REPORT OVERVIEW

In the Fall of 2010, the Bureau of the Census, Geography Division contracted with independent subject matter experts David Cowen, Ph.D., Michael Dobson, Ph.D., and Stephen Guptill, Ph.D. to research five topics relevant to planning for its proposed Geographic Support System (GSS) Initiative; an integrated program of improved address coverage, continual spatial feature updates, and enhanced quality assessment and measurement. One report frequently references others in an effort to avoid duplication. Taken together, the reports provide a more complete body of knowledge. The five reports are:

1. Reporting on the Use of Handheld Computers and the Display/Capture of Geospatial Data
2. Measuring Data Quality
3. Reporting the State and Anticipated Future Directions of Addresses and Addressing
4. Identifying the Current State and Anticipated Future Direction of Potentially Useful Developing Technologies
5. Researching Address and Spatial Data Digital Exchange and Data Integration

The reports cite information provided by Geography Division staff at "The GSS Initiative Offsite, January 19-21, 2010." The GSS Initiative Offsite was attended by senior Geography Division staff (Division Chief, Assistant Division Chiefs, & Branch Chiefs) to prepare for the GSS Initiative through sharing information on current procedures, discussing Initiative goals, and identifying Initiative priority areas. Materials from the Offsite remain unpublished and are not available for dissemination.

The views expressed in these reports are the personal views of the authors and do not reflect the views of the Department of Commerce or the Bureau of the Census.

Department of Commerce
Bureau of the Census
Geography Division

Task 2: Reporting on the Use of Handheld Computers and the Display/Capture of Geospatial Data

A Report to the Geography Division, U.S. Bureau of the Census
Deliverable #4 - Syneren Technologies Contract – Task T005

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Executive Summary

This report provides an overview of the current technology that the Census Bureau's Geography Division should consider for employing in the mobile component of the GSS Initiative. The capabilities of current mobile devices hold great promise for assisting the Bureau in the update and maintenance of MTdb and supporting a targeted address canvas. Since this deployment may begin in less than three years, we have focused on solutions that are being successfully utilized in existing situations and a few emerging technologies that hold promise in the near term. We believe that the current alternatives described in this deliverable offer a more powerful and expansive set of capabilities than those utilized in the 2009 address canvass.

The most significant change influencing the use of handheld computers for future Census related activities is the almost ubiquitous access to web-based resources over wireless networks. As an example, it is now possible to design solutions that incorporate GPS and non-GPS data collection based on utilizing high resolution data and imagery while in the field. Our review of user experiences suggests that it is not only feasible but desirable to closely couple field data collection and validation with geographic applications on network servers. Such a coupling can achieve a near real-time data maintenance program thus meeting a major goal of the GSS Initiative.

A major part of the report focuses on an articulation of the specific desired requirements for a mobile strategy to support the needs of the GSS. Analysis of these requirements leads to a series of recommendations concerning the selection of software and the use of a combination of portable computers and specialized GPS field computers. While we have focused our recommendations on successful solutions that are being utilized by major companies and public agencies, we have also included a review of some evolving solutions using smartphone and tablet technologies that could, at some point in the future, challenge current practices. Based on our interpretation of the requirements for the GSS Initiative and our assessment of current technology and practices, the following recommendations are offered:

1. The Geography Division should conduct a forensic examination of the geography related procedures and operations used in the last canvassing activity in order to derive lessons learned that could be used to improve the accuracy and comprehensiveness of future address canvassing activities, regardless of their size, scope, or geographic focus.

2. The field requirements for the GSS Initiative can be best met by the ArcGIS Mobile solution which can provide a practical, robust bridge between field based and server side data maintenance. (A detailed description of the specifications and functionality of ArcGIS mobile is included in Appendix B.)

3. Mobile technology should be deployed on a variety of devices:

   (a) For operations focused on tabular data, including those relating to the Corporate Listing Device, a range of common Windows based portable computers, provisioned with a WAAS capable USB GPS chip set, could be deployed.

   (b) In some challenging physical environments, the use of ruggedized tablet PCs should be considered.

   (c) For field based creation and editing of features, we recommend deployment of specialized GPS field computers such as the Trimble Juno or Yuma. These devices typically are light weight, equipped with a 3.5 or 7 inch screen, and designed for extensive field data collection. The device should also be able to utilize a laser range finder to capture coordinates for inaccessible locations as well as have the ability to photographically record field observations.

   (d) Recent feedback suggests that the Apple iPad may become a viable field data collection device over the next few years. Significant resources are being devoted by companies interested in increasing the software capabilities of this device for GIS applications. In the near future, this class of platforms could be able to meet the requirements of the Census Bureau and we recommend that this device be on the short list for evaluation at the appropriate time.

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Introduction and Background

In order to develop scenarios for the use of handheld computing devices in the future it is important to have a clear understanding of the Geography Division's previous experience with the use of this technology. While it is not the intent to dwell on the past, our brief review of the history of the use of handheld computing devices for address listing and mapping does provide an important perspective for understanding the intent of the research and the conclusions described in this report.

A useful starting point is a report prepared by Booz Allen titled "Master Address File (MAF)/Tiger Modernization Study for the Geography Division United States Census Bureau" (July, 2000). In this document, it was suggested that GPS enabled mobile computing technology could support the following field operation functions:

- Computer-assisted navigation to lead field representatives to their assignments.
- Detailed maps for field operations could be displayed on portable devices instead of using paper maps in field operations.
- Automated detection of map and listing errors could be provided using portable computers in field.
- GPS-based positioning could be used to locate new structures, as well as to locate features and structures for follow-up operations.
- Data updates transmitted directly from the field, allowing the avoidance of costly office operations involving shipping, keying, and digitizing paper products. Use GPS for quality assurance of private sector and partner geospatial data.

The Booz Allen consultants also offered an interesting flow diagram (Figure 1) that outlines an idealized method of incorporating field based data collection into Bureau workflows.

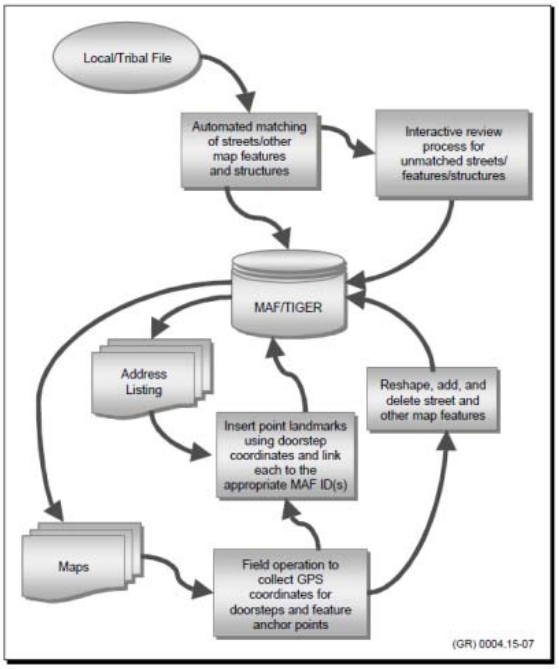


Figure 1 Information Flow to Update MAF/TIGER (Source: Booz Allen, 2000)

The overriding goals of the MAF/TIGER Accuracy Improvement Project (MTAIP) and the Address Canvassing operations were to improve the representation and positional accuracy of the TIGER features and to generate a GPS based address point that was contained within the boundaries of the correct Census Block. The end result of this process is depicted in Figure 2. The map on the left displays GPS captured address points that would fall in the wrong block unless the positional accuracy of TIGER roads is adjusted. The map on the right depicts the correct location of roads and address points.

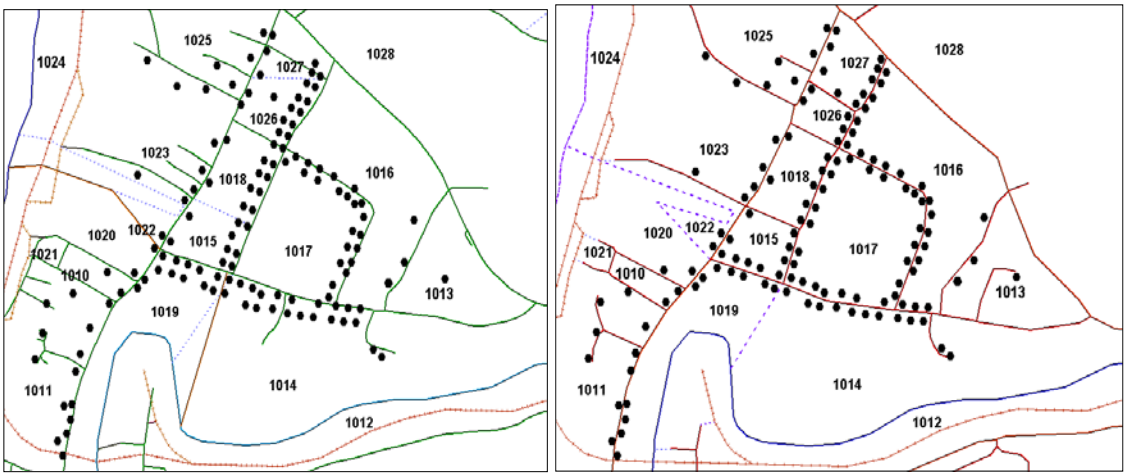


Figure 2 Alignment of MSP with Roads (Source: Census documents)

Many experts in the geospatial field regard the Bureau's 2009 use of handheld GPS devices to collect 145 million point level address features as a major achievement.

The Census Bureau's experiences with using handheld devices for address and map feature data capture make it an opportune time for the Geography Division to incorporate this technology into the GSS Initiative. We believe that the field operations to support the programs of the GSS Initiative will benefit from a more mature technology base and data gathering procedures advantaged by findings extracted from user experiences of others who are employing similar technologies and methods to collect address and geospatial data.

The plans for the GSS Initiative indicate that targeted field data collection and associated validation processes will be major components of the effort. An analysis of a variety of user experiences from relevant field capture of address and spatial data indicates that mobile devices are being incorporated directly into the overall data development and maintenance program throughout many programs in both the public and private sectors.

The remainder of this report reviews the current status of mobile computing and user experiences. It analyses the requirements for a new field based data validation and capture capability and assesses current and evolving technology to meet these requirements. Important objectives are to: precisely define handheld computing devices; provide a comprehensive analysis of the issues and the state of the technology; report the experiences of a variety of users of handheld computing devices; and offer specific recommendations concerning the utilization of field based mobile computing applicable to the GSS Initiative. Our research is intended to complement the work of the Census Bureau's 2020 planning, research, and testing of various

corporate listing devices. It should be noted that the report does not consider the limitations imposed on using a mobile technology by Census Bureau policies, security issues, and Title 13 data restrictions.

How things have changed

The options available for designing a mobile device and its functionality are now markedly different from those available when Harris Corporation designed the HTC devices for the address canvass. The fundamental difference is today's almost universal access to Internet based resources from mobile devices. The consequences of mobile internet access are noted in a recent *Newsweek* article entitled "Android Invasion":

> "So what happens when most of the residents of the planet Earth carry a device that gives them instant access to pretty much all of the world's information? The implications – for politics, for education, for global economics –are dizzying." (Lyons, 2010)

In fact Wi-Fi provisioned laptop computers have rapidly replaced desktop computers. The growth of wireless access is quickly outpacing access through wired LANS. As a consequence, many users participate in a totally mobile universe and are continuously connected to a wide range of web based services. With the addition of an inexpensive USB GPS receiver it is possible to convert any portable computer into a field data collection device. At the same time, some dedicated GPS devices are actually another form of Windows-based portable computers with an integrated set of communication and media options. A third level of device recently has emerged (the new breed of smartphones based on the Apple iOS and the Google Android operating systems) that blurs the distinctions between personal computers, GPS devices and web browsers.

The GSS Initiative should be able to incorporate an incredible and ever expanding set of web services that provide access to geospatial content though any browser. Simply stated, in 2003 no one could have imagined the power and capabilities of geospatial software such as that provided by the Google Earth application on an iPhone. Further, the array of robust, high resolution map reference data has exploded as a result of content wars between companies such as Google and Microsoft, traditional GIS vendors such as Esri, and map database providers such as NAVTEQ.

What once would have been expensive data purchases are now provided freely through easily configured open APIs. At the same time, the wireless service providers are waging their own competition to gain market share and compete for the largest coverage areas. This suggests that the GSS Initiative could mold its data gathering strategy based on the availability and appropriateness of resources. For example in Charlotte NC, (http://vc.charmeck.org/) where there exists a wealth of publicly available, high quality geospatial data, there might be very little need for field operations to verify addresses or other spatial data, as the operator in the field is unlikely to discover significant new information through field work. All of the Virtual Charlotte base maps can be directly accessed and reviewed on mobile devices through web services. The

ability to display these in context with a current GPS derived location could greatly enhance field activities.

In areas lacking good local content and connectivity the user will have to be able to carry the content with them. In 2005 it would have been very difficult to store large quantities of high resolution geospatial data on a small hand held device. Today, with expanded internal storage and high capacity external flash drives, that is not a limitation. For example, BLM has compressed 10.5 GB of digital maps into a seamless 2 GB mosaic of Wyoming that can be inserted to a Trimble Juno GPS device for field reference. This suggests that a variety of solutions should be deployed to meet different needs (attribute versus feature editing) and different situations (connected or disconnected to the Internet).

As the manager of GIS operations for South Carolina Electric and Gas stated in response to our research query (Meyer, 2010):

> "Only recently has it become cost effective for us to investigate taking computers into the field – when you have as many trucks and contractors as we do it gets pricey real quick. Many other companies have been doing it for years, but it has cost them a ton of money without really adding a whole lot of tangible benefit beyond the wow factor. Replicated database, more accurate maps, GPS and aerial photography are finally providing some bang for the buck to go large scale."

Functional requirements for the next generation of mobile computers

Even though the general functional requirements for the next generation of portable computing device may not vary significantly from the capabilities of the devices used last decade, there have been major advancements in the hardware and software technology found in modern handheld computers used for field operations compared to those used during the run-up to the 2010 Census. These advancements include faster and more accurate positioning, enhanced human computer interaction (through advances in screen technology and human factors design), and the ability to host and process a greater variety of geospatial information.

Our analysis is that the needs for field based data collection to support the initiatives of the GSS Initiative fall into these general categories:

1. Address Canvass: This process, which was judged to be one of the most successful of the field based experiences supporting the 2010 Census, basically requires the recording of geographic coordinates (MSP) for dwelling units and validating the corresponding address.

The use issues here are largely procedural and not technical. There are some issues regarding the preferred capture point that best represents the location a specific dwelling. There are also concerns over the availability of physical access to a property in order to locate a specific point. Other issues involve the determination of whether a dwelling is occupied currently or on a

seasonal basis, whether a dwelling with an address in the MAF has been demolished or simply misidentified, or when new construction will have an address to match with a MSP.

2. Update of street and features: Capturing these data would require the operator to record the location of street centerlines and other visible features that exist in TIGER. Although this is a relatively complex task, there are numerous examples of volunteers equipped with GPS receivers collecting such information and reporting these data to commercial companies or actually building entire maps (Open Street Map). While some organizations deploy a mixture of field based and on-screen data capture procedures, the focus here will be on the current state of the art in field data collection.

3. Validating quality: Determining the quality of geospatial data provided by commercial suppliers or partners is a complex task for field operators. It would be beneficial to validate street names and addresses as well as positional accuracy as part of a robust process. Our emphasis will focus on identifying the current state of the art, unimpeded by any particular Bureau work flow or legal constraints, such as Title 13 that might be need to be considered by the Bureau. In addition, during field operations the quality of position information often is determined by the quality of the GPS or the background reference data. While the Bureau's needs are not the same as those of a surveyor or engineer, it is important to understand the alternative levels of positional accuracy that are possible and we will describe these later in this document.

4. Collection of feature attributes: The fundamental concerns we have focus on field based creation and editing of geographic features and their attributes, addresses, and housing unit structures. The generic need is to have a computing device that can be taken into the field that is able to assign coordinate points to dwelling units. The device should allow a user to continuously track their location on a display of geographically registered maps and images. The user should be able to easily retrieve and edit information about existing addresses as well as the coordinates and attribute information about new addresses. The functions should be accessible through a simple user interface. Well-designed pull down menus and word completion functions could aid in this process.

Because of the confidential nature of some Census-based information, only Bureau employees with proper training and secure authentication should be able to collect and transmit data. Sign-in and user authorizations at the appropriate level (including fingerprint recognition) should be used to compartmentalize and secure sensitive data. All data should be transmitted to a central server using a secure, encrypted protocol that does not require any significant training for use by field operators.

Mobile requirements

Based on our understanding of the Geography Division's functional requirements for the GSS Initiative and an assessment of current user experiences outside the Bureau, the following set of desirable capabilities for the field based data review and capture activities have been compiled. It represents an expansion of the technology base deployed during the previous address canvass. Consideration of these expanded features in any future deployment should provide the Bureau with a responsive, flexible, user friendly, efficient, coordinated, and accountable environment.

Communications

- The device should be able to operate while disconnected from a wireless network and in environments where GPS signals are weak or degraded due to multipath interference.
- The availability of 3G or 4G networks is highly desirable both for the downloading of data to the handheld devices and the transmission of field data from the devices to field offices.
- Field data must be able to be stored locally, with capabilities for transmission to the database from wireless networks (both Wi-Fi and cellular) to a remote server or transferred via a local area network (LAN).
- Data should be able to be "pushed" or "pulled" to a mobile device from a remote server.
- Field units should be capable of being tracked by a central facility.
- The communications network will need to support concurrent usage by the entire field work force (whose size is at this point unknown).

Human Computer Interface (issues related to how and where the mobile device is used)

- The screen should support full color and be a minimum of 3.5" diagonally. However, a 7" screen is preferred for intense feature capture, editing and quality control.
- The screen must be adjustable for different lighting conditions and it should be possible to "dim" some layers of the display.
- It must be possible to easily pan and zoom to specific features.
- The pointing device must be able to record coordinates with the necessary accuracy to meet GSS Initiative requirements (<3 Meters for a point). This is a severe limitation for devices that do not support the use of a mouse or stylus.
- The screen must support a high resolution, color display (at least 240 x 320 for 3.5" display, 1024 x 600 for 7")
- Refresh and redraw rates should not impede data collection. Continuous visualization of the GPS position in relationship to the base map should be maintained while walking.

System functions

- Minimum storage for the small devices is 128 MB but the larger ones should have 32 GB with the ability to add several GB of USB flash storage devices.
- Normal password protection level security.
    - Fingerprint recognition
- Backup on USB devices should be available.
- Ability to record voice memos and notes.
- Ability to take photographs and record the location and bearing of the photo of the features.
- Ability to associate a photo with point, line, or polygon feature.
- Time stamping of audio recordings and photographs.

GPS specifications

- NMEA 0183, Standard Position Specification, DGPS (USCG/RTCM) and DGPS (WAAS).
- Meets <3 meter requirement for point features.
- Meets <7.6 meter requirement for street centerlines.
- Support for future expansion of all GNSS (Global Navigation Satellite Systems): NAVSTAR GPS, GLONASS and Galileo.
- Potential utilization of Assisted GNSS via Wi-Fi positioning and cell tower triangulation to combat poor signal quality, multipath propagation, local ionospheric conditions, etc.
    - [A detailed discussion of alternative positioning technology will be included in the Task 3 report - *Identifying The Current State And Anticipated Future Direction Of Potentially Useful of Developing Technologies*]

Image format display

- JPEG, GeoTIFF, GeoPDF format.
- KML (Google's Keyhole Markup Language; adopted as an implementation standard by the Open Geospatial Consortium).

Cost

Budget issues are beyond the scope of this report however for comparison, the Trimble Juno (~$800) and Yuma (~$3700) are representative of specialized Windows Mobile based GPS receivers. Our assessment is that these devices have matured and reached a stage in price, features, and performance that should provide several years of productivity. As noted elsewhere, developments based on the Apple iPad should be followed closely over the next couple of years.

GIS Functionality

- Display any base map or image services (e.g. TIGER, Bing, Google, Esri Community Base Maps, or Open Street Maps) via a Wi-Fi or cellular connection.
- Store and display cached base maps.
- Design maps and images suitable for mobile devices from desktop environment.
- Toggle and rearrange layers.
- Map navigation (pan, zoom, go to coordinate, bookmarks).
- Export and save maps and views.
- Select features through attribute or spatial queries.
- Check for duplicate entries for features and attributes (e.g. same house number).
- Find any feature by a simple one button action.
- Identify a feature by on screen interaction.
- Add and edit attributes of features.
    - Provide drop down list of domain restricted values (e.g. street type abbreviations)
    - Support for word completion and spell checking
    - Generate tables and lists

- Create features from alternative methods.
    - GPS averaging (Point level features)
    - GPS streaming (lines and polygons)
    - Sketching or "heads up" digitizing on screen
        - Required when GPS signals are of poor quality due to multi-pathing and poor Position Dilution of Precision (PDOP)
    - Off sets from existing location, distance and bearing
        - With range finder
        - Manually
        - Adjust street centerlines based on track of vehicle
    - Direct recording of X, Y coordinates
- Establish thresholds for GPS quality (Minimum PDOP)
    - Warn operator of problem with signal strength or multipathing
- Provide continuous tracking of GPS positions and quality.
    - Flag points that do not meet positional accuracy limits
- Record and store a GPS track to monitor activities.
- Edit the location of point and line features.
    - Mark existing features for deletion
    - Move a point to a new location but keep original location
    - Reshape a linear feature but keep original geometry.
- Continuous synchronization with GPS.
- Add new point, line, or polygon.
- Move points.
- Mark points for deletion.
- Reshape a line or polygon or – display vertices, enable snapping, display position before committing.

<u>Topological checks (Available but implemented only as part of approved QC procedures)</u>

- Snap (extend) new lines to existing lines – (eliminate gaps).
- Trim new lines to existing lines – (eliminate overshoots).
- Ensure lines do not self intersect.
- Split a polygon (create a new road that splits an existing block).
- Ensure polygons are closed.

<u>Logical Checks</u>

- Spelling consistency of new road/or other feature names with existing values.
- Address range checks.
- Identify and review duplicate entries.

<u>Synchronization</u>

- User controlled synchronization between mobile device and server.
- Version control on server side to accept data from several concurrent field operators.

- Staging environment to establish QA/QC before transmitting changes to the corporate database.
- Summary information to confirm successful transfer.

In short, the system should enable an operator to easily locate a study area, navigate to a street address, a coordinate point, a bookmark, or a point of interest (POI), retrieve and find MAF features (e.g. addresses and MSPs), TIGER features with appropriate attribution, delete or modify existing features, and add new features with new attributes. When developing the functional requirements, the designers should also consider the following issues:

- Who are going to be the users of the device? Non-GIS trained field workers?
- How frequently will the operators perform field mapping, addressing and GPS functions?
- What is the best way to author and publish maps that are suitable for small screen display for use in outdoor environments?
- Do the 3 meter accuracy specification for address points and related 7.6 meter accuracy requirement for linear features reflect the required accuracy requirements to support the Geography Division's goals for the GSS Initiative?
- Should GPS augmentation be required in real time or can it be a post processing operation?
- Will data collection be designed to take place inside a vehicle in addition to MSP point collection near the residential structure? If so, collection procedures will need to provide a mount and mounting instructions for the device, as in-vehicle collection exhibits differing accuracy characteristics depending on the location of the receiver. Seat mounted devices usually report less accurate positioning than dash or window mounted devices.

Issues relating to collecting geographic coordinates

Method of coordinate capture

The discussion of how geographic coordinates are collected cannot be separated from the overall work flows for data maintenance. In the future, these work flows are likely to be very different from those used in the previous address canvass. In terms of structure points, MSPs, the address canvass usually started with an empty slate. In some areas there were map spots that had been collected for the 2000 Census or the Demographic Area Address Listing (DAAL). The basic goal was to either establish or to review the coordinates for structures to ensure that the MSPs were on the correct side of the street and within the boundaries of the correct Census Block. The only reference materials were TIGER features. The next stage of field operations will start with an updated set of street features and MSPs, some of which have been positionally adjusted using an image base. In reexamining the requirements for the next generation of mobile computers, it might be useful to generically refer to "accurate geographic coordinates" rather than a GPS coordinate. This would separate the coordinate from the method used to record it. Clearly, by using a survey grade dual frequency GPS receiver and augmentation procedures, it is possible to acquire the very precise coordinates required for legal or engineering applications. At the same time, measurements recorded through photogrammetric procedures from accurately

georeferenced imagery with 6 inch or one foot pixels can obtain sub meter levels of positional accuracy. Many of these high resolution image sources can reliably meet the 7.6 and 3 meter specifications established by the Census Bureau for the MTdb. In other words, the coordinates determined from an accurately registered, high resolution image should be at least as accurate as ones collected in the field using a mapping grade GPS device.

A major difference between the previous address canvass and the activities planned for the GSS Initiative will be the potential use of commercial, public and volunteered geospatial equivalency data in form of streets, parcels, building footprints and imagery. These resources will be available either as cached "basemaps" or as web services. Therefore, either before the operator goes into the field, or while in the field, there is a high probably that there exists an accurate representation of the road and structure information overlaid on high resolution source materials. The optimal field data collection activity could consist of direct recording or sketching of positions on the screen of a desktop or mobile device. With accurately georeferenced high resolution imagery the operator should be able to quickly validate the location of existing structures and identify the location of missing ones.

As noted above, in some cases, the task of locating or validating a structure point could be accomplished by reference to the equivalency data such as a current high resolution image rather than by using the GPS device. The operator could validate the location of a residence by visual inspection and determination of the proper address and then capture the geographic coordinates with a tap of the stylus. The combination of field observation and reference to high resolution ancillary or equivalency data sources should enable an operator to accurately determine the location of a residence, its address and MSP, even in areas with poor GPS reception. Of course, the imagery and ancillary data sources must be sufficiently accurate and current that there is confidence that they represent the current conditions on the ground.

Guidelines for collecting structure points

In order to provide effective support for programs in the GSS Initiative it would be useful to review the guidelines and procedures for the selection of MSPs. According to the "Global Positioning System (GPS) Field Data Collection Guidelines" (Version 4.0) the location of a structure should be recorded by collecting a GPS point that is located within three meters of any of the following parts of a structure (Figure 3):

1. front door of structure,
2. side or back door of structure,
3. garage door, or
4. anywhere on a pathway, stairway, or private driveway leading to the structure from the nearest public street.

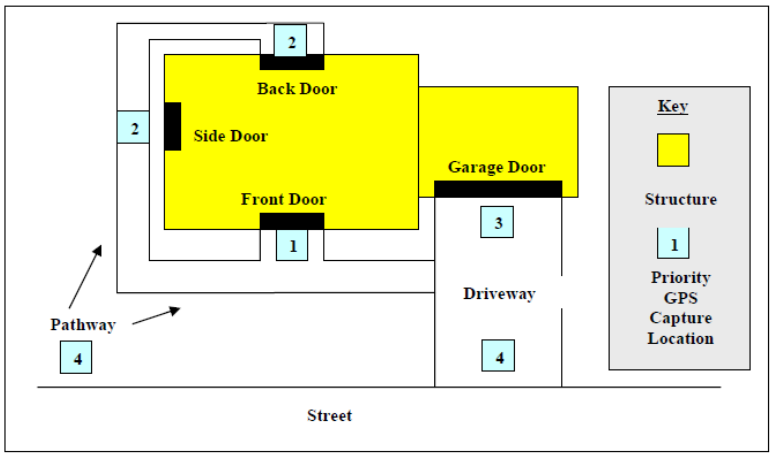


Figure 3 Options for placement of structure points "Global Positioning System (GPS) Field Data Collection Guidelines" (Version 4.0)

Given these options it is not surprising that the address canvass resulted in a range of positions relative to a structure. The variance in locational positioning may not be due to any inadequacy of the GPS device, but rather to the way in which operational procedures were applied.

It is useful to note that the current MSP guidelines differ from the common practices for locating address points in commercial and government organizations. For example, the City of Charlotte, NC has located its address points on building rooftops (Figure 4). Other organizations use geometrically determined parcel centroids. Clearly, any change in the existing guidelines for MSP collection would have enormous impact on all aspects of field data collection.

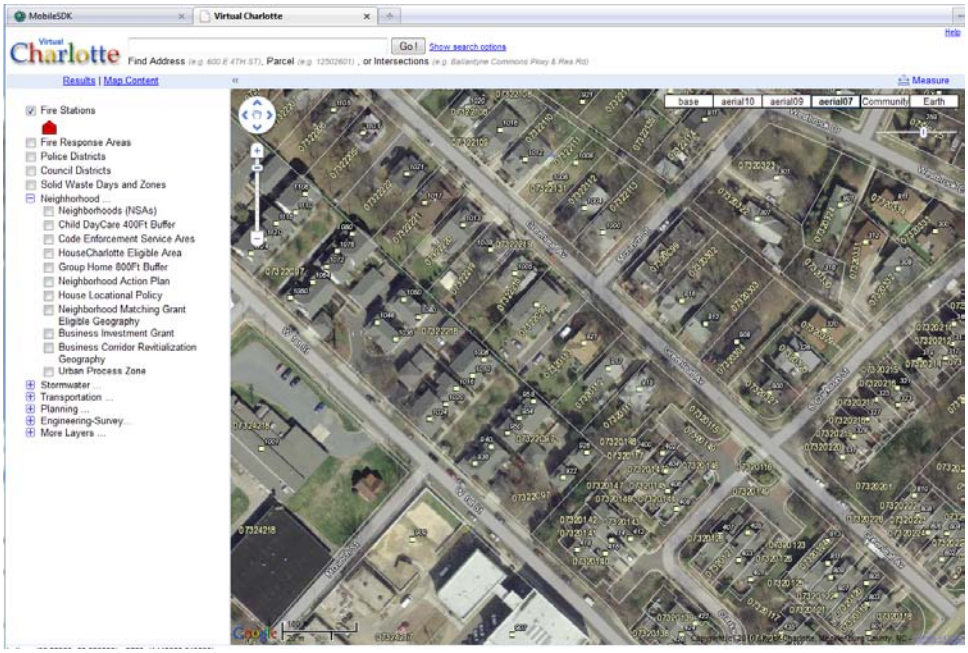


Figure 4 View of rooftop address points in Charlotte NC (http://vc.charmeck.org/)

Mobile map formats

Over the past few years a number of highly portable digital map products have emerged. One of the most popular formats, GeoPDF, could be used in a field-based data collection strategy. The GeoPDF format (Figure 5) is widely used for map distribution by the United States Geological Survey (USGS), the Army Corps of Engineers Geospatial Center, and others. As a specialized format supported by Adobe, the GeoPDF format (created by TerraGo Technologies) provides free readers that support real time GPS tracking, coordinate display, layers, pan, and zoom functionally. The USGS orthophoto topographic quad program products (over 30,000 published to date) are being produced in this format and would be adaptable for field based data collection, although possibly are not current enough to be of significant advantage in the collection of addresses and other geographic features.

Since the GeoPDF format can be specified as a map export option there are no specific technical limitations to the creation of these portable map products. They could be designed at any scale and content. For example TIGER features and existing address points could be combined with up-to-date high resolution imagery. This would provide a useful alternative to data capture in those situations where it is difficult or impossible to populate the database by standing at the location. GeoPDF, also, would work well when the field operators encounters a loss of signal or multi-pathing caused by interference from tree canopies or buildings. Some organizations such as the USDA are using TerraGo's mobile data collection software to capture information about agricultural fields.

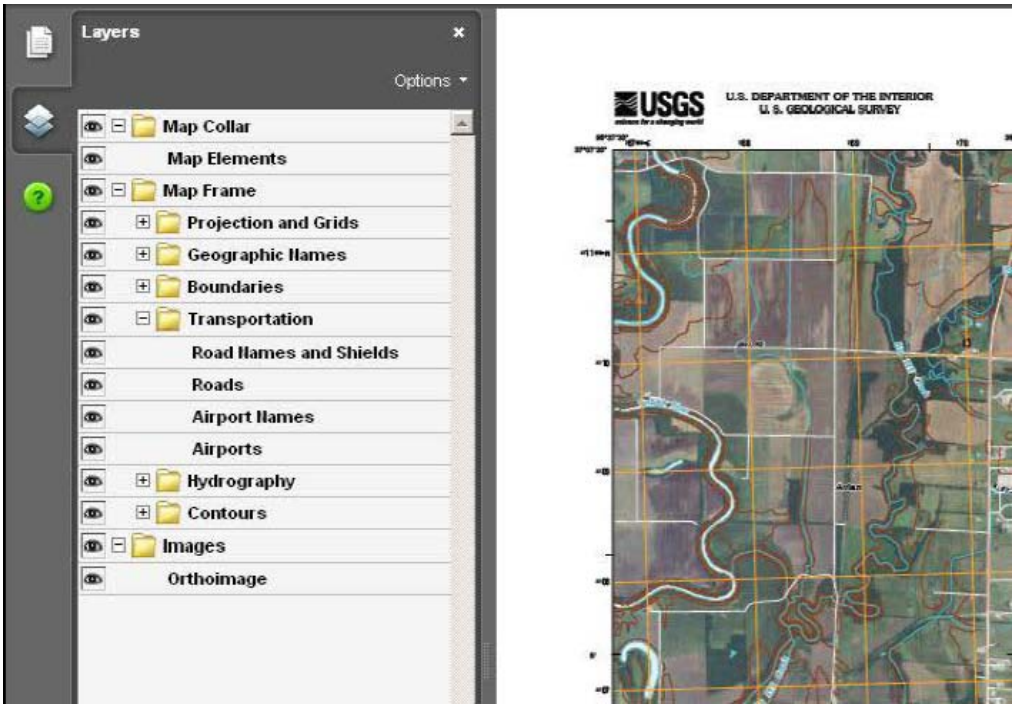


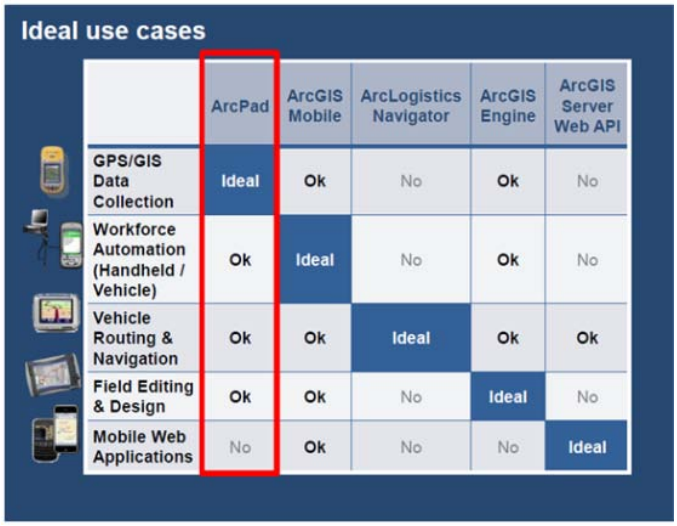
Figure 5 USGS Orthophoto map in GeoPDF format (USGS)

General assessment of current state of the art in GPS enabled mobile computing

Categories of mobile use

In order to examine the alternatives for successful implementation of a new mobile solution, Esri provides a useful matrix (Figure 6) that categorizes mobile tasks into five generic types:

GPS/ GIS data collection
Workforce Automation (handheld / vehicle)
Vehicle routing and navigation
Field Editing and design
Mobile web application



Ideal use cases

	ArcPad	ArcGIS Mobile	ArcLogistics Navigator	ArcGIS Engine	ArcGIS Server Web API
GPS/GIS Data Collection	Ideal	Ok	No	Ok	No
Workforce Automation (Handheld / Vehicle)	Ok	Ideal	No	Ok	No
Vehicle Routing & Navigation	Ok	Ok	Ideal	Ok	Ok
Field Editing & Design	Ok	Ok	No	Ideal	No
Mobile Web Applications	No	Ok	No	No	Ideal

Figure 6 Esri matrix of use cases and applications (Esri)

Although this matrix points the user toward a specific Esri software solution, other vendors offer alternatives for each of these Esri products. Thus, the table provides a useful starting point for matching user needs with generic hardware and software. The following discussion of the use cases provides a comparison of the previous address canvass with potential alternatives for deployment under the GSS Initiative

GPS/GIS data collection (the previous address canvass)

Open Street Map is an example of simple field based GIS data collection activity without any field based data editing. This is an ad hoc process with a very loosely coordinated effort. The previous Census address canvass could be characterized as a coordinated ad hoc process since it was not tightly coupled to the enterprise data base and there was no direct data synchronization. Using a GPS receiver the operator collects points, lines, and polygons. The data collected are then transferred for post processing before they are reflected in the enterprise data base. This activity does not require connectivity with the enterprise database to accomplish its portion of the task, which is data gathering. The data are stored on the device, but could be transmitted via Wi-Fi or cellular network to an intermediate storage device and then retrieved when it is time to translate the field data into a format and use compatible with the enterprise database. While it is

possible to coordinate data collection activities between field operators, some vendors of mobile devices/systems suggest that this functionality should not be used by more than several concurrent operators.

Workforce Automation

This type of field data collection benefits from close coupling with server based data management. It is designed as an IT-centric solution for a large work force that is concurrently checking out, editing, and transmitting data that will eventually become part of a large corporate data base. The goal is to have a team of operators collect and validate data that is transmitted back to the server for post processing into the corporate GIS data. These operators, who are often trained staff, are observing, monitoring, and inspecting events or features. The requirements focus on the creation of a current inventory of features at a mapping grade level of precision. Devices that support this type of field data collection can be laptop computers or specialized field personal computers. The applications can be highly customized and can be quite "lightweight" even when provisioned with a complete set of field tools. The bundle of spatial data required for field operations may be either pushed or pulled from a server directly via a wireless or local area network.

Operators do not need to be continuously connected to a wireless network and could work in a disconnected manner with occasional access when required. In a highly structured environment the field data collection can be synchronized with carefully controlled check out / check-in procedures. In this work setting it is often necessary for the field crew to be in communication with each other and the central base. This can be handled through cell phone communication or GPS based tracking.

Vehicle routing and navigation

While this form of mobile deployment often refers to logistical support for a fleet of vehicles, the ability to efficiently deploy a field staff and have them navigate to a specific address or feature is an important part of the GSS Initiative and should be incorporated into any solution. There are a number of commercial fleet management and navigation tools available on self contained devices or through web services that could be used for these purposes.

Mobile web applications (iPhone, Android and Blackberry)

This category of mobile user is defined more on the basis of the device they use than the application. The embedded location services, quick time of first fix, continuous tracking and network connectivity are clearly aimed at the location based services area. This is the fastest growing segment of field based computing and is being embraced by commercial GIS providers. While there are limitations in terms of the ability to collect non-GPS coordinates, there are some potential applications for field validation tasks that focus on attributes or photographs of features that could be a part of the overall solutions.

Mobile device characteristics

Within the current technological environment there are numerous devices capable of collecting GPS coordinates (Figure 7).

Figure 7 Range of mobile GPS enabled devices (Esri)

The list of devices and solutions that could be used to support the GSS Initiative is expanding every day and the array of choices represents a series of decisions based on functionality, price, performance and human computer interaction. In fact, The Open Street Map web site lists about 120 different devices that are being used by volunteers to collect, store, and transmit GPS positions for street geometry and points of interest.

Device Options for the GSS Initiative

While the range of devices that are locationally aware has grown tremendously, the requirements for field data collection and validation limits the set of devices that will meet GSS Initiative needs. The need to display coordinates in real time in relationship to other geospatial data and to store and edit both the position and attributes for a feature rule out most recreational grade GPS tracking devices and cellular telephones from consideration. One of the paramount questions is the capability of the device to acquire and record coordinates from the Global Navigation Satellite Systems (GNSS) constellations of satellites. Our report *Identifying The Current State And Anticipated Future Direction Of Potentially Useful of Developing Technologies* will cover the technical advancements that are anticipated as additional constellations are added to the existing United States NAVSTAR system, as well as new positioning technologies emerging from telecommunication providers. At this point in time, is useful to refer to the chart (Figure 8) provided by the *American Surveyor* for positional accuracies that can be obtained from different

types of augmentation. The basic finding is that the FAA's Wide Area Augmentation System (WAAS), which was used in the address canvass, continues to be the best alternative for real time augmentation to meet GSS Initiative needs of 7.6 meters for street segments. The WAAS lateral (X,Y) coverage area includes all fifty states and Puerto Rico[1] (Figure 9).

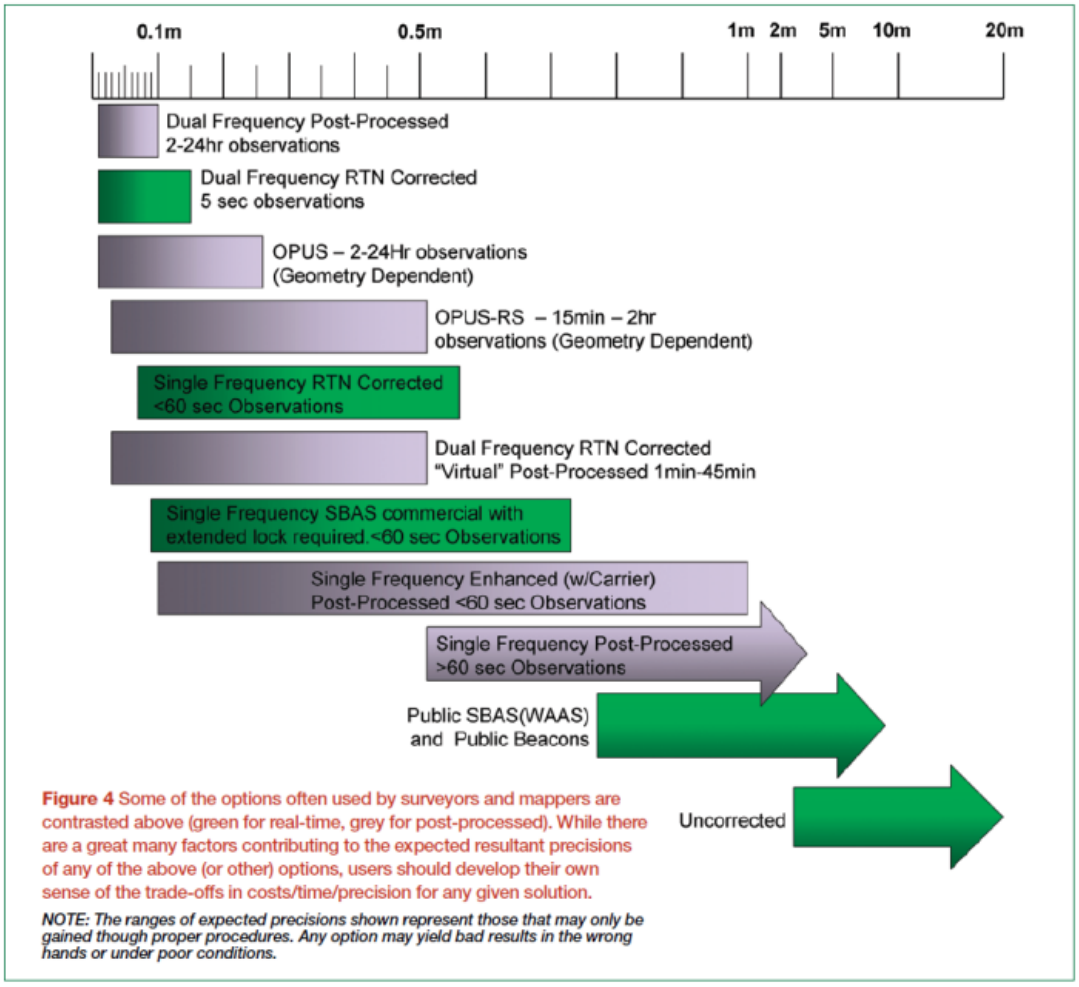


Figure 8 Positional accuracy from different augmentation techniques (Schrock, RTN-101: Part 14. http://www.amerisurv.com/content/view/5357/153/)

[1] Based on telephone interview with Leo Eldredge – FAA GNSS Group Manager (10/27/2010) WAAS does not provide an acceptable estimation of elevation in Puerto Rico and Hawaii; however, the lateral coordinates should be just as accurate as any place in the contiguous 48 states and Alaska.

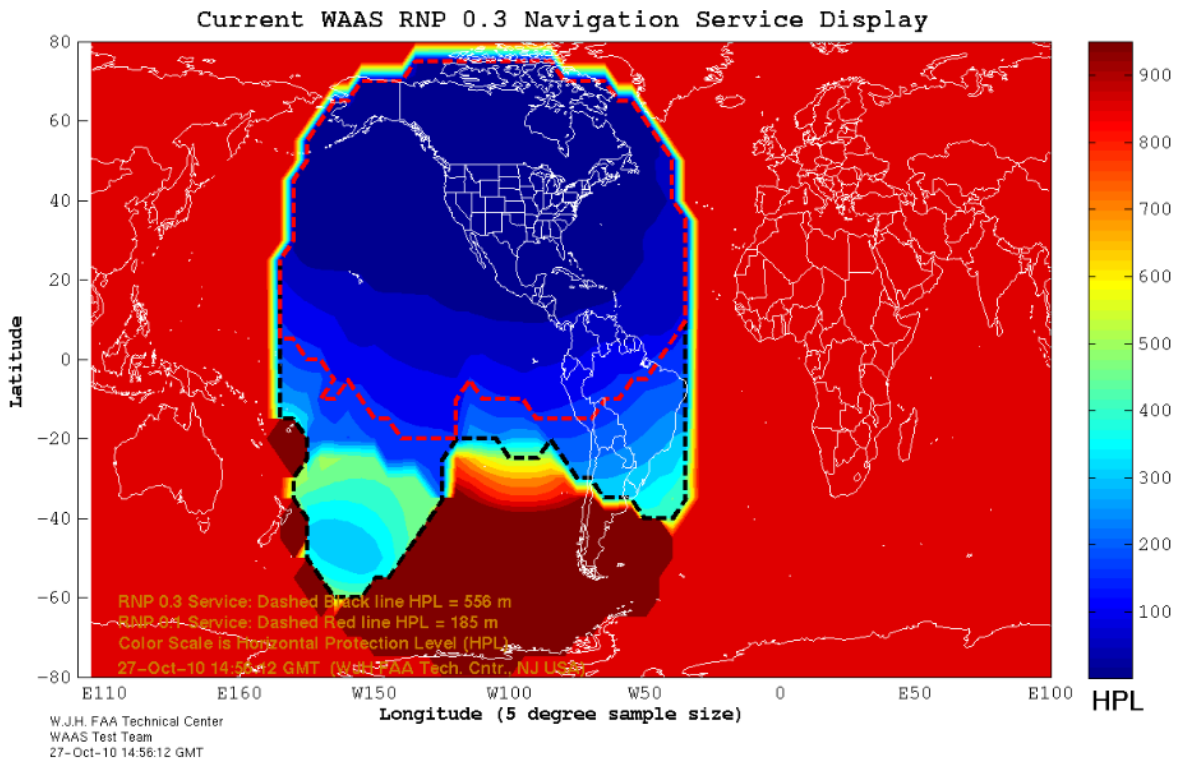


Figure 9 WAAS Full RNP3 Coverage map for October 27, 2010 (http://www.nstb.tc.faa.gov/Full_RNP3Coverage.htm

With the assumption that the WAAS level real time augmentation meets the Geography Division's requirements for positional accuracy, then the choices for mobile devices are limited to the following:

1. Laptops/ Netbooks/ tablet PCs with USB GPS chip set. While several alternatives now exist for these chip sets, it appears that the SiRFstarIII chip set (used in the HTC) continues to be a viable choice. A new SiRFstarIV version, representing a significant upgrade, will be incorporated in a variety of devices in the next few years (See Box 1).

Pros

- There is direct access to a host of commercial GIS software that runs under the Windows operating system (ArcGIS, TerraGo, ERDAS, Cartopac, etc.). This means they can be quickly deployed.
- Low cost (~$50) modification of existing equipment. Interaction with screen via touch pad, stylus, or mouse.
- Unlimited storage via USB.
- Wi-Fi or Ethernet connection or 3G/4G.
- Browser applications.
- Easily accommodated in an automobile.

Cons

- Heavy.
- Awkward to use.
- Limited battery life.
- No native cellular access.
- Limited options for screen lighting.
- No camera and voice memos – without modification of standard package.

Software options

A laptop with the Windows operating system can serve as a low cost of entry field computer. At the same time, ruggedized tablet computers designed for field work such as the Panasonic Tough Book are more than $3,000. Windows based laptops are now routinely used with full function commercial GIS software or specialized applications such as the TerraGo mobile product or a similar offering from CartoPac. Most of these software packages incorporate a GPS toolbar that facilities the tracking of GPS positions and quality. The TerraGo mobile application provides the ability for users to incorporate real time GPS capabilities with any bundle of map and image data exported in the GeoPDF format. This enables one to pan and zoom anywhere on the screen while toggling different layers of geospatial data. Point level features can be directly captured with the device while linear and polygonal features (as well as points) can be generated with the pointing device. Data can be imported from a GPS device using the GPX data exchange format that encapsulates waypoints, tracks, and routes.

SiRFstarIII GPS chip set. –From an operational viewpoint the SiRFstarIII chip set represents a cost effective GPS solution which meets the accuracy requirements for TIGER updates.

This chip set is often considered the "gold standard for GPS receivers "Before this chip, reception in mountainous terrain and in other challenging conditions was often hit or miss" The availability of the inexpensive SiRFstarIII GPS chip set means that low cost mobile devices can be configured in many forms (http://gpstracklog.com/2010/02/getting-over-sirfstar-iii.html).

This chip set provides the following features –

A 20-channel receiver, which can process the signals of all visible GPS and WAAS satellites simultaneously.
Power consumption of 62 mW during continuous operation.
Assisted GPS can reduce TTFF to less than one second.
Receiver sensitivity of -159 dBm while tracking.
SBAS (WAAS, MSAS, EGNOS) support positioning : < 2.2 m, horizontal 95% of time

SiRFstarIV (newest breed – will be widely available in next couple of years)

In 2009, CSR released the SiRFstarIV chipset which is just beginning to appear in new mobile devices. Therefore, we can expect to see many of these available for the GSS initiative. Promotional literature provides a glimpse of additional functionality that manufacturers are putting in the next generation of GPS receivers (http://www.csr.com/news/pr/release/33/en):

"SiRFstarIV's ability to operate in a mode in which the location function is always there, always available on demand, virtually anywhere – even in many indoors and obstructed environments – brings location in line with the way consumers and enterprises alike want to use location. Like turning on the tap and expecting water to come out, the GPS function is there the instant people want and need it. I view this as a very significant development for GPS technology that can enable a broader range of services."
The SiRFstarIV architecture core is comprised of a high-performance GPS location engine, smart location sensor interface, adaptive micro-power manager and active

Box 1 Overview of SiRFstarIII and IV chip sets (http://www.csr.com/news/pr/release/33/en)

2. Field Computers with GPS

(Examples: Trimble Juno, Yuma; Ashtech MobileMapper 6; and Juniper Mesa Rugged Notepad)

Pros

- light weight
- Easy to use
- Good battery life
- Windows Mobile compatibility –
- Integrated Satellite Based Augmentation System such as Assisted GPS, WAAS, etc.
- Integrated Wi-Fi, Cellular, Camera, voice, Bluetooth
- Easy to change screen settings
- Synchronization via Microsoft Active Sync

Cons

- Price
    - Trimble Juno (~$800), Trimble Yuma (~$3700)
- Small Screen

While there are a few other options in this market place, it is useful to examine some technical specfications for the two Trimble devices (Figure 10). While they both have similar functionality, the Juno has a smaller screen and much less storage capacity. The Juno would be a good choice for areas with good wireless connectivity while the Yuma would be able to provide more options for independent field data collection that requires local storage of ancillary data.

Field Computers with GPS	Juno SB handheld	Trimble Yuma Rugged Tablet Computer
DGPS accuracy postprocessed*	1-3 m	2–5 m
DGPS accuracy real-time*	2–5 m	2–5 m
H-Star technology-capable	No	No
EVEREST multipath rejection	No	No
Integrated GPS and field computer	Yes	Yes
Integrated SBAS	Yes	Yes (WAAS)
Integrated beacon	No	No
Integrated OmniSTAR	No	No
NMEA output	Yes	Yes
RTCM input	No	No
Operating system	Windows Mobile 6.1	Windows 7 Professional
Processor	533 MHz Samsung processor	1.6 GHz Intel Atom processor
Memory (RAM)	128 MB	1 GB DDR2
Screen size	8.9 cm / 3.5"	17.8 cm / 7"
Screen details	Portrait TFT color touch screen 240 x 320 pixels (QVGA)	Landscape color touch screen 1024 x 600 pixels (WSVGA)
Data storage	128 MB	32 GB
CompactFlash slots	0	0
SD (Secure Digital) slots	1 (microSD / microSDHC)	1 (SD / SDIO)
Alphanumeric data entry	Soft input panel (SIP) on screen keyboard, Transcriber handwriting recognition	Soft input panel (SIP) on screen keyboard, Transcriber handwriting recognition, Optional keyboard accessory
Integrated Barcode scanner	No	No
Integrated Bluetooth	Yes	Yes
Integrated wireless LAN	Yes	Yes
Integrated camera	Yes	Yes (2)
Cellular modem	Can be added via TDL 3G cellular modem accessory	Can be added via ExpressCard 34 mm slot or TDL 3G cellular modem accessory
Weight	0.23 kg / 0.52 lbs	1.4 kg / 3.1 lbs
Battery life	8 hours: Internal GPS, and backlight	8 hours

Figure 10 Comparison of Trimble Juno and Yuma (Trimble: http://www.trimble.com/mgis_prodcomp.shtml)

Software Options

These devices are essentially a small laptop computer that can run software under Windows Mobile. Software can be provided by the device manufacturer, a software vendor, or a custom developer that integrates components and builds specialized interfaces. For example, Trimble has

its own suite of software to collect and synchronize data collected on any of its devices. Software vendors such as Esri, Cartopac, TerraGO (Figure 11) and ERDAS provide options for these devices.

Figure 11 TerraGo Mobile software on Trimble Juno with sketching capability (TerraGo)

<u>Smartphone</u> (iPhone / iPad, Android, Blackberry)

The new breed of smartphones based on the Apple iOS and the Android OS as well as the Blackberry OS have recently captured the attention of both amateur and professional users. These devices blur the distinction between computers, web browsers, and phones. In the past, properly provisioned cell phones were capable of receiving or transmitting locational information (coordinates) however, they were limited in their ability to store or edit the data. Today the several smart phones have overcome these limitations. These assisted GPS devices utilize data from cell towers and Wi-Fi hot spots to generate coordinates that may be more precise than those collected via traditional non-augmented systems. They also provide a very fast time to fix to the satellites and may provide for improvements in the accuracy of locational data captured in urban canyons or close to buildings. In fact, one objective of telecommunication providers, such as cellular carriers, is to determine locations inside a building. These developments are exciting and suggest that alternative solutions may be emerging – especially in terms of positioning technology.

Of all the recent developments of location services on cell phones, feature phones, and smartphones, those based on the Apple iOS have the greatest potential for the GSS Initiative. The iPhone 4 has many features that are well suited for the GSS Initiative field mobile application. The assisted GPS, three-axis gyro, accelerometer, proximity sensor, and digital compass provide a set of resources that heretofore only were available in much more expensive devices. While it would be possible to design applications that would assist with the capture of address points and even street centerlines, these solutions may be of little utility in terms of field

based editing. A severe limitation is the ability to locate points or lines on the device. These devices are designed to respond to the heat and pressure of a finger. Unlike laptop computers or field based GPS computers these devices do not respond to tapping with a stylus. Therefore one is limited to navigation with a finger or totally relying on the GPS coordinates. Simply put, free form or heads up digitizing is currently limited to the ability to create a point with the pressure of a finger and does not meet Census accuracy requirements.

Pros

- Light weight
- Easy to use
- Voluminous data storage
- Wi-Fi capable
- Small (iPhone) and large (iPad) formats
- Inexpensive applications
- High resolution color display with adjustment for lighting

Cons

- Reliant on web services for basemaps
- Single Internet service provider (AT&T at this time)
- Requires data plan
- Limited to GPS tracking to record coordinates or by pointing at a location on the screen to record coordinates

Software

Esri has launched a free application for the Apple iOS that enables one to display a variety of base maps and perform a few fundamental operations (Figure 12). In the next release of this software, Esri plans to add the ability to capture features.

In the last few months, other application developers and suppliers have quickly embraced the iOS capabilities. A notable example is GISRoam (http://gisroam.com/), an application that allows a user to collect Esri Shapefiles (points, lines or polygons) with attributes, store them, transmit them to a server and download them to an ArcGIS environment (Figure 13). It is possible to visualize these features in relationship to a number of different base maps. It is even possible to transmit the data to a server in the “cloud”. Then, though a web interface, the Shapefiles can be downloaded and used with any GIS software capable of reading them.

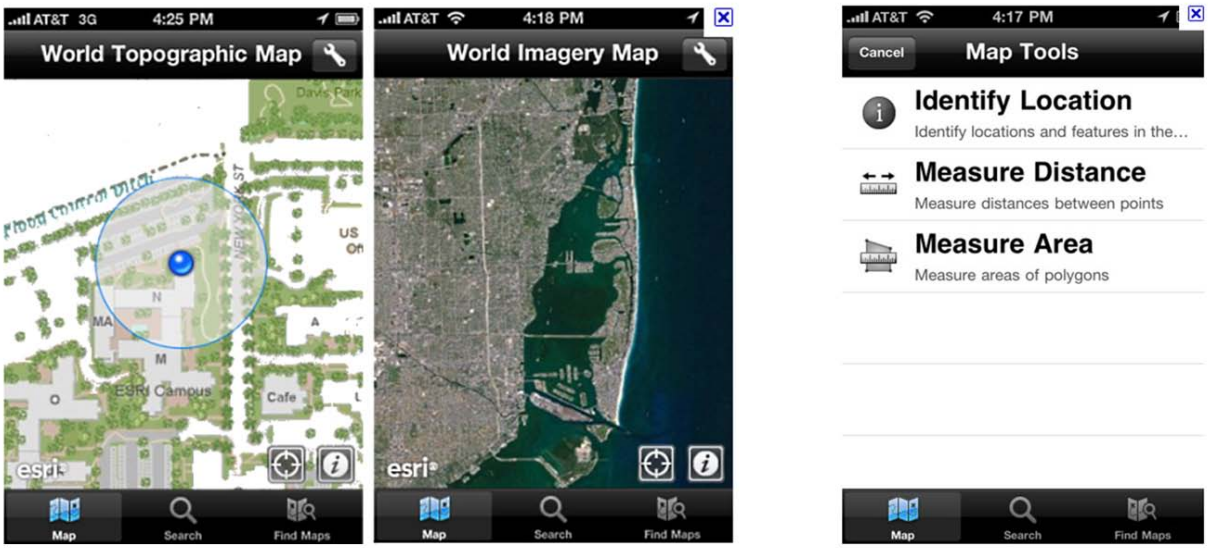


Figure 12 ArcGIS on iPhone (Esri)

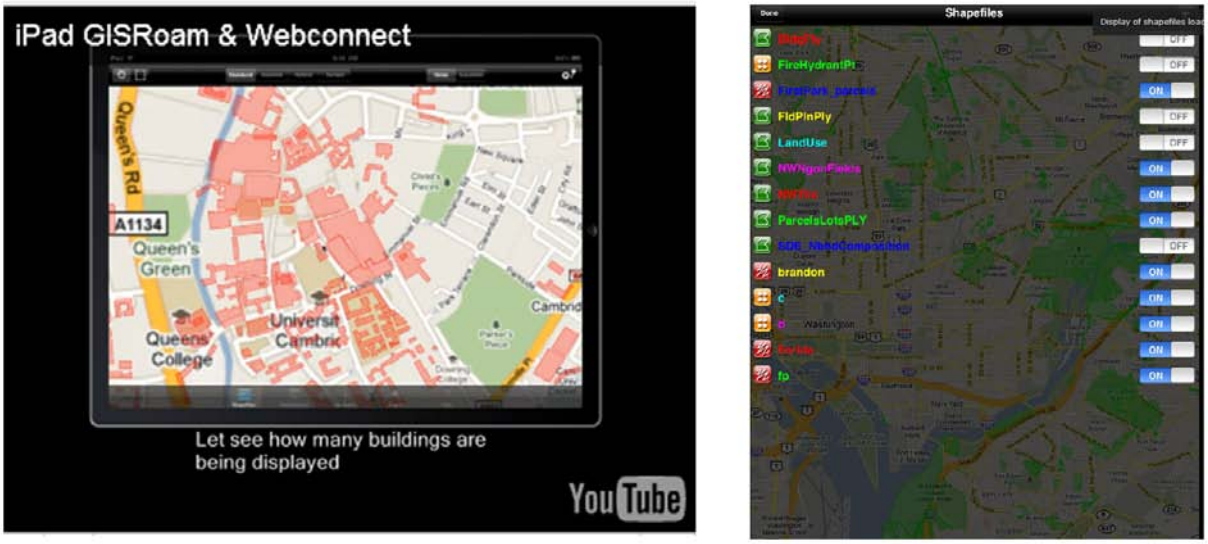


Figure 13 GIS Roam Display and options on Apple iPad (http://gisroam.com/)

The Theodolite Pro application (available for $4 at the iPhone App Store) has potential utility as a range finder. It also enables one to geotag a photo that can then be emailed with all the parameters (lat, long, bearing, and azimuth). The file can be opened and displayed directly in Google Map with the position and bearing (Figure 14). Data from parameters can be used to generate a point level GIS feature. Therefore it would be feasible for a field operator to visit a number of rural sites and email very relevant images and positional information back to the office.

Figure 14 iPhone Theodolite application with range finder (http://hunter.pairsite.com/theodolite/)

The Magellan Tough Case for the iPhone ($179) includes the SiRFstarIII GPS chip set that claims to improve iPhone GPS performance to the 3m range. One of these devices was tested for this research project. However, a preliminary test based on two survey markers was inconclusive with respect to performance improvements.

Android

Android based smartphones are quickly gaining market share and successfully completing with Apple. According to a recent Newsweek article:

> "In August Google announced it was activating 200,000 Android phones each day…. Android now has leapt past Apple to become the biggest smart-phone platform in the United States, the third biggest world wide and by far the fastest growing." (Lyon, 2010)

Since Android is an open-source software stack led by Google, it is much less restrictive to developers than the Apple environment. It is available on a wide range of devices that can operate over many wireless networks. Commercial GIS vendors such as Esri are now supporting Android based devices and several other developers such as City Sourced have comparable applications for Apple and Android devices. One of the most interesting applications has been deployed by GCS research. The GCS app provides statewide access to parcel data in Montana, Washington, and Vermont (Figure 15).

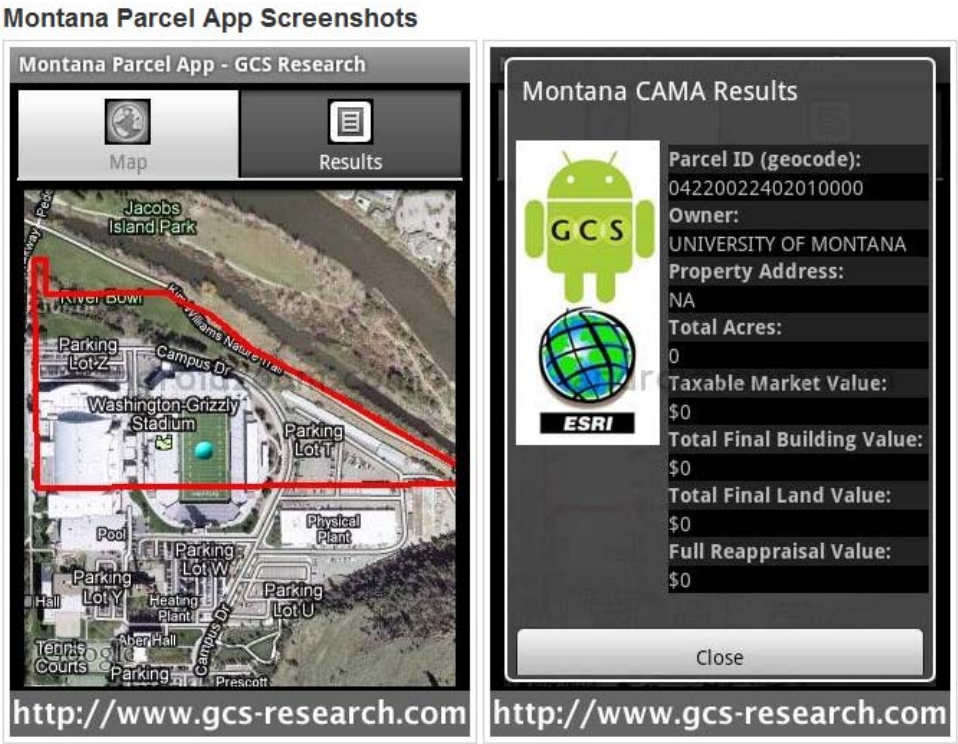


Figure 15 GCS parcel viewer on Android device (http://www.gcs-research.com)

RIM Blackberry

Freeance, an Esri business partner, offers a commercial map viewer and GPS collection application for RIM's Blackberry proprietary operating system (Figure 16). Since these data are saved as Esri shapefiles, the application is proving to be a viable way to create a spatially based inventory.

Freeance Mobile Software Editions

Feature	Pro
Number of MapViewer Applications	Unlimited
Number of MapViewer Searches	Unlimited
Number of MapViewer Feature Identifiers	Unlimited
Number of MapViewer Layer Views	Unlimited
Number of GPS Collector Forms	Unlimited
Number of GPS Collector Fields per Form	Unlimited
GPS Collector Auto Tracking	Yes
Where's My Team	Yes
External Database Search	Yes
Database Web Forms	Yes
Digital Photos – Geotagging	Yes
Number of BlackBerry Users	Unlimited
License Fee – per Server	Call for pricing
License Fee - For Government Agencies	Call for pricing

Figure 16 Freeance Blackberry GIS application (Freeance)

Operating System Options for Mobile Deployment

While there are some very exciting developments emerging on non-Windows platforms, it must be noted that the Microsoft Mobile Operating system (Mobile 6.5) continues to be the platform of choice for commercial mobile GIS development from device and software developers. The rationale for this statement is based on the summary provided by Berg Insights it its recent report on GPS Enabled Mobile GPS and Mobile Handsets (Mark, 2010):

> "To simplify the development experience and improve developer productivity, Microsoft delivers a single integrated development environment (IDE) and platform that meets all mobile application developer needs across all Windows Mobile devices. The Microsoft Visual Studio IDE together with either the Windows Mobile 6 Standard SDK, for devices without touchscreen, or the Windows Mobile 6 Professional SDK for devices with touchscreen, provide all tools and libraries needed for application development. Windows Mobile applications can be written using native code, managed code or web based server side code. Development using native C++ code, which interfaces directly with the Win32 environment of Windows Mobile devices, offers the highest performance and most powerful functionality at the cost of forcing the programmer to be more careful regarding resource handling and memory management. Managed code is code that has its execution managed by the .NET Framework Common Language Runtime. The .NET Compact

> Framework provides a memory manager, as well as a library of functions for commonly performed tasks, thus enabling fast and cost effective programming using the Visual Basic, .NET or C# programming languages."

It is important to note that Microsoft has ceased development of the Windows Mobile 6.5 platform and shifted future efforts to the Windows Phone 7 platform. Software developers and GPS device manufacturers (such as Trimble) who are utilizing Windows Mobile are planning to shift to the Windows Phone 7 environment over time.

Although the Microsoft mobile operating system currently dominates this market, the Berg Insight report identified some interesting developments

- Early smartphone OS including Symbian and Windows Mobile have been joined by proprietary operating systems from RIM BlackBerry, Apple and lately also Samsung's Bada OS. Several Linux-based operating systems including LiMo, Android, webOS and MeeGo have also been released. Symbian has by far the largest installed base with nearly 340 million devices shipped from eight licensees.
- Windows Mobile also lost market share as sales slowed before the release of Windows Mobile 6.5 in October 2009.
- Apple became the biggest winner in terms of unit growth just ahead of RIM's BlackBerry OS. Android also enjoyed increased traction from the release of several models from major handset vendors towards the end of the year.
- The Android platform from the Open Handset Alliance, spearheaded by Google, is experiencing rapid uptake. More than 50 Android handsets have been announced by 12 handset vendors and shipments grew to 7.5 million units in 2009. The importance of the user interface as a differentiating feature has been clearly demonstrated by Apple.
- Many other vendors, including HTC, LG, Samsung and Sony Ericsson have developed their own user interfaces for Android and Windows Mobile.

The rapid developments in the GPS enabled cell phone market may have an impact on options for the GSS Initiative therefore additional findings about the current status and forecasts are included in Appendix A.

Review of current experiences of use of field based geospatial data collection

User Experiences

The following section provides list of users that have experiences with a direct bearing on the GSS Initiative. A full description of user experiences, including contact information, is included in Appendix C. The basis of this review was a combination of Internet searches, user's manuals, trade show interaction, discussion with vendors, and telephone interviews with users who are currently deploying mobile field collection solutions as part of an overall data management strategy.

Summary of findings

Although there has been an explosion in the number and the uses of location aware mobile devices, very few of them are relevant when measured against the requirements of the GSS Initiative. For example, most users of personal navigation devices and smartphones are not interested in editing, capturing or storing the location of features. The relevant user community is characterized by their need to create and maintain a corporate or enterprise GIS database. Given the dominance of Esri among this community, users can be divided into those who directly use Esri mobile software and those who use non-Esri mobile products. The interviews were based on this dichotomy.

Esri Mobile Users

As noted in Figure 6 Esri has a suite of software applications to support different user groups. Based on our interpretation of the GSS Initiative requirements, we focused on users of the ArcGIS mobile environment. (Appendix B includes a detailed discussion of the technical features of the system.) The analysis of user comments suggests that the current release (10.0) is far superior to previous versions and significantly better than ArcPad which was the basis for the HTC software used for the address canvass. ArcGIS Mobile 10.0 was recently field tested by the US Fish and Wildlife Service and state and local governments during the Deepwater Horizon response. The feedback indicates that diverse field data collection efforts were successfully implemented with data being transferred from field personnel to a central server maintained in Houston by BP petroleum. Field staffs, using a range of devices on boats and on the land, were able to capture point and line features using customized routines to enter attribute data and photographs. They were able to work while connected or disconnected to a wireless network. We also discovered that several large corporate organizations such as South Carolina Electric and Gas, CSX railroad, and Norfolk Southern are deploying ArcGIS mobile applications that are linked to a corporate servers and databases. These applications are deployed with customized data and tools on devices that range from simple laptops to highly accurate dual frequency GPS surveying devices. These corporate customers also commented on the relatively low cost of licensing for existing ArcGIS server users and the ease of implementation. It is also worth noting that a couple of new applications are currently being tested at the Virginia Department of Transportation and Fairfax County (VA) Water Authority.

Non Esri Mobile users

Users who are not utilizing Esri mobile software fall into a couple of categories. The first group consists of surveyors and other field data collection professionals who tend to work on single projects. They typically collect field data then use the vendor's (e.g. Trimble) software to transfer, post process, and move the data to a (non Esri) GIS or CAD application. A second group uses non Esri products to collect field observations that need to be integrated with an existing Esri GIS data base. Coordination and version control are more important to these users than those who are project based. Our research revealed that the following software solutions are being deployed.

CartoPac (Microsoft OS)

CartoPac software products (The CartoPac Field Server, CartoPac Data Interchange for ArcGIS (CDI), CartoPac Mobile, CartoPac Studio) probably represent the only integrated solution that is comparable to ArcGIS mobile. Users at the BLM in Wyoming and San Juan County New Mexico provided very enthusiastic reviews of these products. The software enables them to establish a close connection between devices deployed in the field and an ArcGIS server. Users are particularly impressed with image compression and speed of redraw of cached images on field devices.

TerraGo Mobile (Windows)

As noted previously, the TerraGo GeoPDF map format has been widely adopted across the federal government. The US Department of Agriculture and some of its state partners have adopted the TerraGo mobile product to capture and synchronize field data collection with an enterprise Esri data base. The version for ArcGIS 10 was recently released. It is certainly worth following the USDA's experience with the configuration.

GIS Roam (Apple iOS)

GIS Roam represents a recent Apple iOS addition to the options for field data collection of Esri shapefiles. Our interview with Jonathan Caine, a geologist with the USGS, suggests that this software on an iPad constitutes a significant field device for collecting Esri shapefiles.

Freeance (Blackberry)

According to the Freeance web site (http://www.freeance.com/customers.php) close to 30 organizations are using its application to gather point level information and photographs about events and condition of features. This information is stored as Esri shapefiles and can be integrated with an existing Esri database. The users include the National Weather Service, several state agencies and many local governments. Freeance has the advantage of being widely supported on several types of Blackberry smartphones which are covered under several service plans. Therefore, it can be quickly deployed. Its limited field based editing functions eliminate it from consideration as a primary device for data capture; however, it could serve as a practical device for validating existing data.

Observations and Recommendations

System Design Considerations

Planning, designing and provisioning the mobile platform that will support the GSS Initiative will require a careful consideration of several key technical issues. Among these are decisions about the optimal way to interact with the MTdb and how communication is handled between a server and a mobile device. It will also be important to consider whether bundles of geospatial data are pushed from the server or pulled by the device. Another issue with significant implications relates to the content and cartographic design of the map and image features to be ported to the device Next, the capabilities of the operators, their job functions and the use cases that describes these interactions will significantly impact the design and effectiveness of the human computer interface used to perform the tasks required of this platform to support field operations.

It is our belief that the success of the endeavor will be contingent on an appreciation that field based efforts will be an ongoing process and that interaction with the device must be an efficient and satisfying experience for the operators. This will require careful consideration of the design of cartographic and image displays for mobile devices with 3.5 or 7 inch screens. The operator will also need to be provided with easy to use and robust editing tools, as well as to be able to easily create and complete forms to control attribute data.

Many field based processes are geared to supplement the office based maintenance of street segments and address points. Unlike the prior address canvass that added 145 million MSPs to the MTdb, the next round of field operations will focus less on data collection and more on update, validation and quality control. In effect, the goal of field operations is to inspect the situation on the ground to determine whether all the required features exist, that they have the correct attributes and that they meet positional accuracy requirements.

Mobile as Part of the Enterprise

In the middle of the last decade, field based data collection functioned as a standalone operation. Data were collected and brought back to the office for post processing and then converted into a representation of a feature or a control point. Today, organizations have realized that the maximum value of field operations can only be obtained by incorporating the mobile component into an overall, ongoing, data maintenance program. Vendors and system integrators have gained considerable success by creating a seamless integration for all aspects of this workflow. A good example of this is system being deployed by the Virginia Department of Transportation (VDOT) being used to track HAZMAT, cultural resources, water quality and noise features. The flowchart (Figure 17) for the application demonstrates that there are two way communications with the mobile device and that the field data are closely synchronized with web based map viewing.

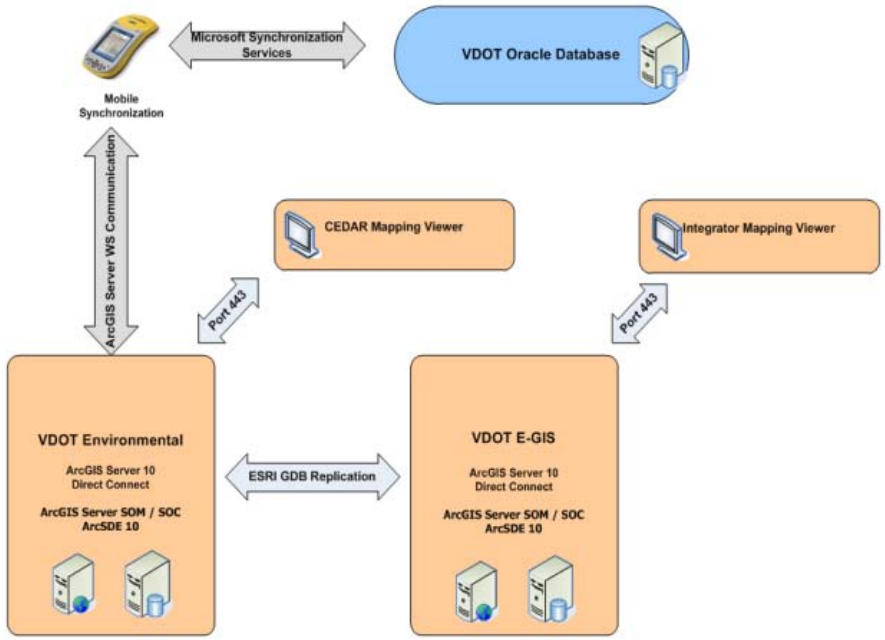


Figure 17 Flow chart of the VDOT environmental system being developed by Timmons Group (Courtesy Timmons Group)

The most advanced of these now mature systems provides a very close coupling of the field (client) and server side processing. There are tools to prepare and transfer map bundles to the mobile device, tools that enhance the design of maps on small devices, tools that enable one to capture point, line, and polygon features either with GPS or by sketching with a stylus. Other tools provide the appropriate control for GPS accuracy and collecting coordinates from offset distances, as well as based on distances and bearings. Further, it is possible to conduct the field work in connected or disconnected environments to accommodate different types of tasks as well as to perform operation in environments where connectivity services are incomplete or, perhaps, lacking entirely.

Most importantly, it is now possible to carefully control the synchronization of field data collection with the host server. There are robust functions for checking out, versioning, and validating field data. Within this mature environment, mangers can design flexible or tightly controlled work flows. For the GSS Initiative this suggests that data can be extracted, edited, and then pushed back to the staged data base before actual edits are performed on the corporate data base. These mature environments are being successfully deployed by railroad and utility companies as part of their everyday business strategies, as well as by government agencies and volunteer relief workers in emergency situations such as those related to the oil spill recovery operations on the Gulf coast.

Software functionality for the Mobile Device

The success of the mobile component of the GSS Initiative will be determined, in large part, by software functionality. For tasks that require significant feature attribution, the mobile unit could be a GPS enabled laptop computer equipped with software that facilitates the selection of and subsequent navigating to features that need checking. Once appropriately located, the device operator then validates and edits text that is then synchronized with MTdb.

The core of the mobile component of the GSS Initiative concerns the ability to accurately add, move or delete features in the field. These desired functions that the operators will execute are the same as those incorporated in the previous address canvass. However, the next round of field editing will be able to incorporate a wider array of existing MAF/TIGER features and a more complex and useful mix of background reference data to enhance positioning and addressing. Therefore, the challenge will be to provide easy to use tools that will enable the operator to validate and edit the features in a way that is advantaged by this richer, but more complex information environment.

While the ability to perform topological edits in the field would appear to be of significant benefit, our recommendation is that topological editing in the field in not a good practice since it may artificially move points or generate mislocated points. During our conversations with companies with experience teams of field users we learned that most advise against allowing field operators to delete features. The preferred practice is to mark features for deletion with final deletions being handled as part of a rigorous, desktop-based QA/QC performed in an office environment.

Recommendations

Our recommendations for the development of a mobile component for the GSS Initiative focus on three general areas.

1. Our first suggestion is that the Geography Division, if it has not already done so, should conduct a forensic examination of the procedures and operations used to support the last canvassing activity in order to derive lessons learned that could be used to improve the accuracy and comprehensiveness of future address canvassing activities, regardless of their size, scope, or geographic focus. This examination should carefully consider where mobile field data collection and editing fits into the “enterprise” work flow for MAF and TIGER

Although it is possible to instrument a field workforce with mobile devices incorporating improved functionalities that should result in enhanced results during address canvassing and map update operations, we note that some field activities may be prohibitively expensive to perform. For example, many communities conduct building inspections based on the use of high resolution (ortho and oblique) imagery sources and parcel data that are examined in the office, not in the field. In fact, most commercial providers of address and map databases (including providers of navigation quality databases) conduct field inspections as a last resort, only after data mining and image processing have failed to reveal the information of interest. Since deploying field crews is an expensive alternative, we recommend that the Geography Division

employ a geographically stratified strategy based on using high resolution content and web services to distinguish areas that would benefit from field analysis from other area where research questions could be resolved through the use of high accuracy reference data In other words, we recommend that the Geography Division use different approaches based on a payoff analysis gated by the availability of appropriate source material.

Next, we recommend an internal review to consider modifying the current guidelines for representing a structure point. While there are some situations in which field recording of MSPs may be of benefit, most commercial and public sources are performing the capture of similar data at the desktop, either digitizing a point on the rooftop of a residence visible in a high resolution aerial image or adopting a parcel centroid as the preferred location of a property. Moving this task off the requirements list for the mobile device would greatly simplify and speed the field data collection process.

2. The second recommendation is that the GSS Initiative should be based on the ArcGIS mobile 10 enterprise solution. (A detailed description of the specifications and functionality of ArcGIS mobile is included in Appendix B.). We believe that ArcGIS Mobile is the system that most closely matches the requirements for the GSS Initiative. The combination of software functions, control over GPS data collection, and the ability to maintain an enterprise data base addresses almost all the desired GSS requirements. When deployed on some of the modern specialized GPS devices, the overarching technical requirements regarding communication, security, media, user interaction, and storage can be fulfilled. During the interview process we learned that ArcGIS Mobile is being deployed by a wide range of users on an extensive array of devices and that it is an affordable solution for existing Esri users. It provides a very flexible environment based on industry standards. It can operate on any Windows based mobile device and can be customized to create light or heavy applications to meet a variety of user needs. It can be used on both Win32 and Windows Mobile platforms; therefore it will be compatible with most Microsoft Office applications that might be used to meet the needs of the Bureau's Corporate Listing Devices. For example, mobile devices such as the Trimble Yuma are essentially portable computers that have Windows 7 on them and can be used with the SDK to create a custom solution on a full OS. Custom forms / user experiences can be created with .NET windows forms to provide "wrappers" around mapping controls. It allows for enterprise wide data maintenance with a tight coupling of field and web based technology. In this web centric environment many users are deploying ArcGIS Web Mapping APIs using Java, Flex or Silverlight. In fact, several users are using the Google Earth API environment to build applications from data stored on the ArcGIS server. This environment is also compatible for future developments that will be created with HTML5. (Appendix A provides a discussion of emerging trends in the mobile computing environment.) Esri will provide more integrated support for the Apple iOS and Android devices in the future.

This new ArcGIS solution has been embraced by many large organizations such as the Fish and Wildlife Service, Virginia Department of Transportation, South Carolina Electric and Gas, and the Norfolk Southern Railroad. While adopting this technology solution would involve a restructuring of some work flows, it should be compatible with the Geography Division's overall approach to MTdb maintenance. Esri software is widely used throughout the Bureau and can be used at no additional cost under an existing enterprise license.

From an overall data management perspective this conversion would require that the field data are synchronized to a Geodatabase as an intermediate staging phase before any changes are submitted to the MAF/TIGER update applications. It should be noted that other Esri products such as the Data Reviewer could be utilized to perform various data quality checks at the staging step. Our review of other organizations indicates that they routinely establish production versus publication versions of their data. They establish firewalls and stage the data before any final edits are performed. The ArcGIS mobile solution will provide an opportunity for the GEO to consider alternative data work flows and we believe that this review will be beneficial to the overall performance of the operation and the ability to quickly validate, maintain, and distribute TIGER.

3. Our final recommendation deals with the choice of a device that could function to meet the requirements of the Geography Division for address and map compilation.

Within the ArcGIS mobile environment several different types of users and devices can peacefully coexist. For many applications a simple attachment of a USB GPS device will convert a laptop computer into an effective mobile device – that could actually take ArcGIS into the field. GEO should evaluate the new tablet computers to determine the user interaction experience. The majority of the mobile effort should utilize specialized field based computers from an established, reputable major manufacturer such Trimble. The choice of the best model will depend on the type and quantity of data that must be stored to accommodate editing when the device is disconnected from a network.

Recommended Devices

With respect to particular mobile devices that could benefit the Geography Division in its field related addressing and map compilation activities, the following devices should be considered:

(1) For operations focused on tabular data, including those deployed to meet the broad requirements for the Bureau's Corporate Listing Device, a range of common portable computers, provisioned with a WAAS capable USB GPS chip set could be deployed. Portable devices such as netbooks might be sufficient for an employee who spends the majority of the time in a vehicle.

(2) In harsh environments ruggedized tablet PCs should be considered. Among those we would recommend are:

Xplore iX104C4™ Rugged Tablet PC
Fujitsu LIFEBOOK T900 Tablet PC
Panasonic Toughbook C1

(3) For field based creation and editing of features, it is recommended that the GSS Initiative utilize field computers equipped with GPS.

These devices typically are light weight and designed for extensive field data collection. Generally, models are equipped with a 3.5 inch or 7" screen. Examples of the small and large form factor devices are the Trimble Juno (~$800) and Yuma (~$3700). Other vendors offer comparable units such as Ashtech Mobile Mapper 6 and the Juniper Mesa Rugged Notepad. Most of these devices are provisioned with integrated Bluetooth and Wi-Fi connections and are based on the Windows Mobile 6 operating system. They are equipped with an extensive array of interfaces for communication, capturing photographs and voice messages.

While the larger devices generally have larger internal storage capacity than the smaller ones, most of them now accommodate flash disks that provide several GB of additional storage for map data and imagery. For the GSS Initiative it will also be useful to integrate a laser range finder such as the Laser Tech TruPulse 360 directly to these devices. These new generation range finders are being successfully used to determine coordinates for locations that are inaccessible or potentially dangerous.

(4) Smartphones/ tablets

It is too early to discount GPS enabled smartphones from consideration for some specialized functions supporting the GSS Initiative. While these devices currently can determine positions based on their internal GPS receivers, they have severe limitations in terms of adding freestyle coordinates (non GPS coordinates). However, they could be used in field validation of data, geotagging photographs of structures, and even as a simple range finder.

Summary

The objective of this report has been to provide an overview of the current technology that the Census Bureau could employ to support the GSS Initiative. Since this deployment is less than three years away, we have focused on solutions that are being successfully utilized in existing situations. We have attempted to define the requirements for the mobile strategy and match those with existing hardware and software. At the same time we have included a brief review of smartphone technology that could challenge current practices. Hopefully this report will aid the GEO division at the start of the process. An important part of the GSS Initiative will be a two year pilot program. During that process we believe that several issues relating to the mobile component can be evaluated. Among them are:

- How extensive are wireless services that will support web mapping services?
- What possibilities exist to establish temporary Wi-Fi hotspots that can connect to broadband?
- Can map services be cached when stored in GeoPDF format?
- Which base map and equivalency data work best in a field environment (images, address points, parcels, etc)?
- What is the best solution to handling gaps and overshoots? Should topological editing tools be incorporated in the field devices or should they only be resolved during post processing?
- Can the WAAS augmentation meet GEO requirements?

- Can ArcGIS server be used as an effective interface between the mobile component and the MAF/TIGER API for updating and maintenance?
- Are cached (raster) base maps sufficient for field work that involves editing of features?
- How can Geotagged photos and voice memos be used effectively to augment field data collection?
- Can acceptable coordinates be collected on a smartphone without a stylus or other similar pointing device?
- Can the iPhone theodolite work as an effective range finder in field data collection?

The handheld computing environment is changing at an alarming rate and the devices, functionalities, and capabilities that will be available over the next three to five years may completely change the use profile of this class of devices. In addition, the addition of Glonass and Galileo to the GNSS environment, as well as the benefits resulting from the addition of a new class of satellites to the NAVSTAR global positioning system, will herald receivers capable of advantaging the accuracy of positional coordinates due to the use of multiple GNSS systems. Finally, advances in 4G data networks will help to increase both the coverage of and speed with which field data can be communicated. Perhaps the greatest benefit, however, is that the combined influence of all of these developments will help field operators to become more than just technicians who digitize. It is possible that these operators will not only capture new observations, but also validate the integrity of the MTdb and by doing so helping to provide the United States with a more comprehensive, accurate and up-to-date MTdb than possible with previously available technology.

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