Strategies and Technologies for Integrated Land Administration and Management of National Resources– the DataGrid Approach

Bo GUSTAFSON, U.S.A.

Key words: GPS, GIS, Land Administration, Database, National Resources

SUMMARY

Efficient and reliable Land Administration is increasingly becoming a global necessity. While adequate accuracy usually can be reached, desirability or need for improved reliability and efficiency is real in all countries in the world. Currently it is often necessary to piece together technologies from several sources. These usually are not optimized for integration with existing and often antiquated Land Administration procedures limited in part by law and in part by tradition. Sensitization leading to broad acceptance of the system remains a challenge and can drive up costs of implementation of new systems or even cause their ultimate failure. The undertaking can be risky and may fall short of expected performance. This text proposes equipment, methods and procedures developed especially for the task. DataGrid Inc. of Gainesville, Florida, is committed to offering "turn-key" solutions that implement these recommendations in systems adapted to local conditions and constraints. The result is improved efficiency of determining, recording and disseminating information about ownership, value and use of land. The system can be tightly integrated with sensitization and may be implemented in a short time frame. I also suggest methods to manage or administer the land data and propose the integration of the resulting land information systems with broader national management. This leads to increased utility and therefore better return on investment. DataGrid offers its state of the art L1 and L1/L2 GPS carrierphase receivers that it can tailor for suitability and ease of use in a specific environment. An integrated software package with modules for processing and display allow creation and administration of land databases in a single integrated package. A system is being developed and implemented for use in Uganda where the testing in pilot projects has met with success[1].

Following these procedures approximately 16,000 rural communities with an average of 50 properties could be demarcated and surveyed within 18 months at an estimated cost of $5M to $5.5M for the entire project, corresponding to $6.25 to $6.70 per property. Disputes would be adjudicated on-the-spot when possible and titles issued either in the field or soon thereafter. Costs are dominated by salaries and therefore vary. Full efficiency will only be reached when procedures become routine.

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1. INTRODUCTION

Many national land administration systems depend on paper records whose upkeep and management are exceedingly taxing on human resources and are vulnerable to natural or man-made disasters. Slow and expensive, these are ultimately unable to keep up with modern expectations on efficiency and reliability even under normal conditions and are likely a limiting factor to economic growth. Many modern systems found in Europe and North America are hybrid solutions where handwritten paper records and digital computer management systems work together. Demarcation, surveying, computer hardware, land management software, and operating procedures were viewed as separable components that could be modernized one by one in multiple steps while development was limited to various degrees by applicable law and tradition. The resulting systems are not necessarily suitable beyond the country they were developed for. Nations with different laws, traditions, infrastructure or other limiting or enabling conditions struggle to either adapt these systems to their needs or develop new ones. Officials tasked with modernizing land management therefore face a set of difficult questions. Can a system suitable for their needs be imported from an environment where it has already been tested and proved? If not, can it be assembled from existing components? Is the development of a custom system economically viable? To what extent does the system need to be independent of infrastructure such as computers, communications, electrical power or other utilities that might not be available in remote areas or may be damaged in conflicts or natural disasters? Should they modernize component by component or overhaul an entire system? Is it possible to systematically modernize component by component to arrive at a fully digitized system that functions effectively as a unit? Non-technical issues too abound. Are the planned procedures for conflict adjudication compliant with local laws and will they be broadly accepted and enforceable? Is sensitization effective and timely? How are these issues interrelated?

This article proposes an approach of broad-scale optimization using standardized procedures where the eventual solution depends heavily on the prevailing conditions. DataGrid Inc. of Gainesville, Florida has developed core components to such systems that it can customize to fit the needs of the customer. The scheme is intended from the start to be implemented either as a full fledged land management system or for deployment in steps. The land management system may even be expanded into a comprehensive tool for national resource management. Use may include identity cards / electronic passports, healthcare management, or Geographic Information Systems (GIS) functions such as infrastructure planning, disaster modeling/planning and more.

Improved services and lower operating costs are often among the goals. In some instances the major improvement goal might be quality of life and poverty reduction through conflict reduction, improved land security, reduced real estate fraud and improved land utilization. On a broader scale, equity documentation should result in expanded and speedier banking activity and might be a step toward compatibility with international banking. The greatest potential for benefits may be improved national management whereby land as a key resource is managed along with other national resources. DataGrid therefore ventured to develop its land management offering in view of its broader applicability.

2. LAND ADMINISTRATION SYSTEM

Much has been written about the potential of land reform or land administration reform to reduce conflicts (Figure 1), improve living conditions and for economic stimulation. See for example the article by Oput[1]. There are now international programs that encompass these goals, see for example the World Bank Policy Research Report entitled "Land Policies for Growth and Poverty Reduction"[2] with related programs in other development banks, funds or support agencies. While challenges are many, land administration reforms are now written into law in many developing countries and more are poised to follow. The task now becomes to carry out reforms in a way that is truly responsive to the goals, is sensitive to local culture and traditions and that is an affordable investment. We also propose to boost benefits through synergies with other national objectives, improved resource management and risk mitigation abilities.

Figure 1. A lady accuses a man of encroaching on her land. Courtesy New Vision, Uganda, Published on: Thursday, 10th July, 2003

2.1 Digital records

Land administration can benefit greatly from modern technology not only to collect and manage but also to decimate large amounts of data. Digital format allows affordable data preservation. Management and analysis tools may be upgraded as needs change and records can be easily distributed. Land data may be used by the private sector and branches of government other than the land titling offices. Such use is already common at least in North America where land data is used by law enforcement, city and county planning departments, as well as real-estate agents and contractors to name only a few. For such systems to be effective, all data need to be in computer readable form and be accessible over the Internet on open or restricted sites. Knowing that the data will be used in digital form, a step toward optimization is to collect data digitally during field visits. Since they are taxing on manpower, these visits are usually the most expensive part of the data collecting process, far overshadowing the expense of equipment. Repeat visits should therefore be kept at a minimum and optimization of field equipment, software and procedures is usually a good investment.

2.2 Adaptation

Systematic demarcation and land survey can easily be a daunting task requiring surveyors, computer skilled personnel and other professionals in numbers exceeding available manpower. Simplification and streamlining of all work procedures, task allocation planning and training therefore become key issues. DataGrid therefore developed a system with flexible components. The GeoID software set includes all processing and housekeeping tasks in an integrated package. Running on standard Windows computing platforms, the system is adaptable in a customization process. DataGrid offers high precision GPSs and integrated data loggers that can also be tailored to customer needs. The GPSs, data loggers, data collecting procedures and handling software may be customized for local needs and best efficiency. Too many options invite the possibility of human errors and may make a system difficult to use. DataGrid therefore offers to streamline its software and hardware combination to remove or hide unnecessary features. We develop hard keyed entries and automated processing to the extent possible once actual needs and procedures to meet these needs are defined. DataGrid developed the Crane version of its Mk-1 GPS and its GeoData database as well as tailored its rapid static on-the-spot postprocessing software for the Ministry of Land Water and the Environment in Uganda. This combination was proposed as an optimized solution for Uganda's national systematic demarcation and survey and testing has so far met with success. DataGrid offers competitively priced optimized solutions for land demarcation and survey because it has developed a combination of hardware, software, and procedures for extreme conditions that it can tailor to a customer's specific needs. DataGrid is prepared to offer adaptation and consultancy trough its application centers in Kampala (Uganda), in Tegucigalpa (Honduras) or through its headquarters in Gainesville, Florida (USA).

2.3 Implementation procedures

The process of developing a modern land administration system that is expandable into a management tool of a broad range of national resources following DataGrid's method starts with planning and scheduling. Specific needs that depend on applicable law, traditions and customer wishes are assessed as are the extent of existing records, known conflicts and available infrastructure. A set of operating procedures is developed accordingly and the corresponding software modules are customized. New software routines may have to be developed. The solution may be tested in a pilot project before it is implemented in full scale. DataGrid uses a teams approach described below and in most cases this approach can be either fully tested or simulated using DataGrid human resources to supplement the customer's personnel. DataGrid can then assist in the hiring process and can provide training either directly or through its affiliates. Assessing and processing of existing records is typically the customer's expertise. Key legal documents might be retrieved and scanned into electronic form for entry in the GeoData database. This is part of the office team responsibilities.

An information and scheduling team divides the region to be administered into sets that can be demarcated and surveyed by a demarcation and survey team in a single one day visit (typically 50 properties) and schedules the visit. This team meets with the stakeholders to gathering information on local issues, identify remaining conflicts and to prepare the community for the demarcation and survey process. For example, some boundaries may traditionally be defined by the run of a stream that may have shifted its course or whose bed may otherwise be poorly defined. There may be other previously unidentified land ownership or rights disputes. The office team needs to be notified of such issues so that they can gather all relevant information and help develop a strategy to deal with the issues. This preparation is paramount since the failure to complete demarcation and survey and to resolve all issues that can be negotiated in the field during a single visit by the demarcation and survey team can rapidly drive up costs.

A representative of the stakeholders may be offered to be trained and to participate in the actual demarcation and survey process as an operator. This requires one to two days training with the first day consisting of a brief introduction and instructions from the chief surveyor who leads the team followed by “on the job shadowing” of a seasoned operator. The first day training culminates in a 30 min competency test and question/answers opportunity observed by the chief surveyor whereby the roles of the trainee and seasoned operator are reversed. It might be advisable to pay trainees only once they pass the test. The optional second day would be as a fifth operator performing control measurements that can be used as additional integrity checking. In this scheme a new operator would typically observe the demarcation and survey process in three to four sites before they start surveying. These operators could serve as valuable sensitization officers and informants facilitating the two-ways communication between stakeholders and the teams. This aspect of sensitization may work well and even be essential in some areas but fail in other regions. It is an example of the importance of adapting procedures to local conditions.

Each demarcation and survey team is lead by a chief surveyor who has overall responsibility for the team of operators and for dispute adjudication. The operators normally follow a DataGrid developed quick static high precision measurement procedure that typically yields GPS coordinates with 10 cm accuracy and includes data integrity checking to practically eliminate the effects of multipath and human errors. GPS position determination and integrity checking is tightly integrated with the process of locating boundaries in the presence of stakeholders and with the demarcation or monument making. Every measurement point is visited by two GPS operators at least 20 minutes apart to make sure that the GPS satellite configuration has shifted sufficiently for any degradation due to multipath or other error in a GPS measurement to have changed. Disagreement between the two determinations beyond tolerances triggers additional measurements until results agree or the surveyor may revert to the use of relative positioning from a nearby point using a totalstation in particularly difficult situations.

The key instruments are DataGrid specially made GPS receivers/dataloggers that use carrierphase differential GPS measurements to achieve high precision position determination. It is often advantageous to use two base stations. One is on a legally acceptable reference point in the vicinity that ideally has known coordinates in some standard datum system. Such points may need to be established which usually also can be accomplished with the same equipment as used for the survey. The second, more centrally located reference point does not need to be on previously determined coordinates and can therefore be selected for good sky visibility. Its position will be determined relative the first base station as part of standard procedures. While positions relative the legal reference point (base-station one) sometimes satisfy legal demands, a local, national, or international datum is often used and has frequently advantages. DataGrid can assist in selection or determination of a suitable datum.

2.4 Equipment

DataGrid custom develops GPS/datacollector combinations (Figure 2) that can collect and store one day to several months’ worth of field data in non-volatile flash memory depending on settings and options. These collectors can merge data from diverse sources such as data controllers, digital cameras or voice recorders. They can be used to photograph or collect biometric data for identification of for example stakeholders or other persons who cannot present adequate identification. This allows swift collection of data and recording of testimony on the spot. Biometrics that can be added through customization includes fingerprint and iris scan as well as any number of card, tag or barcode readers. The collectors can capture data on soil conditions (moisture, pH-levels, Nitrogen levels, etc…), air quality (Radon levels, etc…), or can interface to other instruments or sensors that can communicate over Bluetooth, serial or analogue ports. All GPS/datacollectors can merge data from internal and external instruments with the GPS data stream so the time and location of data collection is saved. Collected data can thus be shown in context on a map using DataGrid GeoMapper software.

Figure 2. DataGrid Mk-1 Crane, GPS receiver and data collector.

Single frequency band (L1) carrierphase GPSs position determinations using DataGrid's Mk-1 Crane GPS and on-the-spot automated postprocessing are suitable and cost effective as long as both base stations are within approximately 15 kilometers. Establishment of intermediate reference points may effectively extend the range. This is economical in systematic surveys. Longer range can also be achieved directly using DataGrid's dual frequency band (L1 and L2) version, the Toughman. Both the Crane and Toughman are small and rugged GPS receivers that can merge and/or synchronize data arriving via external ports (analogue, RS-232 or Bluetooth) with the GPS data stream. This allows great efficiency in collecting data during field visits using any number of devices including sensors that monitor soil or other environmental conditions such as Radon levels. Photographs and notes taken on Pockets PCs or Personal Digital Assistants can also be automatically synchronized with the GPS data for merger into a common GeoData database using the DataGrid GeoID software suit. Figure 3 shows a typical field configuration on a pole with the especially developed low weight high precision antenna, solar panels and a Personal Digital Assistant field computer. The low antenna weight enables use with extremely tall survey poles extendable 7.5 or 8 meters to reach above the dense canopy of banana plantations and the like. Extremely low power consumption and integrated battery controller/charger allows solar power to keep the GPS's internal batteries charged. This is not only

Figure 3. DataGrid Mk-1 Crane or Toughman GPS/Data colloctors in typical field configuration. Shown on a pole with low weight antenna, solar panels and a PDA.

important feature under field conditions where power can be difficult to come by, the equipment is always ready for use. It eliminates the need to schedule time for charging the GPSs and eliminates the risk that equipment is taken to the field discharged. Internal Lithium ion polymer batteries allow operation for an entire workday (over 10 hours) without sunlight. The particular type of ion polymer used allows operation in extreme temperatures. The Mk-1 has operated in extreme environments from the heat of the equator to the cold and darkness of the polar regions (Figure 4).

Figure 4. Measurements under extreme conditions in the Antartic region.

2.5 Software

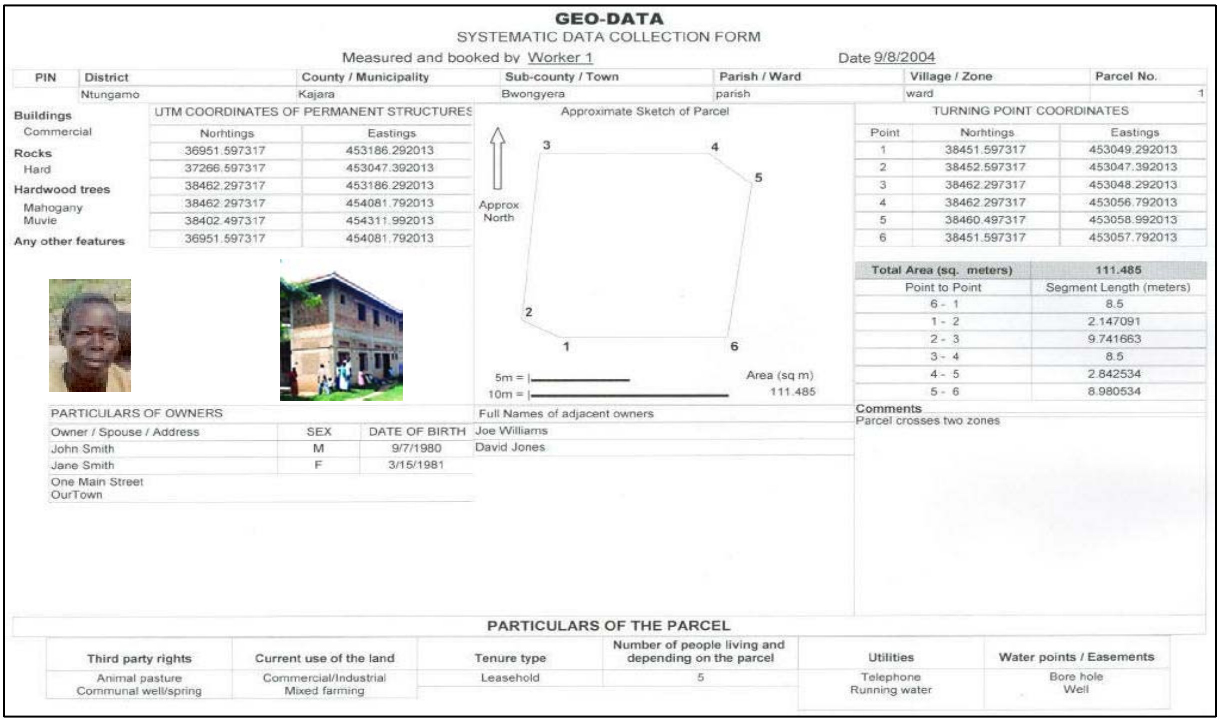
The GeoID software suit, running on Desktop and Notebook computers under Windows, consists of a postprocessing module, a database and mapping software in addition to setup and maintenance tools. There is also software that runs on a Palm-OS, Pocket PC, or Windows CE field computers.

Postprocessing can yield high accuracy GPS solutions but is often considered to be cumbersome and normally requires considerable training. Many who like to see the GPS solutions while they are still in the field tend to rule it out. Others rule it out because of the cost of processing. DataGrid's has therefore developed a highly automated mode for its postprocessing. This mode requires no special training and can be run on-the-spot on a field computer while still delivering decimeter level accuracy as long as instructions for the data collection developed by DataGrid are followed. The measurement sequence involves three to five minutes occupation of every measurement point. A reoccupancy procedure eliminates most effects of multipath and other errors and can be used to estimate the typical accuracy of a survey.

The results of the postprocessing appear in the GeoData database where some human intervention is still required to associate a measured coordinate set with a specific land parcel. This process might be automated in the future, based on adherence to a numbering system for the surveyed points. The organization of the database can be hard-keyed with standard entries to promote consistency and simplicity as demographic and other data is entered in the field. Besides land titles, forms that may be generated include a broad range of claims such as deeds, zoning restrictions, seasonal rights given to nomadic peoples, mining claims, fishing and hunting rights (see example in Figure 5). While the rights as entered in the database are for the most part restricted by two dimensional geographic coordinates the database can also operate on entries that are less strictly defined spatially (exemplified by rights of migrating peoples) or that are defined in three dimensions (such as tunnels, mining rights, and high-rise buildings). Operation can thus be optimized for the task; yet the software is powerful and sufficiently advanced to encompass for example the set of recommendations outlined by van der Molen and Lemmen[3] in their article "Unconventional Approaches to Land Administration". An important advantage with this comprehensive data structure is the ability to handle all aspects of the data in digital format which in turn allows affordable data preservation and affordable upgrades as needs change. The database format and structure is made to allow data export to other software packages and is compatible with PostgreSQL.

Most of the data can for example be exported to ESRI's ArcGIS and other land administration software, including ArcCadastre by ESRI and Lantmäteriet. However, since GeoData uses a flexible structure to be compatible with recommendations by van der Molen and Lemmen[3], data organization and some attributes may be lost or may not work properly in other databases.

The GeoMapper software is a datum transformation and visualization tool where field data such as photographs and for example soil properties may be shown associated with the coordinates where they were collected. Data generated by GeoData such as land certificates or database entries such as land use or demographic information may also be displayed associated with the coordinates of the corresponding parcel. GeoData supports ESRI's shapefile format and can export data to for example AutoCad by AutoDesk. Coordinates may be transformed into a comprehensive array of preset standard datums. These may be edited by the user who may also add new datum definitions. DataGrid can lock the datum during customization to remove the risk for human error and datum ambiguity.



GEO-DATA
SYSTEMATIC DATA COLLECTION FORM

Measured and booked by Worker 1 Date 9/8/2004

PIN	District	County / Municipality	Sub-county / Town	Parish / Ward	Village / Zone	Parcel No.
	Ntungamo	Kajara	Bwongyera	parish	ward	1

UTM COORDINATES OF PERMANENT STRUCTURES

	Norhtings	Eastings
Buildings Commercial	36951.597317	453186.292013
Rocks Hard	37266.597317	453047.392013
Hardwood trees	38462.297317	453186.292013
Mahogany Muvie	38462.297317	454081.792013
	38402.497317	454311.992013
Any other features	36951.597317	454081.792013

Approximate Sketch of Parcel

Approx North

5m =
10m =

Area (sq m) 111.485

TURNING POINT COORDINATES

Point	Norhtings	Eastings
1	38451.597317	453049.292013
2	38452.597317	453047.392013
3	38462.297317	453048.292013
4	38462.297317	453056.792013
5	38460.497317	453058.992013
6	38451.597317	453057.792013

Total Area (sq. meters)	111.485
Point to Point	Segment Length (meters)
6 - 1	8.5
1 - 2	2.147091
2 - 3	9.741663
3 - 4	8.5
4 - 5	2.842534
5 - 6	8.980534

PARTICULARS OF OWNERS

Owner / Spouse / Address	SEX	DATE OF BIRTH
John Smith	M	9/7/1980
Jane Smith	F	3/15/1981
One Main Street OurTown		

Full Names of adjacent owners
Joe Williams
David Jones

Comments
Parcel crosses two zones

PARTICULARS OF THE PARCEL

Third party rights	Current use of the land	Tenure type	Number of people living and depending on the parcel	Utilities	Water points / Easements
Animal pasture Communal well/spring	Commercial/Industrial Mixed farming	Leasehold	5	Telephone Running water	Bore hole Well

Figure 5. Sample land survey form generated by the GeoData database.

3. DEMARCATION AND SURVEY OF LAND CLAIMS

While globally only a modest fraction of land is surveyed and titled, most customers have an existing land administration with recorded titles or land claims. Challenges escalate when land records are lost due to war, natural disasters or mismanagement. In many cases the process to reconstruct such records is painstaking and tedious. While the reconstruction process is not specifically addressed here, we note that the system must cope with unresolved land conflicts that may take years or generations to resolve. One possibility is also to manage the reconstruction and claims process based on the DataGrid system. Receipts could be issued for claims that may be entered in a great variety of forms. Video documentation of testimonials has emerged as a way to cope with the large volume of claims after wars, natural or manmade disasters. The DataGrid system could be adapted to manage such claims and effectively reveal conflicting claims through visualization and other means utilizing all available information including for example maps and aerial or satellite photography.

3.1 Coordinate ambiguity

Most land claims are either in the form of a written description or in situ demarcations that may be traditionally known. In either case it is desirable to translate the claim to a digital record that is manageable by computer. Demarcated data can be effectively recorded using GPS to determine coordinates that can be recreated in the virtual world of the computer, on maps, or in the natural world should that be necessary.

However, any coordinate is subject to datum definitions. Even polar coordinates (latitude and longitude) are subject to definitions such as the position of the polar axis and the prime (reference) meridian. Even when these are agreed to, other complications come from the oblateness of the Earth and traditional ways of determining latitude based on the local horizon. The oblateness causes the vertical to not intersect the equatorial plane at the center of the Earth. The intersection point and therefore the latitude angle depend on the location on the Earth where the vertical was determined. It even depends on the method of determination. A surveyor using the local horizon to orient a total station would in general not agree with a navigator using the ocean to establish the vertical direction for use with a sextant, even if both made perfect determinations. The definition of a horizon is then inherently needed to define the latitude accurately. Differences in definition has negligible effect over short distances so that relative positions on scales of a few kilometers can be accurately determined but translation of their coordinates into a global or even national datum is more difficult since no single definition perfectly preserves relative positions. Also, a definition for shape of the Earth's gravity equipotential corresponding to the horizontal plane is needed. Such a definition at sea level is embodied in the widely used WGS 84 Ellipsoid so that GPS can give consistent positions on large scales. However, since high precision measurements are relative measurements they yield consistent results as long as all measurements relate to the same reference point or to reference points whose positions are accurately known in a common datum. The large-scale accuracy of the survey is limited to the accuracy to which the coordinates in these reference points are known and the accuracy to which the datum they are defined in is known in the Earth Centered, Earth Fixed Cartesian coordinates that are native to GPS measurements. The relation between coordinate systems (datums) is often the limiting factor to accuracy on the largest scales.

We note that records obtained using traditional survey equipment may have used multiple definitions for the horizon. In effect the horizontal plane changes every time a theodolite, total station or other commonly used survey instrument that depend on a reference plane is moved. This limits also their usefulness over large scales unless the errors are modeled. The corrections also require a model for the Earth's shape, which may be the WGS87 Ellipsoid. The scale is in practice limited to smaller distances since all measurements depend on one another so that errors accumulate. Zenith passage telescopes and accurate clocks can be used to extend the range of polar coordinates but only to a lesser degree for map datums.

3.2 Local and national coordinate systems

Many property surveys and other written descriptions are relative some reference point. Distances and directions are given. For this, it is also necessary to establish definitions. Are directions with respect to geographic or magnetic cardinal directions? Are distances along the horizontal plane? Modern surveys use well-defined systems but this was not always the case in historical records or records established using primitive methods. Usually the definition becomes obvious if the method used to generate the description is known.

A further complication can develop if GPSs and projections into a map datum are used to survey large tracts. Distances as measured using a perfect tape measure (free from sagging and thermally calibrated) are accurately reproduced when GPS native Earth Centered, Earth Fixed Cartesian coordinates are used. However this does not immediately give directions or the distance projected on the horizontal plane. To achieve this, some coordinate mapping routine is employed. The horizontal plane is defined in the map datum and this single plane is used to represent the entire region for which the datum was devised. Usually there are national map datums so that the plane represents a substantial portion of the globe. Distances in this system are given as Easting and Northing along this horizontal plane, which usually is well below sea level in the central parts of the map region and well above it in the fringes. Height which, thankfully is not normally part of property description, is not measured from this plane and is usually defined in a different system.

Properties that were defined using a common reference point have relatively high probability of yielding consistent property lines without significant overlap or unclaimed land. Larger problems that may require adjustments usually occur when property descriptions relate to different reference points. For the generation of large-scale consistent sets, it might be advisable to transform all property definitions to a common datum before adjustments are made. All local reference points should ideally be determined relative a common reference station with geodetic quality coordinates. With the possible exception of the polar regions, this can now be achieved anywhere in world using geodetic quality dual frequency receivers as long as the reference points have good view of the sky. This is not always the case and the best strategy might be to establish new reference points that can serve as GPS base station locations. The original reference points may then be determined in this system using a combination of GPS and total stations where necessary. All property lines could now be translated into this common datum and the adjustments made.

The datum could be the GPS native Earth Centered, Earth Fixed Cartesian coordinates as long as all non-GPS data are properly translated. Or, as long as the national datum is sufficiently well determined relative the Cartesian system it could be the reference datum. Advantages with the Cartesian coordinates are that they will remain consistent practically indefinitely as long as continental drift parameters are accounted for. All distances in such systems can be checked to arbitrary accuracy using a tape measure. Its disadvantage is that property definitions usually lack altitude information (nearly all of them) and therefore do not properly translate into the Cartesian datum without an elevation model. Erosion can change the elevations and potentially lead to ambiguities. The national map datum has the advantage of being two-dimensional and maps made in this datum may facilitate the integration of roads, streams and existing GIS data. The GPS native Cartesian system can be translated into a map datum but the reverse process is not possible without the addition of an elevation model. Best is probably use of the national map datum as long as reliable transformations parameters have been established. Map datum definition is therefore preferably an integral part of a systematic demarcation and survey.

3.3 Recording existing land claims

Once existing land claims have been translated and possibly adjusted they need to be recorded. While traditional records are handwritten or typed documents, the most reliable source for these land claims are now in digital and computer generated form. These are ideally the legal claims, if current law permits. Paper copies may be generated as real-world representations. Once the claims have been processed and ratified, they may become titles or similar legal entities. The distinction between the computer data being the legal source data or this status being bestowed upon the paper copy has significant practical ramifications. One is that a computer database can be distributed with the records residing as redundant identical records on multiple communicating computers. Such modern data systems while not immune to data loss or manipulation, never-the-less offer a level of resistance that is hard to duplicate with paper records. Proposed modifications can be stored but need not be transferred to the actual record until ratified by all parties required for a change. Identities may be protected using any number of modern authentication schemes including biometrics. All data in DataGrid’s GeoData land administration database can optionally be protected in this way.

Some land claims or land use claims involve 3-dimentional coordinates while others do not involve precise coordinates. Examples include tunnels, high-rise condominiums respectively fishing, and hunting rights. Many more claims fit in these categories and the desire to include these in land administration databases is increasing. The GeoData database software therefore has entries for these categories that can overlap other claims. In addition, legal rights may include tenure or leasehold alongside ownership and can be customized to a range of local definitions.

3.4 Recording new land claims

New land claims or claims that have not been recorded can be treated similarly to existing land claims as soon as the claim is demarcated. A nearby reference point that may be used for all nearby claims and titles need to first be identified or established. The coordinates corresponding to the demarcations would then be collected using GPSs and/or totalstations. These coordinates and related cadastral, demographic and other information may be recorded into digital format directly while in the field. Collected data can be checked on-the-spot for integrity using the DataGrid system to save the time and expense of return field visits.

DataGrid GPS/datacollector combinations can collect and safely store one day to several months' worth of field data in non-volatile flash memory depending on settings. These collectors can merge data from diverse sources such as data controllers, digital cameras or voice recorders. They can even collect biometric data for identification of for example stakeholders or other persons providing information. This includes fingerprint and iris scan as well as any number of card, tag or barcode readers. The collectors can capture data on soil conditions (moisture, pH-levels, Nitrogen levels, etc...), air quality (Radon levels, etc...), or can interface to other instruments or sensors that can communicate over Bluetooth, serial or analogue ports. All GPS/datacollectors can merge data from internal and external instruments with the GPS data stream so the time and location of data collection is saved. Collected data can thus be shown in context on a map using DataGrid GeoMapper software.

4. LAND ADMINISTRATION COSTS

While the level of initial investment in a land administration hardware and software system is an important factor, the larger expense is the generation (or transfer) of adequate and reliable records. The costs of manpower to maintain and operate the system dominate in the long-term. Simplicity and streamlined procedures are aimed at reducing personnel and training needs for overall cost containment and manageability of the workforce.

As a specific example we consider villages or other rural communities with an average of 50 properties that are to be demarcated and surveyed. Disputes should be adjudicated on-the-spot when possible and titles issued either in the field or soon thereafter. Reference points will be established and related to the local datum or any other reference system. All positions will be obtained relative to one or more such marker(s) near or inside the community. The distance to all markers is assumed to be less than 15 km. The total accuracy requirement for relative position within a village is 10 cm typical. Approximately 16,000 rural communities should be surveyed within 18 months. The end result should be an easy to maintain database since land certificates and titles need to be updated or amended due to property transfers (trade or succession), subdivision/merger, name change, or other changes affecting the certificates. Updates should be made reliably and at a low cost to prevent the database from becoming compromised or obsolete. Our example represents conditions in Central America (Honduras) and in Sub-Saharan East Africa (Uganda) that requires robust systems and procedures that do not depend heavily on infrastructure or extensive training. It might be beneficial to start planning for any environment from such a package. It is easier to adjust and tailor that package for cost and efficiency gains that depend on national or local laws and other restrictions, labor availability and costs, infrastructure and the overall state of development. A customized, more forgiving system may also yield great saving in total cost and efficiency in technically highly developed parts of the world.

The proposed survey process could be used to gather data on the land use and property conditions as well as owner demographic and other data beyond what is normally needed for land administration. This may include data on all stakeholders and dependents and will allow DataGrid's GeoData database to be extended into an efficient tool for the management of resources, the forecasting of future rural development needs and more. A major benefit is increased economic return and the possibility for cost sharing with other government programs or even with the private sector.

5. TEAMS APPROACH TO ESTABLISH EFFICIENT LAND ADMINISTRATION

Sensitization, land demarcation and survey are information and fact-finding activities that call for site visits. Searches of official records already on hand, database updating and maintenance, planning and coordination are activities that are best done in the office. It is therefore beneficial to establish teams with clearly demarcated responsibilities.

An **information / scheduling team** typically consists of a senior communicator and an assistant in training. The villagers and other stakeholders will in this way know the assistant so that he/she can step in for the senior communicator in case he/she is incapacitated. In some regions there is also a security aspect that makes it desirable for the team to consist of a minimum of two. An **office team** of eight operators capable of searching official land records and of computer data handling might be led by a manager. An office team should be capable of supporting several information / scheduling and field teams. The **survey/demarcation team** consists of 1 surveyor, 4 GPS operators, 1 base station guard, and possibly one driver/equipment-guard. The surveyor who has overall responsibility leads the team. He/she adjudicates disputes and performs the data processing in the field to assure data integrity. The four GPS rover operators need only two days of training which can be a brief instruction followed by "on the job shadowing". The base station guard needs no special skills. While there is a need to make sure that all cables are in good working condition and batteries are charged there is no need for a dedicated maintenance crew. It may even be an advantage if the field team is held responsible for the care of the equipment it uses. The composition and salary costs for these teams may be such as indicated in Table 1.

Table 1

TEAM	Personnel	Cost	Cost / team
Information /scheduling team			$45/day
	1 Senior communicator	$25/day	
	1 Junior/training communicator	$20/day	
Survey/demarcation team			$98/day
	1 Senior surveyor	$25/day	
	4 GPS operators	$15/day	
	1 Base station guard	$6/day	
	1 Driver	$7/day	
	(2 Monument makers)	$10/day	
Office team			$92/day
	1 Manager	$12/day	
	8 Operators	$10/day	

5.1 Recommended demarcation / survey procedures

The information/scheduling team plans the sequence in which sites will be visited by first generating a preliminary schedule covering the entire 18 month period. This list is given to the office team to retrieve any existing records. The information/scheduling team meanwhile informs stakeholders of the purpose of the demarcation and of the procedures that affect them. This involves scheduling the initial meeting with local leaders and with property owners/stakeholders. The aim is to first inform and "sensitize". For this more than one meeting might be necessary. The meeting is also used to identify and gain an upfront understanding of any outstanding property conflicts that have not been noted by the office team and to make sure that the information on all known conflicts is up-to-date.
The main objective is to accomplish a collaborative environment in this first meeting or set of meetings in which the survey date can be scheduled. This survey date should be approximately eight weeks after the stakeholders have been adequately informed. This should

accommodate stakeholders that may be working in distant sites or otherwise need adequate planning time. It will also allow the community to clear boundaries and otherwise prepare for the survey. At DataGrid we believe it is important that the survey date does not change except by request from the villagers (usually due to unforeseen events involving large fractions of the community such as funerals). We have seen that confusion about the date and sometimes distrust can result from rescheduling. In addition, effectiveness depends critically on resource management and efficiency may suffer if dates are changed.

It is best if a contact person in the village can be agreed upon at the time of the first meeting. This person should visit one or more other villages while they are being surveyed to be better able to help inform his/her peers. If this person is effective he/she can collect questions from the community and communicate concerns to the information/scheduling team. The information/scheduling team can then decide whether additional visits are necessary prior to surveying. The village contact person is an important factor especially when the initial meeting was not fully successful. Local political and/or cultural leaders can usually arrange or facilitate the meetings with property owners/stakeholders. (Since communities may vary, the setup of meetings may need to be modified in cases where for example traditional leaders still have much influence. Local knowledge can be very valuable.)

The information/scheduling team arranges to visit the community again the day prior to the survey to answer any remaining questions and make sure that the village is prepared for the visit. They also return the day of the survey to introduce the survey team see point B below. The survey team starts with preparations:

A) Charge GPSs, handheld computers or Personal Digital Assistants (PDAs) and any other chargeable equipment such as the drill. Charge MK-1 GPSs overnight or until the charge light is a steady green to guarantee full charge. 80% charge is reached after as little as one hour and allows 8 hours operation of the MK-1s so this may be just barely adequate. The MK-1s can also be charged from the car power outlet or from some standard chemical chargepacks. DataGrid also offers pole-mounted solar panel that will keep the GPSs charged at all times. Visually inspect all cables. The center leader in the antenna cables can be broken if there is a prominent kink in the cable. The connectors should be clean with the thread in good condition and the connector's center pin should be strait. Replace any damaged cable. All equipment should be packed in their protective transport cases or bags. Fuel the vehicle if necessary. Load equipment including instruction material and spare cables.

Once they are on site …

B) Meeting with stakeholders and local leaders. The information/scheduling team introduces the survey team. Part of the survey team can go on to C, D, E and F while the information/scheduling team and the surveyor answer any remaining questions.

C) Selection and demarcation of primary and alternate village reference points. All surveyed boundary points will be recorded relative to the primary reference point. A single reference point suffices to generate a fully self-consistent set of relative coordinates using GPSs receivers and suffices for legally valid certificates in most countries. However, creation of alternate references is recommended in part because of the possibility that monuments might be destroyed unless DataGrid recommended coordinates described below are recorded.

Although it might be possible to recreate marks from any of the surveyed boundary markers the accuracy depends on the information stored for all the points. DataGrid recommends that Earth-Centered, Earth-Fixed (ECEF) three-dimensional XYZ Cartesian coordinates be recorded alongside any coordinates that may be used in the legal description if different. This makes the establishment of alternate reference points obso;ite since any point in the survey can be used as a reference point. See the note on coordinate systems.

Reference points should be permanently marked. This can be using a rod forced into the ground, epoxied into rock, using a concrete monument or any other project approved method. All reference points should be in locations with an unobstructed view of the sky over which the reference or base station antenna will be mounted. Specifically the requirement is that radio waves from all GPS satellites that may be received by the roving GPSs can also reach the GPS at the base. If a given part of the sky is obstructed from all points in a village (such as might occur on a mountain village in the shadow of one or more tall mountains), satellites in the blocked part of the sky cannot be used by the survey anyway and need not be observed by the base station. While it is OK for the base station to be in a location with the same part of the sky obstructed, it cannot have a different part of the sky obstructed than what can be observed from any point in the survey. For example the base station could be on the summit when a hillside village spreads over slopes facing more than one direction, but it could not be to one side of the hill where it would at times be exposed to different parts of the sky than the rover. All reference points should be within 15 kilometers of the area to be surveyed.

D) Base Setup. Use the DataGrid supplied tripod at the base. This tripod extends to a standard height of two meters with a rigid pin indicating this height above the marker as long as the point of the pin is precisely positioned at the mark and the bubble in the integrated bubble level is centered indicating that the pin is vertical. (Consistent use of a preset antenna height reduces processing time since the antenna height entry is a default value and reduces the possibility of human error.) Mount the antenna and the GPS on the tripod before aligning it. The antenna screws onto the top of the tripod and the GPS mounts on one of the tripod legs using the supplied clamp or pouch. Connect the antenna cable to the antenna and to the GPS without forcing the connector to protect the treads. Make sure that the cable is fully seated in the connectors on both sides. To save time, you may turn the GPS on at this stage so that its internal processor may boot and the receiver may acquire satellite signals. You can do so by turning the rotary knob to “KINEMATIC”. The knob is set in the “kinematic” position at this stage so that any GPS data collected during this period will not be used to define the reference point. This is because the antenna is not yet properly aligned.

To align the antenna, first firmly plant the three legs of the tripod using the foot-steps to force the tips into soft ground or carefully select suitable points such a fractures in a rock. Adjust the length of the leg with a screw fixed length first and then that of the other two legs one at a time until the bubble is centered. The bubble will first be centered in the direction between the screw fixed leg and the leg being adjusted first neglecting any displacement perpendicular to this direction at this stage. Finally, the third leg is used to move the bubble in the perpendicular direction until it is fully centered. An iterative process may be used if necessary by adjusting one leg at the time.

Now, turn the rotary knob to the “STATIC” position indicating that the antenna is properly aligned and stationary above the monument. The GPS must acquire signals from a minimum of four satellites and establish a carrier phase lock before rover measurements can begin. This usually takes from two to four minutes. The MK-1 indicates that it is in search mode by a ticking sound. The MK-1 goes silent when it has acquired reception of at least four satellite signals. Phase lock on the carrier signal is achieved soon thereafter and the data is valid.

The MK-1 indicates through an audio signal and by the "Valid Position" status light (labeled V.P.) glowing a steady green that it has established and successfully maintained phase lock for three minutes or more. The MK-1 will indicate changes in the number of satellites it tracks using an audio signal that counts out the number of satellites through an equal number of beeps and through the flashing of a status light. One can make sure that the GPS works properly at any time by simply observing the indicator light labeled V.P. for "Valid Position". The light should glow green. The MK-1 will sound an audio alert as well as changing the V.P. indicator light from green to red if phase lock on the carrier signal is lost for any reason. Loss of lock compromises the ability to yield good rover positions and should not happen as long as the placement of the base is indeed in a location with unobstructed sky. If this still occurs, the antenna cable is likely to not be properly connected or faulty (replace with spare cable). The base station guard is to alert the operators of the rovers and the surveyor of this or any other malfunction such as low battery (also indicated by audio signal) using the Walkie-talkie. The power requirement is modest at approximately 1 Watt which allows a fully charged MK-1 Crane GPS to operate for 10 hours or more. Most DataGrid GPSs, including the MK-1 and Toughman can be connected to external regulated or unregulated power such as a solar panel.

E) Rover Setup. The DataGrid standard package has a two-meter pole in two one-meter sections. (An often-useful upgrade is an extendable pole that needs no assembly and can extend to eight meters thus reaching above many natural or manmade obstructions.) The two one-meter sections of the pole screw together – no tools required - and the antenna similarly screws on top of the pole. Next, attach the GPS to the pole using the supplied bracket and the PDA, also using its bracket. Attach the antenna cable to the antenna and to the MK-1 and check the connections similarly as for the base station. Connect the communication cable to the PDA using its bottom connector and to the MK-1. The red dots on the MK-1 and the cable need to be aligned. Once aligned, simply push until the connector clicks in place. (The cable can be eliminated if the Bluetooth option is ordered. Note that cables can catch on vegetation and are maintenance items so it might be more efficient and also more economical to order the more expensive Bluetooth option.) Position the pole over a secondary reference point or a boundary point to be surveyed. Use the bipod to steady the pole by firmly planting the bipod legs in soil or carefully positioning the legs on hard ground similarly to the tripod setup (see D) and then adjusting the length of the bipod legs, one at the time until the bubble in the integrated level is centered. Turn the rotary knob to "STATIC" and wait for the ticking sound to cease and the "Valid Position" light to come on. The rover GPS has now acquired carrier phase lock on at least four satellites and the base station is logging similar data for the same four satellites or more as long as the procedures have been followed properly. Surveying can now start.

F) – may be needed. Rover Reinitiation. The rover might need to be reinitialized if obstructions interfered with reception of the GPS signals. This is indicated by an audio signal and the Valid Position indicator light changes from green to red. The MK-1 then needs to remain in static position for a minimum of three minutes after the carrier lock is achieved on at least four satellites to again yield accuracies in the acceptable 10-centimeter range. If the rover GPS is allowed to remain stationary for 10 minutes or more, the accuracy of the current and also subsequent measurements may be higher. This higher accuracy mode may be desirable for establishment of alternate reference points or in salutations such as very small properties for which increased accuracy might be called for.

G) Interview with owners/stakeholders, temporary marking of property limits and first GPS occupation. The two most experienced GPS operators carry out interviews with property owners/stakeholders. They make entries such as stakeholder name, property tenure type and deed restrictions directly into the GeoData application program. They also take pictures of the interviewed party and the property. The camera can be standalone or can be integrated in a field computer notebook. (Currently a notebook computer is needed to enter the database information but DataGrid could develop a PDA version of this software for PATH.) The interview is best made onsite where the property, land features etc., can be seen and photographed but can also, in part, be performed in a community house or equivalent prior to the actual site visit. This may be necessary during inclement weather conditions but should normally be avoided. During the site visit the owners/stakeholders indicate their property limits, usually in the presence of adjacent property owners and the village elders. The property corner points (or infliction points) may be marked using permanent markers or, to improve overall efficiency, they may be marked using spray paint. The second set of GPS operators are then charged with making the monument before they carry out the second measurement. Alternatively the first set of GPS operators establish and demarcate the border leaving to the second set the task of collecting data on the property and picture taking. (It is advisable to have a bright primary paint color and a dark or neutral second paint color that can be used as an eraser.) In case of dispute, the team leader (surveyor) might be called (by Walkie-talkie) and attempts to adjudicate any disputed boundaries or ownership issues on the spot. Sometimes adjudication is deferred to a village meeting. In cases where agreement cannot be reached all claims are marked using the temporary marks and are treated equally. The affected property forms are marked as disputed claims. (This is done using a simple checkmark in the GeoData software. There is also an entry for notes on the nature of the dispute.) The first occupation or GPS surveying of the marked point can now take place. Any point can be surveyed following the procedure F. It is also possible to use the faster alternate procedure I. (Note that the first boundary mark to be surveyed could be the rover initialization point F.)

H) Simple measurement procedures. After the initialization F or any other static measurement and prior to any antenna movement, turn the rotary knob to “KINEMATIC” to indicate that the antenna can now be in motion. Walk to the next point to be surveyed, position the surveying rod as described in E and repeat rover initiation procedure F by turning the knob to “STATIC” and collect three minutes of data. You may then repeat until all points have been surveyed.

I)-alternative. Faster alternate measurement procedure for favorable conditions. It is possible to speed up the data collection at each point from three minutes to a single second under favorable conditions. This requires that there is no loss of lock on the satellite data. As soon as there is a loss of lock (indicated by audio and visual signal from the MK-1s) there must again be three minutes of data collection at the next data point to be surveyed (follow procedure F). Lock is easily maintained in an open environment with clear view of the sky as long as the operators take care to not cover the antenna during transportation, tilt the antenna by extreme angles, or otherwise cause the antenna to lose exposure to the full sky. Experienced operators might make this procedure successful in somewhat more difficult environments. Note that the time to move from one point to another, establish the boundary and mark the point and to a lesser extent alignment of the rod may be the dominant time requirement so while the time saving may appear impressive actual time saved may be less dramatic. Still, there can be important savings so we review these practices below. We then propose a hybrid procedure for best efficiency in alternative J.

After the initialization F or any other static measurement, turn the rotary knob to “KINEMATIC” to indicate that the antenna can be in motion and walk to the next point to be surveyed, just as in procedure H. It is sufficient to position the surveying rod and press the push button labeled “Mark” to assure that the GPS data collected at the second the mark button was pressed is associated with the boundary marker. A note can be entered on the PDA or notebook computer to identify the marker. (It is recommended that each marker be given a unique identification number. At first this may be marked with spray-paint and it may be imprinted on the permanent mark.) The survey rod might be hand steadied for even greater time-savings since this is a single second measurement. (The MK-1 will notify the operator if the data is not good through the audio signal and the Valid Position indicator light changing from green to red. In this case, simply revert to procedure F.)

J) -alternative. Best efficiency procedure under most circumstances. Each point is demarcated using temporary point marking and then immediately surveyed since this optimizes overall efficiency by minimizing displacement time (each point is visited two times instead of three times). Alternatively the point is demarcated using a permanent marker and the interview process is left to the second set of GPS operators. These procedures improves stakeholder confidence since they observe the actual demarcation and measurement. It improves reliability since stakeholder presence practically eliminates the risk that the wrong point will be surveyed. In practice, the rover is left stationary (in an arbitrary point) while the boundary point is agreed upon and is marked. This period can routinely be used for re-initialization process F without time loss since this would otherwise be unused time. The initialization can take place at an arbitrary and unknown point but it should have good view of the sky (should not be under a substantial tree, sufficiently small trees or bushes may be OK – again look for the Valid Position indicators). During this time, the operator may also enter an ID code for the surveyed point and record a note on the PDA. Optionally, a picture documenting the demarcated point may be taken for the record.

While re- initialization is only necessary in the even that lock has been lost, this opportunity to reinitialize relaxes demands on the GPS operator who needs no longer be overly concerned about loss of lock and can follow the easiest path to the next point without care to avoid passage under trees or protruding rooflines. Use of what would otherwise be “downtime” for the GPS guarantees that the fast procedure I can be used as long as the rover can be moved from the static reinitializing point without loss of lock. (This means without the sky being blocked by major obstacles. Again, the GPS will automatically alert the operator if lock has been lost.)

K) Second GPS occupation. The less experienced GPS operators (trainees) follow behind the first set so that each point is surveyed twice with a minimum of 20 minutes separating the two survey sessions or occupations. When the second set of GPS operators arrive at a point to be surveyed they first demarcate the point if this was not done by the first set of GPS operators. They may make a concrete monument or use a rod marker in the case of soft ground, or a drill and epoxy to fasten the rod in the case of hard ground such as rock or use any other marker procedures that may be prescribed. The point ID number may be marked on the marker rod in advance or may be marked using any project-approved method. The reinitialization procedure F can take place while the demarcation is made or while property data and pictures are collected (similarly to alternative J).

There should be a minimum of twenty minutes delay between the first and the second GPS occupation. This assures that satellites have moved sufficiently in the sky so that any erroneous solution resulting from multipath or other geometry dependent errors yield different results for the two sessions. (Note that even a small formal measurement error can cause errors that exceed the 30 to 40 centimeter tolerances under unfavorable circumstances. It is therefore best to not depend on formal error estimates alone. Human errors such as caused by incorrect antenna positioning are also usually detected using this method since different persons make the two measurements.)

L) GPS Data Upload. GPS rover operators may have to return to some locations to gather additional data should some of the collected data not be good for any reason. This includes the possibility of erroneous positioning of the GPS rod and other human errors. As indicated above, the double occupancy is used to discover such instances. The collected data is therefore uploaded into a computer and processed to allow for “integrity checking”. Connect the GPSs to the notebook computer one at the time starting with the rovers. (Or simply connect using Bluetooth wireless if this option has been ordered.) The GPS should be left in the KINEMATIC mode they are in since they are being moved. If the MK-1s have been turned off (in case there has been a rest break presumably), turn the rotary knob to “Kinematic” (“Static would also work for this purpose but is not recommended unless the antenna is disconnected. This is only so that any data that might be collected during this period is not temporarily confused for a survey point). Now upload the data using the GeoID software. It is important that the base data covers the entire GPS data collection period, which is the reason that the base data is uploaded last.

M) GPS Data Processing. The primary function of on-the-spot data processing is to assure that all collected data is good. The data is processed using GeoID in its automatic mode right at the field before the base and rovers are knocked-down. The GeoID software will ask if the coordinates of the base are known. Since they are not known, the operator should click on unknown and the software will estimate the position of the base using the base GPS data alone – we could also eliminate this entry in the version for PATH to streamline operation. (The base position does not matter for our purposes since we will use relative positions to the reference point with the base only so those do not depend on the accuracy of the base determination.) Double occupancy for every point allows for a way to check the data for integrity. If the solutions do not agree within preset tolerances, the suspect data point is selected for a third occupancy that usually agrees with one of the previous results which is then deemed to be the correct solution. This way, unreliable data is weeded out and replaced before the team leaves the survey site.

N) Form Generation. A draft form or a land certificate can now be generated and printed on the spot using the GeoData program and distributed to the owners if desired (depending on legal requirements). In many cases it is desirable to wait with this process until the record has been checked, officially approved, and entered into a main database, see points Q and R. In other circumstances it is deemed advantageous to complete the survey on the spot and distribute certificates for goodwill and to economize a return trip.

O) Concluding meeting in village. It might be suitable to have a concluding meeting even if certificates are not distributed on the spot. Villagers are informed of the next step (supposedly either receipts of the certificate, a statement that their record has been successfully entered into the official database, or a notification of a hearing to resolve a land dispute). This might also be an opportunity for stakeholders to ask any remaining questions that may have developed as the day progressed and many of them observed the survey work first hand.

P) Rover knock-down. Simply disassemble the components and return to their respective protective cases. Load onto the vehicle. It is suitable to keep a checklist of all equipment to make sure that nothing is left behind. It may also be suitable for each operator to be responsible for his or her equipment.

Q) Base Knock-down. The base needs to be the last to be knocked down since it is needed should there be a call for more data collection. The base station is disassembled similarly to the rovers (see P).

Back in the office …

R) Disputed forms processing and certification of data forms that are not disputed. All data from the field are transferred from the field computer to the office server (preferably using wireless LAN). Disputed claim forms are separated out using a simple search in the GeoData database. They need to be processed according to predefined legal procedures. This process depends on prevailing law and is not further discussed here. The remaining forms may need to be crosschecked against existing official documents and claims before the forms are certified.

Some countries also require that the GPS data be processed against a second base station and that the results agree within preset tolerances. If this is required it is in principle possible to use online base stations adhering to the standards such as the International Geodetic System (IGS) stations. In practice these are too sparsely distributed and there can be data outage so it is prudent for the demarcation team to operate a second base station should this requirement be in effect. The station can be mounted for example on the field vehicle for easy deployment. If the measurements are to be tied into a national map datum it is best if that station is deployed on a certified survey point. The relative positions in the village can be transposed onto any map datum in which the survey point is certified at any time so such surveying can be deferred without loss of information.

Sometimes sufficiently accurate officially certified survey reference points couldn’t be found within 15 km of the village. In this case a reference point may have to be created (one can use a set of MK-1s for this purpose or DataGrid can supply dual frequency geodetic quality GPSs) or all data may have to be relative to the reference points. In the case of a second base station on a certified point, the local base data (from the unknown point) should be processed first against the known base to establish the position of the local base. Then all data may be processed against both bases indicating that the base coordinates are known when this question appears in GeoID and then simply follow the instructions in the program. This should give four solutions for each point because of the double occupancy. All four solutions should agree to preset tolerance before the survey is accepted and can be certified. Local or national laws may have different or additional requirements.

S) Uploading into master database. Certified forms should be uploaded into a master database. (The GeoData field data collector works like a more limited capacity database holding approximately 100,000 certificates and its related data. The exact number of records depends on the amount of information in each certificate and the size in Mb of the related pictures.) DataGrid can supply the software, hardware and training for the national database as well.

T) Distribution of official certificates if not already distributed. The distribution of certificates or notification that the certificate has been recorded might be the closure of the process to the stakeholders once forms have been turned into certificates and are uploaded into the national database.

5.2 Hardware/software equipment and supplies

5 Mk-1 Cranes, 1 Tripod, 4 survey rods, 4 bipods, 2 digital cameras, 4 PDAs, 1 Windows XP field computer, 1 field printer (for field generated forms or certificates - optional), 1 seven piece Walkie-talkie set, 2 cordless drills (depending on markers used), complete set of cables plus one set of spares, protective cases and bags. Masonry tools for monument-making and a seven-passenger vehicle, nine office computers and one server for the office team, printer, telephone access etc… are the main components. One smaller vehicle may be used by the information/scheduling team. Software requirement is GeoID with the GeoData module. Disposable Equipment includes paint in spray cans, printer paper and ink cartages, markers, epoxy glue, concrete and other monument making supplies.

5.3 Estimates of total project requirements and costs

Survey equipment excluding industry standard cameras, Personal Digital Assistants (PDAs), Windows computers, printers, Walkie-talkie sets, and drills cost approximately $16,000 to $20,000 US per set depending on options. This is based on quantity pricing for 100 or more GPSs and is before any taxes and import duties. DataGrid can also supply office or rugged computers, PDAs, printers, Walkie-talkies, drills and cameras.

Each team demarcates and surveys one village/community per day and can therefore total 450 to 500 villages/communities in the 18-month period. Since there are 16,000 villages or communities 32 to 36 teams are needed to cover the project. According to these estimates equipment costs are approximately $1M (not including vehicles). GPS equipment costs are $720k or less with approximately $300K for computers and related equipment. Wages dominate costs. Depending on the difficulty to retrieve documents, one office team of eight plus a manager might be able to serve all information/scheduling teams and all field survey teams. Wages will then be approximately $3M to $3.5M. Vehicle and other transportation costs might be estimated to be of the order of $1M. The total cost of $5M to $5.5M may therefore be adequate for the entire project. This corresponds to $6.25 to $6.7 per property.

Potential savings are in personnel costs while the largest treat for cost overrun and delay is if the office team is understaffed or if any personnel (office or field) are inadequately trained, under equipped, or otherwise inefficient. Spare parts must be promptly ordered and delivered. DataGrid can deliver to most locations but may have to charge extra for transportation to remote areas. Note that antenna cables (the most vulnerable component) adheres to industry standards and is therefore relatively easy to obtain from third parties. It is economical and prudent to emphasize personnel screening prior to selection and to invest in training. DataGrid offers such training and can also assist in the screening process.

It may be tempting to skip the reoccupancy of survey points but this on-the-spot quality check reduces or eliminates inaccurate data. Errors may surface at a later stage in the absence of this check which may require a return to the survey site and adjustment to certificates. Such quality slips, can easily lead to much higher costs and may damage confidence in the overall process leading to reduced value of certificates. We note that the GPS surveying cost proper is small if we compare to the cost of demarcation without GPS surveying. This is because the GPS measurements are tightly integrated into the demarcation process. The combined demarcation and survey process as recommended here might cost as little as 15% to 20% more than demarcation alone.

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BIOGRAPHICAL NOTES

Bo Gustafson earned a Ph.D. in Astronomy from Lund University in Sweden in 1981. His activities in theoretical and experimental Astrophysicist earned him awards and recognition from NASA and the International Astronomical Union (IAU) who named an asteroid in his honor. Gustafson is President of DataGrid Inc., 1022 NW 2nd Street, Gainesville, Florida, 32601, USA, a company that he founded to bring the technology of space science to bear on the plight of developing countries and for overall improved efficiency and reliability in land administration and other large scale human endeavors. Gustafson is also a Professor of Astronomy at the University of Florida and Director for its Laboratory for Astrophysics where his team has developed and built instrumentation for NASA, ESA and other space agencies in addition to performing fundamental research on radiation and its interaction with matter, a topic of great relevance in GPS technology.

CONTACTS

Prof. Bo Gustafson
DataGrid Inc.
1022 NW 2nd Street
Gainesville, Florida 32601
USA
Tel. +1 352 371 7608
Fax + 1 352 371 3128
Email: bo_gustafson@datagrid-international.com
Web site: http://datagrid-international.com