

# **Use of Smartphone and GIS Technology for Sustainable Forestry in Eastern Ontario**

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# Table of Contents

List of Figures .....	ii
List of Tables .....	ii
List of Abbreviations .....	iii
Abstract .....	iv
Résumé.....	v
Preface.....	vi
Acknowledgements.....	vii
Chapter 1 .....	1
1.1 Introduction and objectives.....	1
1.2 Literature review .....	4
1.2.1 Mobile geographic information computing systems.....	4
1.2.2 Smartphone technology .....	6
1.2.3 Applications of MGIS technologies.....	7
1.2.4 Applications of smartphone technology .....	11
1.2.5 Ontario Forest Management .....	13
1.2.6 Silvicultural management .....	14
1.2.6.1 Silvicultural effectiveness monitoring.....	15
1.3 Methodology.....	16
1.3.1 Smartphone GIS architecture.....	16
1.3.2 Hardware and software .....	18
1.3.4 Data and work flow.....	21
1.3.5 Test sites.....	27
1.3.6 Smartphone GIS usability testing .....	30
1.3.6.1 Usability test design.....	31
1.3.6.2 Participants, tasks, and data collection procedure .....	32
1.3.7 Data analysis .....	35
1.4 Challenges and limitations.....	37
Chapter 2.....	38
Abstract.....	38
2.1 Introduction.....	39
2.2 Methods.....	43
2.3 Results.....	49
2.4 Discussion and conclusions .....	56
Acknowledgements.....	62
Supplementary Material.....	62
Chapter 3.....	67
3.1 Summary and Conclusions .....	67
3.2 Contributions of the research.....	70
3.3 Suggestions for further research .....	71

References:.....	73
APPENDIX A: MLFI Forest Stand Analysis Dot Tally Paper Form.....	80
APPENDIX B: List of Project Hardware and Software.....	81
APPENDIX C: Htc HD-2 Windows 6.5 OS Smartphone Technical Details.....	82
APPENDIX D: Forest Stand Application MS Excel Macro Source Code.....	81
APPENDIX E: Examples of Data Collection Attribute Information Cards.....	88
APPENDIX F: Tabaret Lawn Feature Data Map.....	89
APPENDIX G: Participant Paper GIS Data Collection Form.....	90
APPENDIX H: Participant Survey Questionnaire.....	91
APPENDIX I: Participant Usability Test Performance Data.....	92

## List of Figures

Figure 1.1 Selection of handheld mobile computing devices.....	5
Figure 1.2 Smartphone/desktop GIS architecture.....	17
Figure 1.3 Forest stand tally application GUI.....	19
Figure 1.4 ArcPad mobile mapping software GUI.....	20
Figure 1.5 Work and data flow model.....	27
Figure 1.6 Smartphone GIS usability testing sites.....	29
Figure 1.7 Participant recording geospatial data during usability testing.....	34
Figure 2.1 Smartphone data collection software.....	44
Figure 2.2 Smartphone GIS usability testing sites.....	46
Figure 2.3 Mean data collection and processing times for all participant data states.....	49
Figure 2.4 Mapped GIS data.....	50
Figure 2.5 Example of mapped smartphone GIS data.....	53
Figure S.1 Work and data flow model.....	66

## List of Tables

Table 1.1 Participant background information.....	32
Table 2.2 Usability performance measurements for electronic and paper systems.....	52

## List of Abbreviations

AOC	Areas of Concern
CFSA	Crown Forest Sustainability Act
CSV	Comma-Separated-Value
DRAPE	Digital Raster Acquisition Project for the East
FST	Forest Stand Tally App
GIS	Geographic Information Systems
GPS	Global Positioning System
GUI	Graphical User Interface
HCI	Human-computer Interaction
IT	Information Technology
MGIS	Mobile geographic information computing systems
MLFI	Mazinaw-Lanark Forest Inc.
MNR	Ministry of Natural Resources
MS	Microsoft
OS	Operating Systems
PC	Personal Computer
PDA	Personal Digital Assistants
P&P	Pen and Paper
SEM	Silvicultural Effectiveness Monitoring
SDK	Software Development Kit
USFS	United States Forest Service
USB	Universal Serial Bus

## **Abstract**

This study examined whether the current generation of consumer-grade digital mobile computing technology, so called smartphone technology, is usable to perform and improve field data collection in the context of sustainable forest management. An electronic data acquisition system, based on a handheld smartphone device and desktop geographic information system (GIS), was developed. A proprietary timber cruise application and commercial mapping software were used with the smartphone/desktop GIS to record and process forest stand and geospatial data. Usability testing was carried out to measure workflow efficiency and system performance of the smartphone GIS compared to traditional paper-based methods. The smartphone GIS successfully met performance objectives and significantly increased workflow efficiencies by improving data transfer and processing times over conventional paper methods; however, use of the mobile device resulted in greater data entry errors, increased data collection times, and led to more equipment malfunctions than use of paper recording methods together with a GPS and digital camera. Overall, the prototype electronic data acquisition system was not reliable as a stand-alone solution solely responsible for collecting cruise data, but was found to be well suited for ad-hoc mapping of forest features.

## Résumé

Cette étude s'intéresse à la capacité de la génération actuelle des technologies numériques informatiques mobiles grand public, dites technologies de téléphone intelligent (*smartphone*), à contribuer et à améliorer la collecte de données dans le cadre de la gestion durable des forêts. Nous avons développé un système électronique d'acquisition de données, fondé sur un dispositif de téléphone intelligent portatif et un ordinateur équipé d'un système d'information géographique (SIG). Une application propriétaire d'inventaire forestier et un logiciel commercial de cartographie ont été utilisés en lien avec le téléphone intelligent et l'ordinateur équipé d'un SIG afin d'enregistrer et de traiter les données géospaciales et relatives au peuplement forestier. Des tests d'utilisation ont été réalisés pour évaluer l'efficacité du traitement des informations et la performance du système conjuguant téléphone intelligent et SIG comparé aux méthodes traditionnelles, fondées sur l'usage de documents papier. Téléphone intelligent et SIG sont parvenus à atteindre les objectifs de performances et ont augmenté de manière significative l'efficacité du processus, par l'amélioration des transferts de données et des délais de traitement par rapport aux méthodes conventionnelles. Toutefois, l'utilisation d'un appareil mobile a parallèlement entraîné un plus grand nombre d'erreurs de saisie, une augmentation du temps de collecte des données, et a causé un plus grand nombre de dysfonctionnements des équipements que l'usage de méthodes de saisie papier complétées par un guidage par satellite (GPS) et un appareil photo numérique. Dans l'ensemble, le prototype de système électronique d'acquisition de données ne s'est pas avéré fiable en tant que responsable unique de la collecte des données d'inventaire, mais il s'est révélé bien adapté à la réalisation d'une cartographie ad-hoc des éléments forestiers.

## **Preface**

This research originated from my interest in applied geomatics and GIS science. Dr. Robert McLeman introduced me to Jan Smigielski, a certified professional Ontario forester, who expressed a desire to develop an integrated data management system to support sustainable and adaptive forest silvicultural management. In collaboration with Dr. McLeman, Dr. Michael Sawada, and Mr. Smigielski, we devised the research objective to focus on improving the collection of primary forest spatial information in a digital format to facilitate data processing and analysis. Dr. Sawada and Dr. McLeman suggested incorporating a smartphone as the primary platform for the envisaged electronic data collection system.

This thesis follows the article format. It consists of an introductory chapter, a second chapter composed of an article to be submitted for publication in a peer-reviewed scholarly journal, *Small-Scale Forestry*, and a third concluding chapter. The introductory chapter includes the context of the research, objectives of the study, a literature review, the challenges and limitations faced in this project, and the materials and methods used in this study. The second chapter includes a self-contained research article, presented in manuscript submission format. Some information presented in Chapter One is repeated and/or summarized in Chapter Two. This was necessary in order to provide the appropriate context to situate my research for both uOttawa thesis committee members and journal audiences. The final chapter summarizes the main results and findings of the study, conveys the major contributions of the study, and suggests areas for future research. Additional information, including the materials used during usability testing and the raw datasets obtained during testing that were not included in the text of the article, is provided in the appendices.

The candidate, the first author of the article, was responsible for all empirical research, constructed the smartphone system architecture, led the writing of the journal article, and primarily served as project manager for this research. The second author, Dr. Robert McLeman, provided guidance and direction of research, was responsible for obtaining and directing project funding, and providing editorial assistance in the drafting of the journal article. The third author, Dr. Mike Sawada also provided guidance, direction of research, GIS technical assistance and editorial support in composing the journal article. The article's fourth author, Jan Smigielski provided expert opinion and served as a consultant on the development of the data collection system design.

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# Chapter 1

## 1.1 Introduction and objectives

Silvicultural management is defined as the planned series of treatments carried out during the entire lifetime of a managed forest stand with the objective of controlling the establishment, species composition, and growth of the stand (Elliot et al. 2000). Sustainable silvicultural management practices enable forest stands to maintain their ecological integrity and biodiversity, while providing us with the goods and social, economic, and cultural values that we demand currently, and into the future. Working towards these twin goals of sustainability and productivity, forest managers rely on accurate and timely field data as a basis for numerous planning, operational, and monitoring activities. The ongoing collection of geospatial data is important because it provides us with an understanding of the structure, composition, and regeneration of a forest. Therefore the success of forest management treatments can only be determined through systematic monitoring that includes the collection of reliable data (Bell et al. 2008).

Timber cruising is the process of quantitatively measuring a sample plot of trees in a stand to determine their density, distribution, species, age, and size classes (Wang, 2005). The data collected serves to update forest inventories. Secondary information such as forest disturbances, historical evidence and rare species, and other site conditions are also essential data that contribute to building a more complete map of forest resources within management units. Managers incorporate survey information along with their experiential knowledge as the basis for all forest management planning (Thompson et al. 2007).

The capture of primary spatial and attribute data, however, is widely recognized as one of the most time consuming, expensive, and error prone tasks in any geographic information centric project (Longley et al. 2005). Foresters use a mix of global positioning system (GPS) technology, aerial satellite imagery, survey instruments, maps, and paper-based forms to capture geospatial and attribute data related to forest stand variables (Curran et al. 2000). Often data entry on paper-based forms is unstructured and input values are unconstrained (Jones et al. 2004). This process induces errors or data quality issues during transcription because of inconsistencies. In addition, editing, transfer, and processing of information from paper-based forms to digital formats adds to workload burden and increases the risk of introducing errors (Inman-Narahari et al. 2010). Furthermore, using traditional field data collection systems, information gaps may arise in that valuable observations go unrecorded because data types do not conform to data entry fields on standard forest survey forms (Smigielski, personal correspondence). These site features are important considerations for adaptive management and provide meaningful variables that can serve as inputs for environmental modeling and forest regeneration trend analysis (Matthews, 1991). Although traditional field data collection methods have proven to be adequate for many forestry inventory and monitoring purposes, a growing body of literature suggests that the use of mobile computing technology that integrates GPS, geographic information systems (GIS), and sensing capabilities into a mobile device can improve data collection efficiency, integrity, and capacity (van Tamelen, 2004; Wing and Kellogg, 2004).

Mobile geographic information systems (MGIS) are defined here as an integrated hardware and software framework that allows for the capture, access, and manipulation of geospatial data through a mobile device. In recent years, mobile computing technologies, e.g. laptop personal computers (PCs), tablet PCs, and Personal Digital Assistants (PDAs), have been utilized for

electronic data collection in a variety of applications such as forestry, geological surveys and utility asset management (Green and King, 2004; Zhou, Liu, and Tang, 2009; Yan, et al. 2009). Over the past five years, smartphones have emerged as one of the most ubiquitous mobile telecommunication computing technologies worldwide and are increasingly becoming embraced by a wider community of professional users (e.g. social scientists, biodiversity scientists, and ecologists) as a tool for recording data and accessing information (Raento et al. 2009; Triebel et al. 2009; Aanensen et al. 2009). In essence, smartphones are handheld computers that contain computing, GPS, digital orientation, wireless communications, and sensing technologies. Innovations in smartphone hardware and software technology, their wide-spread availability, ease of use, programmability, and relatively low costs make this type of compact portable electronic device an attractive platform from which to perform field-based geospatial data collection (Kwok, 2009). Recognizing the considerable potential benefits to forestry operators of improvements in the efficiency of data collection and management systems and the ongoing lost opportunities to collect other types of potentially valuable silvicultural data under existing paper-based systems, this research sought to examine if smartphone technology might play a beneficial role in the collection and organization of primary silvicultural data for foresters.

The goal of this research was to develop, test and evaluate whether relatively inexpensive, off-the-shelf smartphone technology can serve as an alternative platform to other more costly and specialized mobile technologies as a tool for electronic data collection in the field of silvicultural management. The idea being that if a smartphone can meet performance objectives, then the platform's wide adoption rate makes it an attractive option for forest managers. Proof of concept was established by:

1. Developing an integrated electronic data collection and management system based on a GPS-enabled smartphone, mobile data collection software, and a desktop GIS
2. Performing context-based field-testing of the smartphone GIS through a series of data collection trials to measure and evaluate system performance
3. Conducting a usability assessment of the smartphone GIS system and comparing it in parallel to traditional paper-based methods for recording and managing geospatial data

Underlining the relevance of this research is the fact that no academic studies have examined the role of smartphone technology usage for silvicultural data collection and management purposes. This study addresses that gap and hence broadens our knowledge of what is possible with conventional technologies. Furthermore, the electronic information acquisition system described in this thesis provides a basis from which other field technicians can assess the feasibility of adopting such a system to support their information gathering needs.

## **1.2 Literature review**

This section provides the relevant background information necessary to situate my research in the context of mobile computing technologies and their applications for electronic field data collection and data management.

### **1.2.1 Mobile geographic information computing systems**

Mobile geographic information systems (MGIS) or mobile computing systems (both terms will be used interchangeably henceforth) are meant here to include mobile computing technologies that allow field-based personnel to capture, edit, manipulate, analyze, access, and display geographic or spatially encoded digital information. Figure 1.1 provides a sample of popular mobile computing devices. MGIS of today are lightweight, compact, portable, durable, and power efficient compared to the state of the technology only 10 years ago. Rapid advances in

computer processor speed, memory, storage, network communication, and graphical display allow for the processing of large volumes of data quickly and more efficiently (Pitt et al. 2011). As a result of improvements in mobile computing technology, vendors have developed commercial mobile GIS software packages (e.g. ESRI ArcPad, Trimble TerraSync) to facilitate collecting location-based data and integrating spatial information with more powerful commercial desktop GIS software which allows for more sophisticated analysis and processing of the data (ESRI ArcPad 10.2 Copyright © 1995-2011, Trimble Navigation Copyright © 2012). Since the opening of GPS services to the greater public by the U.S. Department of Defense in 1996, manufacturers have integrated positioning, navigation and timing systems into portable electronic devices like those shown in Figure 1 to provide anytime, anywhere location-based information to users (Dong et al., 2010). The ability of mobile devices to run powerful mapping software applications and to position themselves allows individuals to capture geospatial information in real-time and real-space. MGIS can operate as a stand alone workstation or communicate with other distributed or fixed servers via wired cable or wireless networks.



**Figure 1.1** Selection of handheld mobile computing devices.

### **1.2.2 Smartphone technology**

The current generation of mobile phones, termed ‘smartphones’, are handheld programmable computers which contain integrated sensing, positioning, computing, and communication technologies. Smartphones are controlled by powerful operating systems (e.g. Mobile Windows, Blackberry Apple iOS, Android, etc.) capable of running mobile versions of popular desktop software applications. The sensor array possessed by smartphones are comparable to, and most often larger than, many professional handheld mobile computing devices with an equal ability to process geospatial information. Most smartphones offer added features such as a digital camera, audio and hi-definition video recording and playback, internal microphone, accelerometers (sense the device’s position and movement to correct screen display), geomagnetism sensor (provides orientation with respect to Earth's magnetic field), ambient light sensor, digital compass, and internal GPS antenna.

Additional advances to smartphone service and functionality result from the free sharing of the device’s programming code structure and the programmability of the device. Driven primarily by economic factors surrounding location based services and social network mobility, the availability of open source code allows users to customize their smartphone for specific applications utilizing all of the device’s functionality. A number of smartphone manufacturers provide software development kits (SDKs) open and free to the public (with the exception of Apple Inc. iOS) that permit the creation, modification, and distribution of custom software applications (apps) to be run on a smartphone and web service (Zheng and Ni, 2006). Open source technology, that is, technologies that allow access to the use of their source code (free access, but not necessarily free of charge) for the development of proprietary and/or free software applications and the pervasive usage of mobile communication has fostered the

development of literally thousands of software applications specifically designed for smartphone devices (Lane et al. 2010). The result of which has been a societal shift in mobile phone usage: from being one of simple communication to a means for consuming and disseminating content-rich, geographic information. According to the International Telecommunication Union (2011), active mobile broadband subscriptions rates have increased from 18.5 to 56.5 in developed countries and 0.8 to 8.5 per 100 inhabitants from 2007 to 2011. At the end of 2011, there were an estimated 6 billion mobile phone users world-wide.

### **1.2.3 Applications of MGIS technologies**

A number of published papers have explored the capabilities of modern handheld computers for information gathering in diverse fields such as geological field mapping, human health, and asset management (Payne et al. 2009, Lane et al., 2006; Whitmeyer et al. 2010). The research focus of studies utilizing mobile computing technologies ranges greatly. Researchers undertaking geological studies have field-tested and compared the utility of several professional MGIS hardware and software to map geologic outcrop features (Pavlis et al. 2010; Clegg et al. 2006). Work done in this field has been useful for relating the advantages and disadvantages of using electronic over traditional pen and paper methods for geological mapping. Among the most common advantages or benefits to using MGIS are gains in data collection rates, reduced data transfer times, and reductions in data error at various stages in the data handling process. Keeping data in the digital domain was also found to facilitate data sharing among stakeholders. The ability to reference other information such as maps, aerial imagery, documents, and photographs on a portable device were also thought to be an asset to the data collection process. Conversely, small screen size, limited battery life, large up front costs, and concern over loss of

data were the most frequent disadvantages cited by researchers regarding the use of MGIS devices for scientific fieldwork (Jones et al. 2004; Montoya, 2002; McCaffrey et al. 2005).

One of the most prolific research areas where mobile computing devices have been documented to record and manage data, has been in the realm of human health and health information technology (IT) (Inman-Narahar et al. 2010). In terms of mobile telecommunication technology, much of the healthcare literature concentrates on the use of PDA's for electronic data collection and integration with medical record systems (Park & Chen, 2007). Studies in this space have examined digital versus paper methods of data entry to compare time savings, data accuracy, and value between the two systems. A review by Lane et al., (2006) of studies comparing electronic versus paper methods for recording clinical trial data showed that overall participants favored handheld computers over paper and pencil for data collection. Their study found that handhelds were preferred for their superior timeliness in the handling of data and improved data accuracy. This agrees with results by Guadagno et al. (2004) in that electronic handheld devices were shown to be advantageous to paper and pen for their ability to export data directly into databases and thus improve data management by decreasing input errors, increasing efficiency of data entry, and providing quicker access to information.

While evidence suggests that the electronic methods do improve data management and compliance, technical difficulties have proven to be a significant disadvantage compared to paper and pen methods. Dale and Hagen (2006) note that the potential loss of data due to technical malfunctions is a critical consideration in determining the feasibility of adopting an electronic collection system and remains an enduring concern for any application utilizing the technology. They are not alone in this assessment. Many of the studies cited thus far report that

the risk of data loss is a central concern when relying upon electronic data collection systems (Lane et al. 2006; Inman-Narahar et al. 2010; Jones et al. 2004). This distrust of technology may be changing though. Chatterly and Chojecki (2008) find that younger generations that have been exposed to electronic equipment from an early age increasingly rely on mobile devices for their many personal and professional activities. Churchill and Churchill (2008) cite a number of studies reporting a variety of contexts for the use of PDAs as an educational tool that for example, allow students to share files, collect field trip data, and serve as an intelligent tutoring system. It would be reasonable to imagine that these long-standing users of handheld technologies will become more comfortable using mobile electronic data collection and archive systems and may therefore come to expect them as a necessary tool in their routine work.

In the past three years or so, a number of technical papers have been put forward presenting novel or improved MGIS architectures. Research in this realm of computer science mainly focuses on the capability of mobile computing technology to integrate with other hardware, software, and wireless technologies (Zhang and Mei, 2008; Fang and He, 2008; Zhou et al. 2009). Shi et al. (2009) point out that much of the current research in mobile computing science is aimed at developing new technologies to improve web access, integration, and performance. While this work has obvious merit, such an approach bypasses fundamental questions involving the usability of MGIS in real-world field data collection applications. In many cases, technical literature of this sort offer theoretical applications of their mobile GIS design, yet is lacking in performance testing and system reporting. Papers of this sort seldom provide a practical assessment as to whether the novel design actually improves established workflows (Pundt, 2002; Haklay, 2010).

Professional industries: utilities, communications, and business are the largest and most prolific users of MGIS technology, however, information regarding their experiences is limited or often lacking in scope (Baraniak, 2010). This lack of information is likely because private industry practices are often protected to maintain a competitive advantage and therefore little public documentation is made available that critically assesses the merits and limitations of the technology. Dowd's (2011) paper, outlining the Western Virginia Water Authority's move from collecting data on paper to electronic forms, serves as a good case in point regarding the challenges industries face implementing new data collection systems in place of existing systems. For instance, Dowd notes the risks associated with committing to proprietary software as users can become bound to a single vendor for support. Depending upon the size and complexity of the operation, the additional costs and the training time required to institute the electronic system could be substantial. These lessons are insightful. In general, white papers published by mobile GIS vendors and their clients tend to overstate the ease of use, reliability, and capability of their products. More often than not, it is the success stories rather than the failures that are given attention in the literature.

Mobile computing and mobile GIS technologies have been shown to have considerable potential for forestry (Li and Wang, 2009; Yao and Li, 2010; Wing and Kellogg, 2004). And yet there is a surprising lack of published academic literature assessing its usage. The majority of information comes from private companies offering technical information regarding their products or an occasional document from various government forestry agencies suggesting MGIS best use practices. Two informative papers comparing electronic and paper-based data collection were found nonetheless. Wang et al. (2003) explored the potential advantages of collecting and keeping forest stand data completely in the digital domain versus recording and

editing data on paper forms and then transferring that data to digital files. Their research showed significant time-savings and improvement in data accuracy using the electronic data collection system. A study by Inman-Narahari et al. (2010) is one of the few articles that directly measured the efficiency of digital versus paper-based methods for collecting forest plot data. In this study, the researchers quantified the increased efficiency resulting from digital data collection for mapping and measuring trees in forest plots. Their results showed similar data collection times to previous data collection efforts but, like findings from other studies, Inman-Narahari et al. (2010) showed significantly improved time savings in data entry times for digital methods. Interest in developing improved mobile GIS designs for forestry related applications continue. Recently, Zhou et al (2009) created a GPS-enabled PDA system for monitoring forest fires, while Li and Jiang (2011) developed a proprietary system for forest inventory management using PDAs with an embedded GIS. Despite advancements in this research area, a gap in the literature exists, in that no studies have documented the efficiency of adapting mobile technology in the context of a particular silviculture workflow and where they occur; nor have any done so using a smartphone as part of the system architecture. Quantifying exactly where within the workflow much of the time is saved is fundamental for determining whether the adoption and implementation of smartphone technology is reasonable.

#### **1.2.4 Applications of smartphone technology**

The use of smartphone technology as the primary platform for environmental electronic field data collection is still in its early stage. Academic research examining the use of smartphone technology for scientific fieldwork is relatively scarce. That said, research has been conducted examining the use of mobile phones in other areas, such as epidemiological studies and household data surveys (Aanensen et al. 2009; Tomlinson et al. 2009). Lwin and Murayama

(2011) reported on their mobile phone, web-based GIS to collect and display university assets to assist with administration and managing activities. Social scientists have also used mobile phones as a vehicle to study people's social networks, movements, and behaviors (Raento, Oulasvirta and Eagle, 2009). Mobile phones fitted with special sensors have also been used to collect data related to air quality, environmental noise, and traffic road conditions (Kanhere, 2011).

A growing body of information relating the use of mobile phone technology pertains to large-scale public participatory sensing and data collection projects. Due to the increasing availability of field science apps, smartphone devices are increasingly being utilized for so called "citizen science", "participatory sensing" or "crowdsourcing" data collection. Such crowdsourcing allows public volunteers contribute to data gathering efforts by directly recording their geographic location and observation information onto their mobile device and then submit the data wirelessly to a central server for processing and analysis (Wiggings and Crowston, 2011; Kanhere, 2011). A popular example of this is *CyberTracker*. CyberTracker is a freely downloadable software application that can be run on many types of mobile devices. The software allows users to record and enter spatial and attribute data on pre-designed forms pertaining to wildlife sightings and then submit that information to online databases to help researchers track endangered or threatened species (<http://cybertracker.org/>). A cursory search on the Internet reveals a host of related apps designed to collect data about phenomena such as watershed information (Creek Watch), the distribution of invasive plants (What's Invasive), and even one's personal environmental impact (PEIR project). The use of smartphones for citizen science data collection has led some researchers to believe that sensor-equipped mobile phones

will revolutionize many sectors of our economy, including environmental monitoring and natural resource management (Lane et al. 2010).

It should be stated that many of the challenges and limitations posed by the use of professional mobile computing devices, such as small screen display, user interface difficulties, and short battery life, also carry over to smartphones. In addition, mobile technologies that depend on network connectivity for user positioning and data processing further confound the use of smartphones in areas where there is intermittent or no wireless reception. Yet despite these problems, clear benefits exist to using mobile technologies and so workers continually strive to improve the data collection process through advancements in data collection tools and methodologies (Hense et al. 2009). The research presented here attempts to do the same.

### **1.2.5 Ontario Forest Management**

Canadian federal and provincial government agencies provide the regulatory frameworks for managing Canada's natural resources. Ontario's Ministry of Natural Resources (MNR) is the main agency in charge of Ontario's public forest lands (also known as Crown Land) and waters. In Ontario, forestry companies seeking to harvest Crown Land must do so through a Sustainable Forest License (SFL), under which the holder agrees to manage Crown Lands for their "long term health" as laid out in the Crown Forest Sustainability Act, 1994 (CFSA). Forest companies licensed by the MNR to carry out sustainable silvicultural management not only record data (regarding forest management operations and planning activities) for internal operations, but are required to share geospatial data with the MNR, and in some cases the public. Data regarding the structure and condition of the forest is used to inform decision-making and provide the rationale for operational and strategic planning and management objectives. Among the information

forestry companies must provide to various stakeholder groups, are mapped information; for example, operational maps detailing stands selected for harvesting, public notice maps outlining areas scheduled for aerial herbicide spraying, and strategic planning maps that provide long-term forest management plans (Bidwell et al. 1996).

As part of MNRs adaptive management approach, the methods and technologies used to capture geospatial data are largely left to the discretion of forest managers and field technicians. The resultant data collection and management system often reflects the available resources and needs of the particular forest management operation. The structure of a data collection system is determined in part by the realization that changes in forest management strategies will result in changes to data requirements, as well as changes to monitoring techniques, technologies, and analysis (Silvicultural Effectiveness Monitoring Manual for Ontario, 2001). Therefore data collection and management systems, in addition to being efficient, reliable, and capable, must also be flexible, upgradeable, and persistent. In an attempt to understand and address these challenges, this research included close work with a professional forester from Mazinaw-Lanark Forest Inc. (MLFI), Mr. Jan Smigielski (head forester of the MLFI) to develop and test the usability of smartphone technology to facilitate forestry silviculture data collection as a counter-approach to traditional pen and paper-based methods.

### **1.2.6 Silvicultural management**

Silviculture consists of actions taken to renew and enhance the forest crop to meet stand management objectives for timber, wildlife, recreation, landscape design, preservation, and water yield (Natural Resources Canada, 1995). Silviculture as a form of forest management is fundamental to ensuring the sustainability of the forest's ecosystem itself. As Bell et al. (2008)

observe, forest management success rates can only be determined through the systematic collection of reliable data. Silvicultural effectiveness monitoring (SEM) is an established program within the MNR regulatory framework that requires foresters to collect and report the elemental information necessary to assess forest sustainability at the management unit scale.

### **1.2.6.1 Silvicultural effectiveness monitoring**

Silvicultural effectiveness monitoring provides the basis for measuring, collecting, analyzing, and reporting information on the renewal and state of the forest as a function of natural and anthropogenic activities (Silvicultural Effectiveness Monitoring Manual for Ontario, 2001). Effectiveness monitoring is used to determine if silvicultural treatments are producing the desired results. SEM entails recording observations, reporting, and the examination of underlying trends. SEM data provide forest managers with information needed to update forest inventories (Brand et al. 1991).

The SEM process amounts to two basic functions: to record information pertaining to select forest stand variables, and to detect or interpret regeneration trends (Jan Smigielski, personal correspondence). Forest stands are an aggregation of trees occupying a specific geographic area, uniform in their composition (species), age and arrangement (Strobl and Bland, 2000). The SEM data collection process mainly consists of timber cruising (Section 2.1 for definition) to obtain understory information related to tree species abundance, composition, health, age, height and location. To collect cruise data on the ground data workers employ many tools like a wedge prism (establishes fixed-radius plots in the field to record and calculate basal area of a stand), compass, digital camera, GPS receiver, measuring tape, and increment borers (to measure tree core-age). Forest inventory cruise data from multiple sample plots are then recorded in log books

and paper tally (counting) sheets (Appendix A). The data are used to create stand, stock, and size class tables that can later be entered and analyzed in a GIS to detect changes in forest composition and landscape patterns.

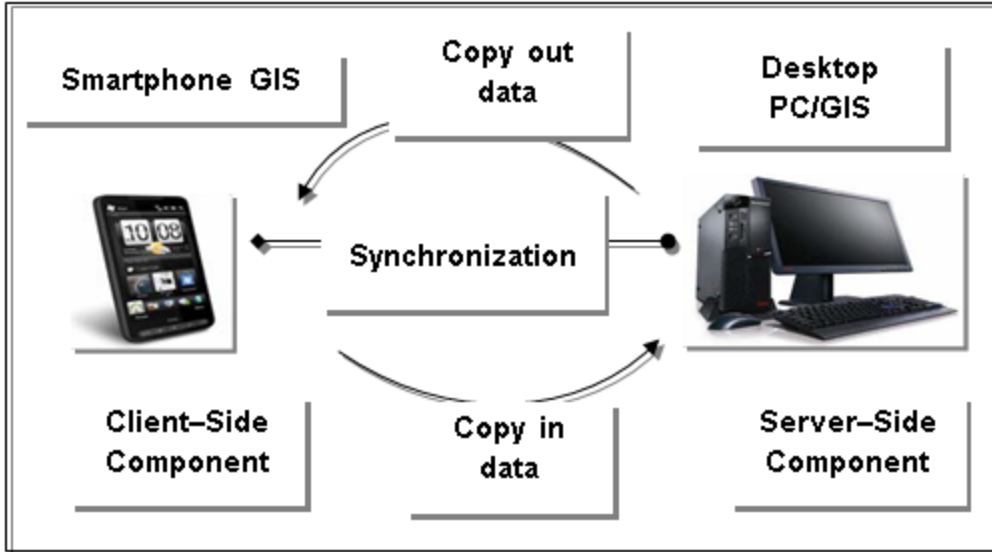
Secondary information concerning forest disturbances, cultural heritage resource value, and species of concern, along with other background information are also important data obtained during the SEM process that contribute to building a more complete map of forest management units. These forest surveys generate a large amount of data that serve to update forest inventories and regeneration assessments and provide the basis for all planning activities (Brand, Leckie and Cloney, 1991). Although MNR requires documenting this type of information when encountered by field workers, standards regarding data quality are not explicit. In reality, the recording of these types of observations often amounts to a field technician making a few handwritten notes on a piece of paper (Jan Smigielski, personal correspondence). Information of this sort may or may not be reviewed or reported upon later. This loss of information is problematic because SEM information feeds into other datasets such as the updating of forest inventories, forest wildlife habitats, and maps of areas of concern (Silvicultural Effectiveness Monitoring Manual for Ontario, 2001). It was this vital aspect of silvicultural management, SEM data collection, that are the focus of this research.

## **1.3 Methodology**

### **1.3.1 Smartphone GIS architecture**

A client-server configuration was chosen as the architecture for the smartphone GIS herein. The client side is a Windows smartphone. The server side is a stand-alone Dell GIS Workstation desktop computer that exchanges content with the client and serves as the master data storage

base. The desktop PC served as the primary repository for all data. Communication between the two computing systems occurs through a wire universal serial bus (USB) cable and Microsoft ActiveSync 4.5 software (Microsoft, 2012). Figure 1.2 illustrates a generic representation of this system architecture. This approach is taken to simplify the backend data transfer of data and concentrate on the main tasks of collecting field data. However in the future the back-end data transfer could easily be via wireless communication with a database server. However, given that many remote work areas may not offer wireless connectivity, the selected configuration for our MGIS is preferred because it is not reliant upon a web server for data processing, storage or GIS services. The straightforward nature of this design allows for future expansion to a distributed system that can include a central Web-based server synchronized to multiple smartphone devices.



**Figure 1.2** Smartphone/desktop GIS architecture.

### **1.3.2 Hardware and software**

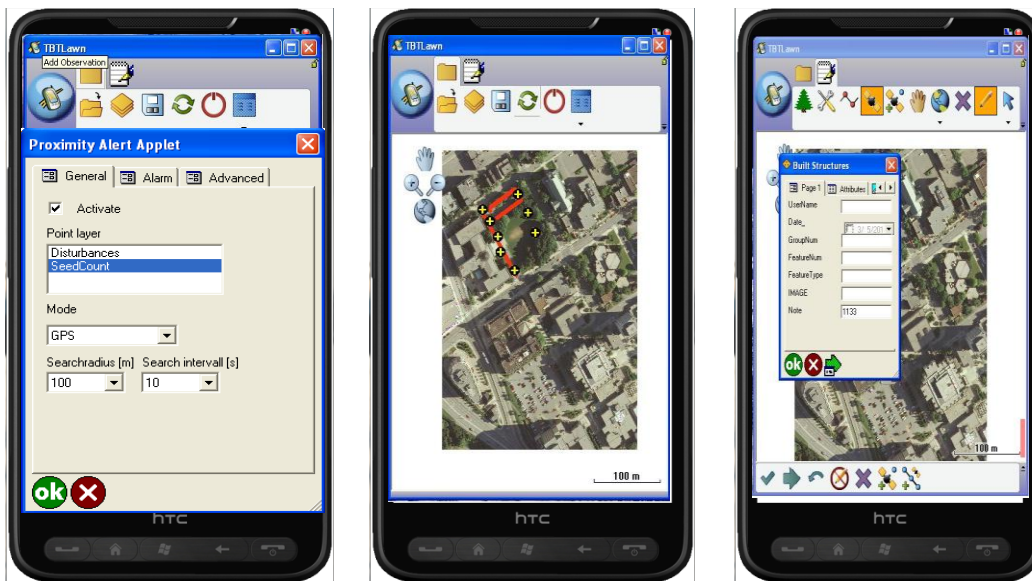
The hardware and software selected for this project (Appendix B) were based on a number of factors including costs, user requirements, technical capability, operability, and software compatibility. The Windows HTC HD2 smartphone was chosen from a wide range of possible platforms and devices for its large screen display (4.3 inches), internal GPS receiver, built in flash memory card capability, and Windows Mobile 6.5 operating system (OS). See Appendix C for HTC smartphone technical details. The Windows OS was favored for its custom software development capabilities and its ability to run mobile versions of popular electronic software, such as Microsoft Excel and the ESRI mobile GIS ArcPad; both of which were utilized for this project based on their functionality and ability to integrate datasets with Mazinaw-Lanark's current data management system. An extra battery, stylus, car battery recharger, 32 gigabyte (GB) micro storage device card, and protective cover were purchased for this project to protect the device and provide additional power and memory storage in the field. The desktop PC was a dual Xeon CPU 3.20GHz, 4 GB RAM operating Windows XP SP2.

To record cruise timber data a custom forest stand tally software application (app) was developed for the HTC smartphone. The design and functionality of the program was developed in collaboration with Jan Smigielski, and a third party computer programmer. Figure 1.3 shows the graphical user interface of the prototype forest stand tally (FST) program. The program allows a user to enter and record text and numerical information on the device by either tapping the appropriate box on the smartphone's touch screen or using the phone's QWERTY keyboard. For reasons of end-user familiarity and to permit comparative testing and evaluation between the electronic and paper-based formats, the application was designed to be similar in makeup to the paper form (Appendix A) currently used by the MLFI. The application allows users to enter data

related to tree species, size class, and site history. The app further facilitates data entry by performing additional tasks such as auto-increment counts of tree species, entry of the user's geographic position by means of the smartphone GPS, mandatory login data entry controls, and storage of multiple stand and plot data into a single Microsoft Excel workbook. Recorded data can be saved and transferred onto a desktop PC as a comma-separated-value (CSV) file formatted to contain embedded functions to permit automated stand structure analysis. The transferred data is imported into Microsoft Excel 2003 with the use of a custom Macro (a series of commands and functions stored in a Visual Basic module that a user initiates to perform repeated or routine tasks) programmed to tally all plot data into a single workbook (Microsoft Corporation, Microsoft© Office Excel 2003). The source code for the Macro is given in Appendix D and the Forest Stand Tally app can be downloaded for free at: <https://github.com/Mustack/ML-Forestry>.



**Figure 1.3** Forest stand tally application. The application allows users to electronically enter and record counts of tree information directly on to the mobile device. Data can then be exported into the desktop PC for automated data entry and analysis in MS Excel.



**Figure 1.4** ArcPad mobile mapping software. The software was used to display and record geospatial field data on the smartphone device. The software allows users to record vector data and attribute information into custom edit forms. Collected field data are then exported from the mobile device into the desktop GIS for further processing and spatial analysis.

Geospatial data were collected using ESRI’s ArcPad 10.2 mobile GIS software. The ArcPad mapping program allows for the display, creation, editing, query, and modification of GIS data on a mobile device in a disconnected setting (ArcPad 10.2 Copyright © 1995-2011 ESRI). ArcPad was preferred from other mobile GIS software for its relative ease-of-use, customization capabilities, and ability to synchronize with ESRI’s complimentary desktop GIS software for additional cartographic display and spatial analysis (ArcGIS 9.3.1.Copyright © 1999-2009 ESRI). By using the ArcPad SDK, ArcPad Studio, I was able to create new toolbars and toolbuttons that when initiated called custom functions to capture and update spatial and attribute information. I also built upon an open source applet<sup>1</sup> for monitoring of point feature layers.

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<sup>1</sup> A mini-application packaged in a single file that contains all the toolbars, forms, scripts, and methods necessary to execute the application within ArcPad.

Utilizing the smartphone GPS and the ArcPad software, the Proximity Alert applet signals users via an audio clip or pop-up message window when they are within a certain distance of a selected layer. Figure 1.4 shows screen shots of the custom ArcPad graphical user interface (GUI), Proximity Alert applet, and edit forms I created to record attribute data in this study.

### **1.3.4 Data and work flow**

Following is a description comparing the general work- and dataflow process taken in this project, with the smartphone GIS and paper-based data collection systems (Fig. 1.5):

**(1. Data Management)** Setup of the integrated desktop-mobile GIS took place over a couple of months. A considerable amount of time was spent learning the ArcPad software and determining the requirements of this project. The first task I undertook was to customize the ArcPad application to facilitate the data collection process and simplify the smartphone GIS user interface. New toolbars, tools, and edit forms<sup>2</sup> were developed on the desktop ArcPad for the mobile ArcPad application. Improvements to the mobile software included simplifying the number of tools available to only those necessary for data collection and editing, a reduction in the number of keystrokes required to record a feature at the user's location, and the creation of custom edit form controls that auto populate (the software automatically enters data into a field based on user input) attribute field values based on user input. Additional basemaps representing Ontario hydrology, road segments, and Digital Raster Acquisition Project for the East (DRAPE) satellite imagery (20cm resolution) were assembled to provide referencing and orientation for field data collection.

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<sup>2</sup> Electronic form associated with a specific spatial layer that allows for user entry of feature attribute information.

New shapefiles to contain feature attribute information recorded in the field were created in the ArcGIS file management software, ArcCatalog. Custom edit forms with unique fields (e.g. rare species name, species type, and worker action taken) developed in ArcPad were associated with the new shapefiles to record and store text, numeric, and photographic information. All GIS data were stored and maintained within a File Geodatabase on the desktop GIS. This configuration allowed GIS data to be exported or 'checked out' from the desktop GIS into a Data for ArcPad folder containing a single ArcPad AXF file<sup>3</sup> and an ArcPad map file. During check out,<sup>4</sup> custom scripts, icons and layer elements such as any dBase files used in the edit form's combobox drop down list were manually copied to the Data for ArcPad folder in order to run all properties and methods associated with that project. Once all the field data that could be used for on-site editing was in the same folder, that folder was transferred (i.e. copied and pasted) to the smartphone's non-volatile, flash memory via Microsoft ActiveSync 4.5 software. The Forest Stand Tally app permanently resides on the mobile device and therefore no exchange of data occurs between the desktop PC and smartphone until after field data has been collected.

With the paper system, maps and aerial images to be taken into the field were printed from digital geospatial data that resides in the desktop GIS or they were photocopied from existing maps or photographs. Other measurement tools including a GPS, camera, paper forms and pens/markers/pencils were assembled for fieldwork.

**(2. Data Collection & Editing)** The smartphone GIS was used to navigate to a field site work zone and to position the user by referencing the ArcPad GPS. Geospatial and forest stand data

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<sup>3</sup> A single file containing multiple feature layers and their associated properties, related tables, and commands.

<sup>4</sup> Process whereby selected layers in ArcPad are copied into a folder on the desktop PC to be transferred into a mobile device

were captured and stored directly onto the smartphone device. The mapping software was optimized to record point and polyline vector data using the smartphone's internal GPS receiver. When a user identified a feature to record, they activated the smartphone GPS and then tapped on the appropriate toolbutton(s) to record the location of the feature. This event automatically opened the feature's edit form allowing users to enter attribute information about the feature. Photographs of an object were captured with the smartphone's digital camera and a file path was associated with the feature IMAGE field of the spatial data layer. GPS information was also attached to the EXIF header of the image file thus "geotagging" the photograph. Other ArcPad tools were activated when needed to allow users to edit, query, or identify feature data.

Cruise timber data were collected electronically with the Forest Stand Tally application. Programmed controls required the user to enter all login information before data collection could begin. When this step was completed, GPS coordinates were automatically recorded for each new plot. The app then allowed for recording information related to tree size, species and regeneration classification, site history, soil composition, plants observed, and ecosite classification. Tree counts were auto-incremented on the application for multiple trees of the same type. Data collection proceeded until a new plot or stand was established and then the same process was repeated. All data was saved to the smartphone flash memory drive.

Paper forms were created to record feature data parallel to electronic methods for comparative purposes. Paper methods required users to enter feature location and attribute information (Appendix E) onto paper forms (Appendix G). A handheld GPS receiver provided the location coordinates. Photographs of features were captured with a digital camera. GPS and photo image ID numbers were noted in the corresponding attribute fields on a paper form. Edits

to a paper map were hand drawn on the map itself and comments were made documenting any changes.

Using traditional methods, forest stand information was entered onto paper tally forms (Appendix A). Dots representing each recorded tree were made into a cell on the form using a pencil. Cells could contain multiple dots. Each tally form contained a sample of trees related to many plots within one stand. Multiple sheets were required to record all the collected data. A new tally form was required for each new stand. Data related to history, soil, ecosite, etc. was hand written on a tally form for each stand.

**(3. Data Transfer)** Electronically collected GIS and forest stand tally data were manually transferred from the smartphone to the desktop PC via cable and synchronization software. Digital images were copied onto the desktop PC and then into a master folder containing the geodatabase feature classes.

Spatial and attribute data recorded on paper were later compiled to create new shapefiles in the desktop GIS during data processing (stage 4). Digital files from the camera and GPS receiver were transferred to the desktop PC manually via cable and synchronization software. Paper tally sheets containing tree counts and supplemental information were either filed in their current paper format, or were transcribed into electronic tally forms on the desktop PC.

**(4. Data Processing)** The ArcPad AXF file in the Data for ArcPad folder was imported or 'checked in' to ArcGIS using the Get Data from ArcPad tool. This action automatically updates the parent geodatabase from which the data was initially checked out with all edits made during field data collection, including adding new features, deleting features, and modification of

attribute values and/or feature geometry (ArcPad Help, Copyright © 1995-2011 ESRI.). Digital images were hyperlinked to a feature on the desktop GIS to allow users to open a dialogue box containing the photo image of that feature.

Forest stand CSV files were moved to the same folder as the master MS Excel Stand Analysis file containing the custom macro. The macro was then run to auto-populate and auto-tally tree counts on the spreadsheet.

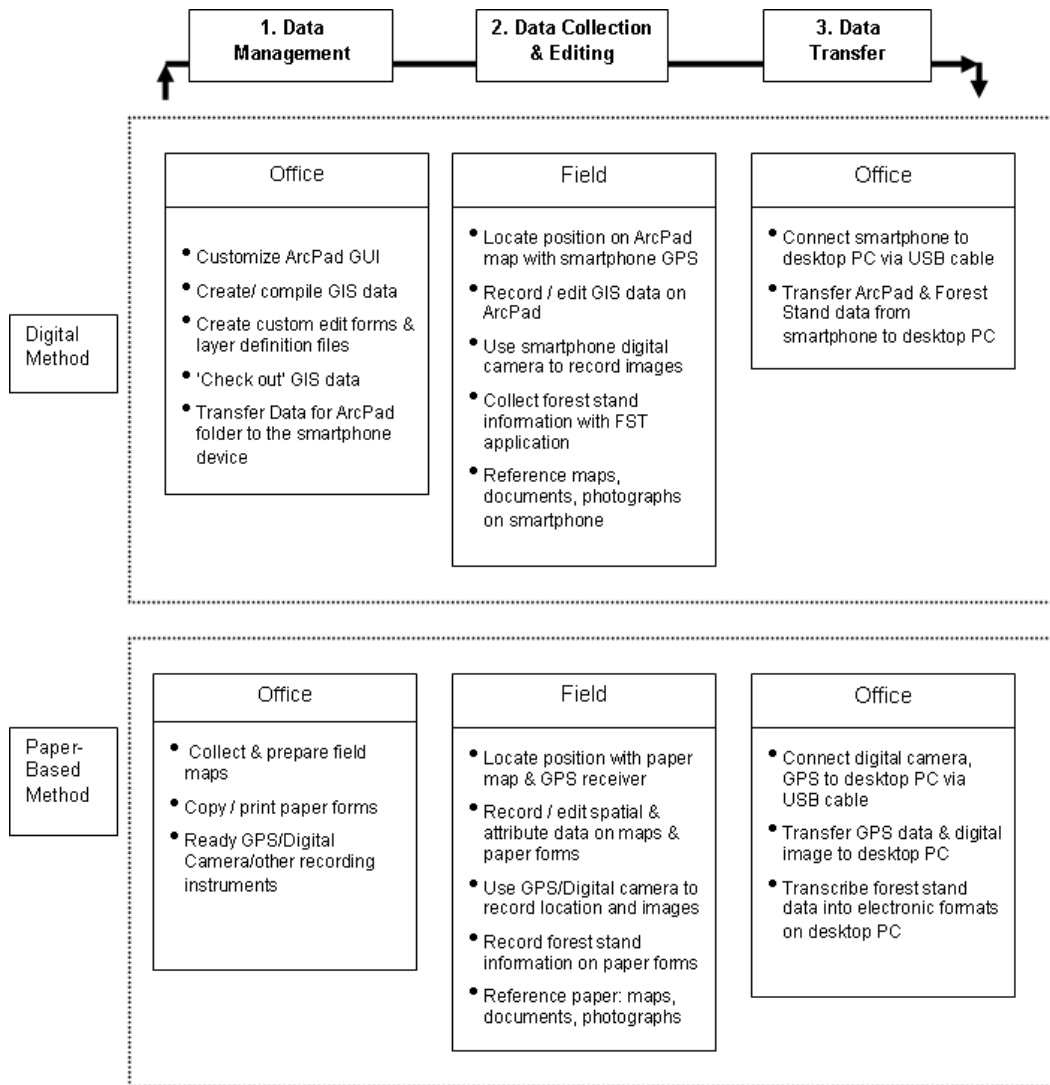
Geospatial data recorded on the paper forms were compiled into an electronic spreadsheet format and imported as tabular data into the desktop GIS. Point geometry entailed creating a table within MS Excel with the same field headings as its related feature in ArcGIS. Hand written data on the paper forms were entered into the appropriate fields, with two additional fields to include GPS x, y coordinates (converted to decimal degrees). The dBase file was imported into ArcMap using the Add x, y data tool. Photo images were hyperlinked in the same manner as ArcPad data. The steps taken to create a polyline shapefile were slightly different than those from creating point features. GPS tracks were recorded to represent line features. Garmin Basecamp was used to import GPS tracks from the Garmin GPS receiver as a series of gpx files. Within ArcMap, gpx files were first converted to a point feature and then a line feature using ArcToolbox conversion tools. New fields were created for the resultant shapefile to hold attribute information transcribed from paper forms.

Paper forms containing forest stand data were manually reviewed, tallied and entered into a separate digital Stand Analysis spreadsheet on the desktop PC.

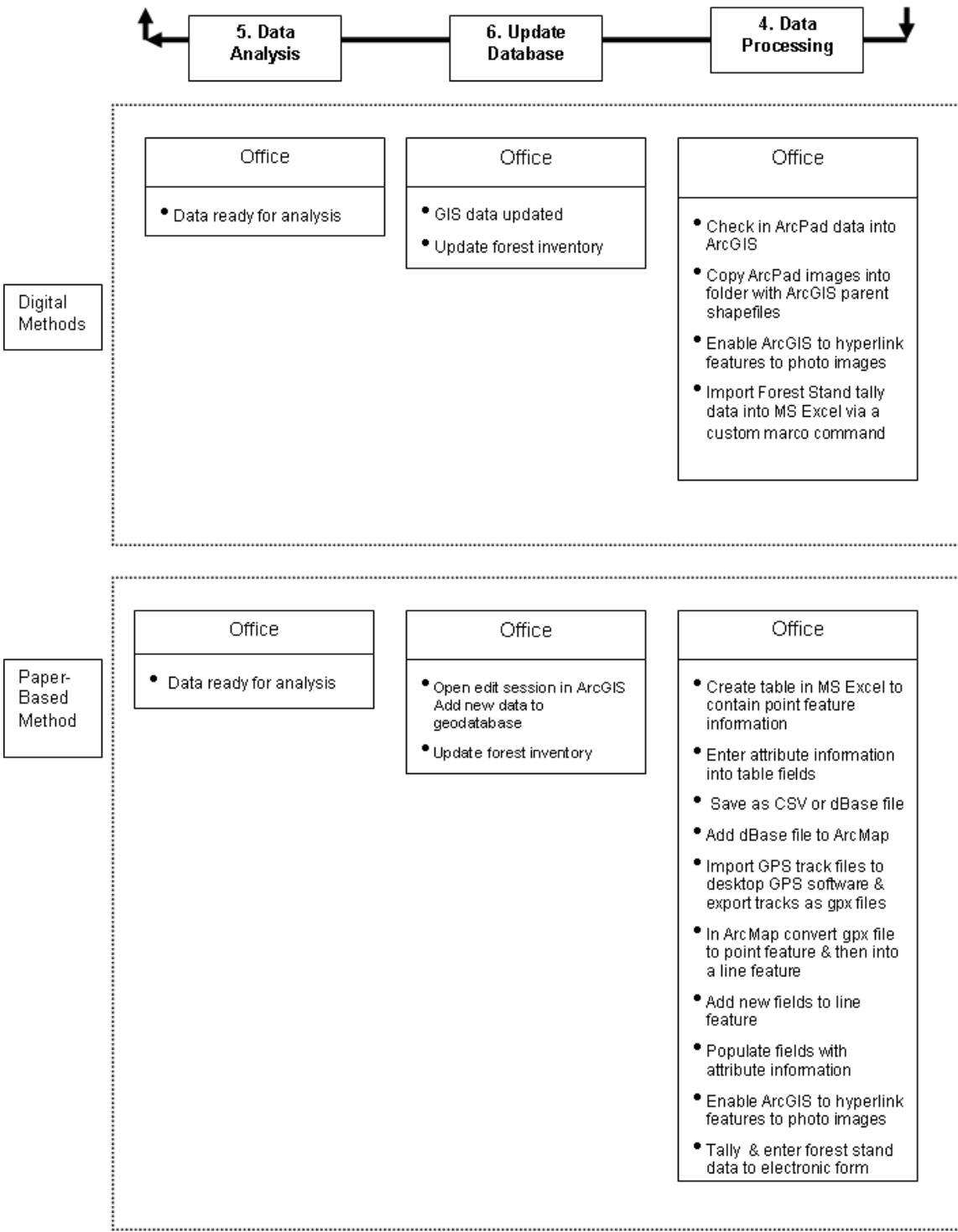
**(5. Update database)** All feature class files within the ArcGIS geodatabase created with the smartphone were automatically updated during the data processing. Updating the master

geodatabase with shapefiles created from the paper forms was done by opening an edit session in ArcGIS and then adding the new shapefiles (i.e. tabular data) to the current data frame. This overwrote the parent files with any changes or additions made in the field.

**(6. Data Analysis)** All digital and paper GIS and forest stand data were now in their digital format and could be integrated with existing digital datasets or used for analysis and reporting purposes.



Model continued on next page

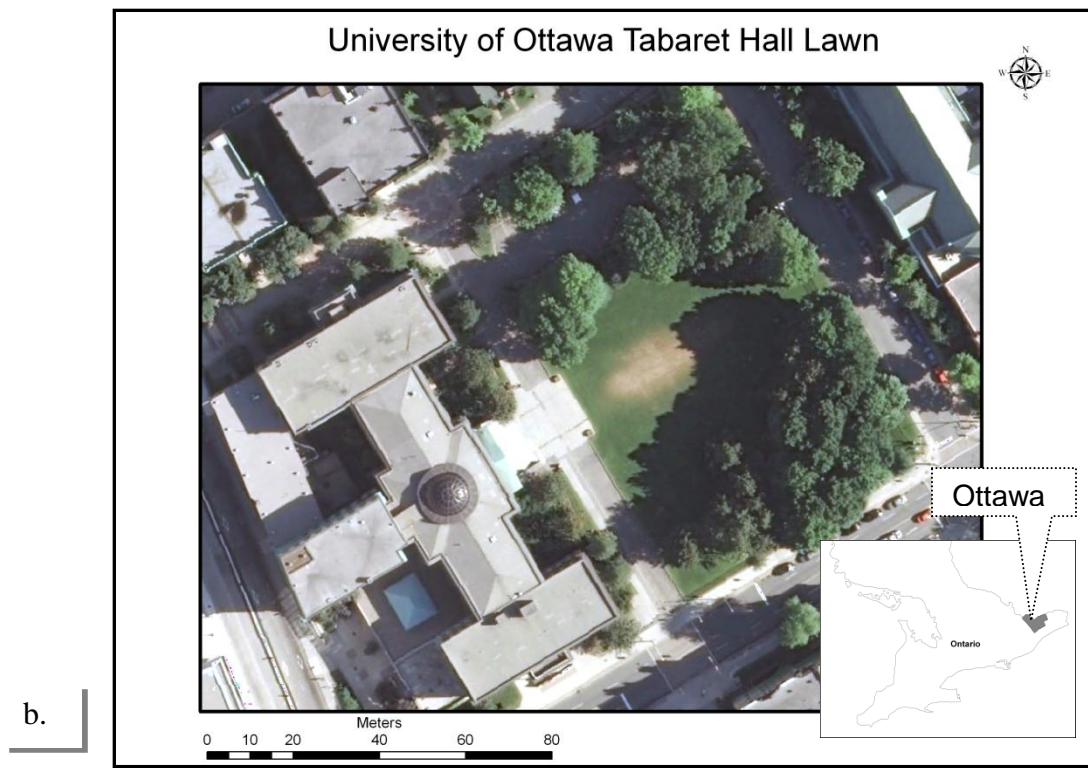
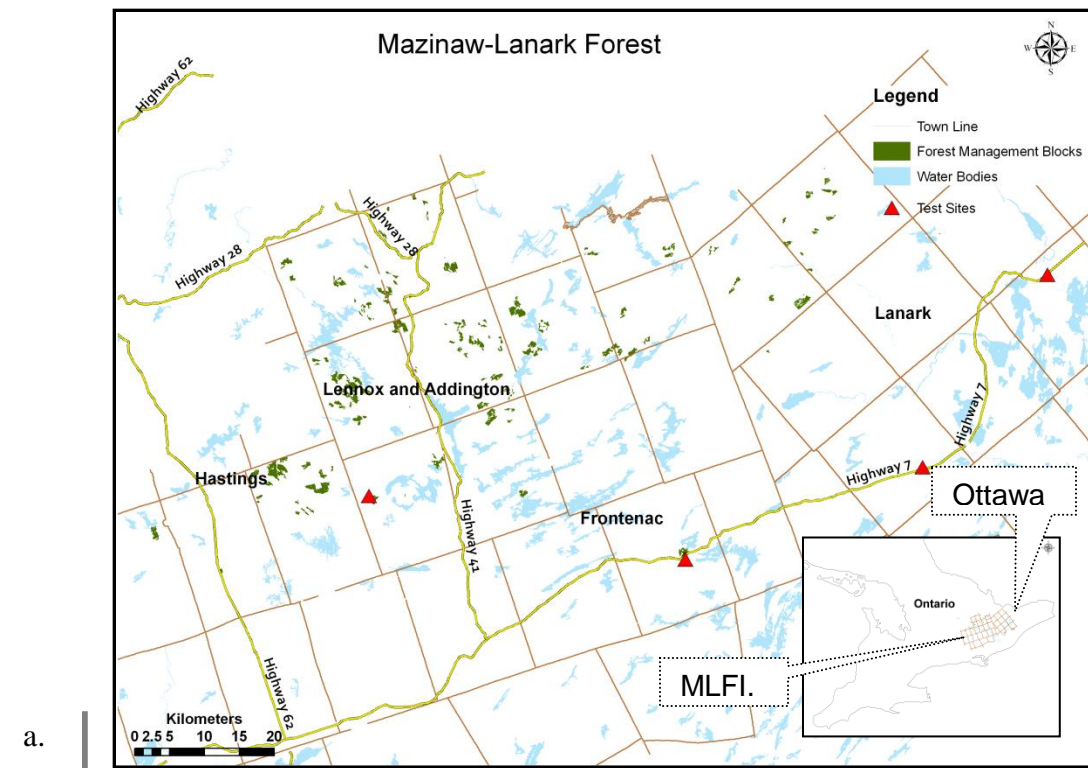


**Figure 1.5** Work- and data-flow model comparing digital and paper data collection and management methods. Work and data moves between the office and field and mobile and desktop computing systems during different phases of the data collection process. Data must be processed to get it into a digital format where it will ultimately be used for analysis and mapping purposes.

### 1.3.5 Test sites

Field data collection trials were conducted at two study sites in eastern Ontario, Canada. One site (Fig.1.6a) consisted of select forest stands within the Mazinaw-Lanark Forest Inc (MLFI) management unit (44°49'19.03"N, 76°57'43.06"W). In total, the Mazinaw-Lanark Forest comprises about 200,000 ha of publicly owned Crown forest. The region supports 17 commercially-viable tree species dominated by hardwood and mixed hardwood stands (Howard et al., 2010). Field data collection trials took place mainly in the Lanark and Frontenac sector forest plots. This area was chosen for its ecologically diverse forest, sensitive wildlife habitat, and mixed industrial and non-industrial usage making it highly representative of the challenging landscape of Ontario's southern forester operations. Field data collection and outdoor prototype testing took place from 2011-2012 in all seasons.

Tabaret Hall lawn at the University of Ottawa, Ontario served as the second testing area. This location (45°25'29.43N, 75°41'08.27W) consists of a large open grass field surrounded at the perimeter by a variety of coniferous and deciduous trees (Figure 1.6b). Within and adjacent to the park are built features such as benches, signage and lampposts. The total area of the park is roughly 0.54ha. This site was chosen as a proxy forest environment so that participant volunteers could be tested collecting data on both electronic and with the paper-based systems while I monitored and measured their progress in a semi-controlled environment. Participant testing occurred during the month of April, 2012.



**Figure 1.6** Smartphone GIS usability testing sites: Smartphone GIS usability testing sites (a) Mazinaw Lanark Forest Inc. management unit. GIS data: Mazinaw Lanark Forest Inc., ODGE Fundamental Data Set. Ontario Ministry of Natural Resources, (b) University Of Ottawa Tabaret Hall lawn. Image data: Digital Raster Acquisition Project Eastern Ontario (DRAPE) Ontario Ministry of Natural Resources Date (creation), 2009-01-10.

### 1.3.6 Smartphone GIS usability testing

Usability testing was applied to measure user's perceptions about various features and aspects of the smartphone GIS design, operation, and performance. Usability measurement is an established method in the field of human-computer interaction (HCI) of evaluating how usable a system is, in this case a MGIS, from the user's perspective (Hornbæk, 2005). Usability can formally be defined as, "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (ISO 9241-11, 1998 in Abran et al. 2003, p324). Usability cannot be measured directly therefore variables are selected to represent user's perceptions about various features and aspects of the system's operation, design, and performance that can be quantitatively and qualitatively measured. The degree to which the smartphone GIS in my study was considered usable was measured using the following criteria:

- **Effectiveness:** success rates-the proportion of tasks completed versus tasks attempted; Error or malfunction rates; positive and negative survey questionnaire responses, and user comments
- **Efficiency:** time-on-task-a measure of the time taken to complete a given task from beginning to end.
- **Learnability:** instruction times-counts of times help was given; survey questionnaire scores and participant comments.

These measures were considered sufficient for my research to provide the necessary range of factors needed to assess the system (Shackel, 2009; Rubin and Chisnellm, 2008; Hornbæk, 2005). Usability of the smartphone was determined based on its ability to out-perform paper-based methods in each category listed above.

### **1.3.6.1 Usability test design**

Testing was applied throughout the project to incorporate findings into the development of the electronic data collection system. Early development of the smartphone GIS consisted of prototype testing of the device in urban and wooded forested areas. Testing at this time entailed performing simple data collection tasks to capture point, line, and polygon data with the smartphone's GPS and ArcPad software and then transferring and integrating field data into the desktop GIS geodatabase. After becoming familiar with the system, further exploratory testing and requirements analysis for both the ArcPad and Forest Stand application systems were conducted with the help of Jan Smigielski of the MLFI. Testing during this cycle sought to identify benchmark standards against which the smartphone GIS system should perform, and to get a sense of the environmental context in which the smartphone GIS would be used. The outcome of this testing produced the final system architecture, hardware and software, and work data flow structure presented above.

The final testing stage involved validation assessments to measure the usability of the smartphone GIS against established paper-based data collection methods. Field-based usability testing was chosen to allow the gathering of qualitative and quantitative data about the performance of the system through user testing and feedback by empirical methods. The main objective of this stage of usability testing sought to answer questions such as: does the smartphone GIS function properly, is data collection using the electronic system more accurate than paper forms, does data collection and management with the electronic system take less time compared to traditional paper methods, and is the smartphone GIS system easy to learn and use? Two field data collection exercises, one using participant volunteers and another through expert review, were devised for usability testing.

### 1.3.6.2 Participants, tasks, and data collection procedure

Participant usability testing was carried out at the University of Ottawa. A total of 12 (n=12) participants were approved and recruited for testing (University of Ottawa Ethics Board file # 03-12-07). This number was felt to be more than sufficient as Virzi (1992) found that 80% of usability information can be obtained from just four or five test subjects. All participants were enrolled at the University of Ottawa and were chosen based on their availability. Table 1.1 gives a breakdown of participant background information. Participants were not asked if they had worked for a forestry operation or if they had performed silvicultural data collection work previously. For their participation, individuals received a \$50 cash stipend.

**Table 1.1** Participant background information.

Age	19-33 years in age
Gender	66% F, 34%M
University Level (number of participants-year)	1-5 <sup>th</sup> , 5-4 <sup>th</sup> , 3-3 <sup>rd</sup> , 2-2 <sup>nd</sup> , 1-1 <sup>st</sup>
Have you taken any GIS or Geomatics courses at the university level?	83% Yes; 17% No
Do you own or have you used/operated a smartphone device?	90% Yes, 10% No
Have you ever used/operated a GPS device?	90% Yes, 10% No
Have you ever used/operated a mobile GIS?	30% Yes, 70% No
Have you ever used smartphone apps for spatial data collection?	20% Yes, 80% No

Participants were given a series of tasks to perform with the general goal of recording tree stand and GIS data using both the smartphone and paper based systems while an observer (the author) simultaneously recorded usability data. Figure 1.7 illustrates the tools and methods participants used to collect and record data. Students were given a paper instruction cards (Appendix E) outlining specific data to be collected and the tasks required to do so. Participants

were also given a map of the ten (n=10) features to be recorded (Appendix F). Using a stop watch and data entry forms, the time taken was recorded for each student to successfully complete, from start to finish, a given task, the number of times participants required help for each task, and any system errors or malfunctions that occurred during participant data collection. Participants were asked at the outset to “think out loud” so that any thoughts they had during the entire data collection process regarding their use and performance of the system could be documented. Any observations that seemed relevant at the time were also noted.

The main tasks participants performed using the smartphone GIS included:

- *Operate ArcPad software:* Select and open correct test map, save and close map
- *Navigate map:* Use zoom and pan tools to navigate map display
- *Collect point/polyline feature data:* Activate GPS, select appropriate toolbar and toolbuttons, enter attribute information into associated form fields, take a picture of the feature, close edit form, save data, save map
- *Edit point feature data:* Navigate to feature on map, select layer for editing, identify point on map, choose select tool, tap on point feature to open edit form or to delete feature, enter or change attribute information, take a picture of the feature, close edit form, save data, save map.

The data collection process was repeated a second time in the same location with the same participant now using a digital camera, GPS and paper forms (see Appendix G) to record and capture spatial and attribute information. At the start of the second round, a brief tutorial was provided that lasted approximately 15 minutes in length that described how to operate the digital camera and GPS equipment and how to enter information on the paper form. The same usability and performance data was recorded as in the first round while participants collected feature data. After a participant completed both data collection trials, they then returned to the office to test collecting forest stand information.



**Figure 1.7** Participant recording geospatial data during usability testing. (a) Participant recording point feature data with a stylus on smartphone GIS. (b) Participant recording attribute information with pencil and paper form. (c) Tools used by participant to record GIS data with paper-based methods.

A second series of usability testing called for participants to enter tree count information on both paper sheets and the smartphone device. Participants were given separate instruction cards (Appendix E) containing information regarding tree species, size and regeneration classification. Because this did not require users to record their geographic location, testing was performed indoors. Participants were first instructed to enter the forest stand information into the smartphone Forest Stand Tally app. The time taken for the participant to consecutively enter information for ten ( $n=10$ ) trees was recorded. When finished entering data on the smartphone, participants were asked to enter the same forest stand information as a series of ‘dots’ into a paper stand analysis form like the one shown in Appendix A. Time-on-task was again recorded during this process. Once participants had completed data collection they were asked about their experiences and perceptions regarding the usability of the system through an informal interview

and survey questionnaire (Appendix H). The survey questionnaire was constructed and based on Chin et al. (1988) revised *Questionnaire for User Satisfaction* measurement tool.

A final step in the usability data collection process required timing the transfer, editing and compilation of each participant's GIS and Forest Stand dataset to the desktop PC. Time-on-task was self-recorded to measure the processing of both electronic and paper data sets into digital formats on the desktop PC. Data entry errors as well as any loss of data were counted and classified for usability data analysis.

Usability evaluation of the smartphone GIS also included an expert review. Under this testing scenario, a professional forester was asked to use and assess the electronic data collection system. Scheduled data collection took place over the course of two days in May 2012 in an active forest management unit in eastern Ontario. GIS data related to forest features were captured on an ad-hoc basis. Forest plot tree counts were collected using the Forest Stand Tally application. Usability assessment was based on user comments and ethnographic observation of user and smartphone performance (e.g. instances of system malfunctions, data loss, successfully captured data, etc.).

### **1.3.7 Data analysis**

All usability related data were compiled and entered into a MS Excel spreadsheet workbook (Appendix I). Usability data were organized per participant and per task to be able to identify trends among and between the two groups. Separate spreadsheets were created for time-on-task data, data errors, system malfunction, data transfer times, survey questionnaire scores, and help needed counts.

Participant survey questionnaire scores were measured for internal consistency using Cronbach's alpha coefficient:

$$\alpha = \frac{k}{k-1} \left( 1 - \frac{\sum s_i^2}{s_T^2} \right)$$

where  $k$  is the number of items,  $s_i^2$  is the variance of  $i$ th item and  $s_T^2$  is the variance of the score formed by summing all the items (Bland and Altman, 1997). The resultant coefficient yields a number between 0 and 1. Higher values indicate a high degree of consistency, meaning that there is evidence of an underlying concept. Participant and expert comments were analyzed for common themes or categories by searching for recurring keywords or phrases. Where applicable, usability data were analyzed using descriptive statistical measurements such as mean, range, frequency, and standard deviation. Paired, two tailed  $t$ -tests were calculated to measure the probability that time-on-task data for electronic and traditional methods have the same mean. Paired, two tailed  $t$ -tests have been shown to be a good measure of tests of difference between in-group comparisons (van Tamelen, 2004; Love, 2005). It was hypothesized that there was no difference in mean time between the smartphone and paper-based systems. Significance was determined for values of  $P < 0.05$ .

GIS data were projected and plotted in ArcGIS to illustrate spatial variance between smartphone ArcPad and handheld GPS features. Standard distances for point feature data were calculated in ArcGIS with the Stand Distance toolbox. This technique measures the compactness or spread of a distribution of points around the mean center of any given point. Values for 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> order standard deviations were plotted on the map as concentric circles with each circle equal to the radius of the standard distance (Mitchell, 2005). The geographic representation of the line data allowed for a simple visual comparison of the datasets.

## **1.4 Challenges and limitations**

Some important challenges and limitations to the approach taken in this research exist. One major challenge in this research was gaining access to forestry personnel. MLFI is a working operation and, understandably, limited time was available to consult with forestry personnel to assist with the development and testing of this project. Although it is felt that sufficient information had been obtained to reasonably assess the usability of the smartphone GIS system, greater insight could have been realized with more testing and feedback from a larger and more diverse group of professional users. As such, the findings contained in this research are largely based on the expert review of only one forester.

Design and testing of the smartphone GIS functionality was limited to the tasks and operations that were considered fundamental to the central thesis of this research. Infinitely more advanced and complex procedures exist with respect to collecting and managing spatial data. Accordingly, usability metrics employed in this study were constrained to evaluating the most relevant and basic aspects of user and system performance. Many other usability measurements, as well as other computer-user performance measurement systems could have been utilized which might have yielded different outcomes.

It is worth mentioning that the environmental conditions under which the smartphone was field-tested were relatively benign compared to what could be experienced by forest workers during an Ontario year. As we only had one smartphone to use for this project, the mobile device was not tested in extreme weather. Such limited exposure adds uncertainty to assessing the long term durability and reliability of a smartphone to operate in a manner that is practical for many field-workers.

## **Chapter 2**

### **Use of smartphone technology for sustainable forestry silviculture: a test of low-cost technology in eastern Ontario.**

By Richard R. Kennedy, Robert McLeman, Mike Sawada, and Jan Smigielski

#### **Abstract**

We examine whether the current generation of consumer-grade digital mobile computing technology, so called smartphone technology, is usable to perform and improve field data collection in the context of sustainable forest management. An electronic data acquisition system was developed based on a handheld smartphone device and desktop geographic information system (GIS). A custom timber cruise application and commercial mapping software were used with the smartphone/desktop GIS to record and process forest stand and geospatial information. Usability testing was carried out to measure workflow efficiency and system performance of the smartphone GIS compared to traditional paper-based methods. The results showed that the smartphone GIS successfully met performance objectives and significantly increased workflow efficiencies by improving data transfer and processing times over conventional paper methods; however use of the mobile device promoted greater data entry errors, increased data collection times, and led to more equipment malfunctions than using paper, GPS, and a digital camera. The prototype electronic data acquisition system was determined not reliable as a stand-alone device solely responsible for collecting cruise data, but was found to be well suited for ad-hoc mapping of forest features.

**Keywords: Mobile GIS - Smartphone - Forestry - Silviculture - Electronic Data Collection - Eastern Ontario**

## 2.1 Introduction

Government regulations in Canada increasingly require the forestry industry to practice sustainable forest management and harvesting (e.g. Ontario Crown Forest Sustainability Act, 1994 (OCFSA); Forest Practices Code of British Columbia Act 1995; Quebec Forest Act as amended 2005). Although specific requirements vary across jurisdictions, the current model of sustainable forestry generally entails managing forests to maintain ecological integrity, biodiversity, and habitat protection while meeting the socio-economic needs of present and future generations (Kneeshaw et al. 2000). In Ontario, forestry companies seeking to harvest on public forest lands (also known as Crown Land), must do so through a Sustainable Forest License (SFL), under which the holder agrees to manage Crown Lands for their “long term health” as laid out in the OCFSA. Forest companies licensed by Ontario’s Ministry of Natural resources (OMNR) to carry out forest management are required to maintain electronic records of spatial data to facilitate the transfer of information between companies, government agencies, and in some cases the public, regarding forest resources, management, and planning activities. To do so requires considerable, ongoing effort to collect data regarding the structure and condition of the forest (Bidwell et al. 1996). These data collection and management requirements, which apply to all forest operators regardless of size, place considerable workload burden on smaller forest companies, drawing resources away from other operations.

Several types of spatial data are commonly collected to support sustainable forest management. One of these is primary data collected through direct sampling and measurement of trees in a given stand to determine their density, distribution, species, age, and size classes, an operation typically described as ‘timber cruising’ (Elliot et al. 2000). Information concerning forest disturbances, cultural heritage resource values, areas of concern, and other similar forest

attributes, which may be obtained through primary observation or secondary sources, are also important data contributions to forest management planning (Brand et al. 1991). To capture and record these geospatial and attribute data, foresters traditionally use a mix of global positioning system (GPS) technology, aerial imagery, survey instruments, maps, and paper-based data entry forms (Curran et al. 2000). The capture of primary spatial and attribute data is widely recognized as being time consuming, expensive, and error prone (Longley et al. 2006). Converting paper-based forms to electronic formats adds to workload burden and increases the risk of introducing errors (Inman-Narahari et al. 2010). Consequently, the data collection and representation requirements imposed by government regulations place smaller forestry companies and sometimes, private landowners, who may be under-resourced to carry out such activities efficiently, at a competitive disadvantage as compared with larger forest companies (Bernard and Prisley, 2005).

Mobile computing technology that integrates GPS, geographic information systems (GIS), and sensing capabilities into a handheld device can improve data collection efficiency, integrity, and capacity (van Tamelen, 2004; Dong et al. 2010). This is achieved by improving data collection rates, reducing data transfer times, and reducing the number of data errors at various stages in the data handling process in comparison to similar paper-based systems (Döner and Yomralıoğlu, 2008; Lane et al. 2006). Mobile geographic information systems (MGIS) offer further benefits to those who routinely collect spatial data in the field. Such portable handheld computing technologies allow personnel to capture, edit, manipulate, analyze, access, and display geographic or spatially encoded information using commercial software. The merits of MGIS to assist in data collection and data management in applications such as utilities management, human health, and geological surveys are well documented (Chen and Xu, 2008;

Byass et al. 2008; Pavlis et al. 2010). Mobile technology does, however, have its challenges: small screen size, battery life, training time, complexity, large up-front costs and concerns over accidental data loss are among the more frequently cited disadvantages (Jones et al. 2004; Montoya, 2002; McCaffrey et al. 2005). Nonetheless, the potential benefits of MGIS are great, and warrant ongoing exploration and innovation (Hense et al. 2009).

Mobile computing technologies and mobile GIS (MGIS) have been shown to have considerable potential for forestry (Li and Wang, 2009; Yao and Li, 2010). Inman-Narahari et al. (2010), building upon earlier work by Wang et al. (2004), who developed a personal data assistant (PDA)-based timber cruise data collection system, have shown that digital data collection and entry is much more efficient for measuring and mapping trees in a large forest plot than paper-based methods. Zhou et al (2009) created a GPS-enabled PDA system for monitoring forest fires, while Li and Jiang (2011) developed a proprietary system for forest inventory management using PDAs with an embedded GIS. While these and other studies have shown the potential benefits of MGIS in forest management data collection, they do not document their efficiency in the context of a particular silviculture workflow through the quantification of the difference in in-field data collection accuracy or time savings across various data collection methods.

Furthermore, we have not encountered any studies that employ over-the-counter consumer-grade smartphones as the primary data collection device for forestry, even though these are the most common potential spatial data collection devices used by foresters today and the general public alike. The use of mobile phones for field data collection is continually expanding, and has proven to be highly successful in epidemiological studies, air quality measurement, and traffic

condition monitoring to name just a few applications (Aanensen et al. 2009; Honicky et al. 2008; Herrera et al. 2010). Smartphones possess integrated sensing, positioning, computing and communication technologies comparable to many other expensive devices, and have an equal ability to process geospatial information (Kwok, 2009). Most important is their relatively low cost and ubiquity; we suspect most foresters already carry one when they enter the field. It therefore seems very appropriate to begin experimenting with smartphones to facilitate data collection, especially given their potential to provide a low-cost method to support small scale forestry by expanding data collection capacity while reducing time and money dedicated to the mechanics of data collection and management.

To this end, our study examined how relatively inexpensive, off-the-shelf smartphone technology might play a beneficial role in the collection and organization of primary silvicultural data for small-scale forestry. Our research team brought together GIS scholars and a professional forester to develop an integrated electronic data collection and management system using a GPS-enabled smartphone, mobile data collection software, and a desktop GIS. The system was designed to facilitate collecting cruise timber and forest resource data required under the Ontario's Sustainable Forest License agreement by a small commercial forest management company, Mazinaw-Lanark Forestry Inc. of eastern Ontario. The system was put through various field and simulation trials to evaluate the smartphone GIS performance, and its efficiency was tested in semi-controlled experiments. Our results found that the smartphone/GIS successfully met performance objectives and significantly increased workflow efficiencies by improving data transfer and processing times over conventional paper methods. However, use of the mobile device resulted in greater data entry errors, increased data collection times, and more equipment

malfunctions than paper-based methods. A detailed report on our methods and findings now follows.

## **2.2 Methods**

Certain key considerations particular to small scale forestry shaped our decisions with respect to deciding hardware, software, and the overall architecture of the system. These included:

- Using low-cost, commonly-used hardware and software wherever possible;
- Integrating the smartphone into existing data collection and management systems;
- Accounting for the lack of wireless internet or cellular connectivity in uninhabited forested areas;
- Minimizing the need to create customized software solutions wherever possible.

### **Selection of smartphone GIS architecture for the study**

A one-to-one client/server configuration was chosen as the architecture for the smartphone GIS. This configuration was preferred because it simplifies the exchange of data between the smartphone and desktop GIS by avoiding connectivity and interoperability issues associated with distributed systems that rely on wireless networks and remote web servers for data processing, storage, and/or GIS services. The client side is a HTC HD2 Windows 6.5 smartphone that can record, display, edit, and store geospatial data. The server side component is a Dell GIS Workstation desktop computer that exchanges content with the client, performs GIS and other data processing operations, and serves as the master data storage base. Communication between the two computing systems occurs through a wire universal serial bus (USB) cable and Microsoft ActiveSync 4.5 software (Microsoft, 2012).

The smartphone was chosen from a wide range of possible platforms and devices for its large screen display (4.3 inches), internal GPS receiver, built in flash memory card capability,

and Windows Mobile 6.5 operating system (OS) (now obsolete). The Windows OS was favored for its custom software development capabilities and its ability to run mobile versions of popular electronic software, such as Microsoft Excel and the ESRI mobile GIS ArcPad; both of which were utilized for this project based on their functionality and ability to integrate with Mazinaw-Lanark's current data management system (Windows Mobile 6.5 © 2010 Microsoft Corporation). An extra battery, stylus, car battery recharger, 32 GB Micro SD card, and protective cover were obtained to protect the device and provide additional power and memory storage in the field. The desktop PC was a dual Xeon CPU 3.20GHz, 4 GB RAM operating Windows XP SP2.

ESRI's ArcPad 10.2 mobile GIS software (Fig. 2.1a) was chosen from other mobile GIS software for its customization capabilities, ability to operate in a disconnected setting, and ability to synchronize recorded field data with ESRI's complimentary desktop GIS software package, ArcGIS 9.3.1 for additional cartographic display and spatial analysis (ArcPad 10.2 Copyright © 1995-2011 ESRI). In addition, when this research was initiated in 2010, neither iOS nor Android offered apps for custom geospatial mapping and data transfer to desktop GIS. However, the conclusions of this research are generalizable to other smartphone platforms (Android, iOS, Windows Phone 8) given sufficient customization or app availability.

We developed a proprietary forest stand tally (FST) software application (app) (Fig. 2.1b) to record and store cruise timber data, as there was no existing commercial application capable of meeting Mazinaw-Lanark Forest Inc. (MLFI) data collection requirements that was comparable to their established paper-based method. The FST application was created with Microsoft Visual Studio 2005 IDE (Microsoft, 2012). The application allows users to enter multiple plot data related to tree species, size class, condition, and other site characteristics. For a shallow learning

curve, data entry fields in the application were designed to be as close as possible to the paper tally form currently used by the MLFI. This similarity also permitted comparative testing and evaluation between the electronic and paper-based forms. The FST application was designed to further facilitate data entry by performing automated tasks such as incremental counts (tally) of tree species, recording of the plot's geographic position by means of the smartphone's GPS, and user-forced data entry controls. Recorded data are saved on the device as a series of comma-separated-value (CSV) files are read into an Excel workbook by a custom VBA program. The custom workbook contains embedded functions that compile and auto tally plot data into a finalized spreadsheet.

**Fig.2.1.** Smartphone data collection software. (a) ArcPad mobile mapping software. (b) Forest Stand Tally app.



## Usability testing design

Usability testing was applied to measure user's perceptions about various features and aspects of the smartphone GIS design, operation, and performance. Field-based usability testing allowed us to gather qualitative and quantitative data about the performance of the system through participant testing and expert evaluation by empirical methods. In this study we compare and assess the performance of electronic and paper and pen methods for data collection and data processing using the following criteria:

- **Effectiveness:** success rates-the proportion of tasks completed versus tasks attempted; Error or malfunction rates; positive and negative survey questionnaire responses, and user comments.
- **Efficiency:** time-on-task-a measure of the time taken to complete a given task from beginning to end.
- **Learnability:** instruction times-counts of times help was given; survey questionnaire scores and participant comments.

Usability of the smartphone was determined based on its ability to out-perform paper-based methods in each category listed above. Two field data collection exercises were designed for usability testing.

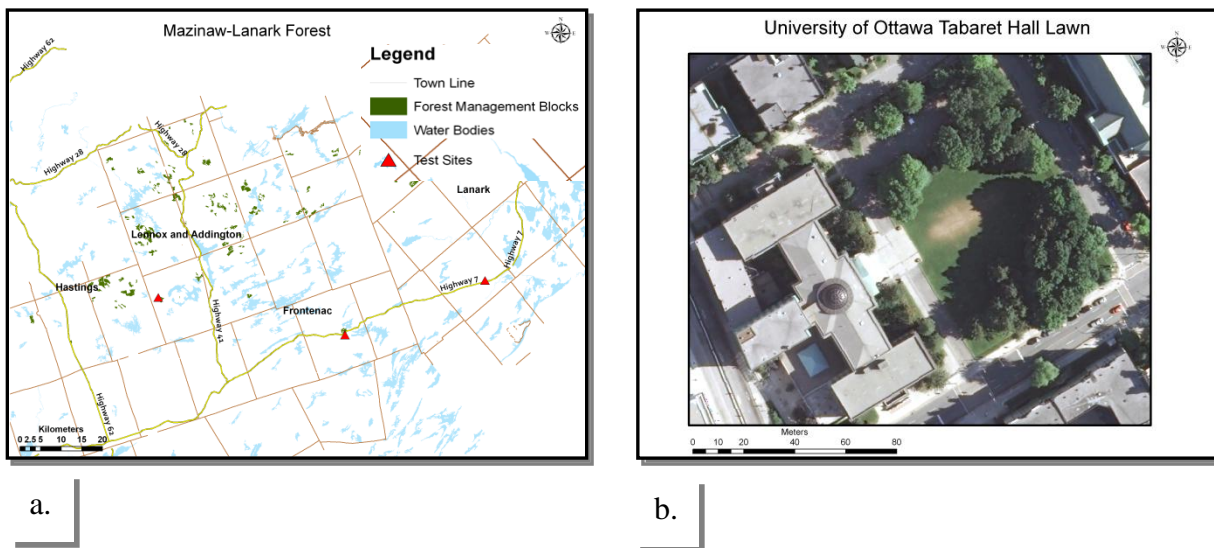
## Study Sites

Field data collection trials were conducted at two study sites in eastern Ontario, Canada. One site (Fig. 2.2a) consisted of select forest stands within the MLFI management unit (44°49'19.03"N, 76°57'43.06"W). Forestry in this area supports 17 commercially viable tree species dominated by hardwood and mixed hardwood stands (Howard et al. 2010). ML is the southerly of the management units created for the purpose of forest management on Crown land in Ontario. This area was chosen for its ecologically diverse forest, sensitive wildlife habitat, and mixed industrial and non-industrial usage making it representative of the complex landscape within which

southern Ontario’s foresters operate. Prototype testing occurred on an iterative basis from 2011-2012 in all seasons.

Tabaret Hall lawn at the University Of Ottawa, Ontario served as a semi-controlled environment, representing a proxy forest setting, where participant usability data could readily be collected. This location (45°25’29.43”N, 75°41’08.27”W) consists of a large open grass field surrounded at the perimeter by a mix of shrubs, coniferous and deciduous trees (Figure 2.2b). Within and adjacent to the park are built features such as benches, paved surfaces, and low-rise buildings. The total area of the park is roughly 0.54ha. Testing occurred during the month of April, 2012.

**Fig.2.2** Maps of study area test sites: Smartphone GIS usability testing sites (a) Mazinaw Lanark Forest Inc. management unit. GIS data: Mazinaw Lanark Forest Inc., ODGE Fundamental Data Set. Ontario Ministry of Natural Resources, (b) University Of Ottawa Tabaret Hall lawn. Image data: Digital Raster Acquisition Project Eastern Ontario (DRAPE) Ontario Ministry of Natural Resources Date (creation), 2009-01-10.



### Expert Evaluation

Usability testing included an expert evaluation of the smartphone system. Under this testing scenario, a professional forester was asked to help develop, use, and assess the electronic data

collection system. Forest stand field data collection took place over several days in May 2012 in an active forest management unit in eastern Ontario. Usability assessments were based on user comments and ethnographic observation of user and smartphone performance.

### **Participants, tasks, and usability data collection procedure**

Participant usability testing was carried out at the University of Ottawa. A total of 12 (n=12) participants were given a series of tasks to perform with the general goal of recording tree stand and GIS data using both the smartphone and paper based systems while usability data was simultaneously recorded by an observer (the first author). Performance data that was recorded included: time-on-task, the number of times participants required help for each task, and any system errors or malfunctions that occurred during the data collection process. Participants were also asked about their experiences and perceptions regarding the usability of the system through an informal interview and survey questionnaire. The survey questionnaire was constructed and based on Chin et al. (1988) revised *Questionnaire for User Satisfaction* measurement tool. In addition, time-on-task was self-recorded by a member of the research team to measure the processing of participant electronic and paper data sets into digital formats on the desktop PC. Data entry errors as well as any loss of data were counted and classified for usability data analysis.

### **GIS and forest stand field data collection process**

On the day of testing, a participant was given a brief overview of the test design and research objective, followed by a 15-30 minute tutorial and a demonstration of how to record data and operate the data collection software, GPS, digital camera, and smartphone device. Students were given paper instruction cards outlining specific data GIS (6 point features, 2 polyline features,

and 2 edits) and forest stand data (tree species, size, and regeneration classification) to be collected and were provided with the main tasks required. Participants first collected data on the smartphone device and then in a second round, they used traditional paper-based methods.<sup>5</sup>

## **2.3 Results**

### **Data collection, editing and processing efficiency**

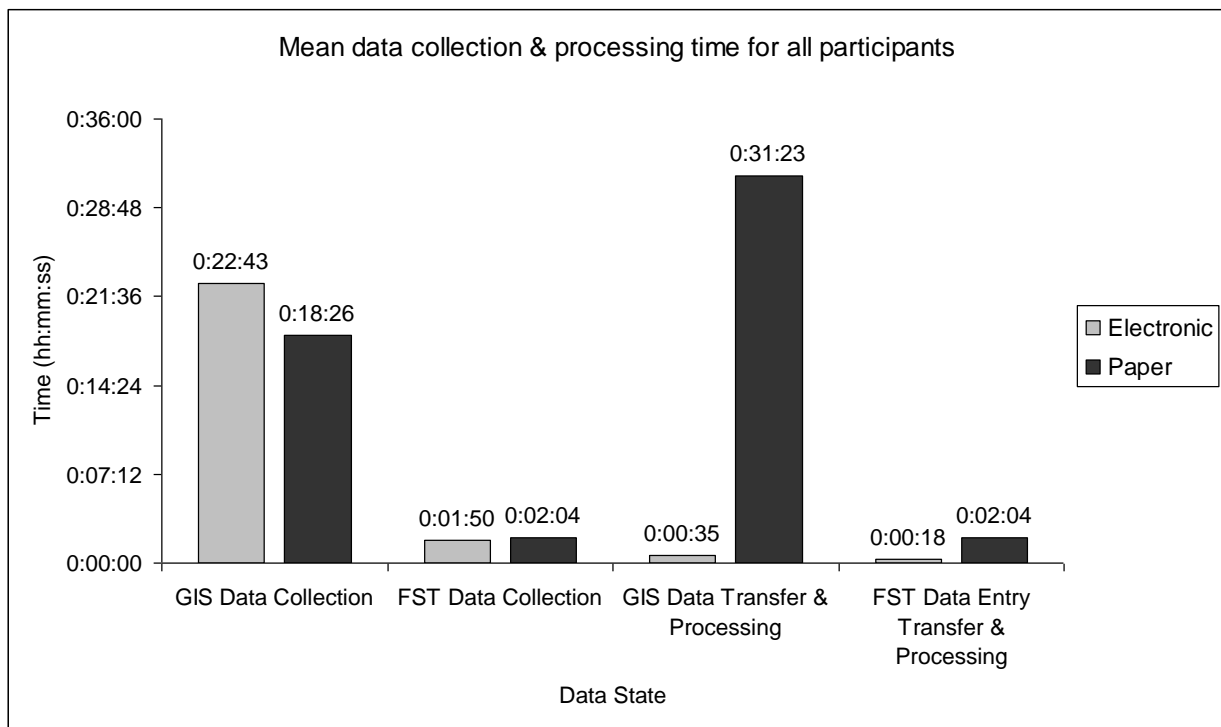
The simulated trials on Tabaret Lawn demonstrated that it took longer to collect GIS and forest stand data using a smartphone than it did using a combination of a handheld GPS, camera, and paper-based forms. Data transfer and processing times for both GIS and forest stand datasets was less for data collected on the smartphone compared to traditional paper-based methods (Fig.2.3). The time required for participants to collect GIS data was significantly smaller ( $P = 0.0013$ ) for paper methods than using the smartphone GIS. GIS data collection times, per participant averaged 0:22:43 (h:mm:ss) using the smartphone while participants using the GPS, camera, and paper forms took an average time of 0:18:26. Average data collection time for participants using the paper methods to record forest stand information was less than those using the smartphone (0:01:50 vs. 0:02:04). Conversely, the average transfer and processing time for a participant GIS dataset was significantly faster ( $P < 0.001$ ) for the electronic system, 0:00:35, than paper transfer methods, 0:31:32. Likewise, the average time required to transfer and process forest stand data with the smartphone was significantly ( $P < 0.001$ ) less at 0:02:04 compared to paper forms that took an average time of 0:01:50 to complete.

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<sup>5</sup> The methods taken in this research to permit the measurement of participant usability data in order to compare the work and data flow between paper-based and electronic methods, are provided in the supplementary material and Fig.S1.

Overall, the total time needed for each participant to record GIS and forest stand data and then transfer and process those datasets was significantly ( $P < 0.001$ ) less using the electronic method compared to traditional paper and pen. On average, the summed time needed to complete a project (i.e. collect and process one GIS and forest stand dataset) using the smartphone GIS was 0:25:26 (data collection + data transfer and processing) where as with the paper system an average time of 0:53:58 was needed to complete all tasks.

**Fig.2.3.** Mean data collection and processing times for all participant data states.

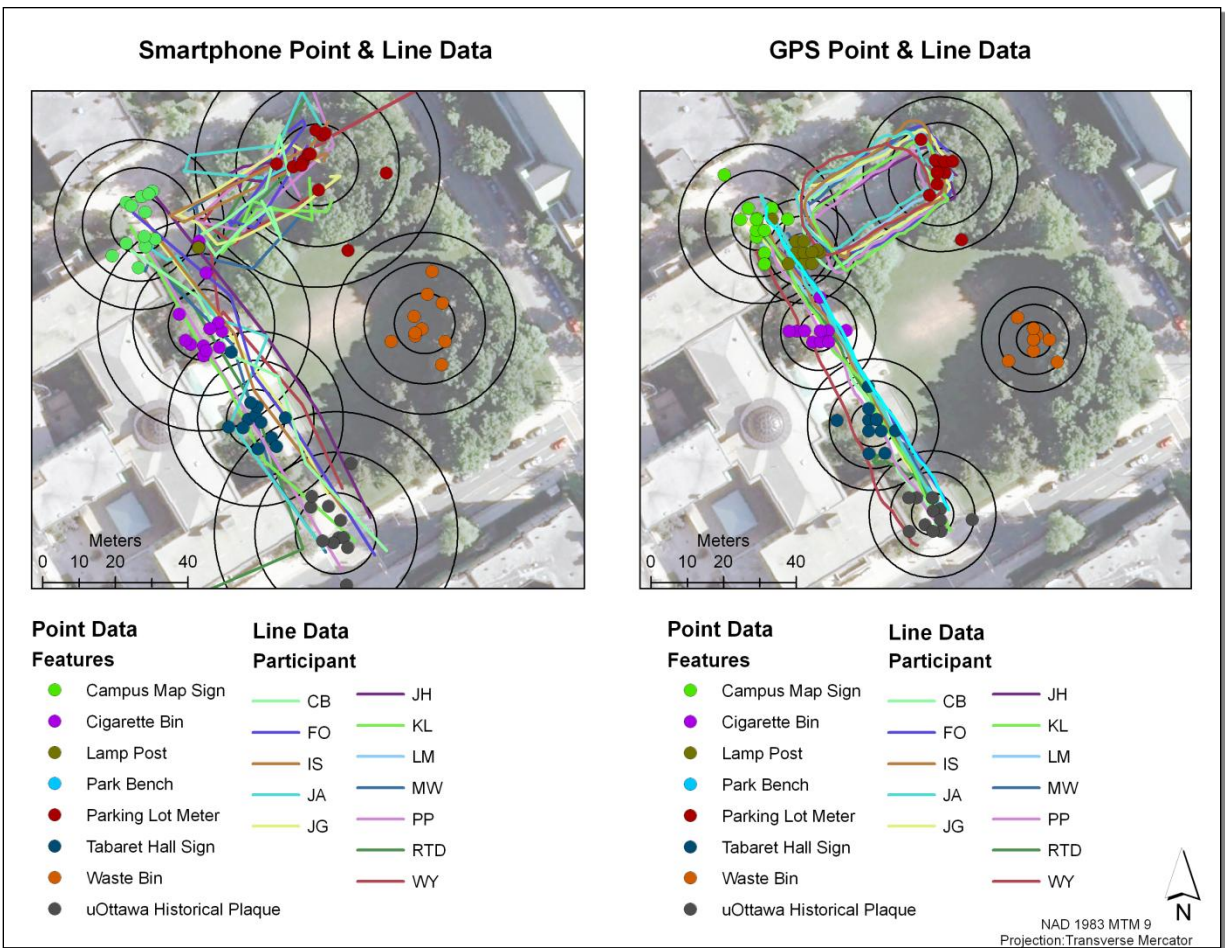


### GIS data accuracy comparison

GIS point and line data were mapped to compare the positional accuracy of each data collection system (Fig 2.4). Spatial data recorded with the handheld GPS were more accurate than those collected with the smartphone. First order standard distances for GPS points were significantly

less ( $P = 0.0030$ ) than those for smartphone. The mean distance from the estimated center (i.e. feature location) was 6.1 meters (m) for GPS points compared to a distance of 9.4m for the smartphone GIS. Visual analysis shows that GPS polyline data had greater positional accuracy than smartphone collected polyline data.

**Fig.2.4.** Mapped GIS data. Values for 1st, 2nd, and 3rd order standard distance deviations are plotted as concentric circles for each point feature with each circle equal to the radius of the standard distance (Mitchell, 2005). Standard distance provides a measure of how precise and accurate position measurements are by how compact a distribution of points are around the mean center. Captured point and line data are shown for each participant. Line data are identified by participant initials for parkinglot and sidewalk features.



## Data errors, malfunctions, and ease of use

Data entry accuracy, equipment functioning, and ease of use were found to be superior among participants using paper methods compared to the smartphone system (Table 2.2). Participants were more likely to commit data entry errors using the smartphone system than students using paper methods. Participants using the smartphone to capture spatial data were also more prone to experiencing malfunctions and difficulty collecting data with the smartphone than participants using paper, GPS and a camera. Paper-based methods were found to be easier to use for collecting data than electronic methods.

**Table 2.2** Usability performance measurements for electronic and paper systems.

	<b>Electronic</b>	<b>Paper</b>
<b>Percent of participants that experienced malfunctions or committed data entry errors during GIS data collection</b>		
Errors: Data missing or entered incorrectly	100	50
Difficulty with ArcPad/GPS/Camera GUI	42	0
Non-critical malfunction: ArcPad/GPS/Camera not functioning properly	17	0
Critical malfunction: ArcPad/GPS/Camera not function properly. Redo task	17	0
Experienced 2 or more malfunctions for a given task	58	0
<b>Forest stand data errors</b>		
Number of participants that entered incorrect forest stand data	1	0
Total number of data entry errors	6	0

## User satisfaction results

In general, participants rated the electronic data acquisition system favorably. Overall, the system was rated easy to learn and use. Screen display was rated easy to see but difficult or hard to interface with, particularly with respect to keying in text. Most of the participants found the electronic system very capable in terms of system speed, reliability, and screen navigation. System feedback relating to error messaging and system functioning were rated as helpful and confident respectively.

Participant satisfaction results indicated that the electronic system was easy to use but entering information and selecting features on the touch screen was at times difficult. Four of the participants indicated that some tool buttons were too small to press or that a tool button did not respond well to user input on the smartphone touch screen. Poor GPS accuracy for capturing line features and dim backlighting of the display screen were considered to be limiting aspects of the smartphone GIS by a few participants. Nearly every participant liked that there were less items to carry during data collection using the smartphone compared to the paper system (e.g. camera, GPS, clipboard). Participants commented that they liked the automated features of the smartphone for data entry. A quarter (n=3) of the participants felt that data entry on the smartphone was faster than with paper, where as one participant responded that data entry on the smartphone was slower. When asked directly, no participant indicated that the tested system was unusable.

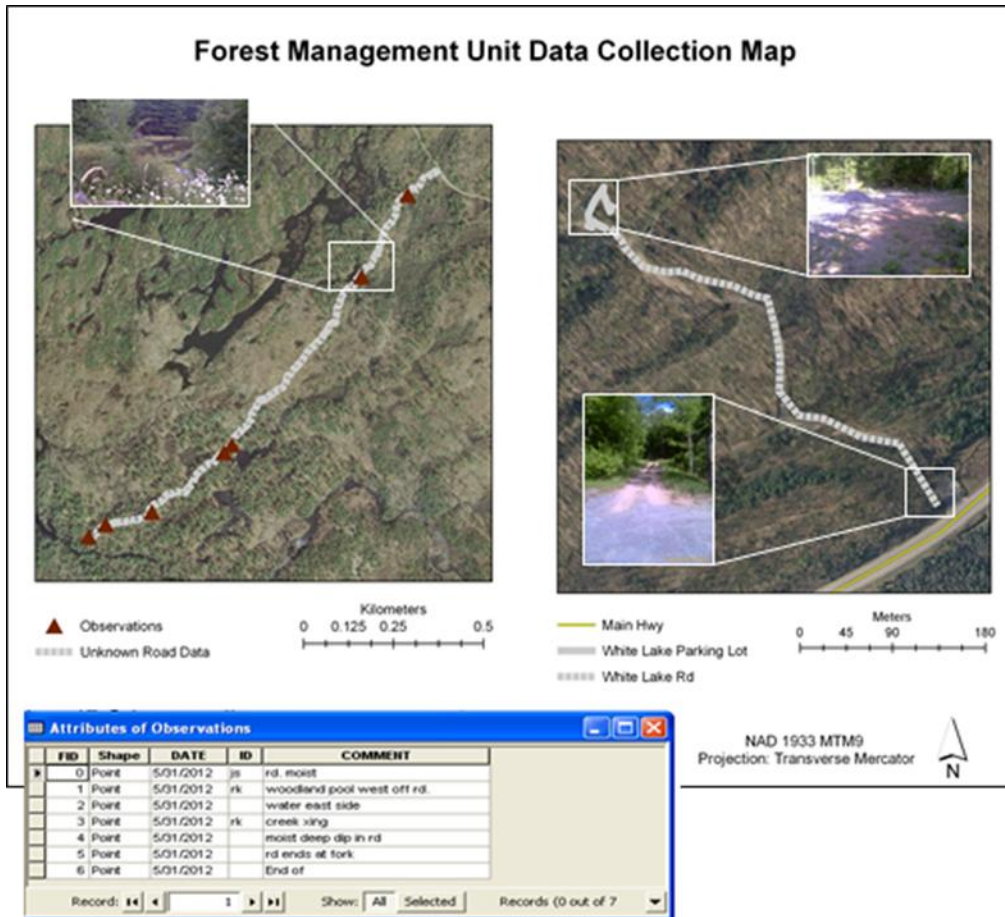
### **Performance under real-world conditions**

Field testing at MLFI proved the smartphone GIS capable of collecting spatial and forest stand data and in improving the transfer of this information into digital formats. Concerns about hardware and software reliability, as well as the need for greater customization of the system to meet data collection quality and efficiency standards, called into question the ability of the current smartphone design to serve as the sole tool for collecting field data.

The integrated GPS, camera, and mapping software technology of the smartphone was found to be especially well suited for ad-hoc geospatial field data collection (Fig. 2.5). The ability to capture photographic images with the smartphone and automatically associate photos with feature class data was found to be extremely useful for analyzing data later during

processing. The custom ArcPad Proximity Alert applet worked well and was found to be useful for alerting users when they were in close proximity to an area of concern. GPS accuracy was thought to be acceptable for the nature and type of data collection for which the smartphone was utilized. The capacity of the smartphone GIS to display a range of GIS data types (e.g., raster imagery) and the user location via the smartphone GPS and mapping software was also found to be effective for location referencing and identifying and editing geospatial data sets in ArcPad.

**Fig.2.5.** Example of mapped smartphone GIS data.



The forest stand app was said to be useful for its ability to record information for several forest stands and plots into a consolidated format on the smartphone device rather than on many paper sheets. The ability to maintain plot specific data and automatically record the user's geographic location for each plot was a key advantage over paper tally forms where all data blend together. The electronic system allowed for plot data to be disaggregated during processing, thereby allowing for a more refined spatial analysis of plot dynamics. Small screen size and dim display of the GUI in direct sunlight were found to be bothersome at times, though neither prevented collection of field data nor was it felt to be a limiting factor in the overall effectiveness of the smartphone system.

Hardware and software functioning was inconsistent. Overall, it was felt that the mapping software was more reliable than the forest stand application in its performance for field data collection. During field trials some GIS data was lost; however, this was mainly due to operator error and not the malfunctioning of the hardware or software: for example, failing to periodically save data on the device after it had been recorded before initiating some other event with the software. On one critical occasion the forest stand app software completely ceased functioning early in the data collection process and all previously recorded plot data was lost. This malfunction was later fixed by reloading the software onto the mobile device and no further errors occurred in subsequent testing, however, this glitch negatively impacted our confidence in the program and subsequently it was determined that the forest stand application in its current form was less reliable than paper and pen.

The level of ease required to learn the electronic data acquisition system varied between setting up the smartphone system and its actual use. Setting up the smartphone system, i.e.,

customizing the ArcPad software, managing data between the desktop and smartphone GIS, developing the FST app, were found to be more complex, cumbersome and/or constraining compared to established techniques for recording spatial data with a paper map, pencil, and GPS. However, once the smartphone GIS had been developed, it was felt that given sufficient time, it would not be difficult to learn how to use the smartphone device and data collection software. The simplicity of transferring and processing GIS and forest stand data was thought to be easier compared to the standard method of transferring data from paper to digital formats.

Workflow efficiencies varied between project setup, system testing, data collection, and data processing. Setting up the software required a large initial time investment - days to weeks were needed to construct the system architecture and test the custom mapping and forest stand software. Training personnel to properly use and integrate the system also took added time and resources compared to traditional data collection systems. However, after familiarization with the smartphone system, primary field data collection proceeded at a comparable pace to paper-based methods. Time savings were diminished when field data was lost or when the smartphone system malfunctioned. To transfer files from the smartphone to the desktop PC took minimal time and allowed for data to be collected and processed immediately.

## **2.4 Discussion and conclusions**

This study demonstrated that a smartphone-based electronic data collection system is potentially capable of supporting sustainable forest management by providing a low-cost, accessible solution for gathering primary forest-related geospatial data. Testing under real-world conditions revealed that a smartphone can assist foresters collect site-specific data that supports forest inventory, reporting, environmental modeling, and operational planning. In addition, on several

occasions during field trials, the lightweight, unobtrusive, and integrated nature of the handheld device promoted opportunistic *ad hoc* data collection of useful information to foresters that would not have been captured otherwise. For example, the road attribute data collected on the smartphone (Fig 2.5) was collected as supplemental information during routine testing of the smartphone system. While unplanned, this data would later be used by MLFI to update their ‘areas of concern’ GIS datasets and passed on to field workers to inform them to exercise caution when operating in the area due to the presence of sensitive aquatic habitat. The capability of the smartphone to take georeferenced photographs of the feature further added to the richness of the data collected and made carrying of a separate camera unnecessary. Given the potential of system to be scaled up to a distributed system synchronized to multiple smartphone devices, one can easily imagine in the foreseeable future that ‘areas of concern’ images could be transferred wirelessly by forest users to open-access web-portals that inform the general public to avoid disturbing these zones. This is but one example of the ability to readily collect and share information through smartphone technology in ways to further the sustainability aspect of sustainable forest management.

The greatest measurable benefit of the electronic system was its efficiency, chiefly with respect to the time-saved during data transfer and processing of GIS and forest stand datasets into digital formats. Our findings support studies elsewhere that demonstrate the ability of mobile devices to reduce backend transfer of digital data (Wagtendonk and De Jeu, 2007; van Tamelen, 2004). The increase in efficiency is accomplished by capturing and keeping data in the digital domain and eliminating steps needed to review, edit, transcribe, and clean datasets. For example, the data management tools within the ArcPad software automated the copying of field data to update the ArcGIS geodatabase and eliminated the need to manually transcribe field edits

made on paper maps to the desktop GIS (similar to findings in Inman-Narahari et al. 2010). Given comparable workloads, the magnitude of time savings obtained by using the smartphone GIS was slightly greater than 2:1, meaning that a technician using the smartphone system could complete double the amount work than one using pen and paper methods.

Consistent with findings by others (e.g. van Tamelen, 2004; Inman-Narahari et al. 2010, Ziefle 2010), GIS data collection with the smartphone did take slightly longer with paper and pen, although the difference was negligible. Selecting point data on the small screen was difficult for some test users, while slow or unresponsive toolbutton commands may have contributed to extra time on some tasks. Using a capacitive stylus helped with selecting some toolbuttons; however, those at the margins of the screen close to the protective casing were still difficult to activate. Suggested solutions include incorporating larger graphic icons and limiting information density to improve system performance. Such complaints may, however, become moot as screen size, resolution and processing speeds for the current breed of smartphones have already increased dramatically since this research was undertaken. Moreover, the tablet format is an option that deserves testing as the current tablet formats include ultra-portable 7" screens for the Android OS and likely soon for iOS and Window 8.

Measures of accuracy for data entry on mobile devices have been found to vary widely amongst various studies (Patnaik et al. 2008). Our results are similar to findings by Lane et al. (2006) in that participants in our study users were more prone to committing data entry errors using the handheld device compared to entering data with pen and paper. Most errors committed during testing were due to participants either omitting or not entering attribute data exactly as they were instructed by the information cards that were provided. Some errors were encountered

in the software programming as well. These errors are not trivial, since inaccuracies under real world conditions would create serious quality issues that data managers rely upon not only to predict harvestable wood supply, but also, to protect wildlife habitats and other forest-related values (Thompson et al. 2007; Pundt, 2002). Nonetheless, by reinforcing best practices for collecting cruise data and incorporating more stringent data entry controls (including application-side validation), mobile technology can overcome these challenges to improve data accuracy (Strobl and Bland, 2000; Cole et al. 2005; Johnson et al. 2009). It is worth remembering too that our test subjects were not foresters, and, it can be expected that regular use by professionals in the field would reduce most human errors to the point where the nature of the data collection system itself plays little or no role.

Perceptions about the learnability or ease of use of the electronic system to record data were mixed between student participants and expert evaluation. Most, if not all of the participants, commented that the electronic system was intuitive and easy to use; however, significantly more help was needed in assisting participants to collect data using the smartphone vs. paper, GPS and camera. Based on the number of errors recorded and the amount of help participants were given, it is apparent that more training time (> 90 min) would have been beneficial. This was, however, similarly true with participants collecting data using the paper system. Often, participants would have to be re-shown how to use the GPS tracks function to collect line features. With repeated use of the tools, participants required less help, suggesting there will be an initial learning curve that needs to be overcome, as there is with any new technology, smartphone-based or otherwise. It is important to note, however, that this learning curve will not substantially impact the 2:1 cost savings the smartphone system provides.

The acceptance and adoption of new technology is partly determined by the belief that it will not pose any excessive time, energy or effort to learn in order to realize the benefits of its use (Davis, 1989). Park & Chen (2007) point out that regardless of the recognized potential for mobile GIS to improve scientific field data collection, the reality is that employing mobile computing methods is not straightforward. Internal and external factors such as the nature of the workflow process, technical and financial considerations, and technical constraints demand careful consideration for implementing new data collection methods. Learning the mapping software used in this study and integrating the smartphone system with the existing data collection and management procedures requires time and resources, and these are invariably in short supply for smaller forest operators. Our study stopped short of designing a fully optimized system for commercial application, and so the question remains as to the degree of customization needed (and full financial cost) to fully integrate smartphone data collection systems into small-scale forestry enterprises on a general basis. The results are nonetheless promising. The smartphone device was found in our expert testing to function well during outdoor field testing, and never failed due to environmental conditions. Our smartphone never exceeded more than two batteries in a typical 8-10 hour workday. Provided that an electrical source was available to recharge one of the batteries, such as a charger connected to a vehicle power supply outlet, the smartphone remained in operation for the time it was needed. The accuracy of the smartphone GIS is comparable to the consumer-grade GPS unit that it was tested against as well as several other GPS receivers. Collected field data residing on the smartphone were lost during one critical testing occasion due to the forest stand app software freezing. The fact that this only occurred once in the course of many practice trials was nonetheless sufficient to raise questions about the

long-term dependability of mobile hardware and software for under rugged field conditions, and how to back-up data on the fly. More research is needed in this area.

The total out-of-pocket expense for hardware and software was approximately \$1200CND. This amount does not include costs for the ESRI software or the desktop PC. The system architecture chosen for this project was in part based on the assumption that forestry companies already possess some form of enterprise mapping software and desktop computing capacity similar to those tested. Low cost or free alternatives do exist to purchasing commercial, licensed mapping software, or creating custom cruise applications. For instance, applications like GISKitPro for iOS, Quantum GIS for Android and Windows, and FScruiser have appeared that provide some ready-made spatial data collection and forest tally capabilities (Apple Inc. Copyright © 2011; QGIS.org; USDA Forest Service). While it is possible to acquire pre-packaged data collection software, technical proficiency, costs, project needs, and software compatibility will ultimately dictate what options are appropriate (Li and Jiang, 2011; Bayarri and Anguix 2008). As was the case in this research, users will be reluctant to implement new systems unless they are adapted to meet their specific needs.

Since the time this research commenced, new mobile telecommunication technologies have become available that can also assist forest managers in meeting their data requirements under sustainable forest license agreements. The current generation of mobile computing technology offers improved display resolutions, larger screen sizes, greater processing capabilities, and operate more sophisticated software applications. In addition, new open source and commercial mobile mapping software solutions that run on consumer-grade mobile devices are continually being developed. Wireless connectivity is also improving in many rural and remote areas. These

developments have real implications for how foresters acquire, process, and share information about forest resources. Though considerable challenges remain for adopting new technologies and new methodologies, small-scale forestry operators can benefit from these technological innovations through improved workflow efficiencies and data gathering efforts that promote the sustainable management of all forest resources.

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## **Supplementary Material**

### **Data and workflow**

Following is a description comparing the general work and data flow process taken in this project, with the smartphone GIS and paper-based data collection systems (Fig. S1):

To permit the exchange of geospatial data between desktop and mobile GIS software, new shapefiles were created in the desktop GIS to contain feature attribute information and a File geodatabase was made to store all GIS data. Additional basemap layers were added to a map for referencing and display purposes. Custom edit forms with auto-fill (the software automatically enters data into a field based on user input) features were developed in ArcPad Studio and

associated with the new shapefiles to record and store text, numeric, and photographic attribute information. All field-ready data were compiled into a single folder and transferred (i.e. copied and pasted) to the smartphone's non-volatile flash drive. The FST app permanently resides on the mobile device and therefore no exchange of data occurs between the desktop PC and smartphone until after field data has been collected.

With the paper system, maps and aerial images to be taken into the field were printed from digital geospatial data that resides in the desktop GIS or they were photocopied from existing maps or photographs. Other measurements tools including a GPS, camera, paper forms and pens/markers/pencils were assembled for fieldwork.

Geospatial and forest stand data were captured and stored directly onto the smartphone device. The mapping software was optimized to record point and polyline vector data using the smartphone's internal GPS receiver. Photographs of an object were captured with the smartphone's digital camera. Other mapping tools were engaged to edit, query, and/or identify feature data. Forest stand data were collected electronically with the Forest Stand Tally application. The app allowed for recording information related to tree size, species and regeneration classification, site history, soil composition, plants observed, and ecosite classification.

Paper methods required users to enter feature spatial information onto paper forms. A handheld GPS receiver provided the location coordinates. Photographs of features were captured with a digital camera. GPS and photo image ID numbers were noted in the corresponding attribute fields on a paper form. Edits to spatial features were hand drawn on the map. Supplemental notes were written on the map, paper form and/or field notebook. Forest stand information was entered onto paper tally forms with a pencil as a series of dots representing each

recorded tree. Each tally form contained a sample of trees related to many plots within one stand. A new tally form was required for each new stand. Data related to history, soil, ecosite, etc. was noted on a tally form for each stand.

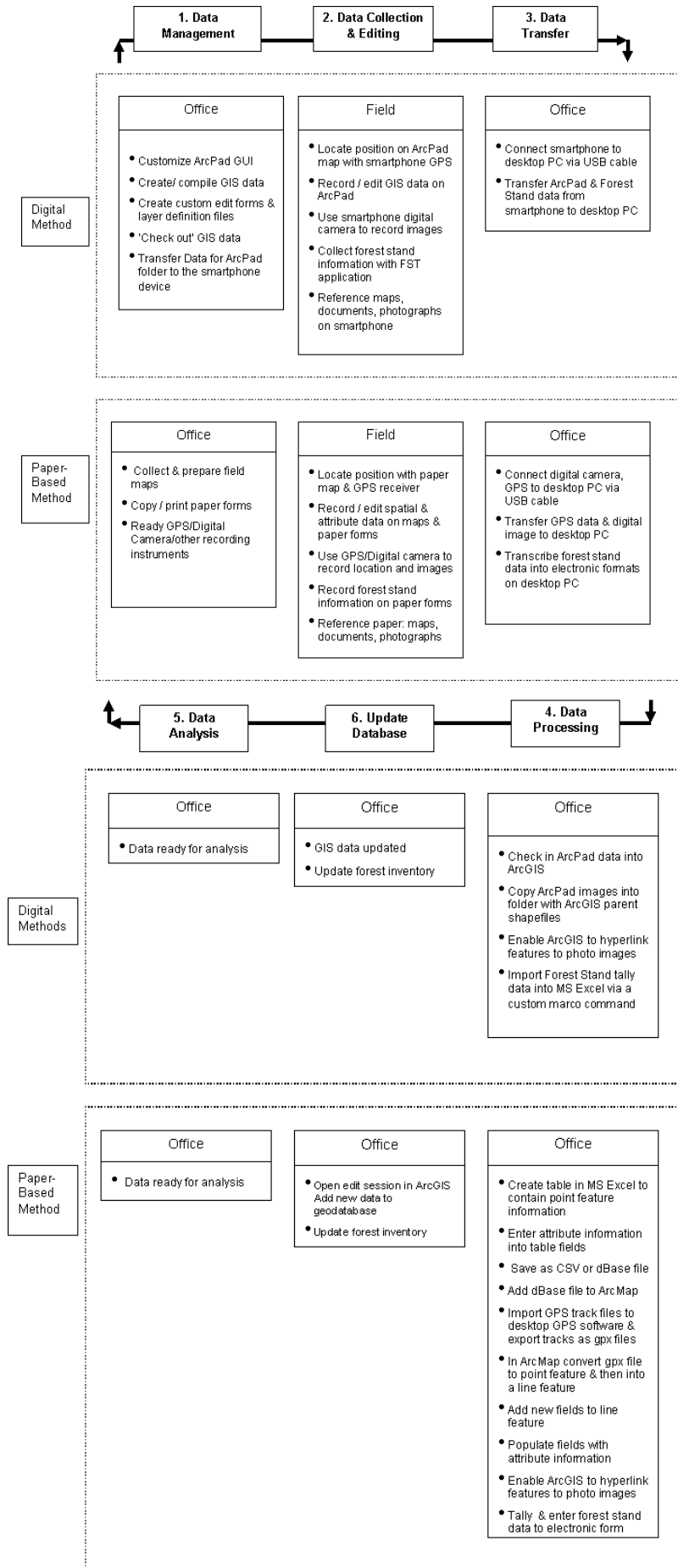
Electronically collected GIS and forest stand data were manually transferred from the smartphone to the desktop PC via cable and synchronization software. Digital images were copied onto the desktop PC and then into a master folder containing the geodatabase feature classes.

Spatial and attribute data recorded on paper were later compiled to create new shapefiles in the desktop GIS during data processing (stage 4). Digital files from the camera and GPS receiver were transferred to the desktop PC manually via cable and synchronization software. Paper tally sheets containing tree counts and supplemental information were either filed in their current paper format, or were transcribed into electronic tally forms onto the desktop PC.

All edits that occurred in ArcPad during field data collection, including adding new features deleting features, modification of attribute values and/or feature geometry, automatically updated the parent geodatabase when added to the desktop GIS. On the desktop PC, digital forest stand CSV files were moved to the same folder as the master MS Excel Stand Analysis file containing the custom macro. The macro was then run to auto-populate and auto-tally tree counts on the spreadsheet.

Geospatial data recorded on the paper forms were compiled into an electronic spreadsheet format and imported as tabular data into the desktop GIS. Paper forms containing forest stand data were manually reviewed, tallied and entered into a separate digital Stand Analysis spreadsheet on the desktop PC.

All feature class files within the ArcGIS geodatabase created with the smartphone were automatically updated during the data processing. Updating the master geodatabase with shapefiles created from the paper forms was done by opening an edit session in ArcGIS and then adding the new shapefiles (i.e. tabular data) to the current data frame. This process overwrote the parent files with any changes or addition made in the field. All digital and paper GIS and forest stand data were now in their digital format and could be integrated with existing digital datasets or used for analysis and reporting purposes.



**Fig. S1.** Work and data flow model comparing electronic and paper data collection and processing methods.

## **Chapter 3**

### **3.1 Summary and Conclusions**

This project examined whether commercial, off-the-shelf mobile telecommunication technology was usable to assist foresters in their data collection and data handling efforts for sustainable silvicultural management in Eastern Ontario. The goal of this work was to develop an electronic data acquisition system based on smartphone and GIS technologies to facilitate the collection and processing of forestry related field data comparable to or better than conventional paper-based methods. Given that forest managers require accurate and timely data with which to make decisions, it is important to examine the potential of new tools and methodologies that support this. Much of the previous research on mobile GIS has tended to focus on the capabilities of the technologies themselves and less on performance measurements that provide a better indication of how well a system successfully meets its intended objective. Therefore in this study a series of real-world and replicated tests were designed, using participant volunteers and expert opinion, to evaluate the efficiency, learnability and effectiveness of using a smartphone GIS to record and process geospatial data compared to paper-based methods. By doing so, new insights were gained into the benefits and challenges of building a new electronic data collection architecture and of integrating it into an established data management system. Results from this research provide new information about the benefits and limitations of mobile technologies as a tool for forestry fieldwork. Following is a summary of key findings:

Collecting data with the smartphone GIS takes longer on average than with paper-based methods. GIS data collection times, per participant averaged 0:22:43 (h:mm:ss) using the smartphone while participants using the GPS, camera, and paper forms took an average time of

0:18:26. Average data collection time for participants using the paper methods to record forest stand information was slightly less than those using the smartphone (0:01:50 vs. 0:02:04).

Processing and transfer times from data collected in the field to the desktop PC were significantly less using smartphone collected datasets than paper-based datasets. The average transfer and processing time, for a participant GIS dataset, was 0:31:32 for paper collected data, and 0:00:35 for smartphone collected field data. Likewise, the average time required to transfer and process forest stand data with the smartphone was less at 0:02:04, compared to paper forms that took an average time of 0:01:50 to complete.

Overall the total time needed for each participant to record both GIS and forest stand field data and then transfer and process those datasets in the office to the desktop PC was significantly less using the electronic method compared to traditional paper and pen. On average, the time needed to complete a project (i.e. collect and process one GIS and forest stand dataset), using the smartphone GIS was 0:25:26 (data collection + data transfer and processing) whereas, with the paper system an average time of 0:53:58 was needed to complete all tasks.

Smartphone GIS users experienced more difficulties with hardware or software functioning, committed more entry data errors, and required more help during data collection than participants using paper forms, GPS, and a digital camera. The main difficulties users experienced related to keying in data onto the smartphone touchscreen, and/or slow or unresponsive toolbuttons. The majority of the data errors committed in this study occurred because participants either omitted or did not enter GIS attribute data exactly as they were instructed to on the information cards they were provided. Participants using the smartphone GIS required three times (3x) the number of helps than participants using paper methods.

Overall, participants were satisfied with the smartphone GIS system capabilities. The smartphone GIS was rated easy to use and learn. Screen display was rated easy to view but difficult or hard for interacting, particularly with respect to keying in text. Most of the participants found the electronic system very capable in terms of system speed, reliability, and screen navigation. System feedback relating to error messaging and system functioning were rated as helpful and confident respectively.

The smartphone GIS was, by expert opinion, thought to be too complex to implement into the existing MLFI data management system. Given the extra resources needed to develop, test, and ensure that the smartphone GIS system functions properly, it was determined that it would be too burdensome for forestry personnel to learn and implement a new data acquisition system within existing work-related demands.

The smartphone GIS was well-suited for ad-hoc field data collection. The smartphone GIS captured point and line features and facilitated editing feature attribute information in operation environments. The integrated GPS, camera, and mapping software technology of the smartphone were found to be advantageous to traditional methods for its lightweight, all-in-one design. The ability to capture geotagged photographic images with the smartphone and automatically associate photos with feature class data was found to be extremely useful for analyzing spatial data later during processing. The ability to create custom applications (i.e. applets) in ArcPad, like the Proximity Alert applet created for this study, was thought to be a very attractive feature and could be of immediate use in the field.

Expert assessment felt that the smartphone GIS was more reliable for mapping purposes than for collecting forest stand data. During field trials some GIS data was lost; however, this was mainly due to operator error and not the malfunctioning of the hardware or software. Conversely, the loss of field data due to the failure of the forest stand app software during field testing negatively impacted confidence in the device and subsequently it was determined that the forest stand application, in its current form, was less reliable than current paper and pen practices.

Spatial data recorded with the handheld GPS were more accurate than those collected with the smartphone. The mean distance from the estimated center was 6.1 meters (m) for GPS points compared to a distance of 9.4m for the smartphone GIS. A visual comparison showed that the GPS polyline data had greater positional accuracy than the smartphone collected data. Even so, it was found that smartphone GPS accuracy was acceptable for the testing in which it was used and was not a limiting factor when considering whether to adopt the smartphone system.

The ability of the forest stand app ability to maintain plot specific data and automatically record the user's geographic location for each plot was cited as a key advantage over paper tally forms where all forest data were summed together. The electronic system allowed for plot data to be disaggregated during processing, thus allowing for a more refined spatial analysis of plot dynamics.

### **3.2 Contributions of the research**

This study contributes to the body of knowledge on the application of mobile technologies for field data collection in forestry silvicultural data management. Work in other fields has shown that the use of mobile technologies can improve work efficiency, reduce data errors, and

facilitate capturing spatial information (van Tamelen, 2004). While new mobile computing technologies are increasingly becoming embraced by a wider community of professional users, no research as of yet has examined the role of conventional mobile telecommunication technology for forestry silvicultural data collection and management purposes (Green and King, 2004). This study is unique in that it developed and tested a novel electronic data acquisition system by integrating smartphone, GIS, and custom software technologies capable of collecting forest stand information of the type required under Ontario's Sustainable Forest Licence agreement. This study is also unique for its evaluation of user performance comparing work and data flow processes using a smartphone GIS and standard paper methods, and for quantifying exactly where within the workflow time savings occur.

### **3.3 Suggestions for further research**

Future research should examine expanding the one-to-one architecture presented in this study to a distributed system utilizing multiple smartphone devices communicating wirelessly in real-time to a remote server. A more sophisticated system could overcome network wireless connectivity gaps with the help of mobile relay nodes that transmit data to a central geodatabase or server (Goodchild et al. 2004). The benefit of a distributed system, it is envisioned, would be further increases in workflow efficiencies by extending the possible number of mobile users, thus achieving greater work savings during the processing and transferring of multiple datasets. Such a system would also eliminate travel time and costs for workers between the field and office to synchronize data. Future research in this vein should continue to incorporate usability testing within real world and scenarios *and* lab-controlled experiments as part of a user-centered design and development framework, to improve system performance and user acceptability of mobile geo-technology (Kjeldskov et al. 2004).

In addition, future work should investigate integrating peripheral sensors (e.g. weather/temperature/wind meters, spectroradiometer, air quality monitor) with mobile devices to capture in situ environmental spatial data. For example, future mobile GIS designs could wirelessly connect a monitoring device to a GPS-enabled smartphone, using short-wavelength radio transmissions (e.g. Bluetooth), to record physical, chemical, and biological properties related to understory light, reflectance, wind, temperature, humidity, acoustics, carbon dioxide and other site specific forest stand variables (Liang et al. 2005). Such an agenda would incorporate well with research suggested by Goodchild et al (2004) who proposed studying the role of contextual information gathered in the field by new mobile computing technologies to inform subsequent analysis. Bridging the two research fronts suggested here would fulfill the original hope for this research - to design an integrated data collection and management system capable of incorporating mixed datasets to detect forest regeneration trends and to predict future states of forest stand succession.

Lastly, the methodology used in this study could easily be applied to research in other related fields and serve as a starting point for other workers seeking low cost alternatives to support their data collection requirements.

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# APPENDIX A: MLFI Forest Stand Analysis Dot Tally Paper Form.

STAND ANALYSIS FORM				OPC for Prescription					
Mazinaw-Lanark Forest									
Date: /201_		Stand No.		Block No.		Twp.			
Species	Sapling	Polewood 10-24 cm		Small 26-36 cm		Medium 38-48 cm		Large 50 cm +	
		AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS
Pw									
Pr									
Sw									
He									
Ce									
Bf									
Lt									
Mh									
Ms									
Or /w									
Be									
Bd									
Aw /b									
By									
Iw									
Po									
Bw									

Plot	Stn. #	COMMENTS		Regeneration	COMMENTS / DIRECTION
1				E ..... A .....	
2				E ..... A .....	
3				E ..... A .....	
4				E ..... A .....	
5				E ..... A .....	
6				E ..... A .....	
7				E ..... A .....	

HISTORY: \_\_\_\_\_ Ecosite \_\_\_\_\_  
 SOIL: \_\_\_\_\_ Plants observed: \_\_\_\_\_

Source: Mazinaw-Lanark Forest Industries, March, 2011.

## **APPENDIX B: List of Project Hardware and Software**

### **Client-Side Components Mobile Device**

- Hardware : HTC HD-2 Windows Smartphone
- Operating System: Microsoft Windows Mobile 6.5
- Flash Drive: eXpansys Memory 32GB High Capacity microSD card
- HTC HD 2 Battery BAS400
- Protective Case: OtterBox HTC HD2 Defender Case
- eXpansys microUSB Car Charger
- Software: Microsoft Excel Mobile 2010, Adobe Reader
- Mobile GIS Software: ESRI ArcPad 10.2
- Software: Custom Forest Stand Application

### **Server-Side Components Desktop PC**

- Hardware: Dell Workstation PWS650; Xeon CPU 3/20GHz; 3.19GHz, 3.25 GB RAM
- Operating System Windows XP V.2002
- Mobile GIS Software: ESRI ArcPad 10.2
- Software Development: ESRI ArcPad Studio; Windows Mobile 6.5 Professional Developer Tool Kit
- Software Development: Visual Studio 2005 IDE
- Software: Microsoft Excel 2003
- Desktop GIS Software: ESRI ArcGIS Desktop 9.3.1
- Synchronization Software: Microsoft ActiveSync Version 4.5; Windows Mobile Device Manager
- Microsoft Excel Macro: Microsoft Excel VBA editor

## **APPENDIX C: HTC HD-2 Windows 6.5 OS Smartphone Technical Details**

Operating System Windows Mobile 6.5

Processor Qualcomm 1GHz Snapdragon

Internal Memory ROM 1GB; RAM 576MB

Compatibility WiFi: 802.11 b/g; GPS/AGPS

Email One Exchange, up to 6 POP/IMAP

Dimensions Size: 122x67x11mm

Weight 157g (with battery)

Display 4.3-inch HD touch-sensitive screen with 480 x 800 WVGA resolution

Technology GSM: 850/900/1800/1900 MHz; WCDMA/HSPA: 1700 MHz (AWS) / 2100 MHz

(For T-mobile North America, and Europe where 2100MHz networks are used)

Battery 1230 mAh Lithium Ion

-Talk Time: 380 min (GSM)

-Standby Time: 490 hours (GSM) (The above are subject to network and phone usage)

Speakerphone Built-in microphone, speaker

Built in Camera 5MP, including widescreen capture, digital zoom and 2x LED Flash

Audio/Video- Windows Media® Player; Albums; Pictures & Videos; FM Radio

Audio supported formats: .aac, .amr, .m4a, .mid, .mp3, .mp4, .qcp, .wav, .wma

Video supported formats: .wmv, .asf, .mp4, .3gp, .3g2, .m4v, .avi

I/O Interface Bluetooth® 2.1 with Enhanced Data Rate, WiFi: 802.11 b/g

Expansion microSD™ memory card (SD 2.0 compatible) (up to 32GB)

Internal Antenna

HTC Sense user experience-Capacitive touchscreen with pinch-to-zoom and haptic capability;

G-Sensor; Proximity sensor; 3.5 mm headset jack

Source information: Expansys, Canada. <http://www.expansys.ca/htc-t-mobile-hd2-windowssmartphone-unlocked-17002100mhz-3g-197241/>

## APPENDIX D: Forest Stand Application MS Excel Macro Source Code

```
Sub ImportPlot()

Dim stand As String
Dim info As String
Dim i As Integer

Dim buffer As String
mypath = ActiveWorkbook.Path & "\"
MsgBox mypath
standFile = FreeFile
Open mypath & "Stands.csv" For Input As #standFile
smallFile = FreeFile
Open mypath & "Small.csv" For Input As #smallFile
polewoodFile = FreeFile
Open mypath & "Polewood.csv" For Input As #polewoodFile
mediumFile = FreeFile
Open mypath & "Medium.csv" For Input As #mediumFile
largeFile = FreeFile
Open mypath & "Large.csv" For Input As #largeFile
extraFile = FreeFile
Open mypath & "Extra.csv" For Input As #extraFile

stand = InputBox("Enter a stand number")
plot = InputBox("Enter a plot number. Enter 'X' to tally the whole plot.")

standAndPlot = stand & "," & plot
stringMatchLength = 3
numberOfPlots = 0
standOnly = False

If (plot = "X" Or plot = "x") Then
    standAndPlot = stand
    stringMatchLength = 1
    standOnly = True
End If

Dim extra(8 To 24)
Dim polewood(0 To 35)
Dim small(0 To 35)
Dim medium(0 To 35)
Dim large(0 To 35)

For i = 8 To 24
```

```
    extra(i) = 0
Next i
```

```
For i = 0 To 33
    polewood(i) = 0
    small(i) = 0
    medium(i) = 0
    large(i) = 0
Next i
```

```
Do While Not EOF(smallFile)
    Line Input #smallFile, buffer
```

```
    If (Left(buffer, stringMatchLength) = standAndPlot) Then
        smallBuffer = Split(buffer, ",")
```

```
        numberOfPlots = numberOfPlots + 1
        For i = 0 To 35
            small(i) = small(i) + smallBuffer(i)
        Next i
```

```
        If (Not standOnly) Then
            Exit Do
        End If
```

```
    End If
Loop
```

```
Do While Not EOF(polewoodFile)
    Line Input #polewoodFile, buffer
```

```
    If (Left(buffer, stringMatchLength) = standAndPlot) Then
        polewoodBuffer = Split(buffer, ",")
```

```
        For i = 0 To 35
            polewood(i) = polewood(i) + polewoodBuffer(i)
        Next i
```

```
        If (Not standOnly) Then
            Exit Do
        End If
```

```
    End If
Loop
```

```
Do While Not EOF(mediumFile)
    Line Input #mediumFile, buffer
```

```

If (Left(buffer, stringMatchLength) = standAndPlot) Then
    mediumBuffer = Split(buffer, ",")

    For i = 0 To 35
        medium(i) = medium(i) + mediumBuffer(i)
    Next i

    If (Not standOnly) Then
        Exit Do
    End If
End If
Loop

Do While Not EOF(largeFile)
    Line Input #largeFile, buffer

    If (Left(buffer, stringMatchLength) = standAndPlot) Then
        largeBuffer = Split(buffer, ",")

        For i = 0 To 35
            large(i) = large(i) + largeBuffer(i)
        Next i
        If (Not standOnly) Then
            Exit Do
        End If
    End If
Loop

Do While Not EOF(extraFile)
    Line Input #extraFile, buffer

    If (Left(buffer, stringMatchLength) = standAndPlot) Then
        extraBuffer = Split(buffer, ",")

        For i = 8 To 24
            extra(i) = extra(i) + extraBuffer(i)
        Next i
        If (Not standOnly) Then
            Exit Do
        End If
    End If
Loop

Do While Not EOF(standFile)
    Line Input #standFile, buffer

```

```
If (Left(buffer, 1) = stand) Then
    standInfo = Split(buffer, ",")
    Exit Do
End If
Loop
```

```
i = 2
Iteration = 1
For Each c In Range("C10:D26")
    If (Iteration Mod 2) = 0 Then
        Index = i + 17
        i = i + 1
    Else
        Index = i
    End If

    c.Value = polewood(Index)
    Iteration = Iteration + 1
Next
```

```
i = 2
Iteration = 1
For Each c In Range("F10:G26")
    If (Iteration Mod 2) = 0 Then
        Index = i + 17
        i = i + 1
    Else
        Index = i
    End If

    c.Value = small(Index)
    Iteration = Iteration + 1
Next
```

```
i = 2
Iteration = 1
For Each c In Range("I10:J26")
    If (Iteration Mod 2) = 0 Then
        Index = i + 17
        i = i + 1
    Else
        Index = i
    End If
```

```

    c.Value = medium(Index)
    Iteration = Iteration + 1
Next

i = 2
Iteration = 1
For Each c In Range("L10:M26")
    If (Iteration Mod 2) = 0 Then
        Index = i + 17
        i = i + 1
    Else
        Index = i
    End If

    c.Value = large(Index)
    Iteration = Iteration + 1
Next

i = 8
For Each c In Range("B10:B26")
    c.Value = extra(i)
    i = i + 1
Next

Range("B3").Value = stand
Range("F3").Value = standInfo(4)
Range("J3").Value = standInfo(3)
Range("P3").Value = numberOfPlots

Close standFile
Close smallFile
Close polewoodFile
Close mediumFile
Close largeFile
Close extraFile

End Sub

```

## APPENDIX E: Examples of Participant Attribute Information Cards

### GIS Data

Built Structures: Information		
<b>Task # 8</b>	<b>Fields</b>	Attribute Information
<b>Record Feature Location</b>	<b>UserName</b>	<b>Assigned UserName/ Id</b>
<b>Enter Attribute Information</b>	<b>Date</b>	<b>Today's Date: dd/mm/yyyy</b>
<b>Take a photo of feature</b>	<b>Time</b>	<b>Current time: hh:mm:ss</b>
<b>Associate photo with feature</b>	<b>FeatureID</b>	<b>1</b>
<b>Save data</b>	<b>Feature Type</b>	Cigarette Bin
	<b>Image</b>	<b>Yes</b>
<b>Move to next feature</b>	Note	<b>Empty bin, clean area, consider replacing with new</b>

### Forest Stand Data

Task # 17	Stand No. 2	Block No. 1	TWP. TBT
<b>Plot: 2</b>	<b>Stn. # 2</b>	(Tree) # 40	
<b>Species: Be</b>	<b>Size: Large, UGS</b>	Name: Bur Oak	
<b>Regeneration:</b>	Age/Ht: -----	History	
Soil	Plants ob: -----	Ecosite	

# APPENDIX F: Tabaret Hall Lawn Feature Map





## APPENDIX H: Participant Survey Questionnaire

Question	Value	Mean	Variance
<b>Overall Reactions to the system</b>			
The system is (0 = Difficult, 5 =Easy)			
The system is (0 = Frustrating, 5 =Satisfying)			
<b>Screen</b>			
Reading characters on the screen is (0= hard, 5=easy)			
Keying in information on the touch screen is (0= Difficult, 5 =Easy)			
<b>Learning</b>			
Learning to operate the system is (0= Difficult, 5=Easy)			
Remembering the commands and features is (0=Difficult, 5= Easy)			
Order of operations is (0=Confusing, 5= Clear)			
<b>System Information</b>			
Error Messages are ( 0=Unhelpful, 5= Helpful)			
You felt system was working correctly (0=Not Confident, 5=Very Confident)			
<b>System Capabilities</b>			
System Speed is (0=Too slow, 5=Fast Enough)			
System reliability is (0=Low, 5= High)			
Entering text is (0=Hard, 5=Easy)			
Correcting mistakes is (0=Difficult, 5=Easy)			
Navigating between applications is (0=Difficult, 5=Easy)			

# APPENDIX I: Participant usability test performance data

## Participant GIS Data Collection Times (h:mm:ss)

### Smartphone Dataset

Task	Time (HTC) P1	Time (HTC) P2	Time (HTC) P3	Time (HTC) P4	Time (HTC) P5	Time (HTC) P6
1	0:02:20	0:03:28	0:01:31	0:02:36	0:03:09	0:01:52
2	0:01:26	0:02:30	0:01:32	0:03:09	0:01:06	0:01:48
3	0:00:52	0:00:46	0:01:08	0:01:40	0:00:19	0:01:43
4	0:02:00	0:02:24	0:01:35	0:02:03	0:01:49	0:03:18
5	0:05:49	0:05:54	0:04:37	0:07:04	0:04:41	0:05:14
6	0:01:17	0:01:45	0:01:33	0:02:11	0:00:44	0:01:30
7	0:01:40	0:03:45	0:01:41	0:04:08	0:03:52	0:02:24
8	0:01:18	0:02:30	0:01:07	0:02:52	0:01:25	0:01:27
9	0:01:00	0:03:29	0:00:59	0:02:47	0:01:08	0:00:54
10	0:06:03	0:01:33	0:03:52	0:04:34	0:02:47	0:03:24

Task	Time (HTC) P7	Time (HTC) P8	Time (HTC) P9	Time (HTC) P10	Time (HTC) P11	Time (HTC) P12
1	0:02:22	0:01:18	0:02:02	0:01:16	0:02:18	0:01:20
2	0:02:23	0:01:04	0:01:14	0:01:01	0:01:57	0:01:00
3	0:01:45	0:00:46	0:02:02	0:01:43	0:01:35	0:00:18
4	0:02:38	0:01:17	0:01:10	0:01:17	0:01:57	0:01:10
5	0:05:23	0:04:41	0:05:36	0:03:50	0:06:49	0:05:34
6	0:01:33	0:00:56	0:01:03	0:01:13	0:02:20	0:00:37
7	0:01:05	0:01:33	0:04:17	0:01:20	0:02:54	0:02:51
8	0:01:58	0:01:20	0:01:28	0:00:58	0:01:43	0:01:02
9	0:01:07	0:00:55	0:01:19	0:00:52	0:01:15	0:00:55
10	0:03:24	0:03:17	0:03:08	0:02:43	0:03:10	0:02:31

### Paper Dataset

Task	Time (Paper) P1	Time (Paper) P2	Time (Paper) P3	Time (Paper) P4	Time (Paper) P5	Time (Paper) P6
1	0:01:55	0:01:59	0:01:17	0:02:24	0:02:01	0:01:59
2	0:01:34	0:01:50	0:01:25	0:01:43	0:01:24	0:01:20
3	0:01:09	0:02:25	0:01:32	0:01:29	0:01:19	0:01:26
4	0:01:34	0:01:50	0:01:21	0:01:56	0:01:31	0:01:28
5	0:03:44	0:03:48	0:04:08	0:03:03	0:03:41	0:03:42
6	0:01:44	0:02:08	0:01:07	0:01:36	0:01:17	0:01:36
7	0:02:07	0:02:02	0:00:58	0:01:24	0:01:21	0:01:13
8	0:01:39	0:01:54	0:01:20	0:01:42	0:01:40	0:01:19
9	0:01:34	0:03:55	0:01:07	0:01:34	0:01:32	0:01:36
10	0:02:57	0:01:38	0:01:45	0:03:17	0:03:25	0:02:42

Task	Time (Paper) P7	Time (Paper) P8	Time (Paper) P9	Time (Paper) P10	Time (Paper) P11	Time (Paper) P12
1	0:01:50	0:01:41	0:02:13	0:01:28	0:01:21	0:01:42
2	0:01:26	0:01:17	0:01:25	0:01:12	0:01:07	0:01:18
3	0:01:17	0:01:11	0:01:22	0:00:53	0:00:54	0:01:14
4	0:01:34	0:01:17	0:01:46	0:01:09	0:01:08	0:01:23
5	0:04:20	0:04:02	0:04:48	0:03:35	0:04:03	0:03:29
6	0:01:10	0:01:14	0:01:40	0:01:00	0:01:14	0:01:05
7	0:01:21	0:01:08	0:01:39	0:01:17	0:01:09	0:01:13
8	0:01:31	0:01:22	0:01:40	0:01:09	0:01:13	0:01:18
9	0:01:10	0:01:27	0:01:21	0:01:05	0:01:06	0:01:13
10	0:02:15	0:02:20	0:03:15	0:02:29	0:02:59	0:02:44

## **Participant Forest Stand Tally Data Collection Times (h:mm:ss)**

### **Forest Tally Data Collection**

<b>Participants</b>	<b>Paper</b>	<b>Electronic</b>
1	0:02:13	0:02:00
2	0:01:58	0:01:48
3	0:01:28	0:01:27
4	0:02:44	0:02:20
5	0:02:02	0:01:10
6	0:03:06	0:03:52
7	0:02:28	0:02:30
8	0:01:54	0:01:28
9	0:02:18	0:01:55
10	0:01:51	0:01:34
11	0:01:19	0:01:00
12	0:01:30	0:01:01

## **Participant Forest Stand Tally Dataset Transfer and Processing Times**

### **Tabaret Hall GIS Data**

<b>Participant</b>	<b>Paper</b>	<b>Electronic</b>
1	0:42:00	0:01:00
2	0:33:39	0:00:20
3	0:24:56	0:00:15
4	0:24:56	0:00:10
5	0:32:38	0:00:30
6	0:32:37	0:00:31
7	0:33:50	0:01:00
8	0:30:01	0:00:32
9	0:35:35	0:00:38
10	0:30:49	0:00:54
11	0:27:30	0:00:27
12	0:28:09	0:00:37

### **Forest Stand Tally Data**

<b>Participant</b>	<b>Paper</b>	<b>Electronic</b>
1	0:02:13	0:00:20
2	0:01:37	0:00:19
3	0:01:30	0:00:21
4	0:01:19	0:00:18
5	0:01:11	0:00:15
6	0:00:53	0:00:16
7	0:01:06	0:00:19
8	0:01:22	0:00:16
9	0:01:02	0:00:17
10	0:01:50	0:00:17
11	0:01:05	0:00:16
12	0:01:06	0:00:22

## Participant Errors, Malfunctions Counts

<b>Errors and Malfunctions Key</b>	<b>Code</b>
Attribute Fields: Data missing or entered incorrectly	A
Difficulty with GUI	B
Non Critical Error: ArcPad/ GPS/Camera not function properly	C
Critical Error: ArcPad/GPS/Camera does not function properly = redo /restart application	D

### **Paper, GPS, Camera**

Participant		1	2	3	4	5	6	7	8	9	10	11	12
Task #	Task												
1	uOttawa Plaque - Collect Point	A	A				A	A	A				
2	Waste Bin - Collect Point	A											
3	Park Bench - Delete Feature	A						A					
4	Parking Meter - Collect Point	A					A						
5	Parking Lot - Collect Polyline	A											
6	Campus Map - Collect Point	A											
7	Lamp Post - Edit Feature	A											
8	Cigarette Bin - Collect Point	A											
9	Tabaret Hall Sign - Collect Point	A					A						
10	Sidewalk- Collect Polyline	A					A					A	

### **Smartphone GIS**

Participant		1	2	3	4	5	6	7	8	9	10	11	12
Task #	Task												
1	uOttawa Plaque - Collect Point	A	A	A	A	A,B		A		A	A		A
2	Waste Bin - Collect Point	A	A	A	A,B	A				A			
3	Park Bench - Delete Feature	A	A	A	A			A,C	A				
4	Parking Meter - Collect Point	A	A	D	A				A				A
5	Parking Lot - Collect Polyline	A	A	A	A		A		A		A	A	
6	Campus Map - Collect Point	A	A	B,A	A				A,D	A		B	
7	Lamp Post - Edit Feature	A	A	B,A	A			C			A,B		
8	Cigarette Bin - Collect Point	A	A	A	A			A		A	A	A	A
9	Tabaret Hall Sign - Collect Point	A	A	A	A			A	C	A	A		A
10	Sidewalk- Collect Polyline	A	A	A	A		A	A	D	A			

## Participant Help Rates for GIS Data Collection

### Smartphone GIS

Participant		1	2	3	4	5	6	7	8	9	10	11	12
Task #	Task												
1	uOttawa Plaque - Collect Point												
2	Waste Bin - Collect Point												
3	Park Bench - Delete Feature												
4	Parking Meter - Collect Point												
5	Parking Lot - Collect Polyline												
6	Campus Map - Collect Point												
7	Lamp Post - Edit Feature												
8	Cigarette Bin - Collect Point												
9	Tabaret Hall Sign - Collect Point												
10	Sidewalk- Collect Polyline												

### Paper, GPS, Digital Camera

Participant		1	2	3	4	5	6	7	8	9	10	11	12
Task #	Task												
1	uOttawa Plaque - Collect Point												
2	Waste Bin - Collect Point												
3	Park Bench - Delete Feature												
4	Parking Meter - Collect Point												
5	Parking Lot - Collect Polyline												
6	Campus Map - Collect Point												
7	Lamp Post - Edit Feature												
8	Cigarette Bin - Collect Point												
9	Tabaret Hall Sign - Collect Point												
10	Sidewalk- Collect Polyline												

## Participant Satisfaction Survey Scores

Participant						1	2	3	4	5	6	7	8	9	10	11	12
Question						Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score	Score
The system is (0 = Difficult, 5 =Easy)						5	5	5	4	5	5	5	4	3	4	5	4
The system is (0 = Frustrating, 5 =Satisfying)						3	2	4	3	4	5	4	4	3	4	3	4
<b>Screen</b>																	
Reading characters on the screen is (0= hard, 5=easy)						5	3	5	4	5	5	5	5	4	5	3	5
Keying in information on the touch screen is (0= Difficult, 5 =Easy)						3	5	5	2	3	5	3	4	4	4	1	4
<b>Learning</b>																	
Learning to operate the system is (0= Difficult, 5=Easy)						5	4	4	4	5	5	5	5	4	5	5	4
Remembering the commands and features is (0=Difficult, 5= Easy)						4	5	4	4	5	5	5	5	3	5	4	4
Order of operations is (0=Confusing, 5= Clear)						5	5	5	4	5	4	5	5	4	5	5	3
<b>System Information</b>																	
Error Messages are ( 0=Unhelpful, 5= Helpful)						3	4	1	4	4	4	5	4	2	4	3	4
You felt system was working correctly (0=Not Confident, 5=Very Confident)						4	2	4	4	5	5	4	3	4	5	4	5
<b>System Capabilities</b>																	
System Speed is (0=Too slow, 5=Fast Enough)						5	5	5	5	5	3	5	5	4	5	4	5
System reliability is (0=Low, 5= High)						4	3	4	4	5	5	4	4	4	5	5	4
Entering text is (0=Hard, 5=Easy)						3	5	4	3	3	5	4	3	4	4	1	4
Correcting mistakes is (0=Difficult, 5=Easy)						4	5	5	3	4	5	5	4	3	4	0	4
Navigating between applications is (0=Difficult, 5=Easy)						5	4	5	3	5	5	5	4	2	4	3	4