Differentiating between recreational and professional grade GPS receivers

Summary

Based on price alone, the purchase of recreational GPS units to act as the core of a GIS data collection system can appear the obvious answer. However a more thorough investigation into the different aspects of GPS receiver performance—the logistics of gathering data in the field, postprocessing requirements, integration of peripheral devices and the ease of workflow—is necessary to make an informed purchasing decision.

This paper discusses the differentiators between recreational and professional GPS receivers that should influence the buying decision of a GIS user. Although professional grade GPS units are initially more expensive to purchase than their recreational counterparts, the return on investment achieved by using these units will very quickly surpass the initial outlay.

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Introduction

With increasing pressure to do more for less, the option of building field data collection systems around inexpensive recreational GPS products may initially seem quite tempting. Aimed at outdoor enthusiasts such as hikers and mountain bikers, these products provide features that at first glance seem sufficient to do the job—and with price tags far below GPS systems specifically built for the GIS professional.

However a more thorough investigation into the different aspects of GPS receiver performance—the logistics of gathering data in the field, postprocessing requirements, integration of peripheral devices and the ease of workflow—is necessary to make an informed purchasing decision.

This paper discusses the differentiators between recreational and professional GPS receivers that should influence the buying decision of a GIS user.

The following questions should be asked:

- Is the GPS receiver capable of the accuracy you need?
- Will it work as part of a GPS data collection system?
- Will it work as part of a larger enterprise system?

Section One: Accuracy of the GPS receiver

In this section we will look at the technology in a professional grade GPS receiver that sets it apart from a receiver designed for recreational use. A section on testing will compare a Garmin Map76 receiver and a Trimble® GeoXT™ handheld. We'll also look at the way accuracies are specified, and the importance of metadata.

1. Designed for different purposes

Recreational and professional GPS units are designed for different purposes. Recreational units are designed to acquire a location fix quickly without the need for pinpoint accuracy. To achieve this, as well as meeting the lower cost requirements of outdoor enthusiasts, most recreational units give a position regardless of the quality of GPS signals they receive. For some uses this is perfectly adequate. Hikers, for example, can generally find what they are looking for once they get within 10 meters of it.

Professional GIS users typically require very accurate placement of features, often within a meter or better, so that data layers can be overlaid and intricate spatial relationships determined. A position that is tens of meters out can lead to mistakes in subsequent decision-making, and for many applications, an inaccurate position may well be worse than no position at all.

2. Professional grade hardware

To reliably achieve the submeter level of accuracy that is the prerequisite of modern GIS systems, professional GPS positioning is required. In addition to real-time differential or postprocessed differential correction, a higher specification in both hardware and software on the GPS receiver is required, to obtain this higher level of accuracy. Many recreational GPS receivers are capable of real-time differential correction, but do not have the ability to postprocess, and even with the availability of the strongest, most accurate differential correction signal, recreational receivers are simply not built to achieve submeter accuracy.

Although many design features contribute to this higher level of performance, three main factors—GPS quality control, electromagnetic shielding, and antenna technology—set professional grade products apart from recreational receivers.

GPS quality control

Professional GPS units give users control over the quality of the position points that are collected. Through a simple interface, the user can establish specific thresholds for acceptable data quality. For example, selecting the minimum geometry requirements of satellites, and elevation above the horizon needed to achieve suitable accuracy, or configuring the receiver to disregard any satellite signals that suffer from excessive noise interference.

These quality control settings essentially allow the user to filter out any poor data that may degrade the overall quality of the location coordinates, resulting in greater accuracy in the final dataset.

Recreational units will typically collect all data—the good and the bad and the ugly—but this 'productivity' can come at the expense of accuracy. And data from a recreational unit contains insufficient information to enable postprocessing, so that if real-time differential correction fails, there is no alternative but to use autonomous data.

Both recreational and professional receivers often support Satellite Based Augmentation Systems (SBAS), such as WAAS in North America, to improve the accuracy of their positions. However, even in areas of SBAS coverage, periodic obstructions in the line of sight to the SBAS satellite may result in a mix of corrected and non-corrected positions. Because recreational receivers do not flag positions with their correction status, the GIS manager has no way of distinguishing between the corrected and non-corrected positions. (See section at right on the importance of metadata).

The importance of metadata

- Metadata is information about the GPS coordinates you have collected. This can include the date, the datum in which you recorded the original coordinates, time of day, maximum PDOP, receiver type, name of base station used for correction and so on.

- Most recreational receivers will only output basic metadata and do not include enough information to enable postprocessing. Even if postprocessing is not required, an organization will find it hard to cope with data that has variable accuracy and no metadata to help them interpret it. Information collected this year might still be sitting in a database or GIS in five years time, and whoever is relying on the data to make decisions—without knowing its origins—could easily end up basing their decision on substandard data. 'Creeping' errors are compounded when already erroneous data is used as the basis for further data collection.

- By contrast, a professional grade receiver will provide additional information about each position. This will include the date and time the position was collected, and under what conditions, as well as information about the quality of the position, and therefore how the data can be used.

- Recreational units that support SBAS corrections will not typically report which positions are SBAS-corrected, and which are not. So even though they might be giving you a 3 m corrected position one minute, accuracy might be 15 m the next minute. And without metadata you have no way of knowing which positions are accurate. But more importantly, you'll never know—especially five years later when you might need to make a decision based on the data.

Electromagnetic shielding

By their very nature, GPS signals are extremely weak and are easily degraded by interference from nearby electronic devices such as laptop computers or Personal Digital Assistants (PDAs). In cobbled together solutions, a GPS receiver is often connected to a computer or a PDA for data collection, and interference from the PDA can 'bury' the signal in electronic noise. High end GPS products by contrast, are designed with advanced shielding technology that minimizes the effects of stray electromagnetic signals from other equipment

Antenna technology

Acquisition of quality GPS signals requires a well-tuned antenna. The antennas provided with professional grade GPS units are designed to allow poor quality signals to be distinguished from high quality signals, for better operation in most environments. Patch antennas—the type commonly used in professional GPS receivers—benefit from a large integrated groundplane to improve signal strength and reduce the number of poor quality signals reaching the antenna.

When receiving transmissions in built-up urban environments and under tree canopy, there is degradation of accuracy due to multipath signals. GPS signals have been degraded by being reflected from buildings and other overhead features on the way to the receiver. While the antennas on professional receivers are designed to recognize and filter out multipath signals, many recreational receivers have no multipath mitigation at all. This means that some recreational receivers appear to track better than professional-grade receivers in difficult environments—however the positions derived from these measurements may be so badly affected by multipath that relying on them is potentially worse than having no position at all.

How is accuracy specified?

If you were to repeat a particular GPS measurement many times over a period of several hours, the horizontal accuracy of individual positions would vary significantly. Some positions would have very small errors and others large errors. Different measures can be used to specify a GPS receiver's accuracy. They all describe the same spread of errors, but in different ways. It is important to compare receiver specifications using the same statistical measure.

The measures of accuracy that are commonly used by GPS manufacturers are as follows:

- Circular Error Probable (CEP): A circle's radius, centered at the true antenna position, which contains 50% of the points in the horizontal scatter plot. Thus the CEP represents the horizontal distance from truth within which at least 50% of the recorded positions fall.
- Horizontal Root-Mean-Square (HRMS): The horizontal distance from truth within which 63% of positions are predicted to fall.
- Twice distance Root-Mean-Square (2dRMS): The horizontal distance from truth within which 98% of positions are predicted to fall.

It is possible to convert between these different measures using the following table of theoretical equivalent accuracies.

	HRMS	2dRMS	CEP
HRMS	1	2	0.83
2dRMS	0.5	1	0.41
CEP	1.2	2.4	1

To convert from a statistical measure on the left hand side to a different statistical measure on the top, multiply by the factor in the intersecting cell.

3. Comparison of recreational and professional GPS accuracy

For this paper, two different tests were conducted to compare the accuracy obtained from a recreational grade GPS receiver with the accuracy obtained from a professional grade GPS receiver.

The first test was conducted under optimal conditions to see how the receivers compared in favorable conditions, while the second test was conducted in a typical suburban park environment, to compare the GPS receivers under more typical mapping conditions.

Open static DGPS accuracy

The graph in Figure 1 shows the distance from truth of positions generated by a Garmin Map76 recreational receiver (the blue line) and the distance from truth of positions generated by a Trimble GeoXT handheld professional receiver handheld (the yellow line).

The data was collected side by side, with the same view of the open sky, for a period of 80 minutes. Both GPS receivers were supplemented with a differential GPS signal from a local radio broadcast.

The GeoXT handheld performed well, with an HRMS of 57 cm for this data set. The Garmin Map76 gave an HRMS of 3.4 m and showed a large degree of variance.

And even though the Garmin data had an HRMS of 3.4 m, some positions were as far as 10 m from truth, despite this being the best possible environment in which to log data.

As conditions become more marginal—as they often are in real world data collection environments—the accuracy of recreational receivers tends to degrade more quickly than that of professional receivers, mostly because of the recreational grade receiver's inability to distinguish and filter out multipath signals.

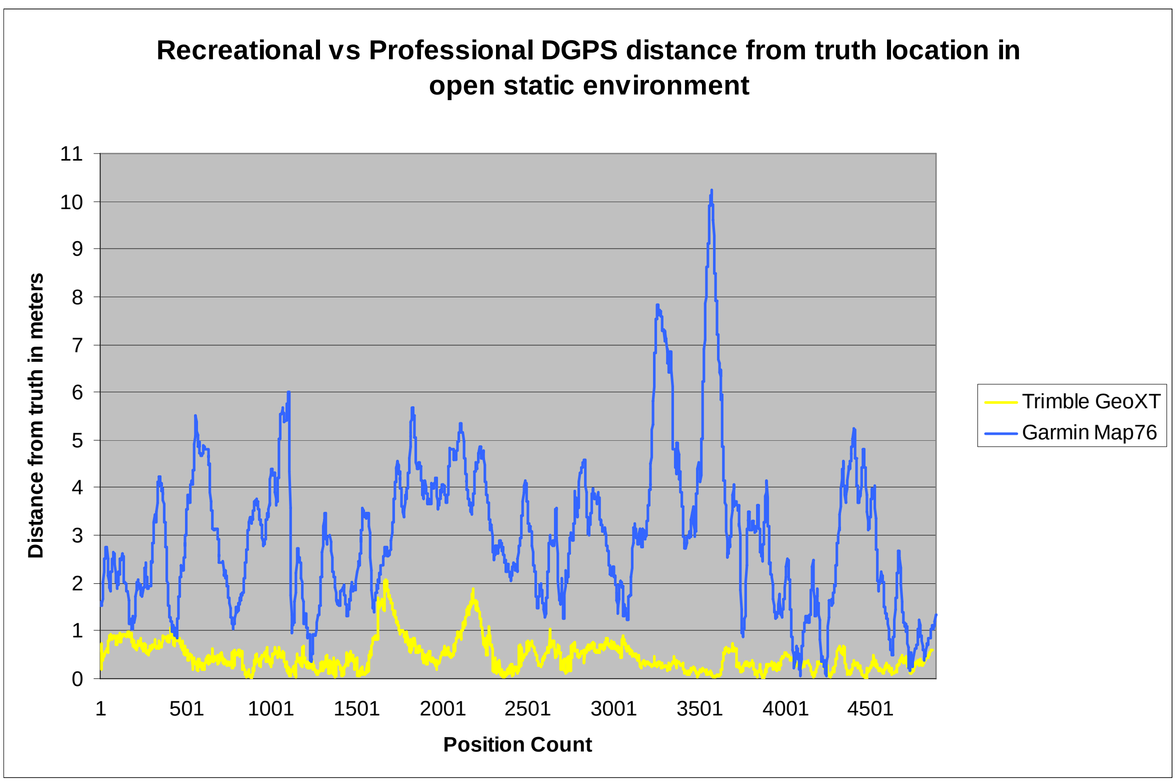

Figure 1: Recreational versus professional GPS receiver accuracy

Park mapping exercise

A simple mapping exercise was undertaken to compare the effects of more typical mapping environments on GPS accuracy.

Suburban park amenities such as trash cans, park signs and gates were mapped, in conditions that included multipath from tree canopy and other structures, and relatively poor satellite geometry due to an obstructed sky view.

Data was collected side by side on the Trimble GeoXT and the Garmin Map76, at each of the features. As with the open static test, both receivers were supplemented with a local radio DGPS broadcast to provide DGPS accuracy in real time.

At each feature, 30 seconds of GPS observations were averaged into a point feature position, concurrently on both receivers. A total of seven features were visited and then the process was repeated, until each feature had been mapped five times.

The HRMS for all 35 mapped points was 87 cm for the Trimble GeoXT, compared to 6.17 m for the Garmin Map76.

The HRMS for each of the individual features mapped is shown in Figure 2 and varies from 4 m to 10 m with the Map76, while ranging from 60cm to just over a meter with the GeoXT.

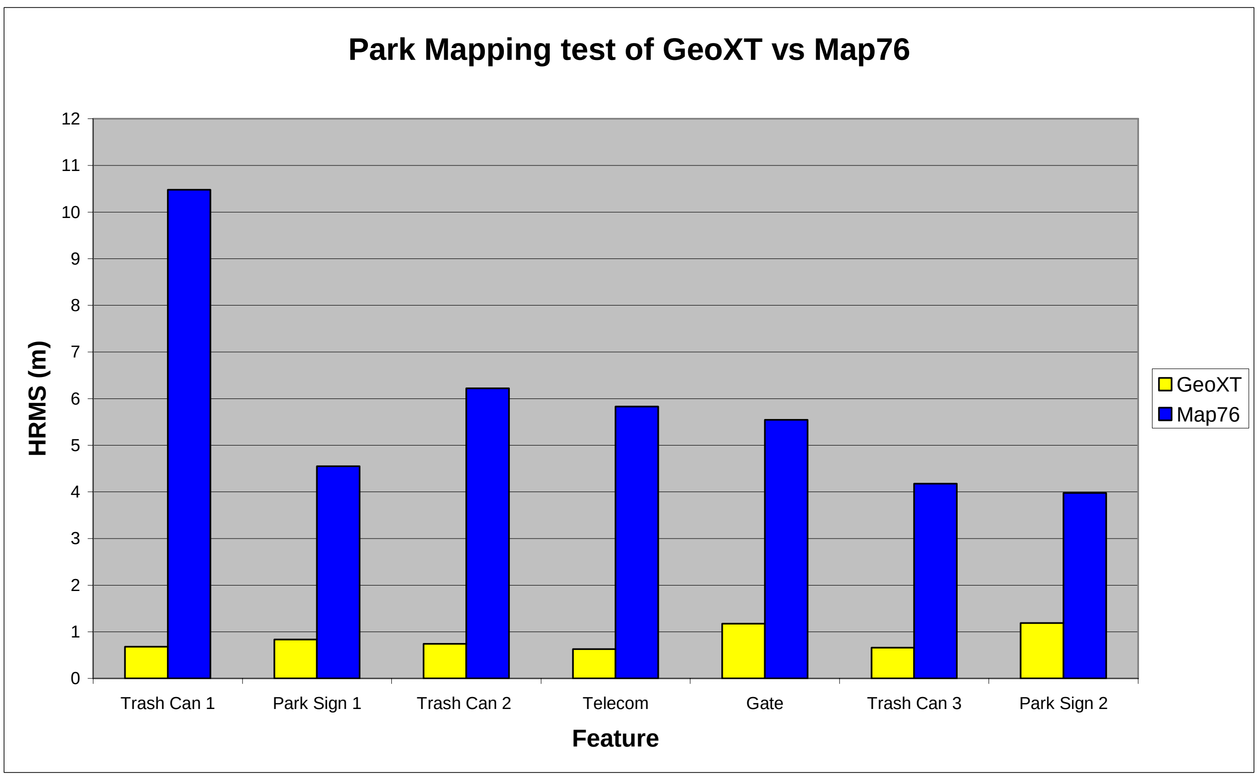

Figure 2: Comparison of recreational versus professional receivers in a park environment

Section Two: System performance

In this section we'll look at how a GPS receiver performs as part of a data collection system, basing our assessment on three key areas.

1. Integration of the GPS receiver with a handheld field computer
2. Compatibility with GIS field software
3. Compatibility with peripheral devices for data access (such as a mobile phone) or data input (such as a digital camera).

1.Integration

Professional GPS handhelds are rugged, purpose-built units providing GPS antenna, receiver, all-day battery and an open software platform, all within a single, handheld computer. Recreational GPS handhelds are typically rugged or semi-rugged units with reasonable battery life, with limited capabilities due to their proprietary operating systems.

To collect detailed data for a GIS requires the use of GIS field software such as ESRI's ArcPad software, which in turn requires a Microsoft® Windows Mobile™ operating system. To use a recreational GPS handheld for this type of work requires it to be cabled to some kind of field computer, typically a low cost PDA (see top left in Figure 3 below).

This immediately introduces a cable connection and a non-rugged computer with poor battery life and poor data security into the equation. No matter how rugged and reliable the recreational GPS receiver itself, it is only part of the system. And the system is only as good as its weakest link. In this way, integration is closely linked to ruggedness.

Figure 3: Recreational versus professional GIS mapping systems

The situation is compounded if a beacon receiver is required for real-time differential correction. Figure 4 show the complexity that results from extending a system based on a recreational receiver, compared to the simplicity of adding to a professional receiver.

In the system built up from the recreational GPS receiver, each device has a separate battery that requires charging and monitoring, and a separate user interface. The recreational type system is clearly unwieldy to use, while the professional system uses cable-free technology and a user interface centered in the handheld software.

Many recreational receivers use consumable batteries which require continuous outlay through the life of the product, whereas a professional GPS unit has a single, reliable, high capacity battery which lasts a full day in the field and is rechargeable in the unit each night.

Integration (and related ruggedness) does add to the initial cost of a professional GPS handheld computer, however, any additional outlay can be very quickly recovered through reduced downtime and fewer return visits due to reduction of field failures, poor battery life, lost data or bad weather.

Figure 4: Recreational versus professional GIS mapping systems with real-time DGPS accuracy

2. Compatibility with field software

Field software is a critical component of a GIS data collection system as it defines what types of data can be captured, as well as how data is stored and displayed to the operator.

In addition to influencing the degree of compatibility with the enterprise GIS system (discussed further in Section 3), the functionality of field software dictates the productivity of field crews and is therefore central to the overall cost of a data collection project.

The following section outlines issues which must be considered when evaluating the compatibility of a GPS receiver with field software.

Choice of field software

Professional GPS receivers have an open (Windows-based) operating system that allows the user to select or create their own field software. Field software is generally one of the following:

- GIS specific—such as ESRI's ArcPad which is the mobile solution for ESRI's ArcGIS product.
- Application specific—such as GeoSpatial Innovation's Pocket Designer software, for design and layout of utility pole installations.
- Off-the-shelf—with the ability to customize data for a particular product, such as Trimble's TerraSync™ software.

With a professional GPS system you can choose the software that best suits your project, as a range of field software can run on the Windows Mobile (Pocket PC) operating system. If you have specific application requirements, there is a range of Software Development Kits (SDKs) and popular, industry standard development tools available for those platforms.

By contrast, most recreational GPS receivers have a proprietary operating system that will not allow you to use any other software. This means that when you buy a low-cost GPS handheld, you need to connect to another computer if you want to use software with more functionality. However this then immediately compromises ruggedness and ease of use, as explained earlier in this section.

Software functionality

For field crews and GIS managers, accurate and fast attribute collection is just as crucial as recording location information. However the built-in software on recreational units will not generally allow you to collect attribute information about a feature, beyond a name.

True GIS field software supports:

- The ability to collect point, line or area features
- Multiple attribute entry for every feature
- A variety of data types, including date, time, numeric, alphanumeric or file data types
- Rules controlling the entry of data, such as maximum field lengths, minimum and maximum values, required values or menu pick lists

Additionally, productive GIS field software supports:

- Repeat and default functions for auto-population of commonly occurring field values
- Auto-incrementing of IDs and auto-creation of date and time values
- External sensors for input of attribute data
- Search, sort and filter functions to identify the appropriate feature from within large datasets

Improving worker productivity by the use of appropriate field software with smart, time-saving features can make a dramatic impact to the overall cost of a mapping project. The importance of collecting data that is compatible with the enterprise GIS is discussed further in Section 3.

GPS functionality

For GPS data collection, the integration and control of GPS functions from within the field software is both an aid to productivity and in ensuring best possible accuracy. GPS functions include the ability to configure the GPS receiver to use real-time corrections, and to record GPS observation data for postprocessing, the control of GPS quality settings, the monitoring of GPS status, and mission planning.

- **Real-time differential correction, and postprocessing**

When combined with the appropriate GPS receiver, GIS field software can both set up the receiver to use real-time corrections (for higher accuracy in the field), and record the data required to differentially correct the GPS positions after data collection, which is known as postprocessing.

For differential correction by postprocessing to work effectively, the postprocessing software requires raw, unmodified GPS positions or measurements. Some GPS receivers apply correction techniques to GPS positions to provide more accurate coordinates in real time. If a GPS receiver also outputs information about how these modified positions were calculated, the postprocessing software can recalculate the raw positions and differentially correct them.

Some GPS message formats such as NMEA, only output modified GPS positions and only provide basic information about them. This information is not complete enough for the postprocessing software to recalculate the raw position, so it cannot differentially correct the GPS positions provided. Although some recreational GPS receivers may be capable of postprocessing output, this is only the most basic data and often in a format that is not compatible with most office postprocessing systems.

The ability to postprocess is a key feature to look for when buying a GPS receiver because in many parts of the world, there are no readily accessible real-time correction sources. Where corrections services are available, they may require additional outlay, in the form of additional equipment or a subscription, or the real-time coverage may be intermittent. Having field software that automatically records all the GPS data for postprocessing, as a background task, is the simplest no-fuss way to ensure that differential accuracies are always attainable. Not all professional GIS field software has this capability, but for those without it, extensions such as Trimble's GPScorrect™ extension for ESRI's ArcPad software may be available.

To find out more about real-time differential sources and postprocessing, read the white papers:

1. *WAAS performance with Trimble GPS receivers*
2. *Why Postprocess GPS data?*

available at http://www.trimble.com/mgis_wp.asp

- **GPS quality control settings**

As noted in the accuracy section, the ability to control quality parameters during GPS data collection is needed to ensure specified accuracies are achieved. These controls typically include:

- Minimum signal to noise ratio (SNR) levels, expressed in DBHz
- Minimum elevation of satellites above the horizon
- Minimum allowable geometry parameters in the GPS constellation. Geometry is measured by an indicator known as dilution of precision (DOP). As geometry degrades, DOP increases, so that DOP masks are expressed as a maximum allowable value.
- Further control may be provided to allow only real-time corrected GPS positions to be collected and this is essential for confidence in accuracy if software does not support postprocessing.

Quality GPS data is difficult to obtain near overhead obstacles such as dense canopy or buildings. To record locations in these environments, professional systems allow the entry of an offset to the GPS location, to specify the actual location of the feature being mapped. Depending on the sophistication of the field software, the different types of offsets available may include distance/bearing, double distance, and triple distance options. The system should also allow auto-population from a laser rangefinder, for a highly accurate offset.

- **GPS status and mission planning**

GPS availability changes from location to location, and up-to-date, rich graphical GPS information such as a sky plot will allow the field worker to make the best decisions on how to capture the best GPS position.

For example, a sky plot may show that if the operator oriented themselves differently at a point, they might be able to improve their DOP, or receive WAAS corrections, by allowing the receiver to track another satellite. Mission planning modules allow the user to predict the changes in the GPS constellation over the coming day, so it is possible to make the most of good periods of satellite coverage and to avoid any poor periods.

Additionally, field software that is tightly integrated with the GPS receiver can show current estimates of accuracy in real time, or even the accuracy that is likely to be achieved after postprocessing. This allows the user to keep working with confidence, in the knowledge that they have recorded enough GPS information to get the accuracy they require.

Many recreational receivers provide this function in their built-in software, but it is not easily monitored in a cobbled together system that typically has the recreational receiver stowed in a backpack or pocket. Professional GIS field software provides this information in a centralized user interface, where it can be used to improve productivity.

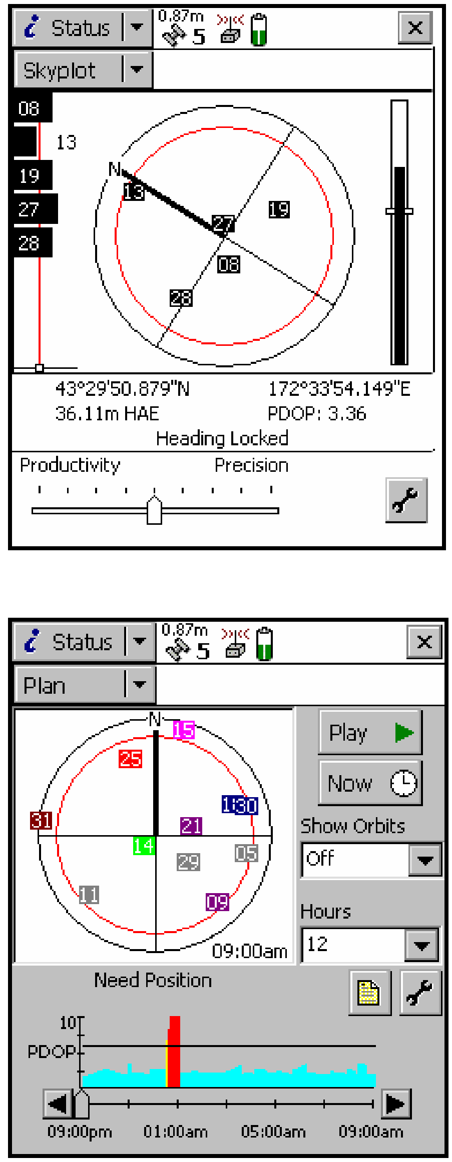

Figure 5: User interface on a professional receiver showing satellites (above) and PDOP (below).

3. Compatibility with peripheral devices

GIS databases today contain richer data types than ever before, now being populated with digital images and video. In addition, the input of unique IDs and attributes can be automated with the use of RFID or barcode scanners, to improve data integrity.

This means that today's field data collection systems must go beyond the simple collection of a position with associated manually entered attributes.

Field work often requires electronic input from a variety of peripherals, such as a laser rangefinder, barcode reader or digital camera. Recreational GPS units are generally not designed for this level of interoperability, whereas professional GPS receivers with open software platforms provide easy communication with a range of peripherals.

Communication to peripherals typically requires a form of serial communication, with RS-232 being the predominant industry standard for cabled peripherals. While recreational receivers typically have serial connections, they lack the field software to interpret and correctly use or store the input data strings.

Wireless communication is being increasingly adopted due to the establishment of Bluetooth® wireless, cable-replacement technology. Bluetooth is the industry standard solution for license-free, wireless communication between portable devices.

While initial uptake of Bluetooth was slow in the marketplace, the technology has now come of age, and a great number of devices are now available.

A typical application that benefits from this advance is a sign inventory project. An operator can record submeter-or-better GPS positions, take a photo of the sign, and wirelessly send it to their handheld computer which will associate the photo with the GPS position. A laser rangefinder, also communicating wirelessly with the GPS receiver, can then input an accurate offset. The end result is a quality photo with a very accurate position—all cable free.

GIS data collection is also increasingly becoming merged with other field operations such as asset maintenance, in a trend known as mobile GIS. Mobile GIS may require querying the GIS database remotely for additional information such as blueprints, specifications or ownership information. A Bluetooth cell phone or wireless LAN connection to the internet, or enterprise network, makes it simple to retrieve additional information from the field. This in turn makes the field service portion of your operations much more responsive to customers needs.

Section Three: Enterprise performance

Field operations are just one component of a mapping or data capture project. For effective data use—including information sharing with the public or contractors—data must be merged into the enterprise database, typically a Geographical Information System (GIS).

The ease with which field data can be merged into the GIS and the degree of confidence that the data meets enterprise standards is a key element, not only in terms of productivity, but also in the success of a mapping project.

1. Workflow

A critical difference between the recreational and professional GPS receiver in their enterprise performance is the workflow required to take the data from the field data capture system and to merge it into the GIS.

Take the following named GPS position:

40°07'53.383965"N 105°13'55.864214"W 1667.613 m Trailhead

This named GPS position, displayed on the screen of a recreational GPS receiver, could be used by a hiker to cross-reference his position on a paper map. Or it could be written down on a piece of paper, or stored on the GPS receiver with a name for later use. Any other information about the trailhead would have to be remembered or captured in a separate system, such as on a paper form.

By contrast, the table of data following, created and stored in the software of a professional GPS mapping system, is a much richer description of the trailhead and the condition of its various attributes—including a photographic image and details of when it was inspected.

Lat	40°07'53.383965"N
Long	105°13'55.864214"W
Height	1667.613m
Feature type	Point
Point type	Trailhead
Trail 1	Rainbow Trail
Trail 2	Waterfall Trail
Trail 3	Loop Trail
Sign	Yes
Sign condition	Needs repair
Gate	Yes
Gate condition	Good
Date visited	31st August 2005
Image	Img0021.jpg

Figure 6: Trailhead description from a professional GPS receiver.

The GPS position is just one of the attributes recorded. The data can be used for reference in the field, where it can be displayed on an interactive color map as one of many geographical layers, or can be downloaded and merged with enterprise GIS data to populate or update a GIS.

For the trailhead as captured by the recreational receiver, the values might simply be displayed on the screen while a staff member manually keys in the degrees, minutes and seconds (including six decimal places) into the office system. Any additional attribute information would have to have been recorded, perhaps on a paper form, and also manually transcribed into the office system. This method has the following disadvantages:

- A large increase in the time taken to complete the data capture, making a large data capture project impractical.
- A risk of manual error in transcribing—either of coordinate values or attribute information

- A risk of mismatch between the data as captured on the paper form and the ranges of values that can be entered into a field in a database.
- A risk of missing information which is required by a database rule.

For the same trailhead as captured on the professional data system, the unit is docked, the data is automatically downloaded and transformed to the GIS database format, ready to merge or add to the GIS data. This has the following advantages:

- Very little extra time needed to process the data in the office, making a large data capture project a reality.
- No risk that error will be introduced at this stage.
- No risk that the data will not match the schema of your database, as the data has been pre-validated in the field during data capture.

2. Scaling up

In the trailhead data capture scenario with the recreational receiver, the field-to-office work ratio is approximately 1:1 as all work done in the field is repeated back in the office. This might be acceptable where you are mapping one or two points of interest, but it is not scaleable.

Imagine the same scenario with one full time field worker mapping park assets. One full time office worker is needed to keep pace. Now deploy ten field workers mapping full time, and you will have already blown the budget on office staff and equipment.

Assuming this happens all day, every day, for the duration of the data collection season, and for each subsequent data collection season, and it will soon be apparent that it is impossible to maintain a database without a scalable system for collecting and transferring data.

If a number of workers are going to be deployed in data collection field work, it is important that the process of data conversion from field to office is efficient and consistent, and can be carried out without the need for manual intervention. The professional system will enable this to happen without the need for complex process intervention.

This presents a dilemma for managers—to equip a large number of field workers, there is an expectation that the cost of field units will need to be cut. However this typically carries the hidden cost of increased office processing overheads.

The astute manager should factor in the office processing costs per field unit, and multiply those out over the projected life of the unit to assess the true cost per unit of a GPS receiver deployment.

3. Training, Support and Service

Finally in terms of enterprise performance, consideration should be given to ongoing technical support, service and upgrades for both hardware and software.

To ensure that equipment bought from hard-won budget will not become obsolete, it is well worthwhile investing in professional-grade GPS receivers from a reputable manufacturer, who is focused on the GIS industry specifically, and is in business for the long term.

The GPS training and support that comes with buying a professional GPS receiver can eliminate costly errors in data collection, ensure data integrity, raise quality-control standards and guarantee compliance with existing standards for digital data collection.

Conclusion

Based on price alone, the purchase of recreational GPS units to act as the core of a GIS data collection system can appear the obvious answer. However careful consideration needs to be given to the logistics of gathering data in the field, the necessary overall system configuration and integration, real-time and postprocessing accuracy requirements and integration with the GIS.

Modern professional GPS receivers are designed and built with the express requirements of the GIS industry taken into account. Although the professional units are initially more expensive to purchase than their recreational counterparts, the return on investment achieved by using these units will very quickly surpass the initial outlay.