Web GIS Tools for Crime Mapping in Toronto

by

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A thesis

presented to the University of Waterloo

in fulfilment of the

thesis requirement for the degree of

Master of Science

in

Geography

Waterloo, Ontario, Canada, 2013

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

The field of crime mapping has an extensive history, yet it has managed to remain an effective tool for policing even in modern times. This success can be attributed in part to the field's willingness to adapt to newer technologies as they have become available. A current trend that is occurring internationally is the practice of online crime mapping. Many police services from around the world have recognized the importance of using the Internet to connect with the public that they serve. To this end, while most police services have an online presence in the form of a Web site, some have opted to go further and to publish their crime data spatially in the form of an interactive Web-based mapping application. Presently, the City of Toronto has opted not to engage in interactive Web mapping and has limited their online publications to only static maps and written crime reports.

This thesis attempts to build upon the capabilities that are offered by Web GIS tools for crime mapping applications in the City of Toronto. To achieve this, two Web applications were developed to help facilitate the process of reporting crime incidents and gang-related graffiti. The services in these Web applications were developed using ArcGIS for Desktop 10.1 and hosted using ArcGIS for Server 10.1, while the Web applications themselves were developed using the ArcGIS API for JavaScript. Each application was designed to support interactive incident mapping, as well as anonymous incident reporting. In addition, the Graffiti Tagger application utilized a mobile-themed interface and image attachments to promote on-the-go graffiti incident reporting. By doing this, it was hypothesized that the overall quality and quantity of data contributed to the Toronto Police Service would increase. To test this hypothesis, a survey was developed and released to a number of participants with varying backgrounds and technical skill levels. The results of this survey showed that a public desire did exist for both of these Web applications, along with a willingness from the majority of participants to voluntarily participate in using these applications. These results suggest that adopting the use of Web mapping applications has the potential to increase the quantity, and potentially the quality, of crime data that is reported.

Acknowledgements

First and foremost, I wish to express my sincerest gratitude to my supervisor, Dr. Su-Yin Tan, for her constant support throughout this entire process. Her endless support helped me to continue moving forward, even when the end seemed so far away. Without her commitment and conviction, this thesis would not exist today.

Secondly, a large amount of thanks goes out to Scott MacFarlane, James McCarthyand the staff at Mapping, Analysis, and Design for their assistance over the years. Scott went above and beyond by spending countless hours working with me to customize the VM and services that were used in this thesis. Without Scott's help, I would not have been able to develop and deploy the applications that were used in this thesis.

I would also like to thank Robert Feick, Jean Andrey and Peter Deadman for volunteering their time and services to be a part of my defence committee.

Finally, I wish to thank all of my friends and family who provided me with so much support and motivation along the way.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AGO	ArcGIS Online
API	Application Programming Interface
CDB	(Toronto) Crimes Database
DB	Database
DBMS	Database Management System
DIJIT	A widget that is based on Dojo
DIV	Division
ECN	Engineering Computer Network
GB	Gigabyte
GDB	Geodatabase
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
IDE	Integrated Development Environment

JS	JavaScript
KML	Keyhold Markup Language
LAN	Local Area Network
MAC	Media Access Control
MAD	Mapping Analysis and Design
MB	Megabyte
OPD	Ogden Police Department
ORE	Office of Research Ethics
OS	Operating System
PDA	Personal Digital Assistant
PDF	Portable Document Format
RAM	Random Access Memory
RDC	Remote Desktop Connection
RTCC	Real Time Crime Center
SDE	Spatial Database Engine
SHP	Shapefile
SQL	Standard Query Language
SSF	Simplified Spatial Format

TOC Table of Contents

TPS Toronto Police Service

UW University of Waterloo

VGI Volunteered Geographic Information

VM Virtual Machine

VPN Virtual Private Network

WFS Web Feature Service

WMS Web Map Service

WRPS Waterloo Regional Police Service

WWW World Wide Web

CHAPTER 1

Introduction

1.1 Introduction

The process of mapping crime has been practiced for hundreds of years. As available technologies continue to improve, so must the techniques we employ to effectively map the distribution of criminal activities. The past decade has seen a measureable increase in the number of people who routinely access the Internet. Approximately 32.8% of the global population in 2011 had access to the Internet. This number was even larger in nations such as Canada, where approximately 82.7% of the population in 2011 had access to the internet (World Bank, 2013). In addition to this trend, the widespread availability of Global Positioning System (GPS)-enabled mobile devices has grown. Today, many people regularly carry smartphones, laptops and tablet computers that allow them to access the Internet wherever they go. As a result of these changes, information can quickly and easily be disseminated from police departments to citizens, allowing citizens to stay informed about criminal activities that are occurring in their local environments. However, the flow of data between police departments and local citizens does not have to be one-way. Web-based mapping applications can be designed to allow citizens to not only view crime incident data, but to actively contribute their own incident reports. By taking advantage of these modern mobile computing devices, citizens can use their GPS-enabled mobile devices to assist in accurate crime incident reporting through an anonymous online system. Data that is contributed can be examined using a Geographic Information System (GIS) and subsequently analyzed to detect trends and patterns.

We are currently in a time of transition where only a limited number of police departments have attempted to integrate these newer technologies into a complete crime reporting system. Although a number of police departments in the United States actively use a Web-based channel to collect and disseminate crime incident information, this trend has yet to catch on with the majority of Canadian police departments. Police departments that choose not to employ modern technologies can be faced with a number of traditional crime incident reporting challenges, such as a lack of citizen participation, inaccurate data, as well as having no effective way of disseminating their spatial results back to the public.

1.1.1 Web GIS

The evolution of Web GIS and Web-based mapping applications has created a new channel for users to create and contribute spatial data. Following the principles of Web 2.0, Web GIS has evolved in such a way as to permit the multi-directional exchange of data. Users of Web GIS applications are not limited to only viewing spatial data, but can also edit existing data or even contribute their own new data. A number of software solutions have been released that allow users to host their spatial data online with the aid of a database management system (DBMS). Once a user's spatial data is available online, the user can develop a Web application, most commonly with the support of a Web API, to assist the end-user in interacting with the spatial data. The adoption of Web GIS in the field of crime mapping could eventually yield beneficial results. A well-developed Web application has the potential to increase the volume of user contributed data, while placing restrictions may help to ensure the quality of the data. In the field of crime mapping, the Web application can also be used to disseminate live crime incident information back to the community, replacing maps and summary tables that are often released only once a month.

1.2 Problem Statement

An issue that many police departments around the world currently face is the underreporting of crime incidents (Oltman, 2011). Victims and witnesses of a crime may not report the incident to the police for a variety of different reasons. Those affected by a crime may be too scared to come forward and to report it, fearing potential retaliation for their actions. Others may feel that certain crimes, such as vandalism or petty theft, are not of a serious enough nature to merit being reported to the police. Others may simply wish not to be associated with a crime, or prefer to avoid going through the hassle of filing a formal police report. As a result of these and other issues, official crime reports only capture a fraction of all criminal activities that actually occur and underreporting of crime remains prevalent (Oltman, 2011).

The field of crime mapping is complex and ever evolving. For generations, police departments have used geography and maps to monitor criminal activity. As newer technologies have become available over time, the ability of police departments to share data externally has also changed, allowing for collaboration between multiple police departments (Chainey, 2005). Many police departments understand the benefits that a GIS can provide and use it internally for tasks such as analyzing crime incident data for trends or hot spots. Some police departments will even use this software to produce static crime incident maps on a scheduled basis. Police departments that do not use a GIS will often report summary statistics for specific time periods. Although highly informative, summary statistic tables provide very little information about the spatial dimension of criminal activities in a community.

As the field of GIS continues to grow, it has in recent years begun to place more importance on bringing spatial data online. Taking advantage of this trend, police departments now have the ability to use this online medium to create a new channel for reporting crime incidents. Creating a Web application that utilizes a Web GIS can offer a cost-effective solution that addresses a number of concerns related to crime reporting. First, Web GIS applications can provide a secure and anonymous environment for reporting crime incidents. As access to the Internet continues to increase in Canada, the web provides a way for police to interact with a wider audience than ever before. Second, interactions can be two-way, with police disseminating updates to the public, while citizens report criminal activities or concerns from their local areas. Third, the interactive and engaging nature of Web GIS applications allows citizens to quickly and easily report crime incidents from an environment in which they feel comfortable. Moreover, the automated and structured nature of Web applications can help to ensure that any new data contains all the information that is required, making the data potentially more accurate and easier to catalog, as well as subsequently freeing up personnel and resources.

The Toronto Police Service (TPS) is the operating police service for the City of Toronto. Presently, the TPS releases static community crime maps for each neighbourhood within the City of Toronto at a schedule of once a month. Although the creation of these static maps supplement their published crime data with an important spatial component, the method that is used for deploying this spatial information can still be greatly improved.

At a small additional cost, the TPS could enhance the GIS that they currently utilize and publish a live and interactive Web GIS application that allows for the two-way exchange of information between the citizens of Toronto and the TPS. Along with other advantages, the incorporation of a Web GIS could potentially allow the TPS to increase the total number of criminal incidents that are reported, thus engaging an additional tool for addressing the underreporting of crime and providing a more comprehensive, though unofficial, data source for analyses.

1.3 Summary of Methods

This thesis will require the development of two Web-based GIS applications. To facilitate this, ArcGIS for Desktop 10.1 and ArcGIS for Server 10.1 will be used in conjunction with SQL Server 2008 R2 Express and the ArcGIS API for JavaScript to produce both Web applications. The Web applications will utilize publically available data provided by *Esri*, the City of Toronto, the Toronto Police Service, as well as spatial data provided by the author and by various anonymous users. Once deployed, both applications will be seeded with a combination of both hypothetical and actual crime incident data for the study area. To gauge the success of both applications, a survey was conducted based on a sample consisting of both GIS and crime prevention industry professionals, as well as a collection of participants with varying levels of familiarity in both of these fields. Once the survey period ended, the results were compiled, analyzed and included in the final thesis report.

1.4 Thesis Outline

This thesis is comprised of the following six distinct chapters:

Chapter 1 – Introduction: This section provides an introduction to the thesis and covers topics such as the problem statement, the methods used, and the outline for the thesis.

Chapter 2 – Literature Review: This section discusses the historical context of crime mapping, as well as a number of causal factors which lead to crime and delinquent behaviour. In addition, a discussion of the benefits and limitations of mobile GIS solutions and VGI is provided. The use of GIS as a tool in the field of crime prevention is also discussed.

Chapter 3 – Research Design: This section will discuss the thesis goals and objectives and will explore the study area that was chosen. In addition, this section will also provide information on the potential users and stakeholders as well as providing the current context for these applications within the study area.

Chapter 4 – Methodology: This section discusses the methodology that was used in order to accomplish the objectives of this thesis. The development process behind the creation of the Web applications is explained and the rationale behind a number of the decisions that were made along the way will also be discussed. The types of data that were used in order to create the Web applications that were developed for this thesis will also be explored.

Chapter 5 – Results and System Evaluation: This section analyzes both the final Web applications that were developed, as well as the results of the survey that was developed to gauge the success of the system. Individual survey results are compiled together and multiple aspects of each of the final Web applications are analyzed individually.

Chapter 6 – Conclusions and Recommendations: This section sums up the conclusions made from the results and examines a number of potential improvements that could be made to the Web applications in the future. A number of recommendations for future research on this topic are also discussed.

CHAPTER 2

Literature Review

This chapter provides an introductory overview of the modern fields of Web-based GIS and Mobile GIS. A number of examples of Web-based and Mobile GIS applications will be provided. Data optimization and ethical issues are also discussed, in addition to the benefits and limitations offered by the new trend of Volunteered Geographic Information (VGI). The chapter will also examine a number of connections that exist between the fields of GIS and Crime Prevention, with a focus on the field of mobile GIS. The history of crime mapping will be explained and a number of causal factors of crime will be discussed. The chapter will conclude with examining a number of GIS and crime prevention applications that have previously been developed.

2.1 Web-Based and Mobile GIS

Web-Based and Mobile GIS solutions have grown in popularity in recent years. Spurred on by the popularization of mobile computing devices, Web-based and Mobile GIS solutions have become an essential tool in many different industries, such as the utilities and tourism industries, and will be discussed later in this chapter. In addition to this trend, the wide-spread availability of mobile hardware has allowed for everyday people to collect and share their own spatial data. Those that wish to work with services and applications that utilize a user's location must also be aware of the limitations and ethical considerations that go along with them. The following sections will examine a number of real-life applications of this technology and discuss the benefits, limitations, techniques and ethical issues that are associated with them.

2.1.1 General Uses of Mobile GIS

Mobile GIS can be a beneficial tool in a number of fields. Industries that require immediate access to spatial data, regardless of location, can benefit from the incorporation of a mobile GIS solution. In particular, an industry that stands out for their successful adoption of mobile GIS solutions into their daily operations is the utilities industry. An example of this successful implementation can be seen in *CartoPac Field Solutions*, a company that develops customizable GIS solutions that are tailored to match their individual client's needs. *CartoPac* focuses their operations on the southern region of the United States and is partnered with both *Esri* and *Trimble* (CartoPac, 2010). By offering customizable mobile GIS and Global Positioning System (GPS) solutions for field data collection, *Cartopac* has successfully been able to increase the efficiency at which data is collected and retrieved from employees in the field (CartoPac, 2010). *CartoPac* believes that their mobile services would be beneficial for any industry that requires the collection of large amounts of field data. The majority of clients that utilize services by *CartoPac* are members of the oil, gas and utilities industries (CartoPac, 2010).

In addition to *CartoPac*, numerous other companies provide mobile GIS solutions to utilities companies within the United States. The Town of Bargersville in Carlsbad, California utilizes a solution titled "*Go! Sync Mapbook"* that assists their employees working remotely in the field. This mobile solution allows for electrical utility crews to access information from a facilities database while in the field, resulting in better informed decisions being made in less time. Additionally in the United States, the Northeastern Rural Electric Membership Corporation (REMC) from Columbia City, Indiana, also utilizes a mobile GIS solution. Northeastern REMC manages a large amount of the electricity industry in northeastern Indiana. By incorporating a mobile GIS solution provided by *Esri* into their daily operations, Northeastern REMC has increased their efficiency when retrieving data from employees working in the field. Furthermore, by providing a well-structured mobile GIS solution, the company has been able to reduce the number of errors that are recorded during data input (Esri, 2010). In addition to this, mobile GIS solutions are used to provide navigation capability and to support optimal route planning for field calls, reducing the amount of travel time required for service calls (TC Technologies, 2010). For REMC, this has resulted in faster response times for electrical outages within their service areas. (Esri, 2010). The incorporation of both the *Go! Sync Mapbook* solution by the Town of Bagersville, as well as the custom *Esri* mobile solution used by Northeastern REMC have yielded positive results. The Town of Bagersville intends to expand the use of mobile GIS into other town-run utilities (TC Technologies, 2010). By updating to the *Esri* mobile GIS solution, Northeastern REMC has increased employee productivity and has completely ended their reliance on paper maps (Esri, 2010).

The use of mobile GIS solutions is not limited to the utilities industry and is highly applicable in many other fields. In the United Kingdom, mobile GIS solutions have been integrated into the tourism industry. In the City of Lancaster, a lack of tools for providing information to tourists was noted. In response to this problem, the *GUIDE* system was developed and deployed (Cheverst, 2000). *GUIDE* is a context-aware application that aids tourists with sight-seeing activities within the boundaries of the City of Lancaster. The *GUIDE* system provides both historical and context relevant information to the user, as well as a tool that allows the user to effectively plan tour routes. (Cheverst, 2000). The *GUIDE* system is an example of an application based approach for producing a mobile GIS solution. An application based approach requires specialized software on your local device to complete a fair amount of the geoprocessing tasks locally, without the need for constant amounts of large communication with remote servers. This was an appropriate approach to utilize in this scenario as custom hardware units were provided to the users, allowing for larger amounts of data to be processed locally on the device (Cheverst, 2000). The various other approaches used for creating mobile GIS solutions will be discussed in greater detail in later sections.

The *GUIDE* system operates using a cell-based wireless infrastructure. By strategically locating a series of base stations throughout the city, the devices that are used in the *GUIDE* system were able to avoid many of the problems faced by traditional GPS units. GPS is unreliable at times when used in a built-up urban environment such as a downtown core, where large buildings can block and reflect satellite signals (Cheverst, 2000). Using this approach gives each device the advantage of more reliable service. On the other hand, each cell covers an area of approximately 300 meters in diameter. This large coverage area could cause a high demand on local servers if too many devices were connecting to a single node at the same time (Cheverst, 2000). A number of tourism-focused applications that utilize GPS also exist around the world and have proven to be successful (Hillenbrand, 2003).

A more interactive experience was created by allowing users to input their own preferences, then matching the user with relevant sites near their current position in the city. This experience was enhanced even more by the system's support for dynamic information updates. Dynamic information updates allowed for live updates on the status of local attractions. If for instance a tourist attraction were closed, a live update would be sent to the user's device (Cheverst, 2000). Users were also able to use the device's communication capabilities to arrange boarding accommodations, as well as to interact with other users through an instant messaging system (Cheverst, 2000).

Recently, the use of mobile devices as a tool for completing everyday tasks has become commonplace. Timpf (2006) states that common tasks such as checking the weather, looking up a location, planning a route, or paying for services such as highway tolls can be aided by mobile GIS solutions. These trends show that the use of mobile GIS solutions are not limited solely to private industries for large scale operations, but are also becoming a common place tool for the general public to use in their day-to-day activities (Timpf, 2006).

In general, location services are used to support a user as a part of the decision making process. A user can be aided in decision making by comparing their spatial location with information provided by external sources. This can be evidenced when a user utilizes their mobile device to calculate a driving route between two locations. Mobile GIS can also be used in the decision making process to limit the number of choices that a user has. For example, a mobile GIS solution can be used to filter results based on the user's current location, providing the user with only results that are available within their specific area. Sabine Timpf (2006) believes that there are three types of knowledge with regard to spatial information, those being: “knowledge in the world, knowledge in your head, and knowledge in your pocket”. To help explain this theory, imagine someone attempting to locate a business. Knowledge in the world would be the street signs they use on the way, knowledge in their head would be their personal memories of the area from past experiences, while knowledge in their pocket would refer to any maps or directions that they possess. People do not always have all three types of information available to them; however, only one type of information is needed to find a location. With this in mind, a mobile device with access to an accurate and up-to-date spatial data library could be beneficial for everyday tasks (Timpf, 2006). As the popularity of mobile device continues to increase, device users rely less on their personal knowledge of an area and more on the knowledge contained in online spatial databases.

The previously mentioned examples all help to showcase the importance of mobile GIS solutions in a number of different industries, as well as its role as a tool in everyday problem solving decisions. By transferring information to and from users while in the field, mobile GIS solutions are able to save a considerable amount of time and resources in a variety of different tasks. The next section will focus more on a number of the decisions that much be examined with regards to data optimization as well as ethical considerations for using mobile GIS solutions.

2.1.2 Data Optimization, Limitations, and Ethical Issues

In order to produce an effective mapping application, a large amount of background work must first occur. The current approach to Web mapping requires the integration of multiple data sources such as basemaps, operational layers, geoprocessing services and geocoders, as well as pre-configured widgets and tools. Since many different types of basemaps can easily be accessed online from various external sources, those that wish to produce effective Web maps must focus on optimizing the map and features services that they publish. Many design decisions must be made along the way that impact the services that are published. Decisions, such as whether a service should be pre-rendered as a tiled map service or whether it should be a selectable feature service, should be determined based on the needs of the user.

Mobile GIS solutions offer many positive benefits to users; however, to ensure optimal performance, a developer must keep in mind the limitations of mobile devices, such as limited processing power, low screen resolution, and restricted transfer speeds (Kim, 2004). In the example cited earlier, the *GUIDE* system was programmed with a basic GUI that mimicked the feel of a generic web-browser, making the system more intuitive for first time users. In addition to the previously stated concerns, considerations must also be taken when any device tracks the location and movements of an individual. With the *GUIDE* system, having access to a user's current location was beneficial as it allowed the system to provide relevant information to the user on a real-time basis. However, when locational data is paired with a specific time and recorded, the potential for a breach of the user's privacy is created. If this private data were to fall into unauthorized hands, it would become easy to track and monitor an individual's current whereabouts and travel patterns without their knowledge or consent.

Ethical issues related to the recording of locational data about individuals have become an even more important topic in recent years due to dramatically increased usage of cell phones. In October 2001, the Federal Communications Commission (FCC) within the United States government mandated that all wireless carriers must adhere to a minimum degree of accuracy in being able to locate a mobile device operating on their cellular networks (Chan, 2007). More recently, the use of GPS in smart phones has greatly improved the ability of these devices to accurately triangulate their current positions. As will be explained in greater detail later, this technology has been able to help police locate victims quickly and accurately, as well as aid in criminal investigations. Although beneficial at times, if limitations are not placed on accessing this locational data, authorities would be able to track the daily activities of any cell phone user without their knowledge or consent (Chan, 2007). To protect the rights of their users, developers of spatial solutions must ensure that they adequately safeguard the personal information of their users, including the locational data associated with a specific user. An example of a spatial system that safeguards their user's personal information will be described below.

At Purdue University in the state of Indiana, a project was undertaken with the goal of providing specific buildings on the university campus with Location Discovery Services (LODS). These services would provide participating users with the ability to locate one another, as well as the ability to locate and use the nearest available university printer (Chan, 2007). The students involved in developing the project established a system where participants would register the Media Access Control (MAC) address of their mobile device, such as a laptop or smart phone, in a central database. A MAC address is part of a device's hardware and cannot easily be altered without physically swapping the device's hardware. The MAC address acts as a unique identifier that can be used to identify a device over a network connection. The MAC address on its own does not contain personal information about a user and can be used to track an anonymous user's activity over a network. Participating users could then access the university's wireless network through the local access points (AP) and authenticate against a central server that was managed by the project developers. Once a user has successfully authenticated using credentials stored on the database server, data such as the current time, the AP being accessed, and the MAC address of a user is recorded to the database (Chan, 2007). To ensure that no user was being monitored unknowingly, consent was required from each project participant in order to register their hardware in the database. Moreover, to help protect the personal information of each participant, the Engineering Computer Network (ECN), a group that maintains the campus APs, only provided locational information in the form of log files that were copied directly to the secure project database server. The database server was accessible only by authorized project personnel. ECN log files were only copied for MAC addresses that were registered within the project database (Chan, 2007). This project demonstrated the importance that must be placed on the security of any server containing personal information.

Upon completion, the aforementioned Purdue University project was deemed a success, and was expanded to include the entire school network. The project goals however were also expanded to track data usage trends for the entire student population. All university students were automatically enrolled in the study and the need to register equipment to participate no longer existed. This expansion could potentially allow for a breach of privacy at a much larger and more serious scale (Chan, 2007). The solution that was adopted to solve the problem involved the scrambling of each device's unique MAC address. Copies of log files were sent directly from the campus APs to the secure project server. The only piece of information in the log files that could identify a user was the device's unique MAC address. As the identity of the user was not relevant to the study, this data could be altered without any significant issues. A random text scrambler altered the MAC addresses into a new, although still unique, string of characters which could no longer be matched to a specific user's device (Chan, 2007). These methods helped to ensure that the privacy of each user was upheld.

As mentioned earlier, mobile devices are restricted by a number of limitations. Factors such as the lack of memory and the absence of a mouse and physical keyboard also limit the functionality of mobile devices. When creating any mobile application, the developer must always consider the limitations of the hardware and work within the range of these restrictions. As such, mobile GIS solutions require the development of high efficiency methods for transferring, storing, and processing spatial data. In his thesis entitled *Sketch-Based Queries in Mobile GIS-Environments*, David Caduff (2002) proposed and designed a solution that could help avoid some of these hardware limitations. Caduff's solution reduced complex text-based querying into simple graphical inputs (Caduff, 2002). The solution was designed with the intent of being used on personal digital assistants (PDAs) with touch sensitive displays. Being able to easily manipulate and edit data in the field can be beneficial to organizations that utilize a GIS solution, such as the Lancaster *GUIDE* system discussed earlier. These improvements in mobile hardware and software have contributed to the migration from traditional to mobile GIS solutions (Caduff, 2002). Although a novel approach, this sketch-based approach is not necessary as modern ArcGIS servers allow users to publish pre-defined complex queries as geoprocessing services that can be easily integrated into any mapping or Web application. In addition, many of the modern Web mapping APIs that will be discussed later enable a user to utilize a set of built-in sketch tools in order to select, edit and create features directly within a Web map.

In recent years, the types of mobile devices that are most commonly used have begun to change. Many users now prefer using handheld mobile devices such as PDAs, smart phones, and tablet computers, as opposed to larger laptops. Although more portable, handheld devices are limited even more with lower processing capabilities, as well as a finite battery life (Caduff, 2002). Moreover, handheld mobile devices are limited by the capacity and coverage of the wireless or mobile network connection that the device uses to communicate. The strength of a connection can be affected by both hardware limitations for a specific mobile device, as well as the remoteness of the user's location. In applications such as Caduff's that require constant client-server interactions, data transfer demands can be very large. This limitation highlights even further the importance of implementing efficient querying practices when developing and using any GIS solution.

Jong-Woo Kim (2004) recognized the limitations of mobile devices. According to Kim, there are three types of architectures that can be used for developing mobile GIS solutions, including: (a) application logic type, (b) HTML browser type, and (c) GIS browser type (Kim, 2004). Each of these architectures has their own strengths and weaknesses which will be discussed later in this section. As a result, the effectiveness of each architecture can change based on the situation. It is important to develop a mobile GIS solution using an architecture that supports the demands of a specific situation. Solutions that utilize an Application Logic Type architecture use a dedicated on-device program and require minimal communication between the mobile device and any external servers. As such, much of the data processing occurs on the device itself. This however requires that the mobile device possess higher than average processing capabilities, or that the device only performs basic processing tasks (Kim, 2004). In addition, locally stored data can take up a large amount of the limited memory that is available on the device. An example of this approach can be seen with Esri's ArcPad and ArcGIS Explorer software. The HTML Browser Type architecture operates through the device's Web browser and relies on a constant stream of communication between the mobile device and any external servers. All of the geoprocessing and data hosting occurs server side, allowing mobile GIS solutions to support a wider range of mobile devices.

Furthermore, because any processing occurs on the server, the developer has less of a need to write custom code for variations between different devices. Conversely, this method requires large amounts of data to be exchanged over a network (Kim, 2004). The GIS Browser Architecture utilizes a customized mobile GIS browser or application that allows for efficient data entry on the mobile device in an application environment designed specifically for handling GIS tasks. Data input is faster, easier, and more accurate as a result, although constant interactions with external servers are still required. This architecture distinguishes itself from the HTML architecture in that it requires the user to download the application onto the device, whereas the HTML architecture can be accessible over the Web without the need to download a dedicated application. An example of the GIS Browser Architecture can be seen in the ArcGIS mobile applications for Android and iPhone.

In general, GIS data is stored in file types such as an *Esri* shapefile (SHP). The relatively larger file size allows for the inclusion of information that is unnecessary in many situations. Although other formats are becoming more common now, file types such as SHP are still often used in mobile GIS computing. Data demands can be considerably reduced in two key areas. First, the level of detail can be reduced when creating and displaying features, and secondly, data can be stored using a more efficient file type. A reduction in file size would allow data to be stored locally on a mobile device, thus limiting the need for a constant connection with an external server (Kim, 2004).

To this end, Kim developed a file type called the Simple Spatial Format (SSF). SSF files include a header, along with records for points, lines, polygons, and text. Data is recorded in binary format and is stored in such a method that a coordinate set requires only eight bytes of memory. This is a reduction from the standard sixteen bytes requirement (Kim, 2004). In large datasets, this storage method can result in massive reductions to the overall file size. When producing mobile maps, Kim also simplifies features by eliminating insignificant data points from the records and lessening the detail included in polylines and polygons. Other data reduction techniques involve collapsing polygons to sets of polylines and polylines to points. In order to ease the demand on mobile devices with limited processing power, the map is also divided into smaller sections (Kim, 2004). According to Kim's findings, the use of SSF files resulted in a noticeable reduction in loading time and drastically decreased overall file sizes when compared to traditional file types. Unfortunately, SSF files are not supported by existing GIS solutions and would require any GIS solution to include an updated SSF Library in order to properly convert and display the spatial data (Kim, 2004). As a result, this filetype did not gain widespread use. Currently however a number of other formats exist that are designed to serve spatial data over the Web. A common example of one such format is Keyhole Markup Language (KML) which was designed for use in Google Earth.

General and common sense techniques can also be used when trying to reduce the demands on a mobile device. Simple querying to retrieve only required data from a map server can considerably reduce the amount of data that must be transferred. Techniques such as searching within a specified buffer of a location, or cropping a desired section from the map can reduce the amount of processing which must occur and filter away countless undesirable results (McAdams, 2000).

2.1.3 Benefits and Limitations of Volunteered Geographic Information

A key advantage that is gained through the use of mobile and Web-based GIS application is the ability to crowd source the data collection process. Supporting this trend is the changing attitude from the public as to what is deemed to be an acceptable and reliable data source. While traditionally, only information that was contributed from a recognized institution may have been deemed as an acceptable data source, today, many users can accurately collect and disseminate their own data at a similar level of accuracy. As a result, many of the traditional approaches to acquiring and creating spatial data have been replaced with modern alternatives (Goodchild, 2007). When data that is collected voluntarily from a crowd sourcing initiative is of a spatial nature, it is referred to as Volunteered Geographic Information (VGI), a phrase that was coined in 2007 by Michael Goodchild. The idea of VGI as presented by Goodchild is summarized in the following quotation:

"The convergence of newly interactive Web-based technologies with growing practices of user-generated content disseminated on the Internet is generating a remarkable new form of geographic information. Citizens are using handheld devices to collect geographic information and contribute it to crowd-sourced datasets, using Web-based mapping interfaces to mark and annotate geographic features, or adding geographic location to photographs, text, and other media shared online. These phenomena, which generate what we refer to collectively as volunteered geographic information (VGI), represent a paradigmatic shift in how geographic information is created and shared and by whom, as well as its content and characteristics." (Goodchild, 2011)

With the popularization of mobile technologies such as smartphones, laptops and tablet computers, the number of potential VGI contributors has grown considerably (Ellwood, 2008).

The practice of crowdsourcing takes advantage of the Web 2.0 framework, utilizing the multi-directional flow of data between both users and developers as a method for both collecting and disseminating information (Girres, 2010). By utilizing contributions from a variety of users at different skills levels, developers can collect large amounts of information at a lower cost than would normally be found when using a professional organization (Girres, 2010). Areas with high household income and younger populations on average provide more volunteered data (Girres, 2010). This multi-directional flow of data found in VGI can begin to dissolve the line drawn between producers and consumers of spatial data (Goodchild, 2007). Many large organizations such as *Google*, *TeleAtlas*, *TomTom*, and *Navteq* have seen the benefits that VGI can provide and have incorporated it into their own professional products (Coleman, 2010).

Applications that incorporate VGI provide a method for tapping into and sharing a massive wealth of knowledge that has previously gone neglected (Goodchild, 2007). This wealth of data is accessible at little to no cost to those involved with producing the application and provides the possibility for targeted data collection on short notice (Ho, 2010). A well-developed application also has the potential to draw contributions from a large number of volunteers, allowing for the inclusion of additional points of view on a topic. Data contributed by volunteers will often contain information that is relevant to the user (Ho, 2010), and is often times richer and more descriptive, while also containing a wealth of local knowledge that cannot be attained from most traditional data providers (Girres, 2010). The process of contributing and sharing spatial data allows users to feel more engaged in a field that has been dominated by large data providers and high costs for purchasing spatial data. The removal of this cost barrier has opened the field of GIS to a wider audience (Ellwood, 2008).

Although automation can provide spatial data through processes such as the digitizing of aerial imagery, one of the true benefits of VGI is the ability to capture attribute information. Much of the attribute information that is associated with spatial data requires human analysis, interpretation, and input. It is this attribute information that makes spatial data truly useful for any analysis. Using VGI is an effective method for acquiring attribute data quickly and at a low cost (Girres, 2010). VGI can also be collected from pre-existing online content such as social media, blogs, news stories, videos and photographs (Ellwood, 2008). Services such as *Facebook*, *YouTube*, *Twitter* and *Picassa* provide the ability for users to georeference new and existing content. This process can be done either manually or by utilizing a computer or mobile device's location services. An example of this trend can be seen in the exceptional growth of the online tool Wikimapia, which experienced a growth of millions of entries into its database within only the first few months of operation (Goodchild, 2007).

In addition, VGI can provide benefits to the global community and has been used on a number of occasions to support disaster relief activities. Open VGI applications such as *Ushahidi* have been deployed in situations such as the Haiti earthquake of 2010 and the Japanese Tsunami of 2011 to help direct aid efforts and to provide relief workers with the locations of those who were affected. *OpenStreetMap*, an online service that utilizes VGI to produce a global collection of street maps, underwent a large surge of VGI contributions following the Haiti earthquake in an effort from the international community to replace the outdated street map information for Haiti with a current post-disaster street map that could be used by relief workers (Zook, 2010). Many other disaster relief VGI applications also exist online, such as GIS tools for disaster relief provided by *Esri*.

Many considerations and limitations must also be taken into account when working with VGI. When working with VGI, a user must always reference the metadata in order to gauge the accuracy and reliability of the spatial data. The metadata should ideally disclose who contributed the data, when the data was contributed, and what tools or techniques were used to capture the data (Goodchild, 2007). The context provided by the metadata helps the user of the spatial data gauge whether it merits inclusion in their analysis. Unfortunately as is the case with some VGI, metadata is not always available or accurate. In addition, VGI datasets are often comprised of multiple users, adding further uncertainties to the reliability of the data (Feick, 2013). Additional legal concerns can also occur with regards to ownership rights and breach of confidentiality rights on some sets of data. If a disclosure of the contributors rights and responsibilities is not made prior to the collection of the VGI, the user or organization responsible for hosting the data may be held accountable (Ho, 2010). If misused, VGI could be used as a form of surveillance, affecting the privacy of the user (Ellwood, 2008). Attention should be paid to applications that automatically use the location services of a smartphone and to photos that capture the user's geographic location at the time the photo was taken and recorded in the metadata.

It is important to also consider the users that contribute data. A poorly designed application will be less appealing and can limit the number of volunteers who participate. Moreover, an application that requires user training prior to contributing as a form of improving data reliability may dissuade users from contributing (Tulloch, 2008). Conversely, applications that experience a large number of volunteers may suffer from an excess of information, where useful data can be lost in a clutter of contributions (Mennis, 2009). In addition, attention should be paid to the motivating factors that lead to a user contributing in the first place. Inaccurate data may be provided with malicious intent, be it for personal gain, or to simply cause mischief (Coleman, 2009). Large groups that rely on volunteered information such as Wikipedia have developed methods for analyzing data for misinformation. Smaller organizations or individuals can look for red flags by examining the frequency of a user's contributions, the nature of the data that they contribute, or the physical location of a user in relation to the spatial data that they are contributing (Coleman, 2010). Groups that have a large volunteer community can have any new volunteered information peer-reviewed by other members of the community. This exemplifies Linus' Law which states that as the number of users who contribute to and review data increases, so too does the overall accuracy of the data (Haklay, 2010). The success of these practices can be seen in the results of Haklay's 2010 study on the accuracy of the English *OpenStreetMap* which found accuracy ratings of approximately 80%, putting it on par with the street network datasets provided by other commercial data vendors (Haklay, 2010).

VGI offers a tremendous number of potential benefits and has the ability to tap into a previously ignored wealth of knowledge. However, VGI contributions must be adequately examined in order to gauge the accuracy and reliability of the data. It is important to note that the VGI described within this thesis refers to a more passive GI collection approach from everyday citizens, many of whom may not be complete aware of how their data can be utilized. This is in opposition to the active or purposeful approach, where users are aware how the data will be used. When working with any type of VGI, the potential for both malicious data contributions and the abuse of the system always exists. Using the applications that will be developed in this thesis as an example, gang members may report their own graffiti in order to highlight their own territory. Alternatively, contributors may provide false data with the malicious intent of making a specific area appear more dangerous and less appealing. It is important to also note that VGI requires specific types of technology in order to participate. As a result, data contributions may not be completely representational of the actual population and the accuracy of any contributions that are submitted are dependent on the reliability of the hardware for the specific device the contributor was utilizing. As both access to the internet and the popularity of mobile devices continue to increase, so too will the importance of VGI within the field of GIS.

2.2 GIS and Crime Prevention

Geography has a long history of aiding with the monitoring and tracking of criminal activity. Historically, police investigators would place pins on physical paper maps to represent crimes that had been committed. By comparing these crime incident pins with the locations of points of interest or persons of interest, investigators could perform rudimentary spatial analyses. Since then, technological improvements have made it possible to digitize large quantities of spatial and non-spatial data and to quickly share it between police departments (Chainey, 2005). In this section, multiple examples are presented that demonstrate how GIS has been used by police forces to improve their ability to actively track suspects, to strategically deploy police personnel, to validate witness and suspect alibis, to engage with and inform members of the public, and to analyze the spread of and the causal factors that lead to criminal activities.

2.2.1 Mobile GIS and Crime

The advent of the Internet has played a key role in promoting the secure sharing of data between police departments. As public access to the Internet continues to grow, it has become a part of everyday life for many people. This has provided police departments with the ability to publically, and cost effectively, disseminate information to a large audience. Some electronic government-to-citizen services have been developed to effectively share this information while ensuring data quality (Boondao, 2003). Providing these online services can improve the performance of public services, increase governmental accountability, and still be cost effective (Boondao, 2003).

An example of a government-to-citizen server that has been developed is the idea of E-policing. E-policing is any online service with the goal of aiding in police work. E-policing can be used to both gather data for local police and also provide important information back to the public. Location-based services can be used by police to locate a mobile device in an emergency situation. Incorporating this technology can drastically reduce response times in situations where every second counts. In Thailand, Roongrasamee Boondao (2003) proposed a system that used an HTML approach to support communication between the local police and the public. Members of the public could authenticate with the system through a Web browser to view spatially relevant crime maps and to perform basic geoprocessing tasks. Requests were directed to a secure map server and a response was then returned to the user's Web browser. Police could also authenticate with the system and were granted access to a higher level of data (Boondao, 2003). Other police services around the world have increased their participation in E-policing initiatives. The Royal Canadian Mounted Police (RCMP) has used E-policing to expedite the dissemination of information to the public. Moreover, with E-policing, police services can support the online reporting of criminal activities. Doing so can free-up additional police resources and personnel that would have otherwise been tied-up with processing these crime reports (LeBeuf, 2006). Additionally, when well-designed, online incident reporting can promote data accuracy by helping to focus user contributions and by ensuring that the same reporting procedures are used for every report that is submitted (LeBeuf, 2006).

When utilizing any location-based data that is associated with a specific time, privacy concerns are raised. To avoid the potential for a breach in user privacy, a two-tier system was proposed by the Thailand case study mentioned earlier for securely handling all personal information. To protect the user's privacy, users would remain anonymous while viewing crime data and performing basic queries. Any personal information that was submitted with each request to the secure server would be immediately deleted once the processing had been completed. However, for events that were deemed to be serious, a record of the user's personal information would be forwarded to the local police service (Boondao, 2003). The proposed system would utilize a PostgreSQL database, as well as PostGIS to handle any spatial data. The database server would support real-time updates to the data tables and store the list of authorized users (Boondao, 2003). The methods used in the Thailand case study are quite different from those used in the aforementioned Purdue University case study; however, both methods have the potential to be effective tools for protecting user privacy.

Mobile GIS can also be used to actively monitor suspects in criminal investigations. The popularity of cell phones has made it possible for police investigators to covertly track the travel patterns and activities of suspected criminals both in real-time, as well as retroactively (Cooper, 2007). In their 2007 presentation, *Using Mobile Phone Data Records to Determine Criminal Activity*, Cooper and Schmitz discuss a system for actively tracking suspects using their cell phones. With their system, an investigator is able to send a blind SMS to the target's cell phone, resulting in a response message being returned to the investigator with information regarding which cellular node is being accessed. Messages are sent at regular intervals and the system calculates an approximated travel route. The route is then overlaid with street network data and snapped to the nearest logical feature (Cooper, 2007). Routes can then be spatially analyzed to determine the suspect's proximity to points of recent criminal activity or to any suspect specific points of interest. Routes can also be created after a criminal activity has occurred as cell phone records are often stored by service providers and can be acquired with a search warrant (Cooper, 2007). Routes that are generated can be used to test the validity of suspect alibis. Although a useful tool, Schmitz recommended that the system only be used as an aid in criminal investigations, and not for prosecution purposes, since a degree of inaccuracy must be assumed.

A real-world example that showcases the benefits of using an active tracking system can be evidenced in a South African court case that resulted in the conviction of two members from a local gang. The gang of four males kidnapped a couple and stole their car and possessions. After raping the woman, the two victims were murdered and their bodies were dumped. During an eventual police shootout, the two gang members who were present at the shootout were killed. The other two suspected gang members were later arrested and when questioned, denied having any involvement in the incident (Cooper, 2002). However, the two deceased gang members had remained in contact with the suspects by calling the suspect's cell phone from the hostage's cell phone. The cell phone records and associated crime maps were subsequently produced and were used in court to break their alibi, eventually leading to a conviction. The map produced contained the travel patterns of both parties involved, as well as their potential activity areas. The data was accompanied by points of interest such as the location of the burned out car, the murder site of the couple, as well as the locations of witnesses (Cooper, 2002).

The previous examples help to highlight some of the positive aspects of using mobile GIS in the field of crime mapping. However, in the book *Mapping and Analyzing Crime Data: Lessons from Research and Practice*, Ken Pease (2000) states that caution should be taken when associating spatial locations with crimes. Focusing solely on locations can take attention away from other pertinent non-spatial variables that may have had an impact on the crime committed, such as the context of the crime or the motivation of the parties involved (Pease, 2000). Pease was of the opinion that GIS should be used only as an aid to, and not a substitute for, non-spatial crime analysis approaches. However, Pease also stated his belief that incorporating GIS analysis with locational data from mobile devices has the potential to provide major benefits to the future of crime mapping (Pease, 2000).

The examples above help to support the notion that the use of locational data and spatial analysis is beneficial to the field of crime mapping. In some situations, using a GIS has improved the response time of emergency services when responding to life or death situations. Nevertheless, it is important to note that locational data can be highly sensitive and strict policies must be enforced to protect the privacy of the user.

2.2.2 Causal Factors of Crime

Much research has been done in the past regarding the causal factors that lead to crime. Of this research, the focus has been predominantly on crime in the Western world, and has showed that causal factors of crime can vary based on one's local environment, be it urban or rural. Understanding the factors that can lead to criminal activities or delinquent behaviour is important knowledge for any police organization in their crime prevention and law enforcement efforts.

As stated earlier, most available literature on urban criminology was developed using case studies focused on North America and Western Europe. As a result, it can often be difficult to apply the same knowledge to Eastern European countries. This phenomenon is evident in a case study conducted by Vânia Ceccato (2009) in Tallinn, Estonia. At the time of the case study, Tallinn was a city that was undergoing a transition into a market-oriented economy. Traditionally, during times of political change, an increase in criminal activity is often noted. This increase in criminal activity is often seen as the result of a perceived decrease in the ability of the government to detect and convict criminal offenders (Ceccato, 2009). When comparing the situation in Tallinn with the western-focused urban criminology literature, the geographical spread of the criminal activity remained consistent. However, the causal factors for the criminal activities differed from what was stated in the literature. Without knowing the true causal factors that lead to crime, it would become impossible to accurately predict future crime trends (Ceccato, 2009). In addition, as any economy begins to grow, so too will the amount of criminal activity. A stronger economy often leads to higher rates of consumerism, resulting in an increase in the number of opportunities for crime to occur (Ceccato, 2009). This may be particularly true for acquisitive crimes due in part to the increased availability of wealth as well as the potential for the polarization of income levels. The difference between the "haves" and "have-nots" will also increase, producing further inequalities between citizens (Ceccato, 2009). Ned Levine (2006) noted that very often, poverty stricken youth are located in close proximity to affluent families. Situations such as this could easily result in criminal youth activity.

The goal of Ceccato's study was to provide evidence of the spatial dependency and geographical behaviour of crime (Ceccato, 2009). To do so, Ceccato divided crimes into two categories, those which were expressive, and those which were acquisitive. Expressive crimes vented emotions and included assaults and vandalism, while acquisitive crimes, such as muggings and robberies, were committed to acquire material wealth (Ceccato, 2009). Expressive crimes were dealt with under the Social Disorganization Theory, which focused on the characteristics of the surrounding area, such as ethnicity and poverty. Acquisitive crimes were dealt with under the Routine Activity Approach, which focused on the incidence specific dynamics of the crime (Ceccato, 2009). Ceccato used a GIS along with geo-referenced crime data that was released in 2002 to complete her study. In her findings, Ceccato found a strong correlation between drug activity and acquisitive crimes (Ceccato, 2009).

A number of causal factors of crime are given within the Western literature, showing that the odds of being involved in a major crime are as high as one in five (Ackerman, 2004). Ackerman (2004) noted that crime rate increases of two to three times had also occurred in a number of industrialized countries. In an international survey of crime victims, 66% of respondents that resided in large cities admitted to having been victimized at least once in the previous five years (Ackerman, 2004). However, according to Ingrid Ellen (2009) in her report entitled "Crime and U.S. Cities", a large decline in criminal activity occurred in the United States between the early 1990s and 2005. Ackerman (2004) hypothesized that higher than average unemployment and poverty may been one of the leading causal factors for the higher than average crime levels during this time period. Other contributing factors that were indicated in the report focused on the concentrations of youth populations with regard to the location of criminal activities. Additionally, the amount of deterioration of the physical environment plays a role (Ackerman, 2004). A report released by Christopher Dunn (1980) stated that concentrations of criminal activity were correlated with single-mother households. In her 2010 report on crime in rural Sweden, Ceccato highlighted that relationships exist between crime and alcohol distribution, irregular family structures, and the general proportion of male youths within the population (Ceccato, 2010).

In Sweden, Ceccato (2010) explained that there was a perception that rural areas were safer than their neighboring urban regions. However, as supported by recent news reports in Sweden, this was not the case. An increase in crime rates in rural regions had occurred over the ten years prior to the study. Increases had occurred more predominantly in accessible rural areas and less predominantly in remote rural areas. It was also noted that during the 1980s, an increase in crime rates in Canada and the United States was observed, especially in violent crime rates, which were higher in smaller townships compared to larger cities (Ackerman, 2004). Violent crime rates in rural areas were in reality, just as high as anywhere else in Sweden. This claim was supported statistically under the assumption that the City of Stockholm, a major outlier within the data, was removed from the analysis (Ceccato, 2010). This was caused in part by a decline in the local labour market which had been attributed to both changes in the traditional makeup of the local population, as well as changes in the average income levels (Ceccato, 2010).

The geography of an offender can also be a determinant of crime in an area. In a study that examined target selection patterns in rape cases, Eric Beauregard (2010) noted that sexual offenders would often use selection criteria that were similar to that of a burglar. Among other factors, the surrounding physical environment had an impact on the offender's final decision. Beauregard indicated two models that sexual offenders would commonly use; the commuter model and the marauder model (Beauregard, 2010). Offenders that followed the commuter model would travel to a new location that was distant from their place of residence before committing a crime. Offenders who followed the marauders model, however, would utilize their home as a base of operations and would perform attacks anywhere within the surrounding area. To help locate marauder offenders, investigators would often build a circle or radius around a crime incident, using the furthest points as references (Beauregard, 2010). Roughly 87% of sexual offenders at the time were said to fall under the marauder model (Beauregard, 2010).

In São Paulo, Brazil, Ceccato (2007) noted a link between poverty and crime rates. Further relationships were also noted between crime rates and the availability of firearms and the strength of the local drug market (Ceccato, 2007). It was shown that in both Brazil and Sweden, alcohol consumption rates were positively correlated with increased crime rates. This trend was most evident in homicide rates. As a result of the higher crime rates, the overall quality of life in the city declined. To attain these results, Ceccato used GIS software to analyze a recently released geocoded local crimes dataset (Ceccato, 2007).

These causal factors, along with countless other factors, such as improved demographics projections, known gang territories, or historical crime trends, are used by crime analysts when attempting to project future crime patterns. The factors that lead to crime can vary not only between countries, but also between neighbouring urban and rural areas. Assuming that data is available; a crime analyst can use these factors as inputs or independent variables for modelling the ever-changing criminal landscape. It is possible that the data gathered from the Web applications in this thesis can provide more insight into the causal factors of crime that may have before been overlooked due to underreporting.

2.2.3 Using GIS for Crime Prevention

As was noted earlier, the practice of crime mapping has had a long history in policing and law enforcement. Levine (2006) believed that a major focus of modern GIS within the field of crime mapping should be directed toward modeling future crime trends. A map that utilizes past trends to model future crime growth could allow a police department to more effectively allocate their physical resources and to help mitigate the growth of crime (Levin, 2006). Statistical packages tailored specifically for crime mapping exist and are often times freely available (Levine, 2006). This statistical software has been used by various law enforcement agencies to support the production of maps that highlight past, present, and future criminal activities. *CrimeStat* is an example of one such statistical application that could be used in conjunction with a number of common GIS programs (Levine, 2006). *CrimeStat* allows for a variety of different input data source types, including .shp and .dbf, and is able to perform comparisons between the various data types. *CrimeStat* can then be used to convert the statistical crime data inputs into a spatial or graphical output (Levine, 2006). Ackerman (2004) believed that the combination of GIS and statistical programs is the most important tool available to crime analysts. Ceccato (2002) also agreed that GIS is best when it is paired with spatial statistical analyses.

William Ackerman (2004) states that there are two types of GIS analyses that are applied in the field of crime mapping, those being, macro-spatial and micro-spatial. A macro-spatial analysis for example allows one to locate a troubled neighbourhood, while a micro-spatial analysis allows one to locate a precise hotspot within that neighbourhood. A crime hotspot is an area with a disproportionate amount of criminal activity (Ackerman, 1998). Locating a hotspot would allow a local police force to effectively focus resources to that area in response. In his study on geocoding locations of crimes in Japan, Yutaka Harada (2006) utilized both a new method of geocoding, as well as a kernel density estimation tool to detect and display crime hotspots in the central 23 wards of Tokyo. The kernel density estimation tool was originally applied to display a smooth distribution on histograms, but was later expanded to produce maps utilizing point data (Harada, 2006). Using the kernel density estimation tool also allowed for irregular-shaped hotspots to be more adequately displayed. This helped to remove the clutter that often appears on high density point maps, producing a smoother distribution of crime incidence patterns, thus allowing for the visualization and monitoring of temporal changes within a selected hotspot.

A.L. Nelson (2001) examined micro-spatial trends in violent crimes within British city centres. According to Nelson (2001), micro-spatial analyses are often overlooked, with investigators more often focusing on broader and more generic macro-spatial analyses. These broader studies often compare multiple cities with one another and are used to determine general trends and patterns. Although useful, Nelson (2001) noted that within an urban area, the largest concentration of violent crimes occurred within the city centre. To further investigate this phenomenon, a more micro-level approach would have to be followed. A benefit of micro-spatial research into the distribution of violent crimes is that it allows for inferences to occur. For example, an inference could be made on a hotspot's proximity to a pub (Nelson, 2001). By locating specific areas that contained the highest concentration of criminal activity, police could dispatch their resources more efficiently. As stated earlier, importance must be placed on the *when* and the *where* of crime, and not only the *who* and the *why*. The importance of this is evident in the field of environmental criminology, which considers the surrounding environment and its impact on crime rates of an area. If specific environmental causal factors of crime are correctly inferred, increased construction and redevelopment of the built environment has on occasion been used to prevent future crime growth (Nelson, 2001). Many police forces across North America recognize the importance of spatial data and the surrounding environment by beginning to geo-reference their crime incident data. However, attention must be made to ensure that the spatial and temporal information being analyzed is not overly generalized.

The impact of a neglected environment can be demonstrated by the broken window theory (Kelling and Coles, 1996). The broken window theory states that a broken window, if left unrepaired, will soon be accompanied by additional broken windows. This phenomenon occurs because the general population believes that no one cares about it. In Bruce Doran's (2005) research on the relationships between disorder, crime, and the fear of crime, he noted that in much the same way as the broken window, disorder when left unattended, can cause further disorder, and even lead to more serious crimes (Doran, 2005). When a person is fearful of an area that is in disorder, they will avoid travelling to it, which can lead to further disorder. This in turn can create a positive feedback loop and result in an area spiralling out of control (Doran, 2005). Doran used a GIS to investigate this phenomenon, specifically focusing on graffiti crimes. The maps produced as a result of Doran's research were used in making recommendations to local police for promoting methods for reducing criminal activity and delinquency. Proposals targeted areas in disorder and proposed that police resources be allocated strategically in an attempt to end the disorder cycle (Doran, 2005).

To support the use of spatial data in the field of public safety, *Esri* developed a Crime Analyst extension that can be run in conjunction with their ArcGIS software (Cottingham, 2007). The Crime Analyst extension allows for the automation of many common crime mapping procedures and provides access to and support for a wide range of data including, but not limited to, socio-economic data. In a study on homicide in São Paulo, Brazil, Ceccato (2007) incorporated official police statistics, health-related statistics, victimization survey results, and civil registry records into her analysis. The *Esri* software that was used allowed for temporal analyses to be conducted, providing information to police departments on when specific types of crimes are most likely to occur (Cottingham, 2007). The South Yorkshire Police department in the U.K. has also used the *Esri* Crime Analyst extension and reported a drastic reduction in data input time as a result (Esri, 2008). Using GIS software also allowed for crime analyses to occur across multiple jurisdictions (Esri, 2008). Police departments such as the Lincoln Police Department of Nebraska and the High Point Police Department of North Carolina have utilized GIS software for crime prevention (Esri, 2008).

GIS can greatly improve a police department's ability to monitor and prevent future crime. Spatial statistical software can further improve on these capabilities, allowing for crime hotspots to be located and mapped at both a macro-spatial and micro-spatial level. Once hotspots are identified, police departments can strategically deploy their resources in an attempt to prevent or mitigate future crime growth. A key benefit of using a GIS in the field of crime mapping is its ability to combine multiple datasets from different sources into a single analytical platform. A GIS can also go beyond being used as a research and analysis tool and be applied in both active criminal investigations and for public information dissemination.

2.2.4 GIS Crime Prevention System Case Studies

The widespread popularization of both internet and mobile technologies has provided a unique opportunity for the public to see the benefits provided by a GIS. Information that in the past was only available to a local police department can now be made available to not only external police departments, but to any member of the public with an internet connection. This has provided an excellent tool for both concerned citizens, as well as police departments that want to distribute important safety information to the public. A number of organizations, such as the RCMP, participate in E-Policing initiatives. E-policing involves the two-way transaction of information and ideas between the citizens and their local police department (LeBeuf, 2006). This has allowed for freeing up of limited police resources, and has helped to ensure that important information can be easily distributed to the public. E-policing has also helped to assess data accuracy of reported crimes through the use and enforcement of stricter guidelines in the crime reporting process (LeBeuf, 2006). An example of E-policing was applied by the City of Chicago where citizens could access up to 90 days of crime-related information using the Citizen Law Enforcement Analysis and Reporting (CLEAR) system. CLEAR used *Esri's* ArcGIS for Server software to quickly inform the public of recent criminal activity (Cottingham, 2007).

A common problem that has occurred when tracking the movements of an offender or analyzing the spread of a crime spree is the lack of communication and data sharing between neighbouring police departments. Even in situations where communication has been fostered, differences in storage systems and data acquisition methods used in each department has significantly hindered any kind of analysis (Hick, 2003). As a result, important connections in crime activities can sometimes be overlooked, especially if an offender has travelled between multiple regional jurisdictions (Hick, 2003). Steven Hick (2003) proposed the development of a large-scale networked crime mapping system that is able to read in a number of different data types from multiple police departments. Users of the system can then utilize data that was provided by multiple departments in their analysis. In order to accomplish this, Hick utilized ArcIMS, along with a SQL Server database to store the acquired crime data. Police departments could then use the data provided by the system to track and eventually help apprehend specific suspects, as well as attain a strategic and tactical advantage in their daily operations (Levine, 2006).

It is important to note that the benefits of using a GIS in the field of crime mapping are not limited only to the quick dissemination of information, tools for crime prevention, and merging of different data sources. A GIS can also be used to provide support in an active criminal investigation (Harada, 2006). Yongmei Lu (2003) utilized a GIS in his study on criminal travel patterns to examine the travel patterns of stolen vehicles. Lu (2003) noted that in recent years, a shift has occurred from criminals stealing cars for joy-riding to criminals stealing cars for profit. In his study, Lu examined the route that was taken between the point of theft and the garage at which the stolen car was sold, or "chopshop". Lu hypothesized that the use of a GIS to determine the most common routes taken by a car thief could aid a police department in preventing future vehicle thefts. By knowing the most common routes, a police department could strategically place officers in locations where they could catch the car thief while they were en-route to the chopshop. Lu (2003) also noted that a GIS could be used to approximate the position of unknown chopshops through the analysis of any recurring routes.

The City of Ogden in Utah has also recognized the benefits that using a GIS can offer as an active tool for crime prevention. The Ogden Police Department (OPD) launched the Real Time Crime Centre (RTCC) in 2011 as an active crime prevention tool (Esri, 2012). The RTCC was built using a GIS and was designed to integrate multiple source data feeds, such as camera systems and crime databases in a single platform. Once data had been integrated, analyses could be performed on the data and the results could be quickly published in the form of a map (Esri, 2012). Using a GIS as an active crime prevention system allowed the OPD to effectively share data between multiple teams within the police department in order to make better informed decisions. The system also allowed for the automation of a number of queries that allowed the OPD to free up resources. As a result, the OPD were able to automate parts of their reporting workflow, deter future criminal activities, and to make additional arrests (Esri, 2012).

The above examples show a number of ways that GIS has been successfully integrated into the field of crime mapping. Both historically and in modern times, crime reports have been displayed with data overlays, such as known offenders and points of interest, to help guide criminal investigations (Cottingham, 2007). Location-based services (LBS) that are found commonly in many modern mobile devices have increased response times in emergency situations (Boondao, 2003) and can be used to monitor criminal activity and aid in active criminal investigations (Cooper, 2007). Having access to this wealth of spatial data can allow police departments to strategically utilize their resources. Officers in the field can use this spatial data to make better informed decisions (Esri, 2008).

2.3 Chapter Summary

There has always been an important relationship between geography and the field of crime prevention. The importance of spatial data has been understood for a long time by many police departments around the world. As technology has improved, so too have the techniques and methods used to monitor and track criminal activity. In addition, the advent of the Internet has allowed police departments to share information with both neighbour police departments and with the public whom they service. As the world becomes more connected and the popularity of GPS units in mobile devices continues to grow, the importance of spatial data and the ability to share it will also grow.

Much research exists in the fields of both Crime Mapping and GIS; however, only a small body of literature exists on how the two can be integrated together. Of the existing research, very little explores the use of Web based applications in the field of Crime Mapping. This is largely due in part to the relatively young age of both the Web and Mobile GIS fields. It is hoped that this thesis will be able to contribute to the growing body of literature on how Web based GIS solutions, as well as VGI, can be used as a highly effective tool in the field of crime prevention. Further research must be made that integrates these two fields and provides an understanding of how these fields can be effectively used together to promote public safety and to create an additional channel for incident reporting and for the creation of spatial data.

CHAPTER 3

Research Design

This chapter introduces the research design of this thesis. The following sections not only introduce the goals and objectives of this thesis, but will also provide the reader with an understanding of the analytical process that was followed in order to complete this thesis. After describing the geographical area that this thesis will focus on, this chapter will then provide an overview of the key stakeholders that can benefit from this research, as well as the potential users that may utilize these Web applications. The chapter then concludes by discussing the current context for these applications within the City of Toronto, by examining a number of similar systems that are in use today, and by emphasising both the current need for further research on these topics and how this thesis can benefit and build upon the existing academic literature.

3.1 Thesis Goal & Objectives

This study examines the potential benefits of combining the application of mobile technologies, Web GIS applications and volunteered geographic information (VGI) for enhancing crime reporting by everyday citizens. More specifically, this study focuses on the development and deployment of two Web GIS applications for contributing anonymous crime incident data. The first Web application contains a general crimes database that allows users to anonymously report incidences of criminal activity in their neighbourhood through a Web browser on their computer, smartphone or tablet computer. The second Web application uses a mobile-focused interface and explores an applied scenario of using VGI and Web GIS to map the spread of youth gang influence using graffiti tags. Although the two Web applications are independent of one another, gang-related graffiti may at times be seen in areas that experience additional incidents of criminal activity and if left unaddressed, may have the potential to lead to more serious criminal activities occurring within that area.

A key hypothesis of this thesis is that both Web applications will allow for the creation of additional unconfirmed crime incident and graffiti data. It is hoped that the design of these applications will provide an effective tool for assisting the public with the reporting of crime incidents. Through this structured and Web-based approach, the potential for improving the quantity of crime data that is voluntarily reported exists. In addition, as a result of a more structured approach to contributing data, data that is contributed has the potential to be of both a higher spatial accuracy, and to contain more detailed and meaningful information that can be easily categorized into pre-existing categories of criminal activity that can be used in future crime-related analyses as an unconfirmed data source. However, gauging the quality of data that is reported is not a part of this thesis and therefore cannot be confirmed. Youth gang graffiti data that is contributed can be confirmed by members of the Organized Crime Enforcement group of the Toronto Police Service (TPS) and can be used to map the ever-changing urban landscape of youth gang influence and provide an indicator of the local neighbourhood environment. Patterns and trends that are found in collected data can be used to highlight areas in conflict or social deprivation, which could potentially benefit from an increased police presence.

The main objectives of this study are to:

- Develop and deploy to a subset of respondents a Web-based GIS application for the purpose of recording general crime and victimisation data in the City of Toronto.
- Develop and deploy to a subset of respondents a Web-based GIS application for the purpose of recording instances of gang related graffiti in the City of Toronto.
- Survey a number of respondents from different backgrounds in order to gauge the relative success and practicality of each application and to determine how Web GIS and VGI affects the quality and quantity of crime-related data that is contributed by the public.

It is important to note that the main goal of this thesis was to analyze the potential benefits that Web GIS and VGI could offer to the fields of crime mapping with regard to crime reporting. As such, the author purposely did not include analysis tools within either of the Web applications. The author intended both Web applications to remain focused specifically on data collection and did not wish to create a "one-app-does-all" Web application. Many spatial analysis tools already exist within ArcMap 10.1 and could easily be integrated into future releases of the Web applications in the form of a geoprocessing service. This thesis will fill the need that exists for further research into how the fields of VGI and crime mapping can be used together, while also providing the City of Toronto with a valuable tool that has the potential to improve public safety.

In order to achieve the goals of this thesis, the overall analysis will follow the approach outlined below in **Figure 3.1**. These analysis steps will occur after all of the relevant background research and planning have been completed.

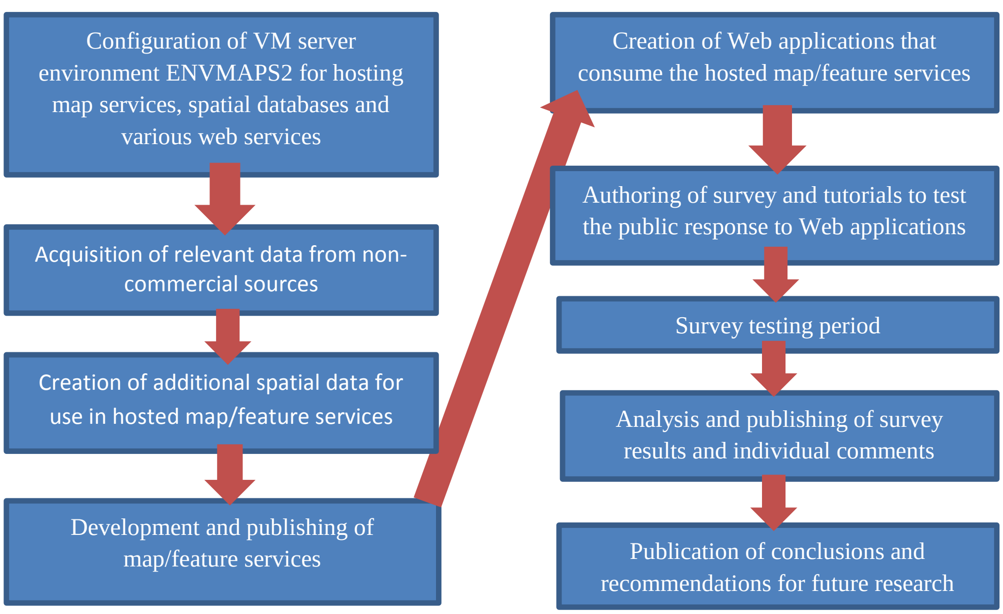


Figure 3.1 – Analytical Flowchart for Completion of Thesis

3.2 Study Area

The City of Toronto (**Figure 3.2**) is located in Southern Ontario and is the capital city of the province. The City of Toronto forms the core of the surrounding Census Metropolitan Area (CMA), also known as the

Greater Toronto Area (GTA). According to the 2011 Census of Canada, the City of Toronto was the most heavily populated city in Canada and had an approximate population of 2,615,060 people. An additional 5,583,064 people lived within the surrounding CMA (Population and Dwelling Counts, 2013). Due to its large geographic size, the City of Toronto contains a number of highly diverse areas with a wide range of socio-economic characteristics. Since the 1970s, the polarization of income levels has occurred, resulting in the City of Toronto containing both high and low income neighbourhoods (Hulchanski, 2007).

Being a multicultural city, the City of Toronto is home to a diverse mixture of people and contains a number of ethnic and culturally focused neighbourhoods. Being in close proximity to the United States of America, the City of Toronto is also influenced by a number of the same trends and criminal groups that are seen in the United States. When compared to other CMAs in Canada, the GTA experiences a relatively low amount of criminal activity (Brennan, 2012); however, the city is home to a number of youth gangs. A number of the local gangs are influenced by larger gangs that exist in other countries.

As depicted in **Figure 3.3** below, the Toronto Police Service currently operates 17 distinct police divisions across the City of Toronto. Nine of these divisions are located within the central field, while the remaining eight are located in the surrounding area field. The borders of the central field are roughly defined by Highway 401, Highway 427, Lake Ontario, and the Don Valley Parkway. In addition to each division having a headquarters, there are also central and area headquarters, as well as various information, reporting, and storage facilities (Command and Divisional Boundaries, 2013). The Toronto Police Service also employs an Organized Crime Enforcement group which monitors gang-related activities in the city (Organized Crime Enforcement, 2013).

The size of the GTA, the socio-economic diversity of the population, the presence of youth gangs, and the location of the author made the City of Toronto an ideal study site for this thesis. Crime incidents occur in Toronto every day, making the city a potential beneficiary of the results of this thesis. In addition, the proximity of the author to the study site allowed for unique opportunities to 'seed' the application databases with real world data. R regards to the Toronto Crimes Database Web application, this seeding was done with completely hypothetical data; however, with regards to the Graffiti Tagger Web application, a total of 95 actual gang graffiti images were collected, geotagged, and displayed within the Web application. Within the City of Toronto, municipal bylaws prohibit the affixing of graffiti vandalism or tags to public and private property. Graffiti that was either affixed to a building without the consent of the owner, incites hatred or violence, contains profane language, or is determined to be a tag can be classified as graffiti vandalism. When a notice is given by the city, graffiti vandalism must be removed by the property owner at their own expense (Toronto Municipal Code, 2013).

Figure 3.2 - City of Toronto
Data Source: ArcGIS Online Topographic Basemap, *Esri*, 2013.

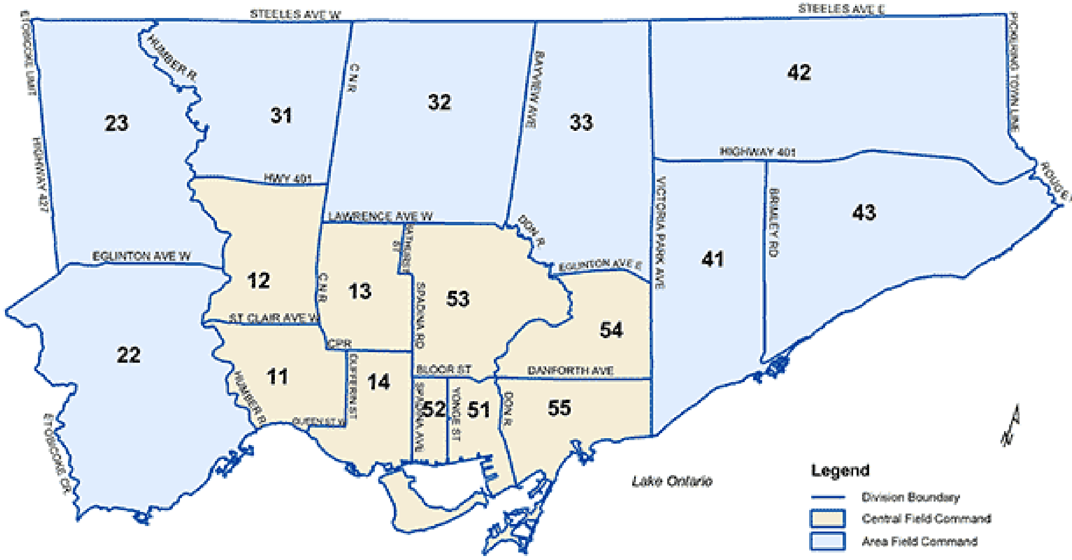


Figure 3.3 – Toronto Police Divisions
Data Source: Toronto Police Services, 2013

3.3 Potential Users and Key Stakeholders

Of the potential users for these applications, three groups of key stakeholders that could benefit from the results of this thesis were identified. Each stakeholder group was subjectively given an importance rank based on how beneficial the results of this thesis would be to them, as assessed by the author. Assessing the potential users helped to identify the needs that the Web applications would have to fill.

The largest and most important stakeholder that was identified is the Toronto Police Service. The TPS operates within the City of Toronto and possesses a public safety mandate which could benefit from the success of the goals outlined for this thesis. An increase in incident reporting would provide more data for the TPS to use in their analyses. Additionally, the use of a new online channel would promote the two-way flow of information between the TPS and the public that they serve and would allow for better public engagement and for the faster dissemination of official TPS information.

Related to the TPS, three groups were identified as having the most potential of benefiting from the results of this study. The first unit is the Crime Information Analysis Unit, which produces the static maps that are currently being published by the TPS. The Web applications that were used in this thesis could potentially be applied as a guide for developing their own Web-based applications that could replace their current mapping workflow. The second unit that was identified was the Organized Crime Enforcement group. This group could directly benefit from data on gang-related graffiti identified through the Graffiti Tagger application. Such data could be used to help identify the distribution of known gangs within the City of Toronto and to track the movements of gang members and potential offenders. The final unit that was identified was the Crime Stoppers unit. Although Crime Stoppers is an external organization that is technically independent of the TPS, it maintains a strong partnership with the TPS. The results of this thesis could benefit Crime Stoppers by providing data that could be used to help determine if the inclusion of an online interactive mapping application for reporting crime incidents could benefit or enhance their current online presence.

The second most important stakeholder group identified was the *Crime Prevention Association of Toronto*, and in particular, the Neighbourhood Watch group. Similar to the Crime Stoppers, the Toronto Neighbourhood Watch group could potentially benefit from the inclusion of an online interactive mapping application for reporting crime incidents. Such a platform could not only increase the total number of crimes that are reported, but it could more importantly provide a common interface that would allow non-technical users to quickly and easily display crime incidents and immediately recognize which incidents could impact their specific neighbourhood.

The final stakeholder group identified was any citizen of Toronto, particularly those who wish to participate in or contribute using the developed WebGIS mapping applications. Members of this group could participate for a variety of different reasons and each member may expect to gain something different in return for their participation. While some participants may wish to only contribute data for the betterment of the city that they reside in, others may wish to use the applications as a source of spatial data for their own personal analyses. For instance, some users may choose to use the Web applications for the purpose of locating a safe neighbourhood when purchasing a new home or the safest areas to walk through at night. The reasons for participation can never be fully known, although the results of this study may provide additional insight into the factors that motivate users to voluntarily contribute information about their victimization experiences.

As a Web application developer, one cannot make the assumption that all potential contributors are familiar with Web mapping or crime reporting. In order to accommodate for the widest range of potential users and to be as inclusive as possible, each application should be designed to be simplistic, fast, easy to use, and visually stimulating. Doing so would potentially increase the number of users that feel comfortable enough to contribute their own spatial crime or graffiti data. In an effort to achieve this, both applications were designed to appeal to novice and first-time users.

Before developing any application, one must first consider the needs of both the users of the application, as well as any stakeholders that will be affected. The skill level of the user dictates the overall complexity of an application as well as the amount of information that can be displayed at a given time. The applications that were developed as part of this thesis were designed to be open and accessible to any interested citizen of Toronto, regardless of their skill level or relevant experience. As such, the skill level of potential users can range from anywhere between advanced and novice. For the purpose of this thesis, users were divided into three categories based primarily on their skill levels and experience with crime mapping. Potential users were classified as, (a) Advanced, (b) Intermediate, or (c) Novice. In addition to skill level and experience, it was assumed that users in the same category would possess similar reasons for using the applications and have similar expectations on how they could benefit from these applications. These three categories are discussed in greater detail in the following sub-sections. It is important to note that at no time were users assigned a skill level by the applications administrator. Skills levels were self-defined by the users themselves and did not impact how the user could interact with each application..

Advanced User

Users classified as advanced were the least common type of application user and made up only a small part of the total number of users for each application. Although there would be a limited number of advanced users, they have the most potential benefit from using these applications. It was assumed that the advanced user group would be made up primarily by members of the TPS. These users would interact with the crime incident and graffiti data the most and use it in their own analyses. In the current setup, data could be transferred on request from the author to members of the TPS; however, if the TPS were to deploy a similar system, TPS analysts would be able to utilize the same data within a desktop GIS environment in real time. By hosting the Web, data, and GIS servers, the TPS could potentially streamline their current processes, allowing for a deeper level spatial analysis to occur within a shorter period of time. Once in a local database, the crime data could be overlaid with other internal datasets, such as known gang areas, past crime reports, demographic data, or points of interest. Hosting the servers would also allow the TPS to moderate and approve incoming data and would provide a system for quickly communicating new information externally to the public. Within the TPS, users who would most likely fall within the Advanced User group would be analysts within the Organized Crime Enforcement group, as well as the Crime Information Analysis unit. It was assumed that users in this category had some level of formal training in spatial analysis and were comfortable using a Web mapping interface. Advanced users from within the TPS would be declared as internal users and in the future, could be granted additional access to restricted or confidential data fields that are not by default made publically available. Internal users could also have access to additional data that is not immediately released to the public due to an ongoing investigation.

Intermediate User

Intermediate users are categorized primarily based on their higher than average interest in either of the developed Web applications. Users within the Intermediate group were likely to be repeat users, accessing and potentially contributing spatial data on multiple occasions. The Intermediate user group would likely be comprised of a mixture of everyday public users, as well as members of crime prevention organizations, such as the Toronto-based Neighbourhood Watch group. Users that are a part of a professional organization or independent business may have wished to monitor crime trends in a specific region due to a vested interest, such as ensuring the safety of their own neighbourhood, investigating leads for a news story, or by simply looking for specific outbreaks of criminal activity in the area where their business operates. An individual would be considered to be an Intermediate user, if they were a repeat user who for any reason accessed and contributed to either of the Web applications on multiple occasions. An individual would also have been categorized as an Intermediate user if they accessed either application on multiple occasions to pull the data for their own independent analysis. It was assumed that users from this category possessed a limited background knowledge of spatial analysis and were familiar with using a Web mapping interface.

Novice User

Novice users are the most common type of user and categorized primarily based on their limited usage history. These users visited either application only once or twice for the purpose of reporting a single incident or simply out of curiosity to view the data. It was assumed that Novice users had little to no background knowledge of spatial analysis and were not familiar with using a Web mapping application. This assumption was used despite the wide-spread popularity of Web mapping applications such as *Google* Maps.

As stated earlier, it was important to design each Web application with the skill levels and the end goals of the users in mind. It was therefore decided that in a bid to encourage overall user contributions, the Web applications would be designed primarily for novice users in mind. In order to minimize the learning curve for first-time users, the applications included detailed instructions on how to effectively use or navigate around them. A minimal number of icons and map controls were used and map functionality was restricted to only a few key functions in order to help guide user contributions and to not overwhelm any first-time users. Additionally, users were only able to select from a predefined list of crime types; however, they were given the ability to expand on their reports through the use of a comment field. Limiting the number of options and using a mobile-themed interface for the Graffiti Tagger Web application allowed users to quickly capture and report crime incidents and graffiti while on the go.

By designing the Web applications specifically for Novice users in a bid to increase the amount of user contributions, it was believed that advanced and intermediate level users would also benefit in the long-term by having more data available for their own analyses. It was expected that users who wished to do any type of a deeper spatial analysis would want to take the volunteered spatial data outside of the Web application environment and would therefore not require analytical tools to be built directly into the Web applications.

3.4 Current Context for Applications and Similar Works

When examining the relevant literature associated with this thesis, it was noted that only a limited quantity of research currently exists combining the areas of mobile GIS, Web GIS and VGI. Of the literature that was reviewed, only a small number featured the use of these tools and methods within the fields of crime mapping and crime prevention. In addition, while researching real world examples of systems incorporating these tools and methods, very few examples were found of comparable systems that were being actively used in Canada. This was in stark contrast with the prevalence of comparable systems within the United States.

Although some examples of crime mapping Web-based applications do exist in Canada, the author discovered that no such Web application is currently active in the City of Toronto. These examples will be discussed in further detail later. However, as the City of Toronto is the most heavily populated city in Canada, the absence of a modern crime mapping Web application seems to be a potential missed opportunity (Population and Dwelling Counts, 2013). In addition to the historical literature available on these topics, the author noticed a recent increase in the prevalence of crime mapping being used by the local media within the study area. At the same time, gang-related activities, especially those of a violent nature, have also become a commonplace occurrence in daily local news. This section builds upon the research previously presented in the ***Literature Review*** section by exploring some of the modern day Web applications that are available, as well as some of the alternative methods currently used in the fields of crime mapping and crime prevention. This section will provide the reader with an understanding of how this thesis adds to the existing body of research on these topics. It is hoped that the results of this thesis can add to and improve upon some of the crime reporting techniques that are currently being used.

Toronto Crimes Database

The Toronto Crimes Database was built in order to provide the City of Toronto with a modern and interactive method for mapping and reporting incidents of criminal activity. Crime mapping has become an important topic in local news as of late as high profile crimes have occurred in heavily populated areas. Major publications such as the *Toronto Star* have seen the importance of these applications and released their own interactive crime maps for the city (Interactive Toronto Crime Maps, 2012). These maps utilized the Tableau software and provided both historical and year-old crime data for a number of different crime categories within the City of Toronto. In addition to this, the *Canadian Broadcasting Corporation* has produced their own set of interactive crime maps that use the *Google* Maps API and *Google* Charts to provide both historic and year-old crime data for the City of Toronto (Freissen, 2013).

Presently, the Toronto Police Service provides static image crime maps that are available to the public over their Web site (TPS Crime Statistics, 2013). These maps cover a number of different geographies that each represent a neighbourhood of Toronto. The maps are difficult to navigate and often appear cluttered as a result of the non-visually appealing symbologies that are used. In addition to these maps, the TPS provides a relatively up-to-date listing of current crime reports (Major News Reports, 2013). Although a number of these reported crime incidents contain spatial information, they are presented only in written form, without any geographical information for conducting any form of spatial analysis. The practice of reporting crimes using only written summaries, end of year statistics, and static maps is commonplace in Canada, evident in current practices of the Vancouver Police Service (Crime Maps, 2013). However, some Canadian police services, such as the Richmond Police Service, have developed their own interactive crime mapping applications, which utilize the Open Street Map basemap (McGee, 2013).

Within the United States, a number of online crime mapping companies exist which develop and manage Web applications that are comparable to the proposed Toronto Crimes Database Web application. Perhaps one of the most predominant and active companies within this field is CrimeReports (CrimeReports, 2013). CrimeReports provides a Web based mapping interface for displaying crime information by using crime data that is provided from participating police services. In addition to the United States, CrimeReports has a presence in Canada. Some police services in Canada, such as the Ottawa Police Service, supplement their crime statistics information by participating with CrimeReports. Applications such as CrimeReports are limited, since they only present confirmed data from participating police services. Users are unable to anonymously report crimes through this system, although a "Submit a Tip" option is available. CrimeReports provides additional functionality, such as online crime analytics at a fee.

Since the inception of this thesis, a number of Canadian police services have since recognized the importance of providing online crime mapping services to the public. A number of these police services from across Canada now partner with the US-based CrimeReports. Some examples include the Halton Regional Police, the York Regional Police, the Victoria Regional Police, and the Abbotsford Regional Police. Crime information is contributed from the police service to CrimeReports and mapped spatially. Each of these police services provide a link to the CrimeReports Web mapping application from their official Web site. Although costs will differ between the various participants, it was estimated that in 2011, it would cost the Victoria Police Service approximately $150 per month to continue to participate (Bell, 2011). An image of how Crime Reports utilizes Canadian crime data is shown below in **Figure 3.4**.

Figure 3.4 – CrimeReports Crime Map
Data Source: CrimeReports, Ottawa Police Service, 2013

Currently, the Toronto Police Service has not partnered with CrimeReports. If the results of the Toronto Crimes Database are deemed a success, the Web application could provide a relatively inexpensive alternative that would allow the TPS to utilize this Web mapping technology without the need to pay a third-party company to manage their data. This could lower operating costs and increase productivity within the TPS by removing the need for a middleman. In addition, the Toronto Crimes Database would improve upon CrimeReports in a number of ways such as by providing a system for anonymous incident and comment reporting directly with the TPS, by temporally-enabling the data, by allowing for the easy overlaying of other spatial data, by allowing the TPS to communicate updates back to the public, and by providing the option for the TPS to select the types of crimes that are reported and to customize the symbologies that each crime type uses. Data that is collected and displayed using this Web application could be directly incorporated into any spatial crime analyses within the organization at no additional cost. Because the data is hosted online, the potential for automating processes such as the development of crime summary reports for senior police officials would also exist.

Graffiti Tagger

Recently, gang-related crimes have become a common occurrence and are widely reported in the City of Toronto's news reports. Among these occurrences, many have been high-profile shootings, such as the Boxing Day (Charles, 2005) shooting in 2005, the Eaton Centre food court shooting (Edmiston, 2012) and the Danzig shooting (Poisson, 2012) in 2012, as well as the Yorkdale shooting (Pagliaro, 2013) and Cabbagetown Seniors Home shooting (Mills, 2013) in 2013. These numerous occurrences have highlighted the dangers that can occur when gang-related violence spills into a crowded public area.

Gangs are traditionally secretive in nature; however, as a way of showing off their territory to rival gangs, many gang members participate in the practice of graffiti tagging. Gang graffiti tags detail a gang's perceived territory of control and can contain useful information, such as the specific gang member who left the tag, their specific gang's affiliation, as well as messages to rival gangs (Otto et al., 2000). This information can be used by police to monitor gang activity, to better understand the relationships between rival gangs, and to define each gang's perceived territory boundaries. When perceived gang territories begin to overlap or gang tags begin to purposefully appear within a rival gang's perceived territory, the potential for a conflict to occur in the near future increases. These areas could benefit from increased police presence to deter future violence. Increased police presence could also benefit areas where trends in gang territory spread can indicate a potential conflict in the distant future. At the same time, the City of Toronto has also placed an increased importance on the removal of graffiti from public spaces. This push was demonstrated in the City of Toronto's *Clean Toronto Together* events of 2013 (Let's Clean Toronto Together, 2013). The significance of these events was underscored by the participation from the City of Toronto's mayor Rob Ford (Moloney, 2013).

Some cities, such as the City of Riverside in California, have recognized the importance that GIS can offer to the field of gang tracking. The City of Riverside utilizes public works employees to record and contribute gang graffiti images using GPS enabled cameras to the local police service before removing it (Keeling, 2009). The Graffiti Tagger application builds upon this idea by expanding it to the public in the form of a mobile designed Web application. Doing so enables any member of the public to become a citizen sensor that can report on gang-related graffiti. With the popularization of GPS-enabled smartphones within the City of Toronto, a large number of potential contributors exist that can report these incidents at a high level of accuracy from within the field. Contributions could then be potentially analyzed for gang affiliations and messages by a trained analyst within the Toronto Police Service.

It is believed that the results of this thesis can be used to strengthen the literature that currently exists for the fields of Mobile GIS, Web-Based GIS, VGI, as well as Crime Mapping. The results of this thesis have the potential to provide a working and documented proof of concept that details how Web-Based GIS solutions can be used in conjunction with mobile platforms by novice, intermediate, and advanced users to effectively complete a series of tasks. Moreover, the data that is collected can be used to help provide additional insight into the spatial distribution of crimes in North America, specifically with regards to crime distribution in built-up urban areas within Canada. In addition, the results of these applications have the potential to provide a successful example of how crowdsourcing a data acquisition process in order to produce VGI can be an effective method for collecting spatial information and can improve on data acquisition techniques that are currently being used.

3.5 Chapter Summary

This chapter discussed the current context for these applications within the City of Toronto, provided examples of similar systems that are in use elsewhere in Canada, and emphasised why there is currently a need for additional research on this topic. In addition, this chapter examined a number of potential users and key stakeholders that could be impacted by the results of this thesis. Moreover, the various datasets that were used in this thesis were discussed, along with their specific role within the Web applications. In summary, a need for additional research on these topics currently exists and is becoming increasingly important and relevant in the City of Toronto's current affairs.

CHAPTER 4

Methodology

This thesis was comprised principally of two distinct Web applications and one survey. The Web applications were the final products of this thesis, while the survey provided the means of assessing the results. In this chapter, an overview of the methods that were used in the planning, development, and testing stages of the Web applications and survey are discussed. This chapter begins with discussing the conceptual design of the thesis and how it was subsequently modified. The hardware and software that was used to integrate multiple servers are then discussed. The data that was produced in order to create the final products will then be discussed. The methods used to implement these Web applications are also explained, focusing primarily on the authoring of the map services, as well as the development of the Web applications that provide these services. The chapter concludes with examining the survey that was conducted to assess the effectiveness of the Web applications and by exploring a number of alternate methods. Throughout this chapter, the rationale behind decisions made throughout the development and testing of the Web applications is discussed.

4.1 Web Application Design

In order to achieve the final product of two successfully functioning Web applications (**Figure 4.1**), a number of different servers and services were integrated together. To have the ability to serve editable spatial data in an online environment required the use of multiple servers. A Virtual Machine (VM) was provided by the Mapping, Analysis and Design (MAD) Team at the Faculty of the Environment at the University of Waterloo and was used to develop both Web applications. Once the operating system (OS) had been installed on the VM, the OS was then configured to support both ArcGIS Server and to act as a stand-alone Web server. ArcGIS for Desktop 10.1 and ArcGIS for Server 10.1 were both installed and used to author and publish the map services and datasets that were used. *Microsoft* SQL Server 2008 R2 Express was installed using the ArcGIS for Server 10.1 installation media. Using SQL Server, a database server was created on the VM and configured to use ArcSDE. ArcSDE was used in order to allow the database to serve spatial data that could be used within the ArcGIS software. This in turn allowed the author to utilize it for hosting editable feature services.

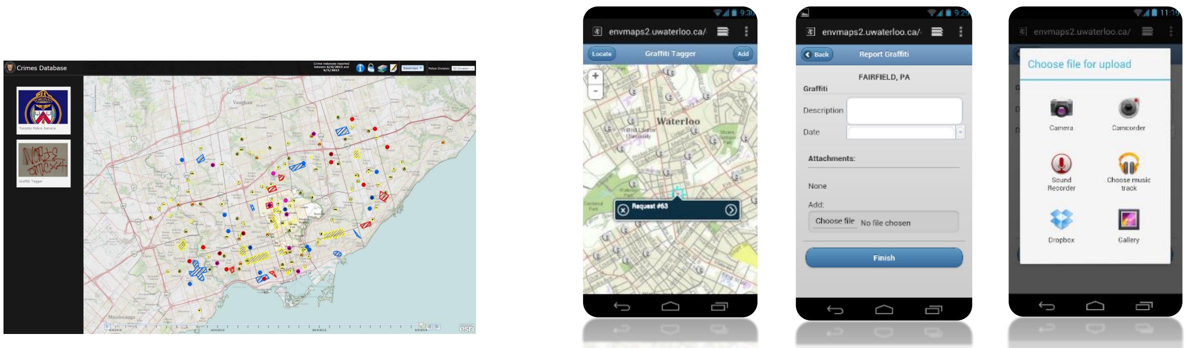


Figure 4.1 – Finished Web Application Thumbnails

Once all map services and feature services had been authored and published, two Web applications were developed using the ArcGIS API for JavaScript and were hosted using the Web server folders on the VM. Notepad++ was used to design the Web applications and a combination of *Microsoft* Internet Explorer, *Google* Chrome, and Mozilla Firefox were used to test them. The survey was developed using *Microsoft* Word 2013 and was distributed to potential participants using the University of Waterloo email system. As a result of the author working remotely for the majority of the thesis, remote access techniques were often used such as mapping network drives from the VM on a remote computer, using Remote Desktop Connection (RDC) to access the VM, and using ArcMap 10.1 and HTTPS to remotely administer the GIS server. In order to use many of these techniques, Cisco AnyConnect Secure Mobility Client VPN was used to establish a connection to the University of Waterloo network. Having only a single VM to host a Web server, Database server, and GIS server helped to limit the overall footprint of this thesis and any associated costs that would result if these applications were to be recreated in the future. Additionally, by maintaining only one VM, data storage and organization was simpler and less configuring was required. The flow chart depicted in **Figure 4.2** below provides a simplified view of the various core components that were used to complete this thesis and how they interacted with each other.

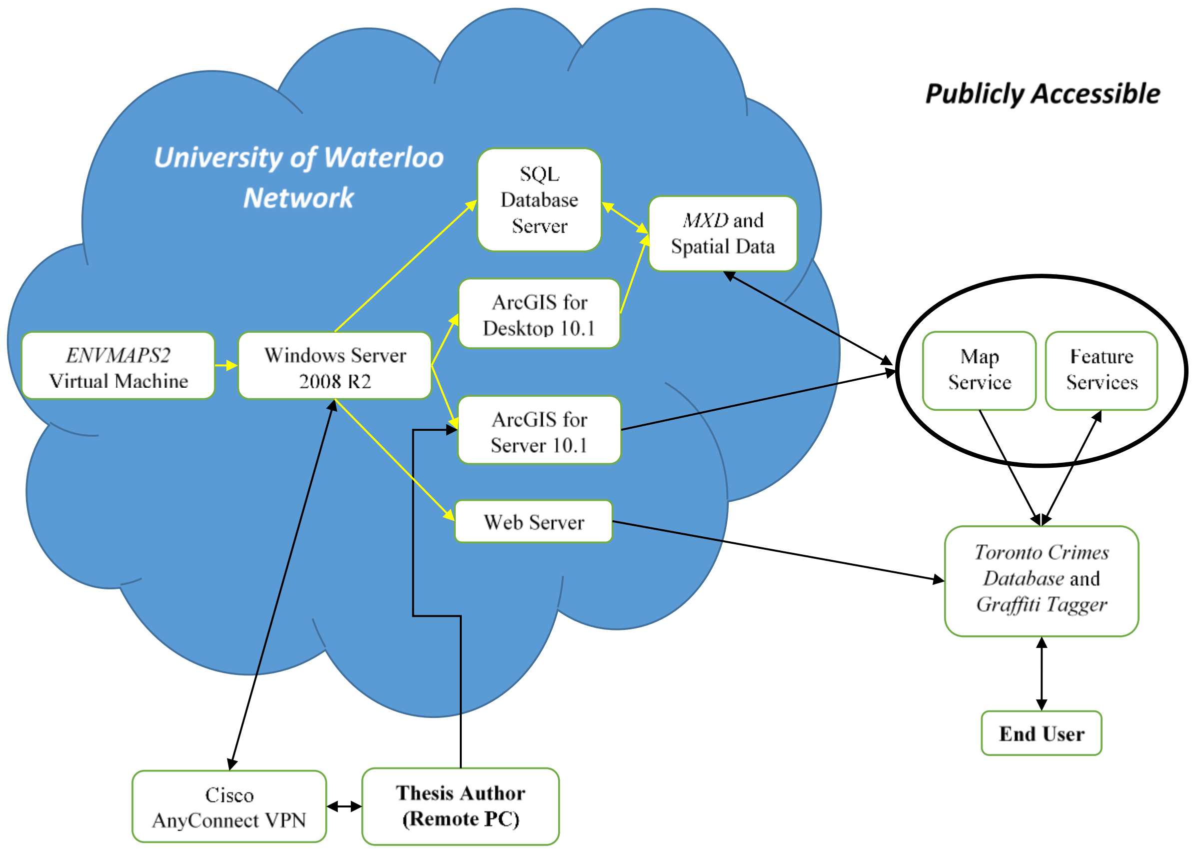


Figure 4.2 – Components of the Toronto Crimes Database and Graffiti Tagger

4.2 Configuring the Development Environment

In 2012, the thesis underwent a series of changes in which both the study area and the server environment for hosting the Web applications was changed. The original study area for this thesis was the Region of Waterloo, but in early 2012, this was changed to the City of Toronto. This change came about primarily as a result of the author relocating. It was believed that changing the study area to the City of Toronto could benefit the application by providing an area that was both familiar to the author and could potentially foster a larger amount of user interest. It was also believed that the Toronto Police Service and the Toronto

Neighbourhood Watch groups would be more established and willing to participate in this thesis. This change in study area resulted in the need to redevelop the data and Web applications, which had originally been designed specifically for the Region of Waterloo and the Waterloo Regional Police Service (WRPS). The design environment was also updated to support a newer version of the *Esri* GIS software, ArcGIS 10.1.

Ensuring proper configuration of the development environment is a time consuming process, but an essential stage of the overall development process. The development environment that was used in this thesis was based out of the Faculty of the Environment at the University of Waterloo in Waterloo, Ontario. A VM with 2GB of RAM was imaged with *Microsoft* Windows Server 2008 R2 (x64) and was provided by the Mapping, Analysis and Design team for use in this thesis. Remote access capabilities were immediately enabled on the VM by MAD staff in order to allow the thesis author to effectively configure the server environment. The VM was assigned the name ENVMAPS2. RDC was used to establish a connection to the envmaps2 VM using the address *envmaps2.uwaterloo.ca* and the author's Nexus domain credentials from the University of Waterloo. Upon gaining access to the VM, the author used *Server Manager* to enable the Web Server (IIS) role and the .NET Framework 3.4.1 features. Once these were configured, ArcGIS for Desktop 10.1 Pre-Release and ArcGIS for Server 10.1 Pre-Release were installed and authorized by MAD staff. The Pre-Release versions of the software were later updated to the full release versions using an automated update procedure.

The ArcGIS Web Adaptor was included as part of ArcGIS for Server 10.1 installation and was jointly configured by the thesis author and MAD staff to enable both admin level and common user access to the GIS server. The ArcGIS Web adaptors were used to enable access to hosted GIS services over the Web. The first Web adaptor was configured on port 80 for common user access and was named "arcgis". The second Web adaptor was configured on port 443, had administrative access enabled, and was named "admin". In order to secure this administrative access, *Internet Information Services* (*IIS) Manager* was used. After selecting **admin** from the sites folder in the connections window, the *Require SSL* option was then checked within the SSL Settings dialog. ArcGIS Administrator was accessed locally and used to enable HTTPS access. Once these options had been enabled, the author was then able to administer the GIS server remotely.

The next step in configuring the server environment was to install and configure SQL Server 2008 R2 Express (x64). An installation of this software was provided with the ArcGIS for Server 10.1 install media and was used to install a SQL database server titled envmaps2 on the local machine. Using the same install media, ArcSDE was also installed and configured to spatially-enable the new database server. A connection to the SQL database server was made in ArcMap 10.1 using the *Add Database Connection* option within the *Catalog* tree. A geodatabase (GDB) was then created in the SQL database server which would subsequently be used to manage the datasets used in this thesis. If needed, authorized users would be allowed to access and download a local copy of the data from the GIS server through SQL Server.

Following the successful installation of the database server, Notepad++ was installed on the VM and used for developing both Web applications using a combination of HTML coding and JavaScript (JS) coding. The ArcGIS API for JavaScript was selected, as it is a light-weight solution that can be implemented in a number of different browsers, as well as on a number of different mobile devices. In contrast, the ArcGIS API for Flex required the use of Adobe Flash to view any applications and would additionally require the use of Adobe Flash Builder for any development. Although the ArcGIS FlexView could be useful for quickly developing basic web applications, the modular approach it took to Web application development could potentially limit the ability of the author to customize each Web application. The ArcGIS API for Silverlight required the installation of the *Microsoft* Silverlight Plugin in Web browsers and would have additionally required *Microsoft* Visual Studio for any development.

The final stages of the configuration process involved configuring the remote desktop to easily access and administrate various aspects of the VM. To accomplish this, Cisco AnyConnect Secure Mobility Client VPN was installed on the remote desktop, allowing it to connect to the University of Waterloo network. Once connected to the network, Windows Explorer could be used to map a network drive into both the C drive and the D drive on the VM. Both were used as the D drive contained the spatial data and map documents, while the C drive allowed access to the Web server folders. Additionally, once inside the network, RDC could be used to remotely control the VM. Because ArcMap 10.1 was installed on the remote computer as well, the author was able to use the Catalog tree to form an administrative connection with the envmaps2 GIS server using the admin Web adaptor that was configured earlier. Once the connection was established, the author could start, stop, delete and publish map services directly from the remote computer. The GIS server was also configured in such a way that the author could administer the server through the ArcGIS Server Administrator interface from any computer using an HTTPS connection to the admin Web adaptor in a Web browser. Each of these techniques allowed the author to have near full control over the development environment during the thesis period.

Table 4.1 below summarizes all the software and operating systems that were used in order to produce the Web applications and survey that were used in this thesis. In addition to the software listed in Table 4.1, a number of other software were used in order to test alternate development methods and in order to enable the author to be able to work remotely.

Table 4.1 – List of Software and Operating Systems Used in this Thesis

Microsoft Windows Server 2008 R2 (x64)	OS used on the VM
Notepad ++	Used when developing JavaScript code for Web applications
ArcGIS for Server 10.1 (x64)	Used to host map and feature services
Microsoft Internet Explorer	Used to view and test the published Web applications
Mozilla Firefox (Firebug Extension)	Used to view and test the published Web applications
Microsoft Windows XP/7/8	OS that was used by the author on his remote computers
Microsoft Paint	Used for capturing, cropping and basic alterations of images
Microsoft SQL Server 2008 R2 Express (x64)	Used to store and manage the data that was used
ArcGIS for Desktop 10.1 (ArcInfo/Advanced License)	Used to produce the maps and data that were used
ArcSDE 10.1	Used to spatially-enable the SQL database
Microsoft Office 2013/2010/2007	Used to develop the survey, tutorials, and final thesis documents
Google Chrome	Used to view and test the published Web applications
www.pixlr.com	Used for more advanced image alterations

4.3 Data

Data is one of the most important components of any spatial analysis. One of the primary goals for both of the Web applications developed in this thesis was to aid in the collection and public dissemination of crime-related data. If deemed successful, these Web applications would have the potential to open a new channel for gathering crime-related data that could be used as an important input in a number of meaningful spatial analyses. Data that were acquired through these Web applications would be inherently spatial in nature but would also contain a wealth of useful attribute information. The spatial data could be used as an input dataset for modelling criminal activity, while the additional attribute information could be used to help qualitatively describe and better understand the incidents of criminal activity that have occurred. Although data that was volunteered would be unconfirmed, it was felt that with an active community of moderators, data errors and misinformation could be kept to a minimum. A successful example of this can be seen with Wikipedia. Wikipedia relies on volunteered users contributions, yet, by the subjective standards of the author, still maintains a relatively higher degree of reliability than other online sources due to its active community of moderators that review new contributions. It was believed that the inherent risks of using volunteered geographic information (VGI), such as malicious misinformation or data inaccuracies caused by inexperienced users with different data collection devices, were outweighed by the potential benefit that a new data source would be able to offer. In addition to the crime incident data that would be produced as a result of the Web applications, data was also a necessary requirement for developing meaningful and effective Web applications.

The Web applications that were developed used three types of spatial data. This section discusses different datasets that were used in the Web applications, including the source of the data, how the data was used, and how the data was processed and optimized for use in the thesis. The first type of data consists of passive basemaps used to provide background context to users when plotting their crime incident or graffiti reports. The second type of data consists of map services that provide additional context to the user, such as the current boundaries of the TPS divisions. The third and final type of spatial data consists of active feature services that allow users to both visualize existing crime reports that were submitted by other individuals, and to contribute their own crime reports. This section will only examine spatial data, while survey data results are subsequently presented in the **Results and System Evaluation** chapter. The following **Table 4.2** provides a comprehensive list of data used in this thesis.

Table 4.2 – List of datasets used in this thesis project for developing WebGIS applications for crime mapping in the City of Toronto

Dataset	Non-Default Fields (type :length)	Projection	Data Providers	Date Acquired	Data Currency	Time-Enabled	Scale
Imagery Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP Swisstopo, and the GIS User Community*	N/A	Ongoing	No	Global
Imagery with Labels Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community*	N/A	Ongoing	No	Global
Streets Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, DeLorme, NAVTEQ, TomTom, USGS, Intermap, AND, ESRI Japan, METI, ESRI Hong Kong, ESRI Thailand, Procalculo Prosis*	N/A	Ongoing	No	Global
Topographic Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, Kadaster NL, Ordnance Survey, Esri Japan, METI, and the GIS User Community*	N/A	Ongoing	No	Global
Terrain with Labels Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, USGS, NOAA*	N/A	Ongoing	No	Global
Light Gray Canvas Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, DeLorme, NAVTEQ*	N/A	Ongoing	No	Global
National Geographic Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*National Geographic, Esri, DeLorme, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC*	N/A	Ongoing	No	Global
Oceans Basemap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*Esri, GEBCO, NOAA, National Geographic, DeLorme, NAVTEQ, Geonames.org, and other contributors*	N/A	Ongoing	No	Global
OpenStreetMap	N/A	WGS 1984 Web Mercator (auxiliary sphere)	*OpenStreetMap project*	N/A	Ongoing	No	Global
City of Toronto Neighbourhood Planning Areas	DAUID (Text:8) PRUID (Text:2) CSDUID (Text:7) HOODNUM(Short) HOOD (Text:33) FULLHOOD (Text:250)	UTM 6 Degree, NAD 27, Zone 17	*City of Toronto – Open Data Catalogue*	2012	Oct - 2009	No	Local
Toronto Police Divisions (x20)	Division (Text:50)	WGS 1984 Web Mercator (auxiliary sphere)	*James Lockyer-Cotter, City of Toronto, Toronto Police Service*	2012	2012	No	Local
Crime Instances	Type (Text:100) Class (Text:50) Description (Text:500) Date (Date)	WGS 1984 Web Mercator (auxiliary sphere)	*James Lockyer-Cotter, Multiple Sources*	2012	Ongoing	Yes	Local

Citizen Comment	Importance (Text:1) Description (Text:500) Date (Date) ContactName(Text:100) ContactEmail (Text:75) ContactPhone (Text:20)	WGS 1984 Web Mercator (auxiliary sphere)	*James Lockyer-Cotter, Multiple Sources*	2012	Ongoing	Yes	Local
Graffiti	Type (Text:50) Description (Text:500) Date (Date)	WGS 1984 Web Mercator (auxiliary sphere)	*James Lockyer-Cotter, Multiple Sources*	2012	Ongoing	Yes	Local

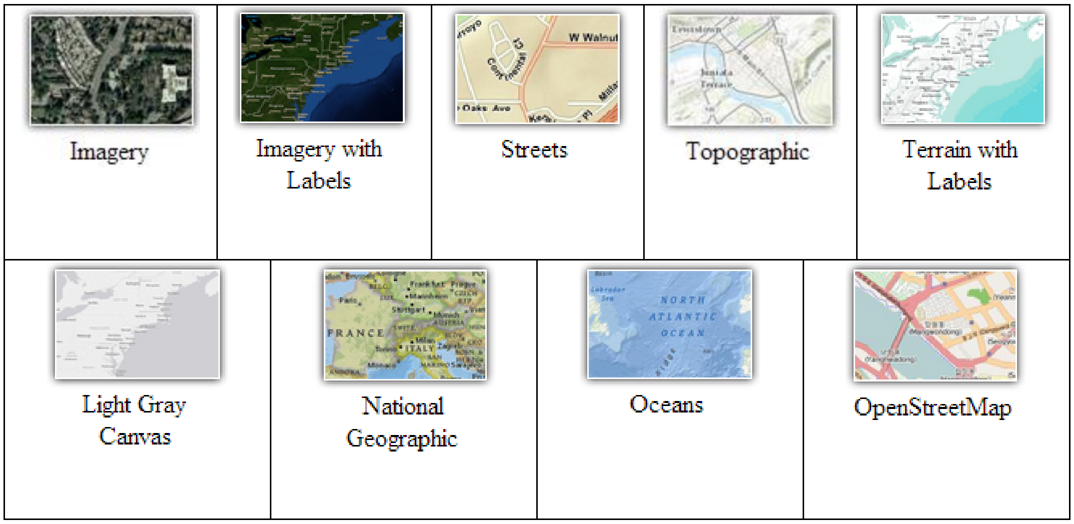
4.3.1 Basemaps

Basemaps are designed to provide the context that is necessary for effectively displaying any type of spatial data. In this thesis, basemaps are included in an attempt to help facilitate the accurate reporting of criminal incidents by providing a spatial context for crime incident reporting and by aiding in the identification of locations of past crime victimization experiences. By providing an abundant source of spatial context, it is believed that first-time and novice users would feel more inclined to contribute. Without spatial context, any user would be unable to accurately plot their crime report. Basemaps have become commonplace for many people who visit Web sites such as *Google* Maps on a routine basis. By including a pre-configured online basemap, the overall performance of any Web applications can be greatly enhanced by removing the additional demand that would be placed on a GIS server to host large amounts of imagery or street network data. The basemaps that are hosted online are cached map services that come from a number of different providers. As a cached map service that is hosted in the cloud, basemaps are specifically designed to render quickly and are able to provide spatial context for large areas. The online basemaps that are provided by *Esri* are used to complement a number of professional-grade Web applications and are designed with colour schemes that utilize a muted spectrum of colours. Using a muted colour scheme allows any additional spatial data that is added to a Web map to "pop-out" from the surrounding features on the basemap. As the basemap is used primarily for the purpose of providing spatial context, the fact that the features which are displayed in the basemap are not able to be queried does not negatively impact its usability.

The Toronto Crimes Database (CDB) application utilized a series of basemaps that were made accessible by selecting the Basemap Gallery dropdown button. By default, the topographic basemap was selected for use. The topographic basemap was produced by *Esri* and was developed using spatial data from a number of professional-grade data providers. In addition to the professional-grade data providers, the topographic basemap also contained data that was provided through the *Esri* Community Maps program (Community Maps Program, 2013). The Community Maps program is an ongoing initiative that collected spatial data provided at no cost from recognized institutions such as colleges, universities and local governments. Contributed data included physical features that make up the landscape, such as roads, building footprints, and natural features. In exchange for providing detailed and current spatial data, *Esri* digitized and hosted the spatial data as a part of the topographic basemap. The City of Toronto was an active contributor to the Community Maps program and routinely provided some of the most current spatial data that was available to the public (Current Contributors, 2013). By using a product that was routinely updated and moderated by an external source, the burden of uploading and maintaining this additional dataset was removed. Additionally, cached basemaps that were hosted by *Esri* loaded in far less time, were less prone to data errors, cost nothing to use, and would potentially consume less bandwidth to load than if a similar dataset were hosted on a single GIS server. Moreover, the visual appeal of each basemap that was provided far exceeded what could have been achieved using simple road line segments and building footprint datasets. The author does, however, recognize that no single dataset can be completely exhaustive and therefore, the option to toggle between multiple basemaps within the *CDB* Web application was included.

The benefits listed above make the topographic basemap the most ideal choice as a default basemap for the application. In addition to the CDB application, the Graffiti Tagger application also utilized the topographic basemap as the default basemap; however, unlike the CDB application, the option to switch between basemaps was not included in the Graffiti Tagger Web application in order to prevent any non-essential features from cluttering the mobile-friendly interface. In addition to the topographic basemap, the following basemaps in the section below were made available. Thumbnails of each basemap can be seen below in **Figure 4.3**.

Figure 4.3: Basemaps used in Web applications



Imagery – The imagery basemap was a product from the Community Maps initiative. This basemap provided aerial imagery for the world at a number of different scales. Imagery that was provided was either purchased from professional-grade data providers, or contributed as a part of the Community Maps program. Although at a global level, this basemap may have been less current in certain areas when compared to similar aerial imagery basemaps from either *Google* or *Bing* maps. Aerial imagery for communities that contributed their data through the Community Maps program could at times be more accurate. To host only a small subset of this imagery that covers the study area would require a large amount of hard drive space and processing time. Users may have chosen to utilize the imagery basemap within the Web application in order to identify a precise location when reporting crimes that may not have been digitized into the topographic basemap. For instance, a user who wanted to report an incident that occurred in a park would have a difficult time using the Topographic basemap, as the entire area may only show as a single coloured polygon. However, if using the Imagery basemap, the user would be able to locate the precise spot based on its relative location to identifiable features within the park.

Imagery with labels – Similar to the Imagery basemap, the Imagery with labels basemap provided the same set of aerial imagery as the imagery basemap; but also included a series of labels that identified specific features, buildings, as well as political boundaries. The advantage of using this basemap comes from the additional spatial context that was provided from the labels. However, this basemap also had the negative impact caused by the potential for some labels to overlap an area of interest, resulting in the unintentional blocking of important features.

Streets – Similar to the Topographic basemap, the Streets basemap provided a detailed roads basemap with global coverage at a variety of different scales. This basemap would have been preferable in situations where a user felt that the topographic basemap included too much unrelated information, such as water bodies or other physiographic features. The schedule for updates to the Streets basemap was less frequent than that of the Topographic basemap.

Terrain with labels – Although less practical in a crime reporting scenario, the terrain with labels basemap provided users with the ability to view changes in the earth's surface. This basemap would have been used in scenarios where a user wished to highlight their data without the clutter of many natural or manmade features, but still wanted to retain some of the context that was provided by the political boundary labels or through the inclusion of large features, such as highways or railways.

Light Gray Canvas – Similar to the rationale for using the Terrain with Labels basemap, the Light Gray Canvas basemap was primarily used for presenting crime reports and graffiti tag locations data without the distraction of the background features and colours that were visible in the topographic basemap. The light gray canvas basemap was designed specifically for this purpose and used muted colours and a minimalistic approach that allowed a user's data to stand out from the background basemap. This basemap would have been the recommended method for presenting contributed data, but lacked the spatial context that was provided by the topographic basemap, which was necessary for promoting accurate data reporting.

National Geographic – Similar to the Topographic basemap, the *National Geographic* basemap provided a global collection of natural and man-made features at a variety of different scales. What makes this basemap unique is the inclusion of distinctly *National Geographic* cartographic styles for producing this basemap. This basemap tends to provide a sense of familiarity to older users who may not have much experience with current Web mapping applications, such as *Google* Maps, but have been exposed to *National Geographic* map illustrations and wall maps in the past. It is believed that the increased familiarity could result in additional crime report contributions.

Oceans – The Oceans basemap displayed hydrographic features and was a default offering in the Basemap Gallery. Although this basemap had limited practicality in applications that were dedicated to urban crime reporting, it was believed that this basemap could also be used as a less cluttered backdrop for displaying crime incident data.

OpenStreetMap – The final basemap offering that was provided was the OpenStreetMap (OSM) basemap. This basemap provided users with an alternate basemap for visualizing natural and man-made features. It was believed that this basemap would appeal to users from the Open Data community that are familiar with the OSM's cartographic design. Users from the Open Data community were believed to be intermediate level users that were active contributors and users of the volunteered crime data. This basemap could be used by users in instances where the default Topographic and Imagery basemaps were missing information. This could occur due to a dataset being incomplete, or out-of-date. OSM contributors have the potential to collect large amounts of high-end spatial data through the process of crowdsourcing.

These basesmaps were provided by default when using the Basemap Gallery widjit provided in the ArcGIS API for JavaScript. Although many of the basemaps may be used in different scenerios, the author would likely customize the widget to limit the number of basemaps that are made available in any future releases of these Web applications.

4.3.2 Map Services

Map services were an important aspect of this thesis as they were the method of choice for disseminating spatial data over the Web. Map services are preconfigured collections of spatial data that are hosted on a GIS Server and can be used as an input layer for a variety of different Web mapping applications. In this thesis, map services were produced using *Esri* software. Map documents were configured using ArcGIS for Desktop 10.1 and upon completion, were hosted using ArcGIS for Server 10.1. By default, any spatial data that was referenced in the map document and was published would be copied to the server and accessible through the map service. This thesis used a dynamic map service, which was designed to allow for user queries and to load subsets of features on the fly when requested. Map services could have also been hosted as cached map services, meaning that the spatial data would be displayed as a series of image tiles at a number of predefined spatial extents. Although using this method would allow data to load faster and require less bandwidth to use, the features would not be able to be queried, removing the possibility for a user to easily change between the different types of features within the Web applications.

Although multiple services were hosted using ArcGIS for Server, only the *TPS_Boundaries* dataset was hosted as a stand-alone map service on the **envmaps2** GIS server at the University of Waterloo. This map service was a composite map service that consisted of a number of layers that each contained data specific to a single police division that was patrolled by the Toronto Police Service. This service was used primarily to provide additional spatial context for users of the Toronto Crimes Database Web application.

A static map containing the divisional boundaries of the TPS was available on the organization's Web site; however, the spatial boundary data was not made publically available. As a result, the divisional boundaries dataset that was used in this thesis was a copy of the original TPS dataset that was produced manually by the author for use specifically within this thesis. The hosted map services would therefore be classified as non-official data and may have potentially contained data inaccuracies in certain areas. In order to produce this unofficial dataset, a variety of sources and spatial editing techniques were used.

The division boundaries data was built using the City of Toronto's Neighbourhood Planning Areas dataset as the original guide. The neighbourhood-based dataset was provided for free from the City of Toronto's Open Data Catalogue (Data Catalogue, 2013). After examining a number of different census based geographic boundaries in an attempt to match the TPS division boundaries, the city's neighbourhood boundaries were determined to be the closest match. The data was available in an *Esri* shapefile format and was projected using a NAD27, UTM 17 projection. Unfortunately the data provided was only current as of 2009 and required additional manual alterations in order to match the boundaries of the TPS divisions. Once the neighbourhood boundaries data was saved locally and loaded into ArcMap 10.1, a new polygon feature class was created. The new feature class was assigned a WGS 1984 Web Mercator (auxiliary sphere) projection and was stored in a local file geodatabase. To help minimize the overall file size, the feature class was assigned only one non-default field. This text field was limited to 50 characters and was used to distinguish between the various police divisions. The aforementioned projection was chosen as it is an international standard for hosting Web-based spatial data. Commonly used basemaps, such as those provided by *Google*, *Bing* and *Esri* are all projected using this projection. In order to quickly and accurately display spatial data on top of a basemap, all data sources were set to use the same projection. Although ArcGIS for Server 10.1 had the ability to project spatial data into a different coordinate system on-the-fly, projecting all the datasets using the same projection prior to publishing would put less demand on the server, resulting in faster loading times.

Once created, the new feature class and the Topographic basemap were both loaded as layers into ArcMap alongside the neighbourhood boundaries layer. The new feature class was then edited using the *Trace* function from the editor toolbar. The trace function allowed the author to use the neighbourhood boundaries layer as a guide for creating new polygon features that represented the TPS division boundaries.

In addition, the TPS divisions map was used along with the individual division-specific maps and the Topographic basemap to guide the creation of areas where the neighbourhood boundaries did not align with the TPS division boundaries.

Once a unique record existed for each division, the data was then edited a final time. Multiple copies of the same dataset were added as unique layers to the map document. A definition query was then applied to each layer so that each layer represented a different TPS division. A negative approach was then used in order to highlight each division. This was accomplished by leaving the area encompassed by the each unique division as clear while darkening the surrounding areas. This cookie-cutter approach produced negative layers that when used correctly, could effectively focus a map on a specific area of interest, while blocking out or dimming any irrelevant spatial data. In order to accomplish this, a large rectangular polygon that covered a significant swath of Southern Ontario was used. This rectangular polygon was used as the input feature in the *Erase* tool, while the division was used as the erase feature. Outputs were given the division's number as its name and saved into the same file geodatabase. This process was then repeated for the remaining TPS divisions. Each output had to have its fields and values reassigned. Once completed, the data was configured in a separate map document and eventually published to the GIS server. The configuring and publishing steps will be discussed in further detail within the **Methodology** chapter. Map services would have been the default choice for hosting much of the additional spatial data that will be discussed later in the **Conclusions and Recommendations** chapter.

4.3.3 Feature Services

The inclusion of feature services was an essential component in both Web applications. Feature services are like map services in that they are both used for displaying spatial data over the Web. Unlike a map service though, feature services have the ability to allow for feature access and editing. When publishing a map document with feature access enabled, ArcGIS Server 10.1 publishes both a non-editable map service, as well as an editable feature service. Depending on how a feature service is configured, users can add, edit, and delete any hosted spatial data. A feature service can also be configured in a number of ways to restrict editing to a specific group of users, or to only permit certain functions, such as adding, but not deleting, data. Although feature services are highly useful for data collection and Web-based editing, they are also limited in how they display. For instance a feature service cannot process group layers in a map document and cannot display complex symbologies for a feature. Methods for getting around these limitations will be discussed later in the following sections.

In order to utilize a feature service, spatial data had to be stored within a spatially-enabled database. In this thesis, SQL Server 2008 R2 Express was used in conjunction with ArcSDE to store and manage the three spatial datasets that were published. Each of the following three datasets were originally created by the author and projected using the standard WGS 1984 Web Mercator (auxiliary sphere) projection. In order to optimize their performance, attribute fields were kept to a minimum and when possible, the length of each field was limited. In addition, a series of domains were used to help ensure data integrity by restricting the types of data inputs that could be made. To further optimize the performance of the Web applications, the author intended to archive older crime incident data in a local database on the VM after it was more than 30 days old.

Crime Instances – The Crime Instances dataset was published as part of the *Instances and Comments* feature service for use in the Toronto Crimes Database Web application. This dataset was a point feature class and contained four non-default fields. The *Type* field was used to determine the type of crime instance that was being reported and was a text field with a limit of only 100 characters. The *Type* field also used a coded value domain in order to ensure that only a predefined list of crime types could be reported. This field was used by the feature service to symbolize the data. The *Class* field was a text field that was limited to 50 characters and was included in order to group similar types of crimes into a shared category. Although included in the data, the *Class* field was not implemented in the application. This field could easily be updated retroactively by using the *Field Calculator* in conjunction with the *Select by Attribute* tool to create categories based on the values in the *Type* field. The *Description* field was another text field that was limited to 500 characters. The *Description* field was included in order to allow users to provide more detailed information about their crime report. This field would be useful when doing any sort of qualitative analysis on the data. The final non-default field that was included was the *Date* field. The *Date* field was a date-type field that allowed users to input the date at which a crime occurred. The *Date* field was important to include as the feature service which contained the Crime Instances dataset was temporally-enabled and managed this dataset based on the *Date* field. Temporally-enabled data will be discussed in further detail in a later section. The Crime Instances dataset was stored in a SQL Server 2008 R2 Express database that was hosted on the same machine as the GIS Server.

Citizen Comments – The Citizen Comments dataset was published as part of the *Instances and Comments* feature service for use in the Toronto Crimes Database Web application. This dataset was a polygon feature class and contained six non-default fields. The *Importance* field was used to gauge the severity of the comment that was being reported and was a text field with a 1 character limit. This field was assigned a coded value domain, so that users could only input specific values. In this domain, only the values L, M, H were permissible and represented Low, Medium, and High respectively. These values were used in the feature service to symbolize the data in the Toronto Crimes Database Web application. The *Description* field was another text field with a limit of 500 characters that allowed users to provide a detailed explanation of why they were highlighting a specific area of interest. The *Date* field was a date-type field that served the same purpose as the *Date* field in the Crime Instances dataset. The *Date* field was important to include as the feature service, which contained this dataset was temporally-enabled and managed this dataset based on the *Date* field. The three remaining non-default fields were each text fields of varying character lengths that were designed to include contact information in the situation that a user required a response. Although included in the hosted dataset, these three fields were not used in the application. This choice was made deliberately, since the final Web applications did not incorporate any security or user-authentication options and could therefore, not adequately protect this sensitive information. The Citizen Comments dataset was stored in a SQL Server 2008 R2 Express database that was hosted on the same machine as the GIS Server.

Graffiti – The Graffiti dataset was published as part of the *Graffiti_edit* feature service for use in the Graffiti Tagger Web application. This dataset was a point feature class and contained three non-default fields. The *Type* field was a text field with a character limit of 50 and was used to differentiate between the various types of graffiti that were reported. It was planned that users would by default report graffiti as unconfirmed within the Graffiti Tagger Web application. Once reviewed by an analyst, the graffiti report would be updated to either indicate the graffiti as either a gang tag or a non-gang tag. The *Description* field was a text field with a character limit of 500 characters that could be used by users to report additional information regarding the graffiti report. The *Date* field was included to allow users to record the time at which a graffiti report was filed. Although the *Graffiti_edit* feature service was not temporally-enabled, it was believed that this was an important piece of information that could be used in any future analysis of the graffiti data. Providing the date information would allow analysts to visualize the spread of related graffiti tags over time.

The Graffiti dataset was stored in a SQL Server 2008 R2 Express database that was hosted on the same machine as the GIS Server. The most distinct characteristic of the *Graffiti* dataset was that the ability to add attachments was enabled. Having this option enabled allowed users to upload image attachments back to the server. Image attachments would then be automatically referenced within each unique graffiti report.

4.4 Implementation in Test Environment

The successful implementation of both Web applications required the authoring and publishing of GIS services that could be hosted online, as well as the development of the actual Web applications that would provide an interface for users to interact with via the hosted GIS services. ArcMap 10.1 was used to author the two feature services and single map service that were used. ArcGIS for Server 10.1 was then used, with the help of the ArcGIS Online Resource centre, to optimize and publish these services (ArcGIS Help 10.1, 2013). The Web applications that utilized these services were developed using HTML and the ArcGIS API for JavaScript. Coding and testing the Web applications required the use of Notepad++ and a variety of different Web browsers and mobile devices.

4.4.1 Authoring and Publishing

TPS_Boundaries

The TPS_Boundaries map service was used in the Toronto Crimes Database Web application in order to allow users to focus the Web application on a specific TPS region. The development of this map service was relatively basic when compared to the two feature services which will be discussed later. Using ArcMap, each of the seventeen TPS divisions that were produced earlier using the erase tool were loaded into the map document as separate layers. Each layer was renamed to effectively display the name of the division which it represents. The layers were also each assigned a single symbol that used a black fill and a Gray 50% outline of 0.4 units. Each layer was subsequently assigned a 70% transparency. Once all of the division layers had been configured and stacked in the Table of Contents (TOC) in descending numerical order, an eighteenth layer was added that featured all of the TPS division boundaries. This final layer was moved to the bottom of the TOC and was assigned no fill, but was given a 1.0 unit thick black border. This layer provided context to users by allowing them to visualize all of the TPS boundaries at the same time, regardless of which specific division was currently selected. As a result of the data that was loaded into the map document based on the WGS 1984 Web Mercator Auxiliary Sphere projection, the dataframe was automatically assigned the same projection.

Using the *Catalog* window, the pre-established administrative connection to the *envmaps2* ArcGIS server was activated. A new folder was created on the *envmaps2* server titled *CrimesDatabase* and the

ArcGIS Server Properties window was accessed. From this window, the *Data Store* tab was selected and the local folder that contained the file geodatabase that had been used to store the TPS boundaries feature classes was added as a Registered Folder with the title *ddata*. Registering a local folder with ArcGIS Server prevented the server from creating duplicate copies of the data any time a new service was published. This feature was new in ArcGIS for Server 10.1 and helped to both hasten the publishing process and to limit the total amount of storage space that was required. The rationale behind ArcGIS Server creating a duplicate copy of data is to support working environments where multiple publishers have access to a single server instance and each publisher is working from a separate remote computer. In this scenario, data that was referenced in the published map document and stored on a remote computer would be compressed along with the map document, packaged, and transferred to the server. Upon arrival, the data and map document would then be unpackaged and placed into a streamlined folder structure in a directory, which the GIS server has uninterrupted access to.

Once the appropriate folder had been registered, the map document was saved and published from within ArcMap as a map service. Within the publishing wizard, the *CrimesDatabase* folder that had been created on the GIS server was used to store the map service. The service was assigned the name TPS_Boundaries and the Web Map Service (WMS), Web Feature Service (WFS), and Feature Access checkboxes were not checked as this service was intended to be used specifically with the ArcGIS API for JavaScript without a new for any editing capabilities. The service was set to draw dynamically, as opposed to as a cached map service. Although a cached map service would display faster and require less bandwidth to transfer, it would have inhibited the ability to turn layers on and off. This ability does exist with dynamic map services and was used within the Toronto Crimes Database Web application. Finally, the analyzer tool was used to ensure that the map service had been configured correctly for optimal performance. Unlike in earlier versions of ArcGIS Server, the analyzer in 10.1 is a mandatory step for publishing a map service. Once the analysis was complete, the map service was finally published.

Instances_and_Comments

The Instances_and_Comments feature service was used in the Toronto Crimes Database Web application and was an essential service that was used for collecting and displaying data. This feature service was also authored in ArcMap and incorporated two editable datasets. Within an empty map document, the citizen_comment dataset was added from the *CDB* database that was hosted on SQL Server. Once loaded into ArcMap, the layer's name was updated to *Citizen Comments* and an editing session was run in order to populate the dataset with some randomized sample data. Upon saving and ending the editing session, the layer's symbology was updated to support unique value categories based on the Importance field. A 10% simple hatch pattern was assigned to each of the three categories and a unique colour which represented the user's perceived importance of the comment was assigned. When selecting the colours that would be used, the HSV characteristics of the colour were altered such that the colour possessed a high value percentage. Doing so allowed the features to stand out from the predominantly muted colour scheme of the accompanying basemaps.

Four group layers were then created within the dataframe and each were assigned a unique scale range dependency in which the data contained in the group layer could be displayed. The scale ranges of the group layers were designed to match the scale ranges that were used in a number of the various scale levels of the Topographic basemap. The crime_instances dataset from the database on SQL Server was then added to the map document and renamed to *Crime Instances*. The new layer was then seeded with randomized sample data. Once the dataset had been sufficiently populated with sample data, the layer's symbology was updated to account for unique value categories that were based on the *Type* field. Each category was assigned a three-tiered symbol to visually represent the type of crime that was reported. Each symbol was circular in format and contained a large black circle that was overlaid with a slightly smaller coloured symbol. The top layer in each symbol contained a default character symbol that was available from the *Esri* Crime Analysis font set. Crime symbols were selected based on how effectively they could represent the reported crime. Doing so improved the symbol's ability to stand out from the surrounding basemap, which used a predominantly muted colour scheme. Some symbols were used multiple times for similar types of crimes, but were assigned different background colours. For instance, the symbol for Assault used the fist symbol with a bright yellow background, while the symbol for Assault with a Deadly Weapon used the same fist symbol but with a bright red background.

Once all the categories had been uniquely symbolized, the Crime Instances layer was copied four times within the document. The layers were evenly distributed into the group layers such that each group layer contained a single copy of the Crime Instances layer. The sizing of the symbology was then altered for each group layer so that depending on the group layer, the symbology ranged from 13 to 18 units. The desired effect was to create a map service where crime reports would vary in size depending on the scale of the map. If the map were viewed at the city level, then the crime reports would be smaller and less overlap would occur between neighbouring features; however, if the map was then zoomed-in and focused on a specific neighbourhood, the crime reports would be larger and easier to identify.

Feature templates were then created for both the Citizen Comments layer, as well as the multiple Crime Instances layers. This was done in order to ensure the overall accuracy of the data by limiting the number of input options that would be available to the user when reporting a crime instance or comment. Features that were declared as a feature template would be displayed along with their associated symbol and title when reporting data via the Toronto Crimes Database Web application. Once the symbology and feature templates had been finalized, the map document was then configured to be time-enabled based on the *Date* fields in both of the included datasets. Enabling time in the map document was done so that the Web application could be designed to visualize the temporal changes that occurred within the data. With a time-enabled map service, users could visualize crimes that occurred during a specific period of time, or view the changes that occurred in the criminal landscape of the city over time.

Before publishing the map document, the standard WGS 1984 Web Mercator Auxiliary Sphere projection was assigned to the dataframe. The SQL Server database was then assigned as a registered database on the envmaps2 GIS server in order to prevent the data from being duplicated. Finally, the permissions for the SQL Database were edited such that the user *envmaps2\arcgis* had Read/Write permissions for the datasets that were used. This was an essential step in order to allow the GIS server to access and edit the datasets. Once these changes were made, the map document was saved and published to the *CrimesDatabase* folder on the envmaps2 GIS server. Within the publishing wizard, feature access was enabled and the options for creating, querying and updating data were selected. Once the map document had been analyzed for optimal performance, the document was then published.

Graffiti_edit

The Graffiti_edit feature service was used in the Graffiti Tagger Web application and was an essential service that was used for collecting and displaying data. This feature service was also produced using ArcMap and featured the attachments-enabled Graffiti dataset which was added from the CDB database that was hosted on SQL Server. Within a blank map document, the Graffiti dataset was added. To populate the dataset with data, actual geotagged graffiti reports were used. A total of 95 geotagged images of graffiti from across the City of Toronto were included. Images were taken by the author using a GPS-enabled Galaxy Nexus mobile phone and were subsequently transferred to the server via the remote PC. Once the images were stored locally on the server, the Geotagged Photos to Points tool was used in ArcMap to produce a point feature class that contained each of the graffiti images as attachments. The feature class was then altered to match the schema of the existing Graffiti dataset and the Append (Data Management) tool was used to append the records to the Graffiti dataset. Once appended, the geotagged images feature class was removed from the map document. To view the results of this process, see **Figure 4.4** and **Figure 4.5** below. This workflow stated above was only used by the author in order to initially seed the database. Application users would use a separate workflow that is described later in this thesis in order to upload and geotag their graffiti photos on an individual basis.

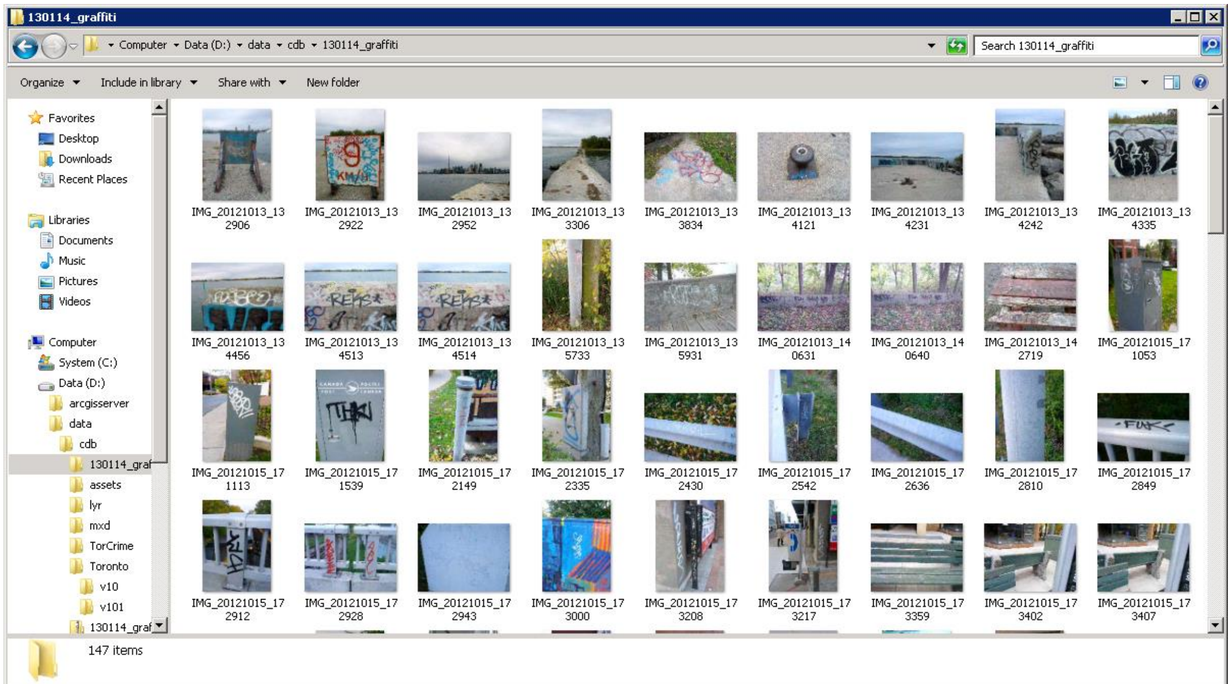


Figure 4.4 – Graffiti Photos viewed through Windows Explorer
Data Source: James Lockyer-Cotter

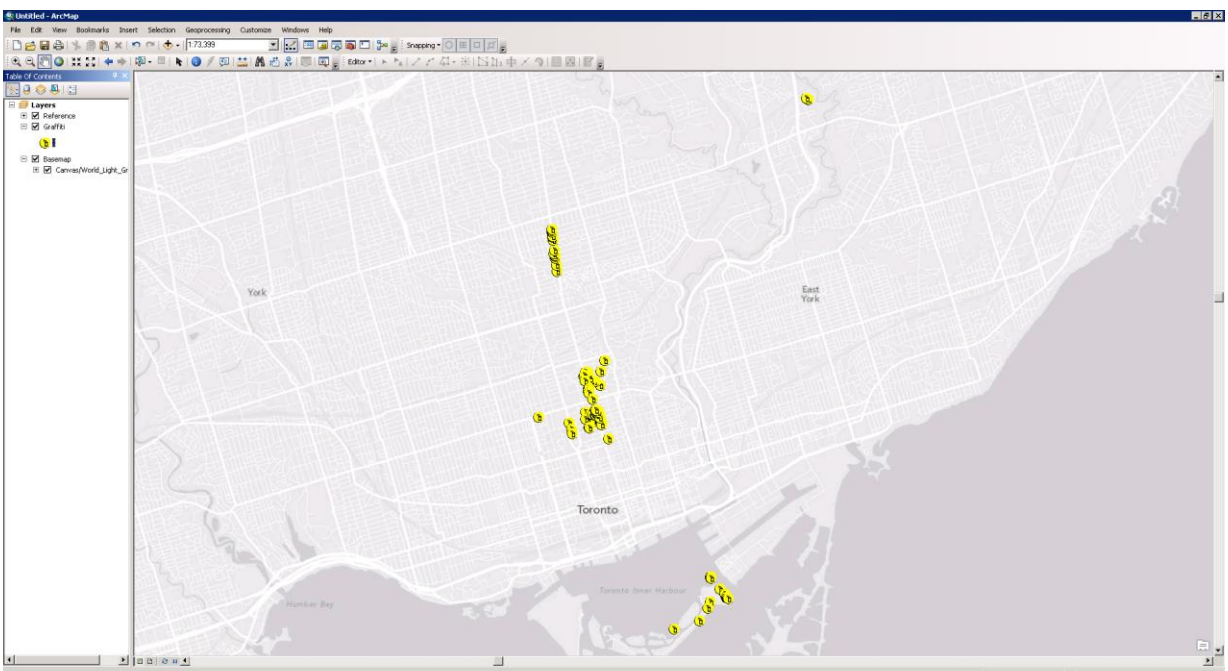


Figure 4.5 – Graffiti Points Georeferenced and Stylized in ArcGIS 10.1 (Overlaid on *Esri* Gray Canvas Basemap)
Data Sources: James Lockyer-Cotter; *Esri*, 2013

Once the dataset had been populated with data, the layer's single symbol symbology was updated to use a three-tiered symbol that was similar to those used in the Crime Instances layer. A large black circle was placed beneath a slightly smaller gray circle with a graffiti icon from the *Esri* Crime Analysis font set placed on top. The gray circle was used to denote uncategorized graffiti reports. It was hoped that with the participation of a professional gangs or graffiti analyst, reports could be updated retroactively to symbolize graffiti reports as either gang-related or not. Once the symbology had been updated, a feature template was created for the unconfirmed feature symbol and the map document was saved and published as a feature service. Within the publishing wizard, the *CrimesDatabase* folder on the *envmaps2* GIS server was selected, and the option to allow feature access was enabled. In addition, the ability to create, delete, query and update features were all selected. Following the analysis for optimal performance, the feature service was then published. Once published, the ArcGIS Server Administrator Directory site was accessed over HTTPS at *https://envmaps2.uwaterloo.ca/admin/admin*. Within the services section, the Graffiti_edit feature service was selected and reconfigured to provide support for a number of common image file types and to limit the maximum image upload size to 5mb.

4.4.2 Developing the Web Applications

Once all the map services that were used in this thesis had been successfully configured and published, the final step in the Web application development cycle was to develop and deploy the actual Web applications that would be used to connect the users with the GIS services. As the services were hosted using ArcGIS for Server 10.1, it was decided that one of the *Esri* Web APIs would be used to design both Web applications. Using any of these *Esri* Web APIs would provide a stable environment for working with the services, as well as the largest number of pre-configured options for working with the ArcGIS services in a Web environment. The available Web APIs to choose from included the ArcGIS APIs for Flex, JavaScript, and Silverlight.

After researching and experimenting with each API, it was decided that the ArcGIS API for JavaScript would be the most practical API for the study. As stated earlier in this chapter, the rationale behind this decision was driven largely by both the software requirements for developing in each language, as well as the software requirements that a user would come across when using each. Developing a Web application using the ArcGIS API for JavaScript could be done using free-to-use software such as Notepad ++. Users could also access a Web application that was designed using this API from a number of different mobile devices and Web browsers without the need for installing additional software or plugins such as Adobe Flex or *Microsoft* Silverlight.

In the end, both the Toronto Crimes Database and the Graffiti Tagger Web applications were developed using the ArcGIS API for JavaScript. Both Web applications were designed using samples provided in the ArcGIS API for JavaScript Resources Centre as a guide for developing many of the functions that were included. The individual features that were provided in both Web applications will be discussed in greater detail in the **Results and System Evaluation** chapter. Of the two Web applications that were developed, the Toronto Crimes Database Web application required the greatest commitment of time for coding and customization. The layout which was developed featured a title bar that contained the map controls, a content pane titled the "discovery window" which was located on the left side of the Web application, a map window which took up the majority of the Web application's real-estate on the page, as well as a time slider bar that overlaid a portion of the map window. To develop this Web application, an html document and an independent JavaScript document were created within the C:*inetpub\wwwroot* directory of the *envmaps2* Web server.

The layout for the Toronto Crimes Database Web application was created using a series of configured divs and a section of CSS code that was embedded in the HTML document. The discovery window consisted of an Accordion Pane dijit, where a series of divs that contained much of the content in the Web application would be either hidden or shown depending on which map control in the title bar the user had selected. Using a single fixed window that could be refreshed to show different sets of information helped to keep the entire Web application to a single page. The map was produced using two dynamic map service layers, one feature service layer, and one tiled map service layer. The tiled map service layer contained the basemap which could be altered based on the *Esri* Basemap Gallery dijit that was included. The feature service layer was an invisible layer that included the *Instances_and_Comments* feature service and was editable. The first dynamic map service was visible and included the *Instances_and_Comments* map service, which allowed the symbology, group layers, time slider and spatial extents to display correctly. The final dynamic map service layer included the *TPS_Boundaries* map service and had a 50% opacity assigned to it. The specific TPS division that was being displayed could be selected in the map controls section. A form selector was used to create the division selection options for the *TPS_Boundaries* map service and a number of predefined default extents were assigned to each division. In the situation that a secure service were to be added to the map in the future, a login div was also included. The following **Table 4.3** contains dijits were also used in this Web application:

Table 4.3 – Additional dijits used in the Toronto Crimes Database Web Application

Legend dijit	Used to display the layers that were currently active on the map
Time Slider dijit	Used to create the time slider bad and to configure the playback of up to 30 days of crime reports and comments. Time range dates were displayed within the Map Controls div.
Attribute Inspector dijit	Allowed the user to edit the attributes of a feature, including any attachments.
Editor dijit	Supported the editing of new and existing features.
Template Picker dijit	Allowed the user to access preconfigured feature templates when contributing new features

The icons that were used within this Web application were provided from the Web site *IconArchive* (IconArchive, 2012). Only icons that were licensed as “Free for non-commercial use” were used. Selected icons were stored in an *images* folder on the Web server and were referenced within the HTML code. PDF instructions for both applications were produced using *Microsoft* Office 2013 and were also included on the Web server within a *docs* folder. These instructions were referenced within the Toronto Crimes Database Web application, as well as the thesis survey. Copies of the Toronto Crimes Database (Appendix A) and Graffiti Tagger (Appendix B) instructions can be found in the **Appendix** section.

The Graffiti Tagger Web application was based on the *Esri* code sample titled "Attribute Editing – Mobile" found within the ArcGIS API for JavaScript Resource Center (ArcGIS API for JavaScript, 2012). The sample used a simplistic graphical user interface (GUI) which was designed to mimic the feel of a mobile application. Very few options and map controls were provided in order to maintain the minimalistic interface design. The *Esri* sample was used to provide the framework for constructing the Graffiti Tagger Web application and was customized to use the *Graffiti_edit* feature service. The Web application included a map with a tiled map service layer and a feature service layer. The tiled map service layer contained the Topographic basemap and the feature service layer contained the *Graffiti_edit* feature service. Further edits were also made to the attribute inspector dijit in order to configure it to support attachment uploads. In addition, a locator service that was provided through ArcGIS Online was utilized.

The benefit of using the aforementioned approach was that users could access the Web application from any computer or mobile device that had a Web browser. As a result, multiple versions of the applications did not have to be developed for each type of computer or mobile device. By supporting a larger number of hardware devices, it would be easier for more potential users to access the applications and contribute data. Both applications were tested for functionality using *Microsoft* Internet Explorer, *Mozilla* Firefox, and *Google* Chrome, as well as the stock Web browsers that were provided with Android OS 4.2 and IOS 6. It was noted that on some versions of IOS, the attachment editor was unable to successfully upload an image attachment.

4.5 Survey

In order to test the usability and practicality of the Web applications that were deployed, an email-based survey was designed to gauge user responses to each Web application. The online-based survey approach was chosen as it could provide an efficient and relatively inexpensive method for administering a survey (Sue, 2007). The email-specific approach was chosen as the participant pool was anticipated to consist of only a small and specific set of participants (Sue, 2007). It was assumed by the author that the majority of users who could access these Web-based applications would also have access to their own personal email account. The average user response was derived based on the aggregated responses of all survey respondents. Participants were selected based on their experience levels with GIS as well as their availability and willingness to participate in an academic survey of this nature. A wide range of experience levels in GIS were desired as this would best represent the various categories of users that were defined earlier in the **Research Design** chapter. In order to include feedback from a number of industry professionals, participants were specifically requested from the *Toronto Police Service*, the *Crime Prevention Association of Toronto*, as well as *Esri Canada*. In addition to industry professionals, participants from the University of Waterloo with a background in GIS were also targeted. Students that were selected to participate were either current graduate students in the Geography program, or former undergraduate students that had graduated from the Geography program. University of Waterloo students were selected on a one-off basis and no formal survey requests were sent out to any specific group. The remaining participants were selected based mainly on convenience and were intended to represent the average novice user with limited Web mapping and crime prevention experience. The desired goal of this survey was to answer the following question: *Can the adoption of mobile technologies, VGI and GIS Web applications result in an increase in the total amount of crime and graffiti incidents that are reported by the public by providing an additional channel for public reporting that is both easy to use and effective?* This question was addressed by asking survey participants about the overall usability of the Web application, their personal willingness to report crimes and graffiti using these Web applications, as well as their perceived thoughts about the effectiveness of this online mapping channel for engaging other members of the public.

The survey was designed to take only fifteen minutes to complete and consisted of three sections, which contained a series of multiple choice and short answer questions. The first section was designed to collect background information about each respondent such as their familiarity with the field of crime mapping, their comfort level with using computers and the Internet, as well as their familiarity with Web-based mapping applications. The second section featured questions regarding the Toronto Crimes Database Web application, while the third section focused on the Graffiti Tagger Web application. Each section was prefaced with a short introduction and sections two and three both contained links to instructions on how to effectively use each of the Web applications. The results of the survey will be discussed in detail in the **Results and System Evaluation** chapter.

In order to distribute this survey to human participants, the survey was first required to receive ethics clearance from the Office of Research Ethics (ORE). Ethics clearance was granted on April 4, 2013. At this time, the author aimed for a response rate target of 10 participants. The survey was designed to investigate the individual user's experience and the results were not intended to be used to make any significant inferences about the general public. No incentives were provided for user participation as this would be representative of the real world situation in which voluntarily contributing data may provide limited or no incentives. A copy of the recruitment email (Appendix C), survey introduction (Appendix D), survey (Appendix E), and participant feedback letter (Appendix F) that were used in this thesis can be found in the **Appendices** section.

It is recognized that user response and ease of use is not the only factor that would determine the success and practicality of these Web applications. A host of additional factors such as cost, maintenance, and ease of deployment would also play a key role but were not explored within the survey.

4.6 Chapter Summary

This chapter explored the methodology that was used in order to complete this thesis. Data was provided from a number of different sources and some new original data was created specifically for use in this thesis. ArcGIS for Desktop 10.1 was used to configure the map documents that used this data, while ArcGIS for Server 10.1 was used to publish these map documents as services on the Web. Editable feature services utilized data that was stored in a SQL Server database. The ArcGIS API for JavaScript was used to develop the two Web applications produced by this thesis. Finally, a survey was produced to gauge the success of these Web applications. The resulting Web applications, as well as the compiled results of the survey that was used to gauge the relative success of the Web applications will be discussed in the **Results and System Evaluation** chapter below.

Chapter 5

Results and System Evaluation

This chapter begins by providing an extensive walkthrough of the Toronto Crimes Database and the Graffiti Tagger Web applications that were developed as part of this thesis. The chapter will then continue by examining the survey that was conducted and by discussing the relative success of both Web applications as indicated by the results of the survey. Following this, a number of alternate methods for development that were considered during this thesis will also be discussed, including the rationale behind why these alternate methodologies were rejected. The chapter will conclude by examining a number of the issues and limitations that were discovered through the development and testing of these Web applications.

5.1 Toronto Crimes Database Web Application

http://envmaps2.uwaterloo.ca/cdb/

In order to assess the Web GIS application's effectiveness in obtaining crime data that is contributed by the public, the Toronto Crimes Database Web application was developed. This application was developed using the ArcGIS API for JavaScript and was hosted on the University of Waterloo's *envmaps2* Web server. Once completed, the Toronto Crimes Database allowed users to view crime in their city and to anonymously report crime incidents, as well as provide citizen comments for a specific region. The Web application was composed of three main sections, those being, the Map Window, the Discovery Window, and the Map Controls toolbar. The final layout of the Toronto Crimes Database, along with the core components that makeup the Web application are shown in **Figure 5.1** below.

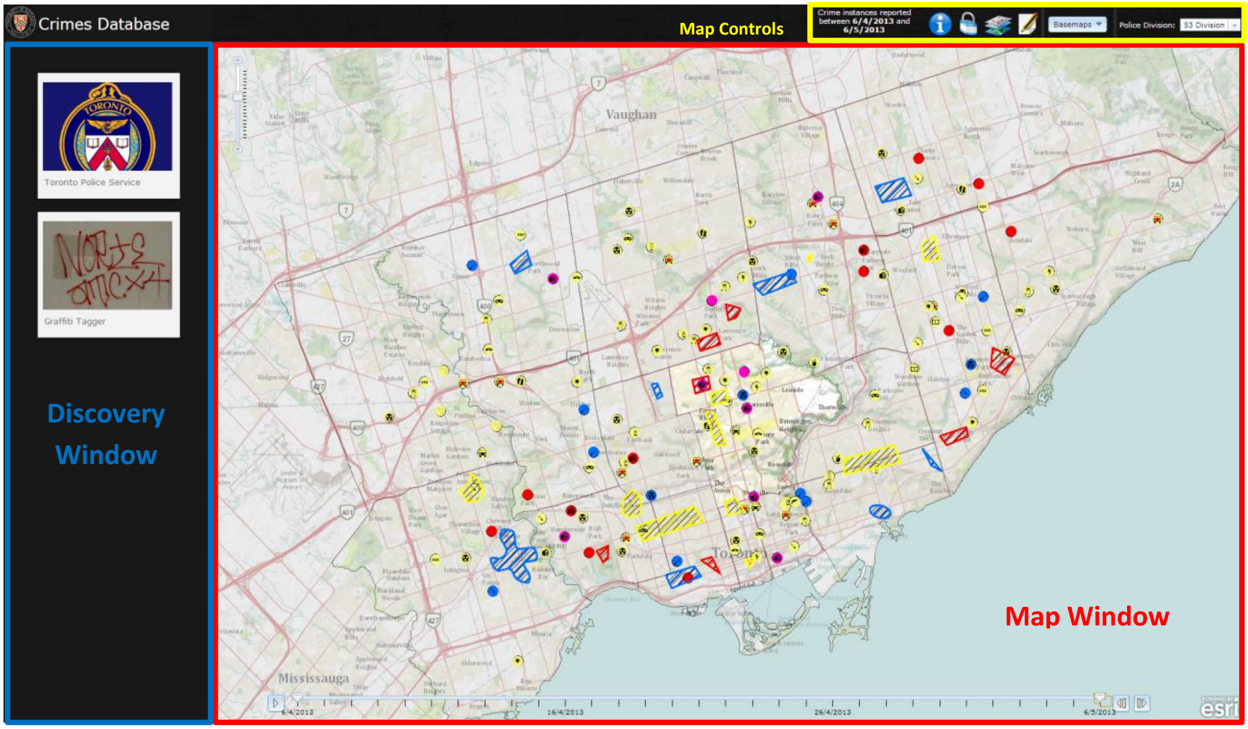


Figure 5.1 – Toronto Crimes Database Web Application (http://envmaps2.uwaterloo.ca/cdb/)
Data Sources: James Lockyer-Cotter; Various Users

Map Window

The Map Window, highlighted in red in **Figure 5.1**, provides the user with a spatial view of crime incidents and citizen comments that were reported during the preceding month. The map was compiled using a JavaScript map variable that drew on a collection of tiled map services and dynamic map services. As a result of the mainstream popularity of Web applications such as *Google* Maps, it was assumed that the majority of users would be able to interact with the map without the need for basic map control icons. Users could pan around the map by click-and-dragging or zoom in and out by using the scroll wheel on their mouse or by using the scale bar in the top-left corner. More advanced users could also use the shift-select method to perform a targeted zoom into a specified area. The size of crime incident icons on the map was designed to change depending on the scale of the map. Additional information for citizen comments could be viewed by single-clicking a feature polygon to create a popup window that contained descriptive information.

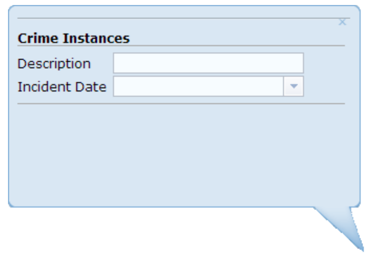


Figure 5.2 – Crime Report Attributes

The contents of the map could be altered using the Map Controls toolbar to toggle between layers or by using the Time Slider bar (**Figure 5.3**) to alter the temporal properties of the map. The Time Slider bar allowed users to configure the map to only display crime reports and citizen comments from a specified period of time. Users could also use the Play feature of the Time Slider bar to animate their map to display the change in the criminal landscape of the city over time. The Map Window was also the drawing pane for adding new features. After reporting a crime incident or constructing a citizen comment feature, a popup window would display allowing the user to input attribute information for their crime instance report (**Figure 5.2**).

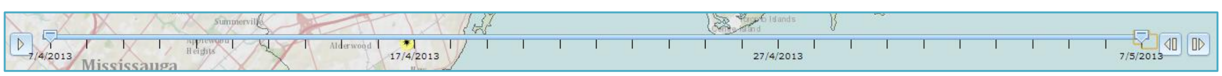


Figure 5.3 – Time Slider Bar

Map Controls

The Map Controls, highlighted in yellow in **Figure 5.1**, provided the user with the tools that were necessary for manipulating the map and for effectively utilizing the Web application. The Map Controls were comprised primarily of six selectable icons. In addition to the selectable icons, the time period that was currently being displayed in the Map Window would be displayed in the Map Controls toolbar. Grouping all the map control tools in one location and using icons to launch the tools helped to remove clutter from the Web application and provided an intuitive user interface. Limiting the total number of icons and options was also done purposefully in order to not overwhelm any novice users. Although a number of additional features could have easily been added, it was decided to focus the Web application on the specific purpose of collecting spatial data. The core components of the Map Controls toolbar are shown in **Figure 5.4** below.

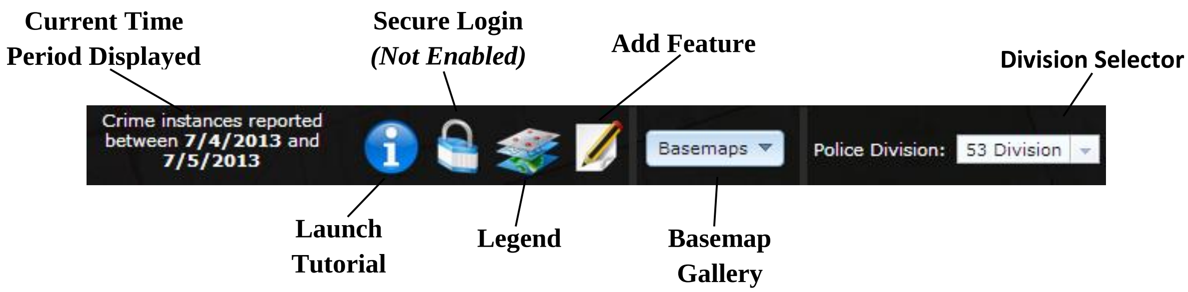


Figure 5.4 – Map Controls Components

The division selector allowed a user to easily swap between which TPS division the application was currently focused on. Upon changing to a new division, the map would refresh and automatically zoom to a pre-set spatial extent that would highlight the selected division. The basemap gallery allowed a user to switch between the various basemaps that were referenced in the **Research Design** chapter. Selecting a new basemap would cause the Map Window to refresh and display the new basemap. Selecting the Add Feature icon would open the template picker window within the Discovery Window. Likewise, selecting the Legend icon would open the legend window within the Discovery Window. Clicking on the Secure Login option would launch a login screen within the Discovery Window; however, secure services were not implemented in this release of the Web application. Finally, by selecting the Launch Tutorial icon, a PDF with instructions on how to effectively use the Toronto Crimes Database Web application would be opened in a new window or tab.

Discovery Window

The Discovery Window, highlighted in blue in **Figure 5.1**, provided the user with a way to utilize a number of the tools and features in the Toronto Crimes Database Web application. By default, the Discovery Window would load two thumbnails for external links using an ArcGIS Online Gallery tool. When options such as Add Feature, Legend, or Secure Login were selected in the Map Controls toolbar, their associated windows would be displayed within the Discovery Window. Any time a new option was selected, the current window would automatically be hidden and replaced by the new window. Using this approach saved valuable real-estate on the Web application and provided a fixed location for the user to look for any new information or tools.

5.2 Graffiti Tagger Web Application

http://envmaps2.uwaterloo.ca/cdb/graffiti.html

In order to show a targeted example of how a Web GIS application can be used to increase the quantity of, and potentially the quality of, crime data that was contributed from the public, the Graffiti Tagger Web application was developed. The Graffiti Tagger Web application was developed using the ArcGIS API for JavaScript and provided an interface for users to report the locations of graffiti within the City of Toronto. A user could optionally upload an image of the graffiti and attach it to the report. Similar to the Toronto Crimes Database Web application, the Graffiti Tagger Web application was designed to have a simplistic interface that would not overwhelm any novice users. The Graffiti Tagger Web application used a template that was designed to mimic a mobile interface. Doing so allowed the Web application to be easily used on most mobile devices, regardless of their operating system. When working in a mobile environment, space limitations can easily become a problem due to the fact that the small dimensions of many current mobile devices provide only limited real-estate on the phone's display. When designing an application for a mobile device, it is best to keep the GUI as basic as possible and to limit the number of options that are presented to the user. Additionally, the application should be designed with the features of the device in mind, such as touch screens, on-board cameras, and GPS. The Graffiti Tagger Web application is shown in **Figure 5.5** below.

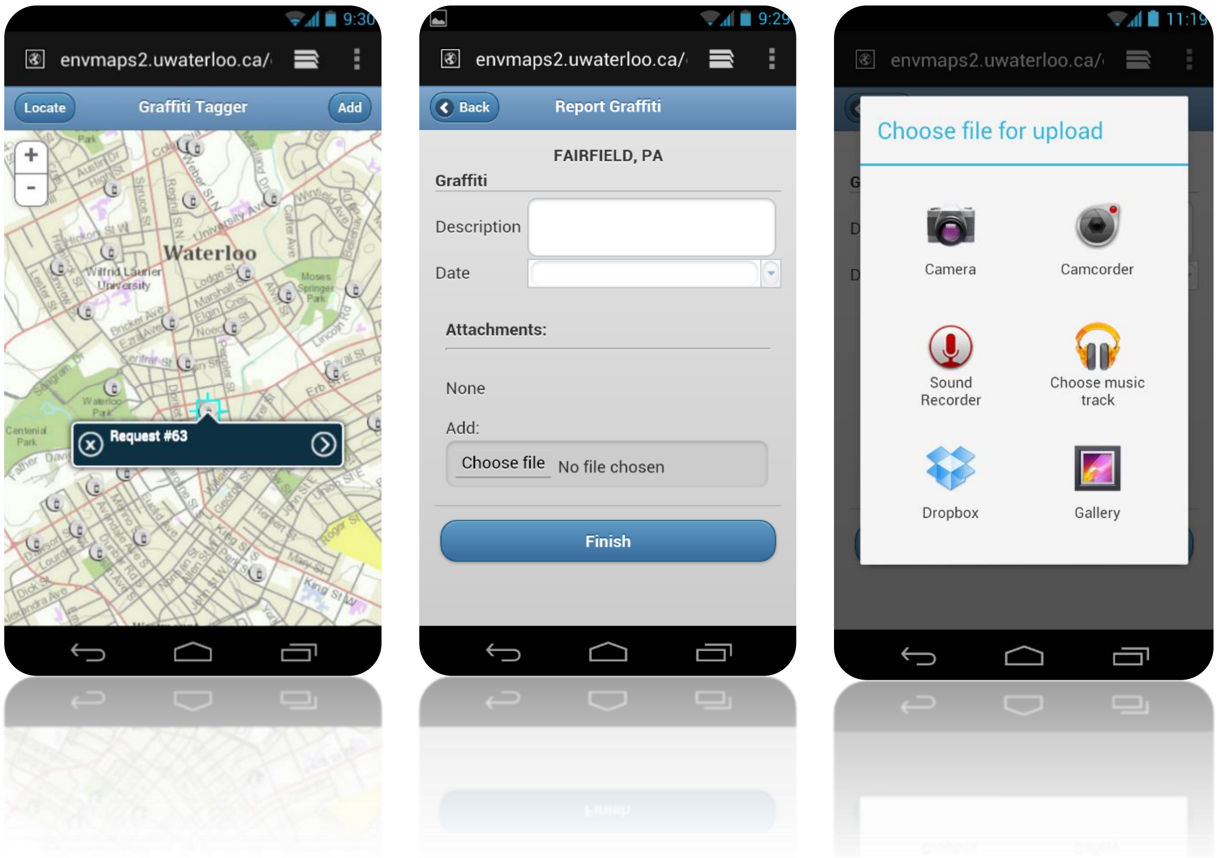


Figure 5.5 – Graffiti Tagger Web Application (http://envmaps2.uwaterloo.ca/cdb/graffiti.html)
Data Sources: James Lockyer-Cotter; Various Users

Within this Web application, a user could pan and zoom around a map using their mouse on a computer, or by utilizing a touch screen to pan and using the + and – icons to zoom. A Locate option was also available that could utilize the location services available on a device to approximate the user's current location. A user could then either tap a graffiti icon on the map to view its details, or select the Add button to submit their own unconfirmed graffiti report. Once the graffiti was placed on the map, a new window would open that allowed a user to add attribute information to the report and optionally upload an image from a variety of sources, such as the device's built-in camera or the device's hard drive.

5.3 Survey

In order to gauge the relative success of the two aforementioned Web applications in meeting the goals of this thesis, a survey was developed to better understand the user's experience with using both Web applications. In order to encourage user participation, the survey was designed to only take approximately 15 minutes to complete. The survey was developed in *Microsoft* Word and included three sections, each containing a series of Multiple Choice, Yes/No, and Short Answer questions. Multiple Choice and Yes/No questions were used to quickly collect quantitative results, while Short Answer questions were used to provide more qualitative results that provided a greater level of insight and a number of useful comments. The survey was designed to gather background information relating to the skill levels and past experiences of participants and to determine the average participant response to each Web application. When examining the user's response to each web application, five-tiered Likert items were used to gauge the participant's level of agreement with a series of statements.

In order to conduct this survey, Ethics Clearance was received from the Office of Research Ethics at the University of Waterloo on April 01, 2013. The survey was run for a period of two weeks, at the end of which, 17 of the 23 surveys were returned. This resulted in a response rate of 73.9% among participants. The survey referenced both Web applications, as well as two tutorials that were designed to facilitate the effective use of each application. Each tutorial focused on a specific Web application and provided descriptive step-by-step instructions that guided the participant through using the various components of the Web applications. Tutorials also contained a Web URL link to each of the applications and included a number of screenshots that supplemented the instructions. See **Appendix A** and **Appendix B** for more information on these tutorials. Participants were contacted using a standardized recruitment email that contained the survey, as well as a survey introduction, as attachments. Participants were selected from a variety of different backgrounds and technical skills levels. Survey participation requests were sent specifically to industry professionals at the *Toronto Police Service*, the *Crime Prevention Association of Toronto* and *Esri Canada*. Additional participants were requested based largely on their technical skill levels and familiarity with the subject matter, as well as their proximity to the author and their familiarity with the subject area. The author hoped to receive feedback from a number of participants with a wide range of technical skill levels and familiarity with the subject matter.

The author's University of Waterloo email was used to communicate with survey participants. In order to quickly contact and adequately inform survey participants, an introductory email was distributed that detailed the purpose and goals of the survey as well as providing some background information on the topic of the survey. Attached to these emails was an introductory document that provided further details on the topic of the survey as well the survey process. Participants were informed on their rights to not respond or to withdraw from the survey at any period. Also attached was the survey document which was to be completed individually by the participants and included links to the Web applications and accompanying tutorials.

5.3.1 Participant Information

As stated earlier, a total of 17 completed surveys were returned. This exceeded the expected response rate of 10 survey responses. Participants came from a variety of different backgrounds and skill levels; however, over 50% of respondents declared that they possessed more than a beginner's knowledge of GIS. This response was likely a result of participants being selected from related industries and academic programs. Although this was useful for providing relevant feedback, this larger than average ratio of participants with GIS familiarity would be unrealistic in the real world. In addition, 29% of respondents indicated that they used GIS as a part of their current professional role. Over 70% of the participants were active computer users and answered in the 20+ hours category for weekly computer usage. In a testament to how commonplace Web mapping has become, 100% of users indicated that they had at some point in their life used a Web mapping application such as *Google* Maps. Moreover, 94% of users were in possession of a smart phone or tablet computer. In addition to the survey responses, a phone interview with conducted with the Executive Director of the Crime Prevention Association of Toronto, Janet Sherbanowski. Unfortunately after many requests with the TPS, no survey responses were received or phone interviews conducted.

Although having feedback from a larger group of professionals and intermediate/advanced users was valuable, a more balanced group of respondents with novice users would have been preferred, in order to gain the insights from more first-time and beginner computer users. As stated in the **Research Design** chapter, the Web applications that were developed in this thesis were designed primarily for beginner and first-time users. Unfortunately although multiple survey requests were sent, 100% of respondents indicated that they were neither an active member of the Toronto Police Service, or had experience monitoring gang-related activities. The survey also found that nearly 25% of respondents had at some point in their life witnessed a crime and not reported it. This statistic was indicative of a need for alternate methods for crime incident reporting, such as those provided in this thesis to capture unreported crimes. Only 12% of participants indicated that they would like to see additional tools used in the City of Toronto for the purpose of crime mapping.

From the user feedback that was provided in the form of short answer questions, one reason cited for not reporting a crime that had been witnessed was because the user did not feel that it was "*important enough to report*". Additionally, two users asked for "*increased public awareness and availability*", since they were not aware of the existence of any of these tools prior to participating in this survey. The aggregated user response to each question can be seen below in **Table 5.1**.

Table 5.1 – Summary of Background Information Responses

	Responses	Percentage Share
How many hours a week do you spend using a computer?		
0-5	2	12%
6-10	1	6%
11-15	2	12%
16-20	0	0%
20+	12	71%
Have you used a Web mapping application such as Google Maps, Bing Maps, or Map Quest?		
Yes	17	100%
No	0	0%
How would you rank yourself as a Geographic Information Systems (GIS) user?		
First Exposure	3	18%
Beginner	5	29%
Intermediate	6	35%
Advanced	3	18%
Do you use GIS as a part of your current professional role?		
Yes	5	29%
No	12	71%
*Have you ever witnessed an illegal activity or been the victim of a crime and not filed a formal police report regarding the incident?**		
Yes	4	24%
No	13	76%
Have you ever used any Web based application for the purpose of crime mapping? (Crime Reports, Crime Mapping)		
Yes	2	12%
No	15	88%
Are you an active member of either the Toronto Police Service or any Neighbourhood Watch Group in Canada?		
Yes	0	0%
No	17	100%
Do you own a smart phone or tablet computer?		
Yes	16	94%
No	1	6%
Do you have any experience with monitoring gang-related activities?		
Yes	0	0%
No	17	100%
Are you aware of the process of "tagging" that is practiced by some graffiti artists and street gang members?		
Yes	10	59%
No	6	35%
*Are there any specific tools that are not currently used in Toronto which you feel would be beneficial to the field of crime mapping?***		
Yes	2	12%
No	14	82%

5.3.2 Toronto Crimes Database Results

The second section of the survey was designed to collect user feedback regarding the Toronto Crimes Database Web application. After being directed to complete a short tutorial that provided participants with a guided tour of the Web application, users were asked a series of short answer and multiple choice questions which used five-tiered Likert-item responses. Questions were designed to gauge how the user perceived the Web application in terms of usability and practicality.

88% of respondents felt that the Web application had an intuitive user interface and was easy to use. In addition, 83% of respondents found the inclusion of the Time Slider to be an effective tool for visualizing the crime incident data, while 100% of respondents were satisfied with the choices of crime types and citizen comments that were provided. Moreover, 82% of the respondents stated that they would prefer to use this Web application to report a non-serious crime incident instead of reporting the incident over the phone to the TPS. 100% of these respondents agreed that this application could allow for more unofficial crime incident data to be collected. Although the term unofficial crime incident data was not explicitly defined in the survey, the term refers to any crime incident data that is not provided from a recognized source, such as the Toronto Police Service. However, although 53% of respondents neither agreed nor disagreed, 18% of respondents stated that they would feel more comfortable using an existing crime mapping system such as *CrimeReports.com*. This response could be indicative of a desire for the increased level of security, confidentiality, and anonymity provided by an established company.

Based on the written user feedback, multiple users expressed an aversion to using verbal phone calls as a method for reporting crime incidents due to a perceived lack of anonymity as well as the tedious nature of reporting a spatial incident verbally.

> *"The anonymity of this application is more suitable for someone who may be uncomfortable talking directly to police, but who want to report an incident that affects their community"*

In addition, some users thought that this application could help minimize the amount of administrative work that the TPS would have to complete on a daily basis. One user expressed a general concern that if a user were unable to use a smartphone to report an incident immediately, they would be less likely to report it at a later date. Although many users agreed that this application would produce additional crime incident data, there was also a shared concern among some users about the validity of the data that was provided.

"My only real concern is the possibility for abuse with fake or biased reports. Businesses could designate their competitor's areas as high crime areas, personal vendettas could lead to fake/exaggerated reports, general spam/abuse of reporting incidents"

This concern highlighted the need for the inclusion of some form of user-verification or moderating system for reported crime incidents and citizen comments.

Multiple users expressed a lack of awareness about online crime mapping as an option for contributing and visualizing crime data. While many spoke to the importance of anonymous reporting, there was a suggestion for the inclusion of a method that could allow police to follow up with a user when requested.

"There should be a way to ensure citizens have to submit their information in case they need to be contacted with regards to the event"

This could be achieved anonymously by including additional attribute fields, which could be populated with police responses and could be displayed when a feature on the map is selected. Additionally, the inclusion of time of day as an input field was requested, as well as the addition of an "Other / Misc. Crimes" incident type. The results of this section showed that public interest in Web mapping capabilities within the City of Toronto did exist, as well as a belief from the public that these tools could potentially increase the amount of crime data that is voluntarily contributed.

In an interview with Janet Sherbanowski, the Executive Director of the Crime Prevention Association of Toronto, it was indicated that CPAT was currently looking at options to adopt this type of technology for use with their neighborhood watch groups (Sherbanowski, 2013). Sherbanowski confirmed that CPAT is actively pursuing these technologies and feels strongly that they can have a positive impact on the field of crime prevention. CPAT intends to launch a similar crime mapping platform within the City of Toronto within the next year. The aggregated user response to each question can be seen below in **Table 5.2**.

Table 5.2 – Summary of Toronto Crimes Database Responses

	Responses	Percent Share
The user interface was intuitive and the application was easy to use.		
Strongly Agree	6	35%
Agree	9	53%
Neither Agree nor Disagree	1	6%
Disagree	1	6%
Strongly Disagree	0	0%
*I would prefer to use this application to report a non-serious crime than to report it over the phone with the Toronto Police Service.**		
Strongly Agree	5	29%
Agree	9	53%
Neither Agree nor Disagree	2	12%
Disagree	1	6%
Strongly Disagree	0	0%
*I believe that this application will allow for more unofficial crime incident data to be collected.***		
Strongly Agree	6	35%
Agree	11	65%
Neither Agree nor Disagree	0	0%
Disagree	0	0%
Strongly Disagree	0	0%
I found the Time Slider to be an effective tool for visualizing crime incidents and would use it when interacting with the CDB application.		
Strongly Agree	4	24%
Agree	10	59%
Neither Agree nor Disagree	2	12%
Disagree	0	0%
Strongly Disagree	0	0%
*I would feel more comfortable using a Web site such as CrimeReports.com or CrimeMapping.com to report local crimes incidents.****		
Strongly Agree	0	0%
Agree	3	18%
Neither Agree nor Disagree	9	53%
Disagree	5	29%
Strongly Disagree	0	0%
I was satisfied with the choice of crime incident types and citizen comments that were included.		
Strongly Agree	4	24%
Agree	13	76%
Neither Agree nor Disagree	0	0%
Disagree	0	0%
Strongly Disagree	0	0%

5.3.3 Graffiti Tagger Results

The final section of the survey was designed to collect user feedback regarding the Graffiti Tagger Web application. After being directed to complete a short tutorial that provided participants with a guided tour of the Web application, users were asked a series of short answer and multiple choice questions which used five-tiered Likert-item responses. Questions were designed to gauge how the user perceived the Web application in terms of usability and practicality.

88% of respondents found this Web application to be intuitive and easy to use. 77% believed that this Web application could be used to produce meaningful data that could be used for the purpose of monitoring and predicating gang activities. Fifty-nine percent of respondents declared that they would willingly participate if an official version of this Web application were released by the TPS. However, 64% of users expressed a desire for this application to be released as a dedicated iOS or Android application instead of in its current Web-based application form.

Based on written user feedback, a number of users praised the mobility and convenience provided by this Web application and agreed that on-the-go reporting was more useful than having to return to a computer in order to upload a photo.

"It's way more convenient to snap a picture on your phone and upload using a mobile app over a camera and computer"

"Since most of the time you see graffiti is on the street and almost everyone has a smartphone with iOS or android and a camera with GPS, this would definitely be useful for a user to report graffiti on the go."

"Although many users expressed a desire for a dedicated smartphone app; others stated that this should not be done to the exclusion of a Web-based application for users who do not own a smartphone. A need for an Address Locator was also expressed as an alternative to using the location services of a device. This would be an easy feature to add into a future release. Other users also expressed an interest in providing a list of known gang symbols that are used within the City of Toronto in order to help educate users on what graffiti could constitute a gang tag. In the interview with Janet Sherbanowski, Sherbanowski also acknowledged that CPAT has also recently been contacted by an additional third party for providing a graffiti reporting application (Sherbanowski, 2013). The aggregated user response to each question can be seen below in **Table 5.3**.

Table 5.3 – Summary of Graffiti Tagger Responses

	Responses	Percent Share
The user interface was intuitive and the application was easy to use.		
Strongly Agree	5	29%
Agree	10	59%
Neither Agree nor Disagree	2	12%
Disagree	0	0%
Strongly Disagree	0	0%
*I believe that this application could produce meaningful data that could be used for the purpose of monitoring and predicting gang activities.**		
Strongly Agree	4	24%
Agree	8	47%
Neither Agree nor Disagree	5	29%
Disagree	0	0%
Strongly Disagree	0	0%
I would willingly participate in this application if an official application were to be released by the TPS.		
Strongly Agree	2	12%
Agree	8	47%
Neither Agree nor Disagree	6	35%
Disagree	1	6%
Strongly Disagree	0	0%
*I would prefer to use this application as a dedicated iOS or Android app instead of as the current Web based application***		
Strongly Agree	5	29%
Agree	6	35%
Neither Agree nor Disagree	5	29%
Disagree	1	6%
Strongly Disagree	0	0%

5.4 Issues and Limitations

Throughout both the development and testing phases of these Web applications, a number of issues and limitations were discovered. While many were immediately addressed by the author, other limitations were left unaddressed for a variety of reasons. This section will explore some of the main limitations that were encountered and will discuss what could be done in order to resolve them.

SQL Database

The SQL Database hosted any spatial data that was used in either Web application that was required to be editable by a user over the Internet. Due to limitations in software availability, *Microsoft* SQL Server 2008 R2 Express was used as it was the default database software provided along with ArcGIS for Server 10.1. Unfortunately Express versions of SQL Server are limited to only 1GB of RAM usage. In addition, any databases that were hosted were limited to less than 10GB in size (SQL Server 2008 R2, 2013). This limited the amount of data that could be collected and created a bottleneck for application users by limiting the speed at which spatial data could be viewed and edited. Ideally, this could be resolved by purchasing a copy of SQL Server 2008 R2 Standard and installing ArcSDE on top of it. It would have also improved performance to have hosted the database server, as well as the GIS and Web Servers, within the City of Toronto, as the majority of users using this data would be connecting from this location. This might alleviate some of the issues that occurred when users attempted to upload large image attachments to the database. The workaround that was used was to limit image attachments to less than 2mb in size.

Map/Feature Services

At present, feature services are editable by any user. This means that a malicious user who understands how ArcGIS Services are accessed through REST could edit or delete existing crime reports. In the current release of the Web applications, this problem was mitigated by not providing the tools required for a user to edit or delete existing data within the application. This problem could be avoided by enabling user based edits; however, this solution would require users to create an account in order to contribute data, thus discouraging potential contributors. This problem could be resolved by disabling the edit and delete functions for all users and enabling versioning of the spatial data. Doing so would allow an authorized moderator to validate crime reports before allowing them to be posted. This approach would improve the reliability of data, but would require a dedicated moderator to review crime reports at least once a day.

Web Application

The Graffiti Tagger Web application was designed to not display image attachments. However, access to view and edit image attachments could easily be incorporated back into the application. This functionality was left out of the current release in order to prevent users from deleting image attachments that were provided by other users. A long term solution would be to redevelop the code so that image attachments could be displayed based on a URL instead of using the attribute editor function provided in the ArcGIS API for JavaScript. To do so may have required images to be stored externally from the spatial data and to have the image URL referenced within the attribute data of each feature.

Testing was conducted in order to ensure that the Web applications worked on a number of different hardware devices, Operating Systems, and a variety of Web browsers. This was done in an attempt to minimize performance issues and standardize the experience for all users, regardless of their hardware platform or browser. However, specific hardware configurations and different screen resolutions may affect the layout for some users and different browsers could cause parts of the applications to display differently.

5.5 Alternate Methods for Development

A number of alternate methods were examined and subsequently rejected during the development, deployment and testing stages of producing the Web applications that were used in this thesis. This section will explore a few of the alternate methods which could have been used during this thesis and explain the rationale behind why they were not included.

ArcGIS 10

When this thesis began, the original design plan featured the use of ArcGIS for Desktop 10, as well as ArcGIS for Server 10. Initial map document authoring occurred in version 10, and the first services were published using ArcGIS for Server 10. During the course of this thesis, ArcGIS for Desktop 10.1 and ArcGIS for Server 10.1 were provided for use at the University of Waterloo. Data was eventually recreated using ArcMap 10.1 and after configuring the *envmaps2* VM, services were published using ArcGIS for Server 10.1. The decision to go with 10.1 over 10 was based on the additional functionality provided by the 10.1 release of ArcGIS for Server.

Within ArcMap, the majority of what was achieved using 10.1 could have also been completed with 10. However, the 10.1 release featured ArcGIS for Server for the first time as x64 compatible. Among other things, this change allowed for faster processing to occur on the 10.1 GIS server. The process of configuring the GIS server at 10.1 was also streamlined and required far less pre-configuration work to occur on the VM. Additionally, only a single additional Windows user account was required with 10.1, as opposed to the three accounts that were required with 10. 10.1 Server also introduced a mandatory analysis of any map document before it could be published, ensuring map service integrity once published as well as helping to optimize overall map service performance. Moreover, 10.1 also introduced a new system for enabling secure services which allowed users and roles to be assigned directly from within ArcGIS Server Manager without the need for an associated DBMS to handle usernames and passwords. Finally, through the use of Web adaptors which were also introduced in 10.1, the GIS server could be configured to support remote access and administration, both through a Web browser, as well as directly from ArcMap. This feature allowed the author to publish, edit, configure and delete map services on the GIS server while working remotely from another city.

ArcGIS Online Subscription

One alternate method that was examined for publishing and managing the map services and feature services over the Web was the use of an ArcGIS Online (AGO) Subscription. AGO Subscriptions are a cloud-based system that allow an organization or an individual to publish and manage their spatial data online. Subscription plans can be purchased at a variety of levels and user credits, which are the currency of AGO, are consumed for tasks such as uploading and transferring data, creating and caching map tiles, or geocoding addresses. Credits are also consumed when a user accesses any services that were published using a subscription (ArcGIS Online Subscriptions, 2013). This method was tested by using a free one month trial subscription. By using an AGO subscription, the need for ArcGIS for Server 10.1 and SQL Server were removed. The author also found that using an AGO subscription allowed the services to display faster and also supported larger image attachment uploads with a higher rate of success. Although there were many benefits to using this method, the ongoing costs that would be accrued, particularly if either application were expected to be publically accessible to a large number of users, would be too high to make this a viable project.

ArcGIS 10.1 on Amazon EC2

Another alternate approach for authoring and publishing the data and services which were used in this thesis involved the use of an *Amazon* EC2 instance. Through a partnership between *Amazon* and *Esri*, a user is able to create a VM hosted in the Amazon cloud that includes ArcGIS for Desktop 10.1 and ArcGIS for Server 10.1. The benefit of this approach would be the increased performance that could be expected from using servers that were hosted on the *Amazon* cloud. Although this option would require a financial investment in order to utilize the *Amazon* infrastructure, a number of education-specific grants did exist which could have been used to finance this thesis for a limited period of time (AWS in Education, 2013). Using this approach, a new *Amazon* VM could have been created and configured within only a few hours. Once created, the University of Waterloo's *Esri* license information could have been used to register the

Esri software on the *Amazon* VM. Although this approach could have provided a powerful server for use in this thesis, it was decided that the time commitments that would have been required to investigate and pursue this alternate approach would have outweighed the potential benefits that it could provide. Additionally, to have followed this approach would have introduced an additional level of risk into this thesis, as there was no guarantee of receiving an education grant from *Amazon*. Moreover, the requirement of using the *Esri* license information from the University of Waterloo would have required additional coordination with MAD staff and would have necessitated more time and resources.

Google Maps API

In addition to the three ArcGIS APIs that were referenced earlier in the methodology for use in developing the final Web applications, a fourth option also exists. The *Google* Maps API was briefly investigated for inclusion in this thesis as an alternative to using the three *Esri* produced APIs. Using the *Google* Maps API would have provided the benefit of familiarity that *Google* Maps has created over the years for many users. This API would have enabled the map services and feature services which were published using ArcGIS for Server to be overlaid on the popular *Google* basemap. To do so, the map services would have had to be published with WMS capabilities enabled while the feature services would have had to be published with WFS capabilities enabled. An additional benefit would have been the easy inclusion of other useful *Google* tools within the Web applications, such as *Google* Chart Tools. This API was not pursued due to the fact that a large amount of professional-grade documentation was readily available about using ArcGIS services specifically with the ArcGIS APIs. It was believed that a third-party API would have introduced a new level of complexity and the potential for incompatibilities between the services and the API.

Applications for iOS or Android OS

Developing OS-specific applications for both iOS and Android OS mobile devices was considered as an alternative to developing Web applications. This approach would have provided users with an application that was designed specifically for use on their mobile device, and could potentially provide a better user experience. This idea was turned down as the time required to learn two new programming languages and to double the number of applications that would be developed would be far too large. In addition, in order to program for iOS, the X-Code IDE would have been required. This would have also required the use of a computer running a Mac OS.

5.6 Chapter Summary

To achieve the goals of this thesis, two Web applications were developed and deployed. Each Web application contained a number of features, but maintained a simplistic interface in order to not overwhelm first-time users. In order to gauge the relative success of these Web applications, a survey was conducted to determine the usability and practicality of each application. The survey received Ethics Clearance from the Office of Research Ethics at the University of Waterloo and was released to a select number of participants. The survey exceeded the expected response rate by receiving a total of 17 survey responses. Results showed that a public desire exists for both of the Web applications, along with a willingness from the majority of participants to voluntarily participate and volunteer information using these applications. The results of the survey further demonstrate the potential applicability of Web mapping tools for crime incident reporting in the City of Toronto.

Chapter 6

Conclusions and Recommendations

This chapter will explore some of the conclusions that were made based on both the results of the survey, as well as the observations of the author. The chapter will conclude with a series of recommendations for both future research, as well as recommendations for any future releases of the Toronto Crimes Database or Graffiti Tagger Web applications.

6.1 Conclusions

Crime is an ever evolving issue that exists in societies around the world, regardless of their geographical location. To help deter crime and to mitigate the negative effects that crime can have on the general population, crime prevention techniques have evolved over the years to keep up with both the ever-changing criminal landscape as well as the technologies that are currently available. To this end, many police services around the world have adopted online Internet based methods for sharing information between multiple police services and for communicating important information to the public. A deficiency was observed when examining the current system in use by the City of Toronto for communicating crime-related information with the public. It was believed that the incorporation of Web GIS technologies could improve upon current existing systems that are in use in Canada by providing an alternative method for effectively collecting and disseminating crime-related information. After consulting much of the relevant academic literature on this subject, it was noted that many organizations have successfully implemented a Web GIS or Mobile GIS solution into their workflow. The inclusion of Volunteered Geographic Information had provided the opportunity for many groups to quickly gather large amounts of spatial data at little to no cost.

To improve upon the current system that was being used in the City of Toronto, this thesis proposed the development of two Web-based GIS applications for the City of Toronto that could showcase the potential benefits which these technologies could provide within the fields of crime prevention and crime mapping. To achieve this, ArcGIS for Desktop 10.1, *Microsoft* SQL Server 2008 R2 Express, and ArcGIS for Server 10.1 were used to develop and deploy the relevant map and feature services, while the ArcGIS API for JavaScript was used to develop the actual Web applications. The Web applications were designed to be used for both data gathering from the public, as well as for information dissemination from the Toronto Police Service. The first Web application provided a general crime reporting tool for a large variety of crime incidents that could occur, while the second Web application provided a focused view of how these technologies could be deployed for a specific purpose, such as graffiti tracking. These applications offer a new Web-based channel in which the public could have two-way communications with the TPS, while retaining their anonymity over the Internet. It was hypothesized by the author that the two Web applications that were developed could provide an additional method for members of the public to report crime incidents. This in turn could potentially lower the total underreporting of crimes and improve data accuracy by enforcing a structured approach to incident reporting. These applications also presented the novel idea of using temporally-based tools as a way of visualizing change within a crime mapping Web application.

In order to test the success of these Web applications from the public's perspective, a survey was developed and circulated to a number of participants from different backgrounds and with varying levels of technical skills. Participants provided background information anonymously and were asked to use both applications and to provide their reactions to each through a series of five tiered Likert-item questions. Participants were also given the chance to expand on their replies by including written responses to specific questions. At the end of the survey period, a total of 17 surveys were returned. Participants had varying levels of previous exposure to GIS, ranging from first-time users to advanced users that utilized GIS as part of their current professional role. Nearly a quarter of the respondents admitted that they had witnessed or been the victim of a crime in the past that had not been reported to police authorities. When asked about the Toronto Crimes Database Web application, the majority of users found the application to be intuitive and easy-to-use. All participants agreed that the Web application would increase their likelihood of reporting a crime incident. With regards to the Graffiti Tagger Web application, the majority of participants also found the application to be intuitive and agreed that the application would encourage them to contribute meaningful data for the purposes of monitoring and predicting gang-related activities and vandalism. In addition, the majority of users expressed their willingness to voluntarily participate, if this Web application were made publically available through the TPS.

These results highlighted the need for crime-focused Web mapping applications within the City of Toronto. A public appetite for such Web applications was also noted based on user feedback. As indicated by the results of the survey, the infrastructure for using these applications currently exists within the study area, as the overwhelming majority of users indicated that they possessed either a smart phone or a mobile tablet computer. As a result, during the survey period, a sizeable amount of spatial crime data was collected using these Web applications. Since the inception of this thesis, the importance of Web Mapping applications has been acknowledged by a number of Canadian police services and public safety organizations from across the country through their adoption of this technology. This further underscores the need for this technology within a major urban centre such as the City of Toronto. Although the Web applications which were developed for this thesis are by no means production-ready versions, they did succeed in identifying the need and potential for such Web applications, as well as providing a framework for which future Web applications could be developed from. In addition, based on survey responses, this thesis showed that the use of temporally-enabled tools within a crime mapping Web application is an effective and engaging tool for the purposes of visualizing criminal incidents over time.

It is the author's opinion that this thesis has added to the existing academic literature for the fields of Crime Mapping, Web and Mobile GIS, as well as VGI. This thesis has also provided a case study of how these fields can be successfully integrated together, as well as a framework for future projects to expand upon.

6.2 Recommendations

If the Web applications and GIS services that were developed in this thesis were to be re-released in the future, the author would recommend a number of changes and updates that could benefit the overall performance and usability of the Web applications. Such recommendations were not included due to the financial costs associated with these Web applications or simply due to time constraints that were not possible during the timeframe for this thesis. While some of these recommendations are provided directly from the author, others are adapted from user feedback that was returned via the surveys. The author will also provide several recommendations for future research that may be conducted on this topic.

Future Enhancements

Any changes that would be made to the developed Web applications would be determined primarily by the group or organization that ultimately adopts this technology. Based on whether this technology is adopted by either the Toronto Police Service, a public safety organization, or a third-party researcher, the overall purpose and direction of development of these Web applications would change. As such, the tools and functionality that are included would also differ.

In order to improve system performance, the VM that was used to host the various servers should be relocated to a centralized location within the study area, in this case, the City of Toronto. Performance could also be further enhanced by improving the virtual setup of the VM. This could be achieved by allocating additional cores or storage space to the VM. Depending on funding availability, upgrading from SQL Server Express 2008 R2 to SQL Server Standard 2012 would also increase the performance of the feature services that were used in the Web applications. This could help to mitigate any connectivity issues that could arise when multiple users connect simultaneously, and it could improve upon the speed at which images are uploaded as attachments. In the current setup, images were limited to a specific file size and would often fail to upload. If funding options were available, the *ArcGIS Online* or the *Amazon EC2* alternate methods of deployment that were proposed in the **Methodology** chapter could also be utilized and tested.

The map services and feature services that were used could be improved by utilizing a custom font file that includes more descriptive graphics that could be used within the map document to symbolize specific types of crime. In addition, to improving performance, automated procedures could be used to automatically archive reported incidents that are over 30 days old. These incidents would not be displayed within the Web application and would only increase the file size of the feature service and limit performance. Moreover, before publishing the services, it would be advisable for future releases to include the ability for moderating user contributions. This could be achieved by providing ownership based access to the data and by enabling the versioning functionality of the geodatabases that were used in this thesis. By doing so, anonymous users would be able to write to a temporary version of a given feature class; however, an authorized moderator would have to review and approve the user contributions before they are reconciled to the main version (base table) of the feature class that is visible to the public. This feature was requested by several survey participants in this study.

Within the Web application, the author would recommend the inclusion of instructional videos to replace the tutorial documents that were used. These videos could be recorded using software such as *Camtasia Studios* and could be easily embedded within the Web application at little to no cost. In addition to this, the Graffiti Tagger Web application could benefit from the inclusion of a loading icon for use when image attachments are being uploaded. In the current release, no indication is given that data is being transferred to the server. This could easily cause a user to inadvertently cancel their image upload or to incorrectly assume that the Web application was not functioning correctly. Within the Toronto Crimes Database Web application, the author would recommend providing division specific contact information and summary statistics within the Discovery Window when a TPS division is selected within the Map Controls toolbar. In addition, it is also recommended that the default links section that is loaded in the Web application be replaced by a list of current news alerts for the TPS. This would further promote the two-way flow of communication between the public and the TPS. Finally, the inclusion of a splash screen upon loading the application can provide important disclaimer information to potential users before they begin using the applications.

The author would also recommend including the ability to switch between the types of crimes that are displayed. This change could easily be incorporated using either checkboxes or a dropdown list, in a similar way as to what was implemented with the TPS division boundary layers. This Web application could also be improved upon by including a simple hotspot overlay based either on each individual crime type or by combining the various crimes types using a weighted calculation to produce an overall crime severity overlay. In addition, the author feels that it would be beneficial to include different fields and inputs in future iterations of these applications. For example, expressive crime reports may require a different set of questions to be asked than acquisitive crimes in order to determine the motivations behind the crime. Expressive crimes may also require additional analyses and data overlays in order to sufficiently determine the context in which the crime took place. Finally for both Web applications, including *Google* Analytics to monitor the usage statistics for each Web application is highly recommended. Data that is gathered could include useful information, such as the general geographic areas from which participants are connecting, as well as their language preferences, operating systems, and the Web browsers that they use. This information could be used to further refine the Web applications to better suit public needs.

Based on the feedback that was given within the surveys, a number of additional recommendations were provided by users. Among other things, users wanted to see additional publicity about these tools as many were unaware of the existence of Web mapping applications being used for the purpose of crime mapping. In addition, the survey responses showed that a large public preference existed for the creation of dedicated mobile applications for various types of smartphones. However, this should not be implemented by excluding a Web application, which could still be utilized by those without a smartphone. Within the Web applications, users recommended including a system that allowed the TPS to respond to specific incident reports. They also requested the ability to undo their edits and to delete the features which they contributed. This could be resolved in part by having a moderator approve any incident reports that are contributed. Finally, some users requested the inclusion of information on gang tags and gang symbols, so that they could identify gang-related graffiti when they saw it and be more selective in the types of graffiti that they chose to report.

Future Research

The author recommends multiple testing phases to be conducted before any official version of future applications be released publically. In addition, if the infrastructure can support a larger user base, increasing the length of the survey period and collecting more participants from a larger pool of people would be recommended.

Further research into how data produced by Web applications can be incorporated into current workflows of groups, such as the Toronto Police Service, is required. For example, ArcGIS models and stored procedures on SQL Server can be used to automate the analysis of crime incident data, and to summarize it by division without the need for any manual processing from an analyst. This summary data could then be used to automatically populate pre-configured reports, which could be produced for use by senior members of the police service. An automated procedure could be achieved at no additional cost through the use of stored procedures in SQL Server and through the use of macros in *Microsoft* Excel. Focus should also be placed on additional data sources that could be used to enhance the usability of this data, for instance, POIs, known gang territories, or demographic data for the City of Toronto.

Since 1991, the volume of police-reported crimes in Canada has in general decreased each year. In 2011, police-reported crime rates were the lowest that had been seen in Canada since 1972 (Brennan, 2012). In addition to this, the CMA of Toronto has one of the lowest calculated crime severity index values among Canadian CMAs (Brennan, 2012). Both of these facts indicate the need for future research to potentially explore other geographical areas, both within and outside of Canada, where the severity of criminal activities are greater and more common.

It is highly recommended that any future releases spend significant time addressing many of the privacy and safety concerns that were raised earlier in this thesis. In addition, it is recommended that any future research should explore alternative ways of displaying the crime incident data. It was noted that a number of different types of crime incident data, such as homicides, sexual assaults, and burglaries, may be too sensitive in nature to be displayed publically. Releasing this type of data publically has the potential to both severely and negatively impact the privacy and security of the data contributor. In addition, misinformation reported with malicious intent can negatively impact the targeted individual without their knowledge or consent. As such it is highly advised that any future research or iterations of these applications remove the ability for anonymous users to immediately post new incident reports directly to the map without first being reviewed by a moderator. Moreover, some incident reports that are highly sensitive in nature, such as ongoing cases, should be supressed by the TPS and not made publically available at all. This highly sensitive data should only be used internally within the TPS.

As expressed earlier, alternate methods for data visualization should be explored in order to safely displaying different types of crime incident data that are inherently sensitive in nature. The reporting of certain expressive crimes may negatively impact a victim future by inadvertently releasing personal information such as the victim's home address or the specific nature of a crime. The need for protecting the privacy of victims of acquisitive crimes also exists. Crime reports such as residential burglaries may highlight a specified residence as a potential target due to the fact that past burglaries could indicate both a vulnerability in home security as well as a recent purchase of new items by the homeowners to replace those that were stolen.

To this purpose, two methods are proposed by the author for ensuring that user privacy is upheld. The first method involves the aggregation of data based on a small and standardized level of geography, such as a Canadian Dissemination Area. This is a common method that is practiced by both Statistics Canada, as well as a number of private data providers. Crime reports could be aggregated this way and could ensure user privacy, while still allowing a certain level of spatial accuracy that is often times within the City of Toronto equivalent to a few city blocks. This could be used for dealing with highly sensitive crime incidents such as homicides or sexual assaults. The second method that is proposed by the author involves the randomization of each reported incident through a scripted procedure that is run automatically before any data is published publically. A scripted procedure could be used to alter the latitude and longitude coordinates of a point using randomly generated numbers that are within a predefined range of values. This predefined range could determine the maximum distance from the original point that a randomized point could be plotted at. If incident point randomization were implemented, advance notice of this should be presented to the user in the form of a disclaimer upon accessing the application. In addition, using this second method would also address the issue of perceived accuracy. As many of the incidents that are reported will be based primarily on the memory of either the victim or of a witness, the potential for reporting inaccuracies exists. In addition, a wide range of devices and GPS sensors are expected to be used by the various contributors, further adding to the potential for reported data to be of a lower spatial accuracy than it is assumed to be. By providing this automatic randomization, along with a disclaimer, the issue of data being perceived as more accurate than it actually is should be limited.

6.3 Chapter Summary

This thesis showed that significant potential currently exists for the inclusion of Web GIS applications within the City of Toronto as a tool for crime reporting and public information dissemination. The two Web applications that were developed for this thesis, although not production-ready, did succeed in providing a proof of concept of such tools, as well as providing a framework from which future Web applications could be designed from. The author's hypothesis that the inclusion of Web mapping applications within the fields of crime mapping and crime prevention could provide an effective tool for assisting the public with the reporting of crime incidents was supported by the results of the survey that was conducted. Using this Web-based approach could potentially improve both the quality and quantity of crime data that is voluntarily reported. It is hoped that the results of this thesis can help to identify the large number of potential benefits that these Web GIS tools can offer. It is also hoped that these results can provide any interested parties with an example of how Web GIS applications can be successfully used as a modern tool for acquiring crime related spatial data. As mobile technologies and connectivity continue to improve, so too will the importance of applications similar to those developed in this thesis.

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Appendices

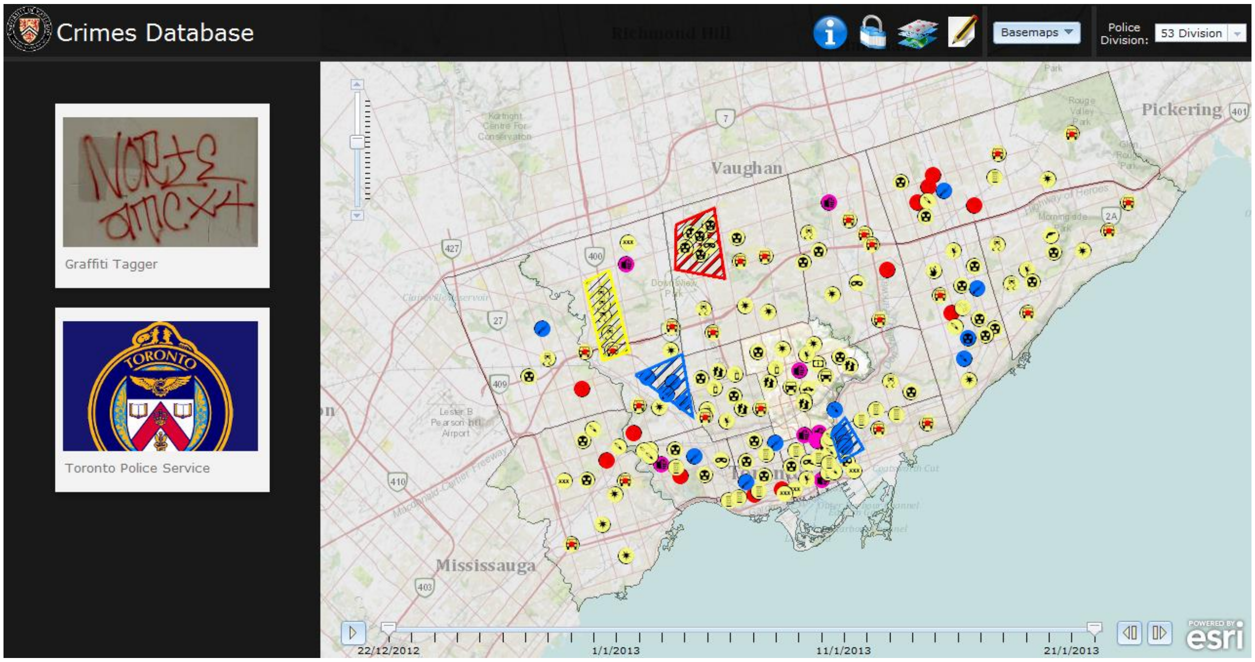
Appendix A: Toronto Crimes Database Instructions

The CDB Application

The ***Crimes Database (CDB)*** application provides a platform for concerned citizens to unofficially report instances of criminal activity in their neighborhood. Users can spatially visualize recent crimes that have occurred and easily spot negative trends in areas that affect them. Users can also submit general citizen comments for an area such as an unsafe park or a dark alley.

1. Access the ***CDB*** application at the following URL: http://envmaps2.uwaterloo.ca/cdb/index.html

You should be presented with a screen that looks similar to the following:



There are four main components to the CDB user interface. The map, the map controls, the discovery window and the time slider.

The Map

The map window takes up the majority of the application. By default, the map focuses on the 53 Division of the Toronto Police Service (TPS). Divisions that are not currently selected in the map controls are partly greyed out. In addition to division boundaries, the map window also displays unconfirmed crime reports and citizen comments. When a user changes the scale of the map, the size of the icons automatically updates as well.

The Map Controls

The upper-right corner of the application houses the map controls. A user can click on any of the icons or drop down menus to update the map contents or the discovery window. The **Login**  icon prompts a user to authenticate against the server in order to view secured services with confidential data. This functionality is not included in the current release of the ***CDB*** application. The **Legend**  icon creates a dynamic legend for the current map contents, while the **Report a Crime**  icon allows users to report new crimes and add citizen comments to the map. The **Basemaps** dropdown menu allows the user to cycle through a selection of nine unique basemaps. By default, the topographic basemap is displayed. The **Police Division** dropdown menu allows a user to select which division the map window should be focused on. For additional information regarding the application, select the **Info**  icon.

The Discovery Window

The discovery window appears to the left of the map and allows users to understand and interact with the contents of the map. When a tool is selected from the map controls, the tool's contents are displayed in the discovery window. When a new tool is selected, the contents will automatically be updated. By default, the discovery window displays a list of links, including the ***Graffiti Tagger*** Web application.

The Time Slider

The final component of the user interface is the time slider. The time slider allows you to view the change in crime reports temporally. By adjusting the start and end time arrows, users can highlight a specific time range in the map window. Selecting the play button will allow you to view the change in crime reports over time. By default, only crimes that were reported in the preceding month are displayed. When the time range is updated in the time slider, the current time range will displayed to the left of the map controls.

We will now use the application to run a hypothetical scenario from the perspective of a concerned citizen who just witnessed some type of criminal incident.

2. Use your mouse to **zoom** and **pan** around the map. Locate an area that is familiar to you where you would like to report a hypothetical crime.
3. Select the **Report a Crime** icon to open the crime reporter in the discovery window.
4. **Select** a crime incident of your choice by clicking on its icon in the discovery window.
5. With the crime incident highlighted in the discovery window, click once on a location on the map to report this hypothetical crime.
6. In the dialog box that appears, provide a *Description* of the crime and use the calendar to help select an *Incident Date*.

Note: Only crimes that occurred within one month of the current date will display on the map.

7. When you have finished reporting the crime, select the **exit** icon in the top-right corner of the dialog box to return to the map.
8. Using the same steps as above, try leaving a **citizen comment**. Begin drawing your area by clicking once on the map. You can add extra vertices to your area by single-clicking on the map. Double-click on the map to finish drawing your citizen comment area.

Citizen comments are ranked based on their level of importance and can be used to highlight potentially dangerous areas or areas that are in need of repair.

Your crime incident icon and citizen comment should now be visible on the map. The descriptions and comments that you provided can now be viewed by a crime analyst.

9. Take a minute to explore some of the static maps that are provided on the following TPS Web site:
http://www.torontopolice.on.ca/statistics/
10. Compare the current system used by the TPS for viewing police calls for service with the CDB application for reporting and visualizing unconfirmed crime incidents.

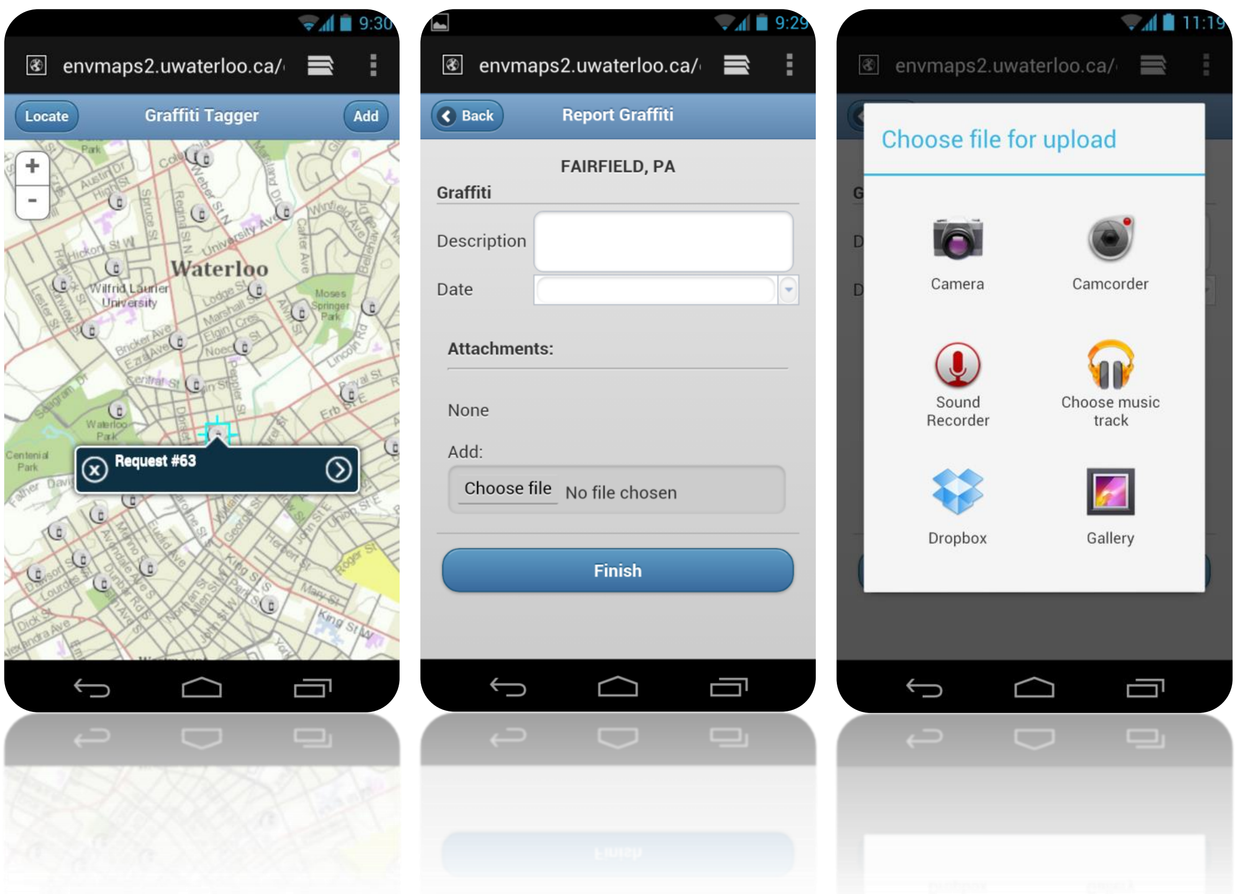
Appendix B: Graffiti Tagger Instructions

Graffiti Tagger Application

The ***Graffiti Tagger*** application was designed for use on smart phones and tablet computers. However, a user can also view and interact with the application from a Web browser. The application is designed to allow a user to anonymously report the location of a graffiti tag in their city. Users can optionally choose to support their report with a description or a photo attachment. Reported graffiti tags will then be forward on to an analyst to determine if they were left by a graffiti artist or a street gang member. Once confirmed by the analyst, the map is then updated to reflect the analyst's findings.

Note: The upload attachments feature of the application may not work on certain iOS devices.

1. Access the ***Graffiti Tagger*** application at the following URL: http://envmaps2.uwaterloo.ca/cdb/graffiti.html



The user interface for this application is very basic and consists of a map and a header bar.

The Map

The map takes up the majority of the application and displays a collection of point locations where graffiti tags have been reported. Points that are displayed are either grey, blue, or red depending on whether they represent unconfirmed graffiti, graffiti artist tags or gang tags.

The Header

The header contains only two buttons. The **Locate** button uses the location services of the smart phone or computer to approximate the user's current location. The **Add** button opens a menu that allows a user to report an unconfirmed graffiti location on the map. After placing a graffiti location on the map, a user can also provide a description, acquisition date and image attachment to support their report.

2. Tap a graffiti icon on the map to view its specific request number. Try selecting the **details** icon to view more information about the specific incident. Select the **exit** icon to close the incident request window and return to the map.

3. Tap the **Locate** button to zoom the map to your approximate current location.

Note: You may be prompted at this point to allow your Web browser to access your location services.

4. Try reporting some hypothetical graffiti by tapping on the **Add** button.

5. In the *Feature Type* page that appears, tap the **Unconfirmed** button. Once the map loads again, tap once on the map to place your graffiti point location.

6. In the *Report Graffiti* page that appears, add a brief *Description* and use the calendar to provide an acquisition *date*. You can also choose to upload a photo that is stored on your device or to capture and submit a new image of the graffiti.

Note: Adding an image attachment may take up to a minute to complete. Do not tap the finish button until the image name shows up as a hyperlink in the *Attachments* section.

7. When you are ready, tap the **finish** button to return to the map. Your graffiti report should now be visible on the map.

Users are limited to only submitting unconfirmed graffiti reports. Reports that are submitted can be passed on to analyst in the gangs unit at the Toronto Police Service. If an image is attached, the analyst can then confirm the origin of the graffiti as either a graffiti artist's tag or a gang-related tag and reclassify the feature on the map accordingly. As a security precaution, uploaded images are not displayed by default to the public.

Appendix C: Survey Recruitment Email

Hello,

My name is James Lockyer-Cotter and I am an MSc student working under the supervision of Dr. Su-Yin Tan in the in the Department of Geography and Environmental Management at the University of Waterloo. The reason that I am contacting you is that I am conducting a study that examines the use of Web Geographic Information Systems (GIS) in the field of crime incident mapping. To this end, I have developed two Web GIS applications that allow users to view and contribute crime incident data from either their computer, smartphone, or other mobile device. The purpose of this study is to understand both the practicality and effectiveness of using Web GIS applications to aid in the collection and dissemination of crime-related spatial data.

Participation in this study involves taking part in a survey conducted by email and completing two small tutorials that will familiarize you with the applications that are being analyzed. Upon completion of each tutorial, you will be asked a series of short multiple choice and short answer questions to gauge your experience with each application. The survey questions are designed to provide an understanding of the participant's background, as well as their experience while using both of the applications. It is estimated that this survey will take approximately 15 minutes to complete. In order to successfully complete this survey, you will need a computer with Internet access and a Web browser.

Participation in this survey is completely voluntary and there are no personal benefits or risks anticipated, nor incentives provided. In order to ensure the anonymity of the participant, all completed surveys will be stored digitally with any personally identifying information removed. The survey does not ask for any personal information and any survey responses that are received will be will be downloaded and given a randomized title. After being downloaded, the respondent's email being immediately deleted. Once the survey period has ended, all responses will be compiled together and summary statistics will be included in the final thesis document.

If you are interested in participating or wish to learn more about the survey, please open the attached Microsoft Word document titled ***WebGIS_and_Crime.docx***. If you choose to participate, please read through and answer the questionnaire in the attached document. Once you have finished the questionnaire, please save your answers and respond to this email with the completed document. As a participant, you may decline to answer any questions and can withdraw from the survey at any time by not returning it. By voluntarily responding to this questionnaire, you give your consent to participate in this study. If you have any questions regarding the survey, please feel free to contact me using the information listed below.

Sincerely,

James Lockyer-Cotter

MSc. Candidate
Faculty of Environment
University of Waterloo
jlockyer@uwaterloo.ca

I would like to assure you that this study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Committee. However, the final decision about participation is yours. Should you have comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca

Appendix D: Survey Introduction

Crime Mapping and Web GIS

The following set of applications provide a portal for citizens to become engaged in local crime reporting initiatives with the hope of building safer communities in the future. These applications provide citizens with an online channel for reporting and visualizing unconfirmed incidents of criminal activity in the City of Toronto.

As one of the most heavily populated cities in Canada with an estimated population in 2011 of approximately 2.6 million people, the City of Toronto experiences a significant amount of criminal activity. The City of Toronto was chosen as it contains a wide assortment of urban neighbourhoods, each with their own unique socio-economic characteristics. In addition, the increasing polarization of income levels has resulted in the city containing a number of both high and low income neighbourhoods.

The ***CDB*** application has been developed to allow users to anonymously report incidents of criminal activity that they witnessed in their local area. Users can submit a predefined crime incident report and provide a description of the incident, along with the date that it occurred. The time slider can be used to visualize past incidents and highlight temporal changes in criminal activity. Users can also use the application to submit citizen comments for areas that they feel are unsafe or require attention. Currently, the Toronto Police Service (TPS) releases crime data in PDF-based static maps on a bi-monthly basis.

The ***Graffiti Tagger*** application has been developed to allow users to anonymously report graffiti locations from their smart phones or personal computers. Users can also choose to optionally include a description and attach an image to support their report. Graffiti reports will be forward to the TPS where an analyst can determine the origin of the graffiti. Potential origins include street gangs, graffiti artists, or even utilities maintenance staff. By isolating and deciphering known gang tags, an analyst can then predict future gang activity.

The following survey is split into three sections. The first section is a background information questionnaire that allows us to gauge a user's technical abilities and determine their level of exposure to GIS, Web mapping and crime analysis. The second section introduces the ***CDB*** application for reporting crime incidents and highlighting areas of concerns with citizen comments. This section contains a set of instructions on how to use the application, followed by a set of questions. The third section introduces the ***Graffiti Tagger*** application that allows users to anonymously report graffiti tags using their smart phones or other mobile devices. This section also contains a set of instructions for using the application, followed by a set of questions.

Please fill out the attached survey to the best of your abilities and email it to jlockyer@uwaterloo.ca.

Appendix E: Survey

Background Information

This section will explore your background to help us gauge the experience and skills sets for the survey respondents.

1. How many hours a week do you spend using a computer?

☐ 0-5 ☐ 6-10 ☐ 11-15 ☐ 16-20 ☐ 20+

2. Have you used a Web mapping application such as Google Maps, Bing Maps, or Map Quest?

☐ Yes ☐ No

3. How would you rank yourself as a Geographic Information Systems (GIS) user?

☒ First Exposure ☐ Beginner ☐ Intermediate ☐ Advanced

4. Do you use GIS as a part of your current professional role?

☐ Yes ☐ No

5. Have you ever witnessed an illegal activity or been the victim of a crime and not filed a formal police report regarding the incident?

☐ Yes ☐ No

If you answered yes to the above question, please explain why.

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6. Have you ever used any Web based application for the purpose of crime mapping? (Crime Reports, Crime Mapping)

☐ Yes ☐ No

7. Are you an active member of either the Toronto Police Service or any Neighbourhood Watch Group in Canada?

☐ Yes ☐ No

8. Do you own a smart phone or tablet computer?

☐ Yes ☐ No

9. Do you have any experience with monitoring gang-related activities?

☐ Yes ☐ No

10. Are you aware of the process of "tagging" that is practiced by some graffiti artists and street gang members?

☐ Yes ☐ No

11. Are there any specific tools that are not currently used in Toronto which you feel would be beneficial to the field of crime mapping?

☐ Yes ☐ No

If you answered yes to the above question, please list them below.

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12. Please leave any additional comments in the space provided below.

Section 1: The CDB Application

Please review the following tutorial to learn more about the CDB Application. Once you have completed the tutorial, please answer the following questions regarding your experience using the application.

CDB Application Tutorial: http://envmaps2.uwaterloo.ca/cdb/docs/tutorial_1.pdf

1. The user interface was intuitive and the application was easy to use.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

2. I would prefer to use this application to report a non-serious crime than to report it over the phone with the Toronto Police Service.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

Please use the space below to further explain your above answer.

---

3. I believe that this application will allow for more unofficial crime incident data to be collected.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

Please use the space below to further explain your above answer.

---

4. I found the Time Slider to be an effective tool for visualizing crime incidents and would use it when interacting with the *CDB* application.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

5. I would feel more comfortable using a Web site such as CrimeReports.com or CrimeMapping.com to report local crimes incidents.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

Please use the space below to further explain your above answer.

---

6. I was satisfied with the choice of crime incident types and citizen comments that were included.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

7. Please use the space provided below to expand on any of the above questions, recommend any additional features that could be included or to leave any other comments.

Section 2: Graffiti Tagger Application

Please review the following tutorial to learn more about the Graffiti Tagger Application. Once you have completed the tutorial, please answer the following questions regarding your experience using the application.

Graffiti Tagger Application Tutorial: http://envmaps2.uwaterloo.ca/cdb/docs/tutorial_2.pdf

1. The user interface was intuitive and the application was easy to use.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

2. I believe that this application could produce meaningful data that could be used for the purpose of monitoring and predicting gang activities

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

Please use the space below to further explain your above answer.

---

3. I would willingly participate in this application if an official application were to be released by the TPS.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

4. I would prefer to use this application as a dedicated iOS or Android app instead of as the current Web based application.

☐ Strongly Disagree ☐ Disagree ☐ Neither Agree nor Disagree ☐ Agree ☐ Strongly Agree

Please use the space below to further explain your above answer.

---

5. Please use the space provided below to expand on any of the above questions, recommend any additional features that could be included or to leave any other comments.

Appendix F: Survey Participant Feedback Letter

<Date>

Dear <Participant Name>,

I would like to thank you for your participation in this study entitled Web GIS and Crime Mapping. As a reminder, the purpose of this study is to identify the potential benefits that the use of Web GIS applications can have in the field of crime mapping.

The data collected from the survey will help me gauge both the practicality of using Web GIS technologies in this field and its effectiveness as an internet-based channel for crime reporting.

Please remember that any data pertaining to you as an individual participant will be kept confidential. Once all the data are collected and analyzed, I plan on sharing this information with the research community through presentations and my thesis report. If you are interested in receiving more information regarding the results of this study, or would like a summary of the results, please respond to this email, and when the study is completed, anticipated by April 15, 2013, I will send you the information. In the meantime, if you have any questions about the study, please do not hesitate to contact me. As with all University of Waterloo projects involving human participants, this project was reviewed by, and received ethics clearance through, the Office of Research Ethics at the University of Waterloo. Should you have any comments or concerns resulting from your participation in this study, please contact Dr. Maureen Nummelin, the Director, Office of Research Ethics, at 1-519-888-4567, Ext. 36005 or maureen.nummelin@uwaterloo.ca.

Sincerely,

James Lockyer-Cotter

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