this point participants were encouraged to interact with the map via the computer mouse. Now the participants were using the interactive tools of orbit, pan and zoom to visually inspect the space-time paths.
The addition of time onto the map interface was a new concept to some participants. One practitioner participant noted “This is interesting! I am not used to seeing time in a map in this way. What I am used to is time as a bar chart or histogram that accompanies the map. This is quite different!” The resulting search strategies coming out of the introduction of the space-time paths drew some participants more towards area C. Likely more influential at this area than the gallery is the fact that participants were attempting to see the location on the ground (the 2D map) where the space-time paths appeared to be at their closest. Most participants did this by orbiting to a top-view of the map and attempting to see where the two space-time paths were at their closest. This was in fact area C, and indicates positive usability of the space-time paths.
With the final map iteration, the *Space-Time Prism Map*, participants were offered a chance to select a new search strategy. And while some participants were not swayed from their previous selections the plurality of participants (42%) selected Area B, which had rarely been selected on any of the previous four maps. As it turns out, Area B is the location at which the two victims were at their closest in space and time. Though some expressed a challenge in doing so, participants who selected this area did so by orbiting the map to realize the area where the prisms intersected on the ground (the 2D map). And so, based solely on the metric of distance and known information, the correct area was found by 42% of the participants (in contrast with the original, more conventional flow map which led to a correct choice by only 5% of the participants). One practitioner participant in selecting Area B noted, “It looks like this is where the two cones are closest together,” demonstrating an awareness of the concepts embodied in the space-time prism map as well as an ability to read it as a visualization.

However some participants expressed frustration with this maps usability and usefulness. One participant noted, “This is difficult for a layperson to utilize these tools.” Additionally, some participants noted a particular challenge of cognitively connecting the prisms to the 2D map.
One practitioner participant noted while panning and orbiting that he was interested particularly in the area of intersection of the prisms “… but I don’t know how to show it on the map. It is difficult to get from the space-time prism to the map. The victimized area should be in the vicinity of the intersection of the prism.” Still another research participant, with professional background in emergency management, clearly stated that he felt the 3D environment was too complex for mapping crime events saying, “I feel like a 2D environment would be more efficient. When looking at a crime event you have to act rapidly and this is too complex for that. The 2D could depict the same if you labeled the time at the points.”

Finally, some participants, particularly those focusing on environmental context, continued with a search strategy area near the market areas or what they perceived to be busy thoroughfares. These participants seemed to be drawing on their experience or knowledge about crime. As one participant noted regarding his search strategy selection, “An offender operates in a place where he can victimize someone as they are leaving the shopping area. The offender can then move on the next potential victim. You don’t want all of the victims coming together at once.” The reality is that even with the constraint of similar velocity to the victims the offender’s potential paths could have overlapped the victims’ in many different areas. Therefore, a single correct answer to the best search strategy was not really possible. And it was very informative from both a crime mapping and time-geographic perspective to hear the researcher and practitioner participants’ feedback regarding what they thought was the best search strategy.

5.4.2 An Explicit Test of Time Geography

During the usability interviews participants were shown first a space-time path map and then a space-time prism map. Participants were then tasked with locating the time at which two victims, represented in the maps, were at their closest. With the addition of the space-time prism, participants should have been able to conclude an answer in the range of 12:25 and 12:30. During this iteration participants were encouraged to interact with the map through the available tools (e.g. pan, orbit and zoom) which was required to answer this question with certainty through visual inspection. This certainty would come only from visual inspection of the only intersection of the two space-time paths by the two represented victims (Figure 5.6).
And while some participants answered by selecting a certain narrow time range, others selected a wider range signifying the uncertainty of their answers (Figure 5.7). The results in Figure 5.7 illustrate a notable difference between the researchers and the practitioners with regard to perspective usability of the space-time prisms to tell the time at which the two victims were at their closest.
Any selected time between the 12:25 and 12:30 range indicates a correct reading, and positive usability, of the space-time prisms. Any selected time outside of the 12:25 and 12:30 range indicates a lack of usability. This usability was dependent, of course, on the user’s ability to utilize the space-time prism as a tool. Six of the nine researchers (66%) found the space-time prism to be useful for locating the time at which the two victims were at their closest. However, only two of the ten practitioners (20%) found the space-time prism to be useful for locating the time at which the two victims were at their closest. The standard deviation for the practitioners was 7.061 compared to the researchers’ 5.617 (denoted by lower case Greek letter sigma, σ). This difference in results may be accounted for by the fact that researchers were more likely to have been exposed to alternative methods of mapping (e.g. 3D maps). Practitioners were more likely to have only been exposed to mainstream commercial GIS products and process. One practitioner interviewed at a large metropolitan police department remarked when introduced to space-time paths and prisms that “this is something quite different than we are used to… we are point people.” On further clarification the practitioner explained that it is the standard on her police department’s crime mapping team to represent crimes primarily as dots on a map and that time-geographic crime maps were a novel idea.

5.4.3 The Influence of Paths That Cross In Space (but Not Necessarily Time)

During each map iteration the participants were asked the question “At what time do you think the two victims were at their closest?” For the first two maps, the 2D Flow Map and the Potential Path Area Map, the question was not answerable based solely on the visual information represented on the map. However, this question was asked in order to gauge the participants’ understanding of the map area and to see their thought process as it relates to incorporating temporal questions into the map. During the asking of this question the participants were given a hint that the question was not answerable by emphasizing that their assessment should be made using “the visual information presented in this map.” Absent from the Flow Map were any time labels. In retrospect the addition of time labels into the 2D maps might have been useful. However, they were left out because the temporal axis had not yet been introduced. Nonetheless, an interesting result of this question was that most of the participants were drawn early on to the intersection of the 2D paths from the Flow Map as their choice of the area where the two victims were at their closest regardless of the fact that they had no data to
support this conclusion (Figure 5.8). One participant on introduction to the Flow Map remarked with certainty about where the victims were at their closest, “I would say where they crossed paths!”

Upon further consideration, and as the interviews progressed, most participants realized that they could not conclude with certainty, from the 2D maps, that the victims were at the closest at the 2D intersection. One practitioner participant noted, “At a glance you can’t tell what time they were at their closest. Intuitively I want to say they were moving from different start points moving at the same speed, but you can’t really tell for sure.” Though the questions were asked with the map as the focus the participants still had access to the tabular data from the pretest briefing which was the known victim space-time point data. And some participants referred back to this data but noted that it would take some time to analyze it and determine at where the two victims were at their closest based solely on the 2D maps.

5.5 CONCLUSION

A key factor in testing the usability of the maps within this dissertation is the determination of whether the 3D time-geographic approach can reveal patterns where traditional 2D GIS methods usually cannot. To this end it seems natural to correlate the goals of geographic visualization with that of geographic profiling. MacEachren (2001) describes geographic
visualization as the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions, and construct knowledge. This description correlates well with the goal of geographic profiling as a criminal investigative technique that attempts to provide information on the likely “base of operations,” or offender residence, of offenders thought to be committing serial crimes (Harries 1999; Rossmo 2000; Rich & Shively 2004). It seemed appropriate, then, to consider the use of geographic visualization techniques to reveal geographic profiles.

The results of the usability studies conducted in this chapter have revealed certain potential benefits and challenges for the application of time-geographic tools. The implications of these results can be contrasted with previous results from similar usability inspection projects. There is an ongoing debate as to whether current geographic profiling software is practically useful for locating offenders (Paulsen 2006; Rossmo 2000). This debate, in turn, led Snook et al. (2007) in their research considering whether heuristics were viable alternatives to the complex actuarial strategy being implemented by geographic profiling software (e.g. CrimeStat, Rigel and Dragnet). This approach hypothesized that with appropriate training police investigators could be as accurate in their predictions as actuarial driven computer predictions of crime areas. Utilizing an experimental scenario, this research compared the predictive accuracy of a trained participant group to a comparison group of untrained participants, an actuarial geographic profiling system, or both (Snook et al. 2007). Their results showed that the human predictions, with training, were equally accurate to the results of the geographic profiling software. Paulsen (2006) conducting similar research found that human judges did on average as well as the algorithm-based methods.

The research conducted in this dissertation relied on a heuristic method similar to Snook et al. (2007) and Paulsen (2006). However, the focus of the usability testing in this dissertation was on the potential usability of time-geographic tools and not necessarily on the accuracy of the predictions. This assessment placed the usability of time-geographic methods within the context of crime mapping methods (particularly geographic profiling). Kristensson et al. (2008), conducting assessment more generally on the usability of the space-time cube, showed that space-time cube representation resulted in more errors in novice users answering simple questions such as “Are two persons in the same place at 9:00?” This finding is consistent with the results of the usability test conducted in this dissertation where practitioners experienced a
higher error rate with similar questions (Figure 5.7). However, Kristensson et al. (2008) did find that the space-time cube is advantageous in conveying complex spatiotemporal data to users. And this finding is seemingly consistent with the results of the usability test conducted in this dissertation where participants’ answers became more focused with the addition of the time-geographic tools (Figure 5.5). In short, this study reveals mixed results regarding the overall usability of time-geographic maps for crime mapping, a point that is explored further in the concluding chapter.
CHAPTER 6

LESSONS LEARNED, IMPLICATIONS, AND FUTURE WORK

6.1 LESSONS LEARNED

Chapter five specifically discussed measurable results from the usability interviews. Although usability challenges were uncovered, the overall results indicated that time-geographic tools such as the space-time prism do provide some value to map users. Additionally feedback from participants informed on ways in which to improve, or make more usable, time-geographic maps.

6.1.1 The Visual/Cognitive Complexity of Time-Geographic Maps

As mentioned, feedback from participants during the interviews indicated some level of usability challenges with time-geographic tools. Putting the actual design of the maps aside for a moment (e.g. color or other specific interface issues), it is useful to consider where participants were challenged with using time-geographic maps. A focus on these challenges may indicate, in part, why time geography has seen so little adoption in mainstream GIS applications to date. As the map usability interviews revealed, map user cognition was challenged by the visual complexity of time-geographic tools.

While the results are geometric graphical map symbols, a fair amount of mathematics goes into actually constructing time-geographic tools and as such the meaning of a time-geographic symbol is not necessarily apparent to the untrained (or even semi-trained) user. In the usability tests undertaken for this study this was especially apparent in the case of PPAs, whose meanings were not intuitive to all map users. When the map interview participants were introduced to the PPAs most of them did want to focus on the areas of intersection between PPAs, indicating that most understood the concept of potential paths and how they might be used. However, some participants who understood the conceptual meaning of PPAs and how they could be used to implement a search strategy nonetheless indicated visual challenges when actually applying the tool. One participant remarked, “I don’t see any other obvious areas where they were in the same spot. The circles are too busy!” Further answers (search strategy selections) varied greatly between when participants were shown the PPA maps with and without the intersections highlighted. This variance in search strategy selections indicated that
participants had a difficult time with the complexity of the Potential Path Area Map, which illustrated many areas of PPA intersection between the two mapped paths.

6.1.2 Possible Alternative Approaches to Space-Time Mapping

The map scenario in this dissertation was purposefully simple so as to focus specifically on the usability and usefulness of time geography within a specific context. Alternative visualization approaches were possible and could have proven to be more usable, especially for depicting a more complex scenario.

Consider first a case where there would be significantly more than two victim space-time paths represented on the map. With only two space-time paths the map may have been readable, but if we were to include fifty space-time paths the map interface would quickly become visually complex, and therefore highly unusable or useful. One obvious approach to solving this problem would be to include some level of filtering, such the temporal brushing method used by Harrower et al. (2000) and discussed in section 2.4.1 of this dissertation. This filtering would require a map interaction approach such as the one described by Ahlberg, Williamson & Schneiderman (1992), where map users can easily reduce visual complexity by specific query. Another possible approach when faced with a more robust data set would be to use some level of aggregation as proposed by Andrienko, Andrienko, & Gatalsky (2002). By aggregating space time points into proportional symbols we could reduce the visual complexity of the map interface. A map of this type moves from being micro-geographic to macro-geographic but still makes use of the time-geographic framework. This type of aggregated map would also be useful where we are interested in seeing space-time point clusters, and not so interested in particular path information.

Finally, the map scenario in this dissertation did not consider the street network (e.g. La Rambla) and instead relied on straight-line, Euclidean, distances between known space-time points. However, an even more applied, and contextual map would consider the possible network segments that would constrain mobility and how that would influence the construction of time-geographic tools. For instance, Kent et al. (2006) evaluated the usefulness of applying functional distance measures to criminal geographic profiles using mathematically calibrated distance decay models. These models compared Euclidean and non-Euclidean methods and found that non-Euclidean performed better when input into popular geographic profiling software packages. Relating this back to the map usability interviews, a few of the participants
noted difficulty, or perceived limitations with the Euclidean approach. For instance, one practitioner remarked, “It looks as if the victims walked through the buildings!” And, another participant noted, “This is probably not exactly how people behave.” Therefore, as suggested by Miller & Han (2001), an approach that utilizes the transportation network in creating the space-time paths could prove more functional.

Finally, map usability participants’ feedback suggests alternative visualization methods that might have enhanced the map scenario time-geographic tools. For instance two participants noted that it would be quite useful to have a number, or statistic, associated with the volumes of the space-time prisms. With this number, as was noted by one practitioner participant, pattern of risk surface could be developed. This same participant added, “If the space and time area could be weighted by what the victims have reported, then both a spatial and temporal surface that had values associated with it would be quite useful.”

6.1.3 Improving the Design of Time-Geographic Maps

Another product of the interviews was feedback on possible ways to improve the design of time-geographic maps. As there are not many mainstream GIS products utilizing time-geographic mapping, the maps in this dissertation were modeled largely on the maps depicted in the literature. For example, in order to fit mainstream ESRI software to the time-geographic framework, Yu (2006) had to program an extension with Visual Basic. Still most of the literature on time geography has been theoretical and focused on how time-geographic tools might be used. A study of the kind conducted in this dissertation placed time-geographic maps in a certain context eliciting specific feedback as to their usability.

The primary area of focus coming out of the map usability interviews related to improving the visual association of items depicted in space-time with those depicted on the base 2D map. For instance although their colors were the same, it was not readily apparent to most participants that the PPAs were simply projections of space-time prisms. Further, some users noted difficulty in associating the space-time paths with the 2D flow paths on the base 2D map. What this seems to indicate is a broader challenge with 3D mapping as a tool for visual cartographic exploration. Additionally, non-transparency of the 3D map elements such as the prisms presented challenges because they obstructed views as participants attempted to pan to the top view and look down onto the base 2D map. A couple of participants also suggested utilizing a line (or dashed line) to connect the points along the space-time paths back down to the
flow paths. All of these suggestions are helpful and could assist in designing improved time-geographic and 3D maps in general.

Current and ongoing research into how to best build usable geovisualization tools should continue to improve time-geographic map design. And time-geographic maps have the potential to fit Slocum et al. ’s (2005) definition of cartographic visualization being a method of data exploration in which unknowns are revealed in a highly interactive environment. However, considerations of both the practicality and the importance of context reveal future areas for research on the time-geographic approach. The cognitive walkthroughs were primarily directed to inquiring about the maps’ usability, and usefulness issues – whether the maps would help to guide police practice even if the user was successfully able to infer the likely meeting point of victims’ space-time paths – were considered only secondarily. However, the numerous times in which participants (especially practitioners) ignored the space-time data in favor of contextual factors when designating their search area suggests that issues of usefulness as well as usability need to be considered up front if the time-geographic approach is to add value to application areas such as crime mapping.

Finally, given that certain map users focus on context over metrical time-geographic tools, the maps could have been designed differently. For instance, using English language map labels instead of Catalan and delineating market areas or crowd density would have ensured that all users had equivalent contextual information, and this, in turn, could have been used to measure how different users balanced contextual with time-geographic information.

6.2 RESEARCH IMPLICATIONS

6.2.1 The Usefulness of Time Geography
Prior to participating in the map usability study nearly all of the participants had likely never considered utilizing time-geographic tools for crime mapping. Therefore, an important outcome of the map usability study was feedback as to whether, after going through the scenario, the participants saw the tools of time geography as practical and useful within their respective practice or research. And, although the responses varied, most participants felt that time-geographic maps were useful. However some participants felt that only certain parts of the time geography framework would be useful.
When asked if they felt that utilizing time-geographic tools would be practical in their work, one researcher participant responded, “I think so, particularly if you could animate it you could use it to locate places best suited for surveillance methods such as cameras. Space-time paths would have practical application where they do canine tracking. You could combine this with crime density to see where you defuse the crime. Fascinating stuff here!” A practitioner participant responded, “This is practical for the crime analyst. But, if you were to bring this to a police briefing and give it to a law enforcement officer you could easily lose them. But, for the analysts in a case where space, time and geography are important this could be very useful. I recommend that this type of analysis would be particularly useful in a sexual predator case where there are lots of clues.”

Research implications coming out of the map usability study were encouraging for the future of time-geographic maps and the outlook for innovation in crime mapping methods. On the question of whether the tools of time geography assisted in exploring spaces of crime where mobility presents challenges, the answer appears to be “yes”. And since this type of mapping has potential to be useful in mapping crime types where some portion of the crime triangle is missing, alternative crime types could be considered. For instance, crimes such as internet-based fraud present nuanced challenges to crime mapping where one part of the crime triangle, the opportunity, is typically classified as a “virtual” concept that provides little guidance as one attempts to map the crime’s location in time and space. These types of crimes, which occur through communication modes, can be carried out where the victim and offender meet at the same time, synchronously, or at different times, asynchronously (Janelle 1995; Miller 2005b). And even if synchronous communication-based crimes reveal temporal factors surrounding the opportunity for crime, spatial factors become all but impossible to map. Therefore, absent any clues which can be associated with an offender or opportunity space, we are left with only victim space-time data. And victim space-time factors may, or may not, offer insight for the investigatory process depending on the context within which the crime takes place.

It should be noted that the results of the usability studies conducted in this dissertation were largely qualitative. This methodology favored a breadth of response over a quantity of response. This was done in order to put time geography into a particular context, crime mapping. Still, alternative approaches to assessing the usability of time-geographic methods could have yielded differing results. For example a control group of unskilled participants could have been
utilized to benchmark the domain expert results of the usability studies. Or the study could have been designed to attract a larger sample size, with maps distributed by means of a web-based survey. With a larger sample size, one could have applied tests of statistical significance to differences in responses to various maps, and between practitioner, researcher, and lay-person user groups, although some of the rich data from comments made by participants as they worked their way through the maps would have been lost in the process.

6.2.2 The Enduring Importance of (Spatial) Context
Pred (1984) argued for time geography as a contextual and not compositional approach. However, it is not clear from the early literature of Hägerstand (1970) and even more contemporary time geography scholars whether the context dilemma has been solved. By including the variable of time explicitly within the map space, time geography does add certain contextual factors as it maps elements of human activity spaces that typically are absent in mapping. And the construction of the time-geographic tools is informed by context through the application of constraints. Additionally, recent efforts to account for such factors as varying velocities between known space-time points are adding to the potential ways in which time-geographic tools can be applied (Miller & Bridwell 2009). Still, despite the innovate approach of time geography to the process of map design, the technique remains vulnerable to the pitfalls of generalization that are faced by all forms of cartographic representation. This generalization is required because all maps are smaller (and necessarily less complex) than the realities they represent (Monmonier 1996).

While many participants in the usability study conducted in this dissertation found the tools of time geography (e.g. the space-time prisms) to be usable in map reading, others (primarily in the practitioner group) found them less useful and preferred to focus on environmental context factors such as nearness to market areas. These participants felt that context was an equally or more important consideration in selecting their search strategies than the metrical distances that could be calculated between two victims’ space-time paths. For instance, one practitioner participant noted that it would be helpful to see how many other people (non-victims) were there. The importance of the difference between seeing movement as an abstract mathematical phenomenon and seeing it as an embodied practice performed by environment-interpreting agents was not lost on these participants.
The enduring importance of spatial context leads us back to Lynch’s (1960) focus on the influence of (city) form and cognition on human activity. Arguably the participants in the map usability study who focused on context (e.g. the market as a site conducive to pickpocketing activity) over metrical space (e.g. the point in time and space at which the victims were at their closest) were influenced more by their perceptions of urban form. People’s perceptions of space, and in turn, their behavior therein, are strongly influenced by their mental images of what different localities mean to them (Lynch 1960; Buttimer 1980; Cosgrove 1984). Some participants expressed a strong interest in what they perceived as particular spatial contexts that were relevant to a pattern of crime. And the influence of urban form on patterns of crime is clearly communicated in the Brantinghams’ theory of environmental criminology. This only serves to reinforce the declaration that any map is always a representation, and not reality itself, for a map can never capture the cognitive feedback loop between perception and practice (Del Casino & Hanna 2005; Kitchin & Dodge 2007).

6.3 CONCLUSION AND FUTURE RESEARCH AGENDA

The existing time-geographic literature features a wide range of potential application areas, from tracking grizzly bears (Baer & Butler 2000) to exploring the spatial patterns of women’s everyday lives (Kwan & Lee 2000). A commonality among the potential application areas proposed for the time geography framework is the factor of movement. Time is a constant, and representing space without it is problematic. But, the challenge has always been how best to incorporate time along with space. The application of time-geographic tools to crimes and, in particular, crime types where mobility plays an inherent role seems well suited to the time-geographic approach. The scenario used in this dissertation was purposefully made simple. A future research project then would be to obtain real case data, such as mobile phone data. This type of case should be illustrative of a spatially complex crime where mobility plays a key role. Then the application of the time-geographic tools to analysis of that crime could be used (potentially by algorithm) to reveal an optimal search strategy.

Because of the nature of the type of data required (space-time points) by the time-geographic approach, considerations of misuse/misrepresentation and privacy should always be addressed. As discussed in chapter two of this dissertation, crime data is socially produced and collected. Accordingly, it should be noted that maps and their representation are socially produced. Monmonier’s (1991) somewhat tongue-in-cheek book *How to Lie with Maps* lists
ways for polishing the cartographic image including such suggestions as to generalize creatively and frame strategically. Along with blatant misrepresentation of geographic data, Monmonier (1991) posits the unintentional, embedded or subconscious misrepresentations that occur and can have serious consequences for those being misrepresented. Here we can take a lesson from postmodern thinkers who point out that every representation (map) is a discourse. A map has a subject and an object. Geographer Denis Wood explains that a map lacking a subject would be like that of an empty mirror. A map, he explains, is always of something, always has a subject, even when that something is a fiction alive exclusively in the map that is of it. Wood (1992) concludes, “Of something (its subject), it is also through someone (its author), for its presence in the world is ever a function of the representing mind, and as such, it needs repeating, prey to all the liabilities (and assets) of human perception, cognition and behavior” (p. 24).

Finally, the research conducted in this dissertation revealed some of the ways in which academic theory may, and may not, always translate into practice. Geographic information systems and science can greatly inform practical applications such as crime mapping. It is a worthwhile goal to develop theories and always be motivated in discovering whether those theories are practicable in application. As a researcher I would like to continue to discover ways in which novel approaches to map representation can be applied in solving societal issues. The technologies, methods, and theories of GIS and GIScience hold great promise for solving many of society’s challenges such as the challenge of mobility in crime mapping. These solutions must be tendered with practicality and considerations of context.
APPENDIX I

PROFILES OF MAP USABILITY PARTICIPANTS

Practitioner 1: A senior management crime analyst within a large metropolitan police department. Also, has a strong military background that complemented this participant’s understanding of how crime is carried out within an urban environment.

Practitioner 2: A senior crime analyst within a moderately sized metropolitan police department. Also, had a strong understanding of how investigative data is managed and analyzed.

Practitioner 3: Manager of crime analysis at a large metropolitan police department. Also, has extensive background in law enforcement operations and crime analysis.

Practitioner 4: Intelligence analyst at a large metropolitan police department. Also, has strong statistical background and utilizes this for analyzing crime data.

Practitioner 5: Senior investigator for large international metropolitan police department.

Practitioner 6: Former police officer, in a leadership position, and now a professor of criminology. Also, utilizes background in law enforcement to inform academic research on policing and investigation.

Practitioner 7: Retired crime intelligence analyst at a large metropolitan police department. Much of this participants’ career work preceded modern GIS, but was very spatial in nature.

Practitioner 8: Retired crime intelligence analyst currently instructor of crime analysis. Much of the work done by this participant is related to the development of geographic profiling methods.

Practitioner 9: Retired detective at a large metropolitan police department. Much of this participants’ career work preceded modern GIS, but was very spatial in nature.

Practitioner 10: Police captain at a medium sized metropolitan police department. Much of the work done by this participant draws on a background in crime analysis and administration.

Researcher 1: Professor and researcher in geography and criminal justice. This participant has done extensive research and publication in geographic profiling methods and policing and society.

Researcher 2: Graduate student in Geography (GIS) with a focus on connecting GIS with crime and emergency management. This participant has a professional background in emergency management.

Researcher 3: Professor and researcher in geography and criminal justice. This participant has published and researched extensively on the spatial and temporal aspect of crime and place.
Researcher 4: Researcher in Geography (GIS). This participant has published and researched extensively on the spatial and temporal aspect of crime and place. Also, this participant has a brief background in law enforcement.

Researcher 5: Professor and researcher in geography and crime analysis. This participant has published and researched extensively on the spatial and temporal aspects of crime and place.

Researcher 6: Graduate student in Geography (GIS) with a focus on connecting GIS with crime mapping and geovisualization.

Researcher 7: Researcher in crime mapping and practice. This participant’s work focuses on connecting crime analysis theory with practice.

Researcher 8: International graduate student in Geography (GIS) with a focus on connecting GIS with crime mapping and spatial analysis.

Researcher 9: International graduate student in Geography (GIS) with a focus on connecting GIS with crime mapping and spatial analysis.
APPENDIX II

CONSENT FORM FOR MAP USABILITY PARTICIPANTS

I am recruiting subjects to assess whether a time geographic approach can be used to map crime events that otherwise cannot be represented meaningfully as a single point on a map. The interview will take approximately 30-45 minutes. I am a graduate student under the direction of Professor Dr. Philip Steinberg in the Department of Geography at Florida State University. I am conducting a research study to explore the extent to which cartographic visualizations of activity spaces can reveal locations for unique crime events in which victims and offenders do not converge in space at the incident.

The maps in this dissertation will be built in such a way as to lead the viewer towards a particular search strategy, and this will provide a means for assessing the practical efficacy of various time-geography representation scenarios. The actual offender base of operations, a search area that is predefined, will be unknown to participants. A key indicator of the utility of the maps will be how close the participants actually come to selecting an appropriate search strategy. This type of usability testing has been carried out on geographic profiling software for determining whether or not training assisted in creating a search strategy. Additionally, both structured questions (e.g. on a scale of one to five rate the utility of the map in revealing time of offense of the incident?) and unstructured questions (e.g. how do you think the visualization could be improved?) will be used to solicit feedback specific to the utility of each round for revealing geographic profiles with the tools of time geography. Since the group of participants will be relatively small -- fewer than 50 -- statistical analysis of the results would be inappropriate. However, the outcomes of the structured/unstructured questions will be summarized in a table and categorical format so that the results can be easily concluded.

Interviewees will be recorded by audio recording, note taking and form. The interview materials will be stored, with the researcher (John.D. Morgan), on computer disk recorded audio device. Once the audio has been transcribed the recordings will be erased before the end of the project. Your participation in this study is voluntary. If you choose not to participate or to withdraw from the study at any time, all relevant material will be erased or destroyed at your request. The results of the research may be published, but your name will not be used at your request. At each session, the participant will be presented with three different crime scenarios. The participant will be asked to develop a search strategy to reveal the location of the offender. A search strategy represents a hypothesis of where the offender’s bases of operations are. In attempting to thwart or catch offenders, resources, such as increased police patrols or installation of security cameras, should be directed with a search strategy in mind.

After a crime scenario is explained, the participant will go through a semi-structured interview process. During this interview there will be four map iterations, and, with each iteration, the participant will be asked to develop a search strategy. Thus the participant will generate four different search strategies for each crime scenario with each subsequent search strategy being enhanced by using the tools of time geography. The concepts of time geography will be explained as they are introduced in the exercise. All interviews will be recorded.
The following steps will be conducted for each of the three crime scenarios:

1. Participant is given a copy of a handout containing a 2D map and provided the known details of a crime scenario. If this is a victim space-time path, then the information is a list of activities leading up to the discovery of the incident. If this is an offender space-time path, then the information is a list of known offender anchor points.

2. Participant is given access to an interactive map on a computer that has the ability to zoom, pan and orbit. The map depicts the crime event space. Basic techniques for zooming, panning and orbiting are explained. This map is presented in four iterations as follows:
   i. In the first iteration, the graphical map on screen is a 2D format and matches the provided handout. Points representing the activity/anchor points will be provided on the map. After reviewing this map, the participant will be asked to develop a search strategy.
   ii. In the second iteration, the graphical map on screen is also a 2D format that matches the provided handout, except space paths are displayed. The paths are color coded and displayed as lines indicating the movement between activity/anchor points. After reviewing this map, the participant will be asked to develop a search strategy and to compare that search strategy with the one that (s)he had developed based on the previous map.
   iii. In the third iteration, the graphical map on screen is a 3D format with the space-time paths provided. This map will contain potential path areas (PPAs) at each node of the space-time path. These paths represent the movement in space and time between activity/anchor points. As discussed in the Theoretical Framework section, 3D maps can challenge user cognition. By providing the map on screen with its interactive features, users are able to better explore and conceptualize the map. Multiple preset view angles (orthogonal view, top view, etc.) and time queries (e.g. 3PM-4PM) of the map will be available along with the ability to zoom, pan and orbit through the map. After reviewing this map, the participant will be asked to develop a search strategy and to compare that search strategy with the one that (s)he had developed based on the previous maps.
   iv. In the fourth iteration, the graphical map on screen is also a 3D format with the space-time prisms provided. This map will contain potential path spaces (PPSs) at each node of the space-time path. Also multiple preset view angles, time and velocity (3 miles per hour) queries of the crime space will be available along with the ability to zoom, pan and orbit through the map. Additionally an animation scene will be used to represent how the events unfold in a time-geographic context (Figure 4). This animation scene will further provide a cognitive grounding of how the tools of time geography are used in explaining these crime spaces. After reviewing this map, the participant will be asked to develop a search strategy and to compare that search strategy with the one that (s)he had developed based on the previous maps.

3. The interview concludes with a number of structured and open-ended questions concerning the participants’ experiences using the various maps, their usability, and the likelihood that they could be helpful in studying crime patterns, whether for investigation or analysis.

This research is being conducted as work towards a doctorial dissertation. To contact the advisor of this research contact Dr. Philip Steinberg at Phone#: (850) 644-8378. If you have any questions for the researcher concerning this study, please call me at (407) 421-2808 or email jdmorgan@fsu.edu

The below will be signed by the interviewee and the interviewer:
Contact the Human Subjects Office for further questions about this project at: 850-644-8633
APPENDIX III

MAP USABILITY PARTICIPANTS PRETEST BREIFNGS SHEET

Scenario description: Incidents of pick pocketing are occurring while victims are moving through a crowded shopping district. The primary mode of movement in this district is walking. Each victim discovers that his/her personal property has been stolen at a certain point during the same shopping episode and is able to recount, or provide information on, known space-time points leading up to the discovery of the crime event.

Key Facts of the Case:
- The maximum velocity for this map is set at 88 ft/min based on a leisurely pace in a crowded shopping district.
- This area is approximately one half of a mile by one half of a mile wide.
- Though this velocity is applied explicitly to the victim space-time path, it implicitly defines the offender space-time path as well.
- Therefore, a key assumption for these maps is that all three individuals, the two victims and the single offender are traveling the same maximum velocity.

### VISUAL TIME GEOGRAPHY TOOLS

1. **Space-time path**: straight lines connecting known space-time points
2. **Space-time prism**: lower cone represents the possible paths, in space-time, of travel from a given starting control point through space and time, while the upper cone represents the same path possibilities, in space-time, approaching the destination control point

<table>
<thead>
<tr>
<th>Space</th>
<th>Time</th>
<th>Minutes Elapsed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Victim 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X Coordinate</td>
<td>Y Coordinate</td>
<td>Date</td>
</tr>
<tr>
<td>1043.0398</td>
<td>563.7279</td>
<td>4/4/2009</td>
</tr>
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<td>335.5850</td>
<td>1268.319</td>
<td>4/4/2009</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4/4/2009</td>
</tr>
<tr>
<td><strong>Victim 2</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3. **Potential path space (PPS):** ellipse created by the intersecting cones, depicts points in space and time that an individual could possibly have reached during a given time period.

4. **Potential path area (PPA):** the 2D projection of the PPS and is defined by velocity and time budgets.

5. **Space-time Cube:** horizontal face of the space-time cube represents the 2D geographic space while the third dimension of time is represented along one of the vertical edges the cube, orthogonal to the 2D geographic space.

A Space-time Cube with Space-Time Paths
Potential Paths (Space-Time Prism)

Space-Time Paths – Meeting In Space

Geographical Space

Meeting (in space)

Time

Geographical Space
INSTITUTIONAL REVIEW BOARD HUMAN SUBJECTS APPROVAL LETTER

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673, FAX (850) 644-4392

Date: 7/8/2010

To: John Morgan [jdmorgan@fsu.edu]

Address: 3611 S. Gardenia Ave. Tampa Fl 33629
Dept.: GEOGRAPHY

From: Thomas L. Jacobson, Chair

Re: Re-approval of Use of Human subjects in Research
Locating Communication-based Crime Events through Cartographic Visualization of Space-time Activities

Your request to continue the research project listed above involving human subjects has been approved by the Human Subjects Committee. If your project has not been completed by 7/7/2011, you are must request renewed approval by the Committee.

If you submitted a proposed consent form with your renewal request, the approved stamped consent form is attached to this re-approval notice. Only the stamped version of the consent form may be used in recruiting of research subjects. You are reminded that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition, federal regulations require that the Principal Investigator promptly report in writing, any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor are reminded of their responsibility for being informed concerning research projects involving human subjects in their department. They are advised to review the protocols as often as necessary to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

Cc: []
HSC No. 2010.4692
APPENDIX V

MAP USABILITY QUESTIONNAIRE

QUALIFYING THE MAP USER:

Map User is crime mapping practitioner or research:

Map user’s familiarity with geographic profiling:

MAP USABILITY INTERVIEW:

Flow Map

Note: Hand out map user cheat-sheet and briefly go over the items. Map user is given access to computer interface, and base map

1. Question: Can you tell me what is going on in this map?

2. Question: at what time do you think the two victims were at their closest?

3. Task: please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

4. Question: how/why did you select this area?

Flow Map with Potential Path Area (PPA)

Note: Briefly explain PPA. Map user is given access to computer interface, and base map

1. Question: What does this map add to better identify a search strategy for the offender?

2. Question: at what time do you think the two victims were at their closest?

3. Task: please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

4. Question: how did you reach this conclusion?

**Map user is given second map with intersections only

5. Task: please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

6. Question: how/why did you select this area?

Space-Time Path Map with PPA

Note: Briefly explain space-time paths. Map user is given brief explanation of the two tool bar sets of Camera and Views.

1. Question: What does this map add to better identify a search strategy for the offender?
2. *Question*: at what time do you think the two victims were at their closest?

3. *Task*: please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

4. *Question*: how/why did you select this area?

**Space-Time Prism Map**

*Note*: Briefly explain space-time prisms. Map user is given brief explanation of the two tool bar sets of Camera and Views.

1. *Question*: What does this map add to better identify a search strategy for the offender?

2. *Question*: at what time do you think the two victims were at their closest?

3. *Task*: please circle the area on the map where you think the pickpocket operated out of based on the visual information provided in this map.

4. *Question*: how/why did you select this area?

5. *Question*: Are these types of tools practical in your job research?
REFERENCES


Bennett, J. Butler, K. and Whiteside, J. Usability Engineering. Tutorial presented at CHI'89 (Austin, TX, May 1, 1989).


BIOGRAPHICAL SKETCH

In 1998 Derek Morgan completed his BA in Economics with a minor in Applied Computer Science, while serving in the US Marine Reserves, at The University of Central Florida. From 1998-2001, while working fulltime as a web developer, he completed his Master’s degree in Management Information Systems, also at The University of Central Florida. He has worked fulltime as a geographic information systems (GIS) web developer, and part-time as an instructor in The Florida State University’s Geography department, while pursuing his doctoral studies.

Derek’s research focuses on how novel approaches to geospatial representation, such as time geography, can be fit to the challenge of exploring and representing dynamic human activity spaces (e.g. the spaces of tourism and crime). The approaches to geospatial representation he is currently interested in finding applications for are time geography, studies of cognitive map usability, and volunteered geographic information (VGI) systems.