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Electronic Mapping Systems, Inc.

e-maps

PRIMER ON THE

OPERATIONAL USE OF GPS

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Oct 22, 2003

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PRIMER ON THE OPERATIONAL USE OF GPS

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CHAPTER 1

WHAT IS GPS?

101. Purpose. To provide information for users of Global Positioning System (GPS) equipment to better understand GPS uses and limitations.

102. Background

a. General. An overview of GPS is necessary because much geographic data collected and stored in computer databases is acquired with GPS equipment. Additionally, many people use GPS equipment to determine locations either actively or passively. Surveyors and engineers actively use GPS equipment to collect data while infantry uses GPS equipment passively to transmit their location to large command and control systems.

b. GPS equipment is so "user friendly" that many untrained users are not aware of its limitations. GPS training is often brief and focused on manipulation of operator menu items and options. Because little, if any, instruction is given on GPS concepts, operators have limited equipment use. As with any electronic instrument, GPS equipment is adversely affected by a number of external influences. GPS equipment operators with an understanding of GPS concepts can effectively modify their use of this new technology when problems arise.

c. Users of GPS-acquired data also must understand the nature of GPS instruments and the data they generate. Command and control systems provide accurate and useful information. Increasingly, GPS instruments generate location information for these systems. As anomalies inherent with data collection generate problems for operators unfamiliar with collection tools, so too do GPS anomalies create problems for users of command and control and targeting systems who do not fully understand basic GPS concepts. Examples of these problems include aircraft consistently missing their bombing targets in Libya and Kuwait.

103. Advancements in Technology

a. The accuracy of location-measuring equipment has steadily improved over time. Both commercial and military needs drove this development. The recent introduction of laser rangefinders and other advanced distance and location-measuring devices have produced improved location accuracy.

b. Celestial navigation has been effective for centuries. After manmade satellites became routine, it was a natural progression to use them as navigation devices. But these new manmade celestial bodies were not easily viewable as visual navigation aids. Instead, satellites produced electronic navigation signals.

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104. What is GPS?

a. The heart of GPS is a constellation of 21 satellites precisely orbiting the earth at a very high altitude. The system includes ground-control facilities and GPS receivers. The GPS system was developed by the Department of Defense and is correctly called NAVSTAR GPS (Navigation Satellite Timing and Ranging Global Positioning System).

b. Initially, 11 satellites were launched between 1978 and 1985. The remaining satellites were subsequently added. The GPS goal is to orbit 24 satellites with three as active spares. The satellites are high enough to avoid the problems of land based navigation systems and GPS technology is highly accurate so precise locations can be determined anywhere in the world at anytime.

c. Each satellite is basically an orbiting radio station continuously transmitting electronic coded signals that can be received by GPS equipment. Each satellite possesses an extremely accurate atomic clock that enables GPS receivers to determine and display very accurate locations.

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CHAPTER TWO

HOW DOES GPS WORK?

201. Introduction. This chapter introduces GPS concepts that users must understand to effectively use GPS equipment. Only general concepts are covered. Many books and online material are available that more fully explain GPS concepts and details.

202. Concept

a. A GPS receiver processes and triangulates GPS satellite radio signals to accurately determine the receiver's location. A GPS receiver measures the travel time of signals from GPS satellites and performs simple math to determine the receiver's distance from the satellites. Using a simple high school equation, *distance = velocity x time*, a GPS receiver can very accurately calculate its location on the earth.

b. GPS receivers do not transmit signals - they only receive satellite radio signals. A GPS equipment operator need only point a GPS receiver antenna towards the sky and turn on the receiver. It will automatically search for and receive satellite radio signals. Normally in a short time, the receiver will acquire sufficient GPS satellites signals to determine an accurate location.

c. To accurately determine positions on earth, a GPS receiver must acquire radio signals from four satellites. The accuracy of a position determined by a GPS receiver depends on the geometry of available GPS satellites. GPS receivers automatically select the four satellites that provide the best position geometry and, therefore, the highest location accuracy.

d. The satellite radio signals GPS receivers depend on to determine location can be slowed down or adversely affected as they move through earth's atmosphere. The signal received by a stationary GPS receiver includes small errors introduced by the signal's passage through the atmosphere. If a user remains stationary with a GPS receiver, the position readout window (displaying the GPS receiver's location) will indicate movement as if the receiver was moving around. This does not mean the GPS receiver is malfunctioning; it is an indication that the atmosphere is influencing the GPS satellite radio signals. GPS atmospheric signal changes are usually very small and so insignificant that they should not interfere with routine GPS use by a military user. If very precise location data is required, a user may take several GPS readings and refine them using techniques such as data "post-processing."

e. Anything that interferes with the satellites GPS signal will either degrade the signal or completely eliminate it.

203. Accuracy

a. General. Military GPS equipment can usually determine location to an accuracy of ± 10 meters. The mariner's classic navigation handbook, *The American Practical Navigator (Bowditch Manual*), states that the GPS Precise Positioning Service (PPS) position accuracy shall be 16 meters or better. GPS devices can be very accurate but not perfect because of several variables impacting on GPS satellite signal transmission and reception.

b. Interference With GPS Signal. Signal interference plays a significant role in the decreased accuracy of a GPS receiver. GPS satellite signals are exposed to and degraded by numerous sources of atmospheric interference such as charged particles in the ionosphere and water vapor in the troposphere. Additionally, slight orbital drift and slight clock inaccuracies in GPS satellites may contribute to position measurement inaccuracies.

c. Multipath Error. This GPS error is introduced by signals arriving at a GPS receiver along multiple paths. While most GPS signals follow a path directly from a GPS satellite to a receiver, some GPS signals are reflected off objects such as large buildings. Since a GPS receiver determines its location based on the time and distance a GPS satellite signal travels, the extra distance inherent in a signal "bouncing" off a building introduces errors. This effect is similar to a "ghosting" effect seen when televisions receive multiple and overlapping channel signals.

d. Equipment. The many models of GPS receivers have different levels of accuracy due to differences in design and components. Internal clocks vary in accuracy and some models introduce more internal noise or interference than others. These factors, in addition to the limitations listed in paragraph 204 below, may produce slight inaccuracies. This does not render the equipment useless; it means that users must understand several factors influencing GPS-derived locations so they can properly use the output and understand its limitations.

204. Limitations

a. Antenna Interference

(1) Anything that interferes with a GPS receiver antenna or blocks its view to the GPS satellites will degrade its performance. For proper operation, GPS equipment must have an unobstructed view from the antenna to the satellites. Tall buildings or overhanging vegetation will interfere with the signal reception. This is why GPS signals seem intermittent or absent when a GPS receiver is used in deep ravines, behind hills, in heavy vegetation or under trees.

(2) If a GPS receiver is used in a dense forest or jungle, a clearing may need to found to obtain a stronger GPS signal and produce an accurate location or the receiver antenna may need to be raised high in the vegetation.

b. Weather. GPS is an all-weather system. Fortunately, a GPS receiver works well at night, in fog, in a blizzard, and other extreme weather conditions. However, severe weather may degrade GPS signal reception. Operating a GPS receiver in rain or snow can degrade its accuracy because small precipitation particles may reflect GPS signals. When using GPS receivers in inclement weather, users should be aware that GPS locations may include small errors due to signal reflection.

c. Batteries. Most GPS receivers use batteries and encounter common battery problems. Although recent improvements in battery technology, including the switch from nicad to alkaline power sources, have increased equipment operating time, basic concerns remain. Extreme cold temperatures reduce battery service life. Spare batteries should be readily available to sustain GPS receiver performance. Unfortunately, when regular GPS receiver batteries are depleted, the receiver usually draws down on the ***internal*** lithium battery; this battery is critical for storing and maintaining GPS receiver data. When an internal lithium battery runs down, a GPS receiver suffers significant down time because the internal battery usually cannot be replaced in the field. Recharging a rundown internal battery requires a very slow and long charge, best done in a rear area. Battery use is discussed further in Chapter 3.

CHAPTER THREE

USING GPS EQUIPMENT

301. Introduction

a. GPS training usually includes practice with a GPS receiver. The manufacturer's operating instructions should be provided with the instrument. A user should thoroughly understand a GPS receiver's operation before using it in the field. Ideally, GPS training should include enough hands-on experience to identify, learn and practice all receiver functions before using it in the field. If proper instruction is not available, a user should take sufficient time to learn and practice GPS receiver functions.

b. Military expediency often dictates that one takes what he is given and does the best job that he can. Operation of most GPS receivers is intuitive but a user should be aware of all receiver functions and options so (1) field operations can be modified to exploit the capabilities of a GPS receiver and (2) problems can be solved when they arise. Users should take advantage of every opportunity to learn about their GPS receivers.

302. GPS Receivers

a. General

(1) GPS receivers have knobs, dials, and buttons with which users can quickly select and activate particular functions. While such flexibility may permit easy and rapid equipment adjustments and operation, it also may contribute to catastrophic results if the user does not fully understand all equipment functions. It is impractical to address all functions of all models of GPS receivers, but it is possible to address several characteristics and functions common to most models so that users can achieve satisfactory results.

(2) The most basic common and universal GPS receiver functions are (a) an on / off switch, (b) a position location readout or display, and (c) a battery status indicator. A user should locate these early in training, particularly if he is teaching himself from a users manual.

b. Datums

(1) It is very important to understand that a GPS receiver can display locations in different ***datums***. A datum is simply a mathematical model of the earth used to calculate position coordinates on the earth. There are many datums but the one most commonly used is the World Geodetic System of 1984, referred to as WGS 84. Most GPS devices use WGS 84 as the default datum when displaying or communicating a position.

(2) Most GPS devices permit users to change datums. However, a user should exercise extreme caution when changing datums. Unless required by the situation at hand or directed by higher authority, a user should not change receiver datums. WGS-84 should remain the default

datum. Usually the receiver's selected datum will appear in a display window so a user can easily ensure he is using the correct datum.

c. Position Readout

(1) General. There are several options for identifying geographic locations. The most common are projections of geodetic coordinate and grid systems.

(2) Geodetic Coordinate System Locations. This system defines positions as latitude and longitude. Latitude states location as an angle between the equator and a location point. A location with latitude 45 degrees north is halfway between the Equator and North Pole. Longitude states location as an angle between a line running north and south through Greenwich, England, and a location point. San Diego, California is located at latitude 32º 51' 09.36" North and longitude 117º 06' 36" West. The º symbol represents degrees, the ' symbol represents minutes, and the " represents seconds. There are 60 minutes to a degree and 60 seconds to a minute. San Diego's location is read as 32 degrees, 51 minutes, 09.36 seconds north latitude and 117 degrees, 06 minutes, 36 seconds west longitude.

(3) Grid System Locations

(a) Grid systems are usually easier to use than geodetic coordinates. Grid systems are represented on a map by a regular "grid" of straight, parallel lines - one set running north and south and the other set running east and west. Grid systems enable maps to be marked in units of distance (i.e., meters or miles) rather than in units of angle (i.e., degrees, minutes and seconds).

(b) Grid systems use distance offsets from a reference point to determine specific locations. Offsets are often referred to as "Easting" (east of the reference point) and "Northing" (north of the reference point). The most common grid systems are the Military Grid Reference System (MGRS) and the State Plane Systems used throughout the United States.

(c) MGRS. MGRS divides the world into zones and zones into 100 kilometers grid squares. Each square is assigned a unique 3-letter designation. Positions are stated using (1) zone number, (2) square identification and (3) easting and northing offset distance in sets of three, four or five digits. Although it seems that MGRS coordinates define a specific location, they actually define a square around a specific location. MGRS coordinates with 5 easting and 5 northing digits define a point in a 10 meter square. MGRS coordinates with 3 easting and 3 northing digits define a point in an 100 meter square. A MGRS location example:

18 S	UT	12352	35540
Zone Number	Square Within the Zone	East of Reference Point	North of Reference Point

The MGRS number would appear in the display window of a GPS device as a string such as 18SUT1235235540, or it might have spaces to differentiate each location element such as 18 SUT 12352 35540.

303. Using GPS in the Field

a. Determining Location

(1) If users continually operate their GPS receivers in the field, their location is continuously displayed in the GPS data display window. As a user moves, his GPS receiver constantly updates and displays his new location. When asked for his location or his unit's location, a GPS user can quickly respond simply by reading his location from his GPS data display window.

(2) When using GPS receivers in the field, users should be aware that obstacles (e.g., hills and buildings) may interfere with reception of GPS satellite signals. When GPS signals are blocked, a receiver cannot update its position. This may cause a moving GPS receiver to display an old location or it may cause a blank location display. This problem can be solved by moving the receiver to a different location to re-acquire better satellite signals. Rotating helicopter blades can block GPS signals. After moving away from a helicopter, a GPS receiver will require some time, perhaps several minutes, to accurately determine its location.

(3) There may be times when the geometry of accessible GPS satellites is not suitable for a GPS receiver to acquire a good signal and determine its location. In this case, a user must either (a) wait until the satellites move to create an adequate geometry or (b) determine his location with other means (e.g., a map) and update or verify his location when his GPS receiver acquires a good GPS signal and accurately determines its location.

(4) If a user is equipped with a GPS-based device that automatically and regularly reports its location to an automated command and control system, the user should be concerned with the potential adverse effects of obstacles and satellite geometry. A user's tactical situation and mission remain the most important factors governing his actions, specifically whether he should move to a position to acquire better GPS signals. Higher and supporting headquarters that receive and monitor automated GPS location reports must be alert for location inconsistencies. When headquarters detect questionable data, they should contact the reporting member or unit to verify location. They may direct the reporting member or unit to move to higher ground for better GPS signal reception. At times, this may comprise a mission and endanger men. This is a new variation of an old military theme - conflicts between higher headquarters and subordinate units. Solving these problems requires understanding and patience by all concerned, whether they are in headquarters or in the field with a GPS device.

b. Batteries. The improper use of batteries can lead to incorrect location data at critical moments in action. GPS devices may be turned off to conserve battery strength. This is a good practice when users remain in a fixed position. However, once turned on, a GPS receiver requires "warm up" time to determine a new position. This presents a potentially significant danger if a GPS device is (1) turned off, (2) moved to a new location (e.g., carried on patrol) and (3) turned on. Initially, the GPS receiver will provide incorrect location information as it "remembers" and displays its last known location until it acquires adequate satellite signals to calculate a new and correct position (from a cold start). This may take several minutes. If a user reports his GPS position immediately after turning on his receiver, there can be tremendous confusion including, as experience has shown, fires being delivered directly on the user.

304. Using GPS Data in Command and Control Systems

a. GPS-generated location data can be used to remotely monitor the locations of friendly units on a battlefield. Units can automatically transmit their locations to central command and control facilities. An advantage of this approach is that units do not have to prepare and submit position reports during fluid operations but confusion can result if the command and control facilities receiving GPS data don't understand its limitations. The same GPS problems addressed in paragraph 303 apply to command and control facilities that receive and process GPS data. A GPS user in the field who is aware of possible GPS signal problems can quickly solve them if headquarters reports a lack of updated location data from the field.

b. GPS data system adjustments must be well understood. As field-generated GPS signals are entered and processed by a command and control system, anything that delays the signals will degrade location accuracy in real time. This may produce disastrous results if fire support missions are delivered based on the latest reported locations of battlefield units. Inconsistencies between GPS-reported unit locations and actual unit locations may be caused by (1) delays as information is routed through servers, (2) procedural delays from system information updates and (3) communication failures.

305. Navigation

a. Waypoints. Most GPS receivers are small computers that allow a user to enter words or numbers to associate with location data. This important feature can be used to create waypoints or checkpoints or to note an important characteristic of a feature. For example, intelligence data can be collected for selected points such as the condition and location of a bridge. GPS receivers handle waypoints and remarks in a variety of ways so a user must check his instruction manual.

b. Use of Map and Compass. Depending on GPS devices as the only navigation aid can cause problems. A GPS receiver can provide direction information only when it is moving at several miles per hour. A GPS receiver always calculates its position in relation to GPS satellites but it can only determine direction of travel when there is a measurable difference in subsequent locations. Effective navigation still requires a map and compass. A GPS receiver contributes to significantly more accurate navigation but it does not replace all other navigation tools.

c. Navigating in Difficult Situations

(1) Occasionally, operations in rugged terrain (e.g., jungle or mountains) may prevent a GPS receiver getting continuous satellite signals. A method for compensating in these circumstances is to determine locations of "known GPS points" and use dead reckoning navigation from them. A user could travel a fixed direction and distance from his last accurate GPS location. For example, a GPS user could get a good GPS position in a clearing and head 90º for a pre-determined distance to reach a point on high ground where a good GPS signal can be acquired or tactically important task could be completed.

(2) GPS receivers can be difficult to use in urban areas. GPS signals frequently reflect off buildings and other structures in built-up areas and produce multipath error signals. GPS signals usually do not reach inside buildings. Again, offsets can be used but other location identification methods might be necessary. For example, positions can be reported in reference to other units with known locations (e.g., second squad is 500 meters north of third squad whose location is determined by GPS). Higher headquarters must be aware and sensitive to GPS problems in urban areas and not unnecessarily burden warfighters with location questions based on an assumption that location is easily determined with GPS receivers.

(3) Desert navigation is challenging because of little, if any, landscape relief to guide navigation or obtain navigation references. In this environment, GPS receivers may help tremendously, particularly if operations are fast moving and cover large open spaces.

CHAPTER FOUR

USING GPS DATA WITH MAPS AND COMMAND AND CONTROL SYSTEMS

401. Introduction

a. This chapter discusses the use of data generated by GPS receivers with maps and command and control (C2) systems. Used alone, GPS receiver location data is not very helpful. However, when linked with map use, it is very helpful. When a user of a GPS receiver plots his position on a paper map or views his position against a background map, he better understands his situation. He can see his relationship to friendly forces, enemy forces and important terrain. When a user sends his GPS-derived location data to higher headquarters and it is overlaid on an electronic base map, headquarters can better understand the user's situation and his contribution to mission accomplishment.

b. A major advantage of using electronic (i.e., digital) maps is the capability to combine data from different sources to see relationships not otherwise obvious. While this capability provides tremendous advantages, it can cause problems for users who don't understand some basic mapping concepts, particularly ***metadata***. Metadata is data about data. It is comprehensive information about the content, quality, condition, source, history and other characteristics of map data. It usually includes map data reliability, precision, accuracy, completeness and consistency. Map sources may include the National Imagery and Mapping Agency (NIMA), U.S. Geological Survey (USGS), other federal agencies or commercial companies. Metadata usually includes map data collection sources (e.g., satellite imagery or GPS device). Legend information on paper maps is metadata. Basic knowledge of metadata and other mapping concepts discussed here may help GPS users get the best possible results from GPS-derived data.

402. Computer Maps

a. General

(1) Probably the most widely used digital computer maps are scanned copies of paper maps. This paper-to-digital conversion process, called digitization, enables computerized C2 tools to use many excellent current paper maps. Digital maps have significant advantages over paper maps: (1) digital maps are much easier to share than paper maps and (2) electronic data from GPS and other computer-based C2 tools are easier to overlay on digital maps than on paper maps.

(2) An additional digital map advantage is that digital map data can be manipulated and changed. Because paper map images and text are printed, paper map changes are difficult or impossible. An unfortunate aspect of the capability to change digital map data is that inexperienced users can (a) inadvertently make and save erroneous changes to a computerized map and (b) disseminate the revised incorrect map throughout an organization, sometimes causing tragic results.

(3) All cartographic issues that apply to paper maps also apply to digital maps. The introduction of digital computer maps has changed the ability of users to manipulate map data but not the nature of maps. Some significant cartographic issues are discussed below.

b. Datum

(1) A map datum is simply a mathematical model of the earth that provides a foundation for designating the location of a point using latitude and longitude or coordinates such as the military grid reference system (MGRS). A datum greatly facilitates location identification and the mapmaking process. Locations defined in one datum can be converted to locations defined in another datum. Because datums can be converted, older maps and maps created by foreign nations that use different datums can be used by our American military.

(2) Datums continue to be overlooked at critical moments; this repeatedly leads to significant problems. Missed targets in the Libya bombing raid and consistent B-52 bombing errors in Operation Desert Storm are examples of datum errors.

(3) Locations recorded by a GPS receiver are stated in a particular datum. Most GPS receivers have a capability to select a datum to display and communicate data. This selection is usually made from a menu of the most popular and common datums. The American military standard datum is World Geodetic Datum of 1984 (WGS 84) which is the default datum on most GPS devices. It is important a user know the datum of his GPS data because GPS data is readily consolidated with other mapping data to display map relationships. Data collected in one datum and overlaid on a map in another datum will misrepresent relationships and be inaccurate (e.g., terrain features and targets may appear to be on the wrong side of a road).

c. Generalization

(1) Generalization is the simplification of data to ease understanding. Generalization sacrifices accuracy to maximize ease of understanding, situational awareness and decision superiority. Every good briefer practices generalization by telling the audience being briefed what is important in the present situation. Generalization flows from the need to emphasize and display a few important features rather than many minor and unimportant features that may obscure important information. Using generalization, some less and unimportant features are simplified, others aggregated, and many eliminated. As a general rule, the larger the area displayed on a map, the greater the generalization use.

(2) When gathering location information with GPS devices, there often are discrepancies between GPS-derived locations and locations read from a map. Many of these discrepancies are due to generalization. The smaller the scale of a map (i.e., less detail), the greater the generalization and observable discrepancies. This is because more information competes for possible representation in the same display area. Understanding generalization may guide map users inquiries into apparent discrepancies in location data rather than discarding GPS-derived data because it does not match data on a small-scale map.

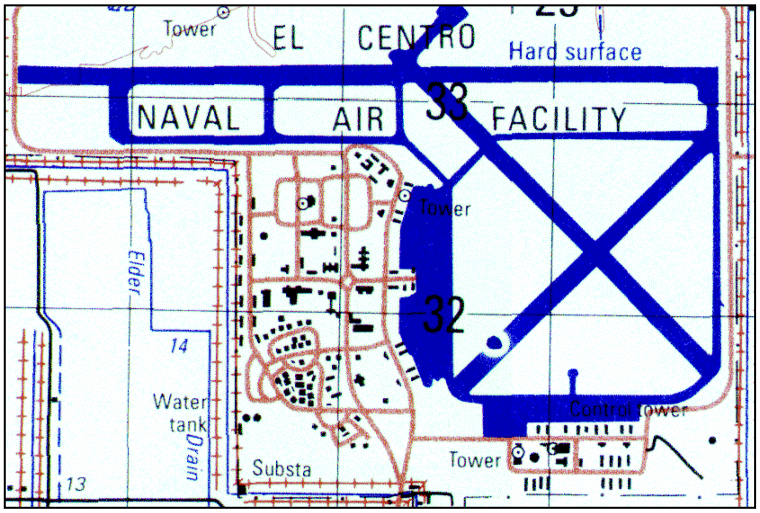
(3) Determining which features to generalize or discard depends on the purpose of a map. On a road map, streets, highways and roads are fairly accurate while secondary features such as airports and forests are highly generalized. Conversely, on an aviation map, radio beacons, tower locations and runway headings are represented with great accuracy while roads are generalized. Generalization on special purpose maps is significant whether using a 1:250,000-scale aviation map or a 1:50,000-scale tactical map.

d. Exaggeration

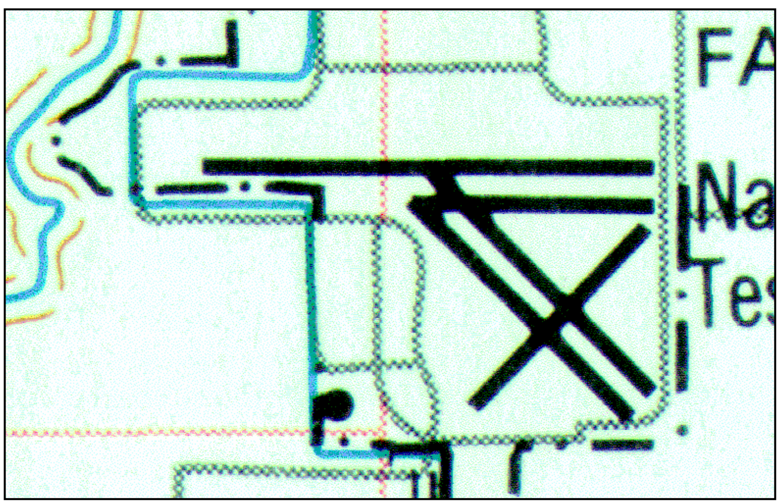
(1) Exaggeration is the representation of a map feature drawn several times actual scale size to highlight it. Road maps use this technique. If interstate highways were drawn to scale on road maps, the widths of lines representing highways and roads would be too narrow for an eye to see. If road map scaling factors were accurate, the thick red interstate highway line would represent a road several miles wide. The thick interstate highway lines do not cause confusion or mislead map users because even though they are unaware of "cartographic exaggeration," they know the road line width indicates the quality of a road, not its width.

(2) When GPS data is overlaid on a map containing exaggerated features, users will see conflicts between the map and GPS locations plotted on the map. For example, some points that should appear off a road may appear to be on a road. Some points that should appear near a building may appear to be in a building. If a map user understands exaggeration, he will not be unhinged when GPS data appears in conflict with a map.

(3) Examples of Generalization



1:50,000-scale map of the airfield at El Centro, California taken from a NIMA-produced map



1:250,000-scale aviation map of El Centro taken from a NIMA-produced map

Note the lack of detail on the 1:250,000-scale map and the focus on the runway, not the surrounding area. Roads are generalized with only important ones represented. Runways and taxiways are presented as a pilot sees them from the air. The 1:50,000-scale map shows far more surface emphasizing its use by people on the ground. GPS data used with the 1:50,000-scale map would closely match roads and runways locations, but if GPS data is used with the 1:250,000-scale map it would probably be noticeably different.

e. Scale

(1) Scale is the ratio between the dimensions of a map feature representation and the feature's actual dimensions. A scale of 1:4 indicates a map's representation of a feature is one-fourth the feature's actual size. The scale is fixed on a paper map and usually stated in the map's legend. However, digital map scale is often difficult to determine and is best used as an indicator of a map's level of detail.

(2) While paper map scale is fixed, a digital map's scale varies because of several factors including the: (a) resolution of the computer monitor in use (e.g., 800 pixels by 640 pixels), (b) scan density used to scan the map (e.g., 300 dots per inch [dpi]), (c) scale of the original input map (e.g., 1:50,000-scale), (d) monitor screen size (e.g., about 14.5 viewing inches for a typical 17 inch monitor) and (e) "zoom" setting used by mapping software.

(3) Most mapping software programs include a "zoom" feature that increases or decreases a computer monitor viewing area. Some mapping software is capable of increasing the level of detail on display as a user zooms in and less detail as the user zooms out. However, most mapping software uses only a single digital map created from a paper map. Zooming out and in on a digital map changes the map scale as less or more map area is viewed but it does not change the amount of detail being displayed. Zooming into a digital map provides only a magnified image of a fixed level of detail.

(4) Zooming in or out on a digital map can degrade the quality of the map display. A user seeking a greater level of detail when repeatedly zooming in on a digital map often finds the quality (technically the resolution) of the image degraded and not useful. Uninformed computer map users tend to blame the poor image quality on the map, software or computer equipment. However, the real problem is the user's misunderstanding and misuse of computer maps and computer-mapping functions.

403. Data

a. Accuracy and Precision. Understanding the concepts of map precision, and accuracy (which sometimes confused with scale) contributes to the effective use of map scale.

(1) Precision is a measure of how exact a location is specified without reference to its true value. An example is longitude 117.1214^{o} west which is more precise than 117.12^{o} west.

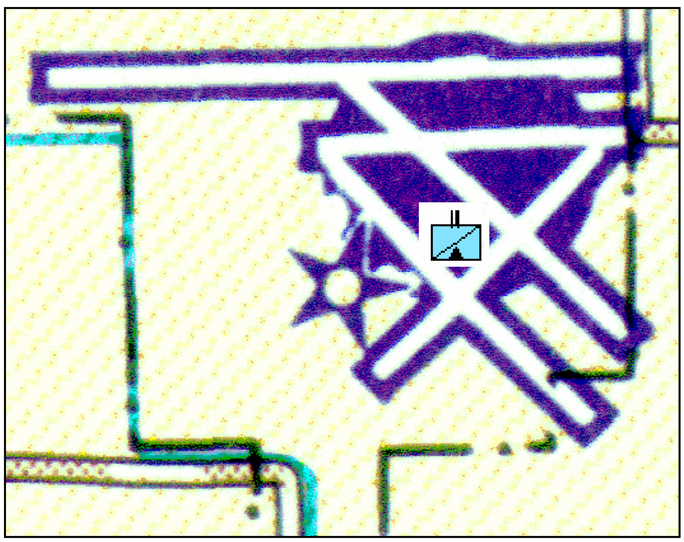
(2) Accuracy indicates how close a stated location is to its true value. The difference between a stated value and a true value (or accuracy) is listed in map legends and GPS devices as "plus or minus" (±) a stated distance, such as ± 10 meters.

(3) GPS receivers vary in accuracy by model. However, most military GPS equipment is accurate to ± 10 meters. This accuracy is sufficient for most military uses. Before GPS was widely used by the military, MGRS coordinates, calculated to six places (e.g., 658352) with a 1:50,000-scale map, ensured an accuracy of only ± 100 meters. See paragraph 302.c.(3)(c). GPS receivers have greatly improved location accuracy for military members.

(4) Precision and accuracy of data from GPS receivers and maps.

(a) Although most GPS receivers have an accuracy of ± 10 meters, the most commonly used military maps are considerably less accurate. For example, a 1:250,000-scale NIMA map has an accuracy of ± 125 meters. Location data from a GPS receiver is more precise than data generated from a fixed position on a 1:250,000-scale map. A map may indicate a longitude of 117.12° west while a GPS reading at that location might indicate 117.1214° west. The greater number of GPS display digits implies greater precision. However, care must be exercised when using precision to indicate greater accuracy for recording position data. Mixing GPS data with position data from other sources may produce false representations of a situation due to varying degrees of data accuracy.

(b) The map image below illustrates the result of mixing data of different accuracies. A GPS reading was taken at the intersection of the runways and electronically plotted on a NIMA 1:250,000-scale digital map. Due to different data accuracies, the icon representing the GPS-derived location plotted west of the runway intersection.



b. Metadata

(1) Metadata is information about the content, quality, condition and other characteristics of map data. It should include information about the source, reliability, precision, accuracy, completeness and consistency of map data.

(2) As discussed in paragraph 402.a.(1), a significant advantage of digital map use is a capability to combine data from multiple sources. This is also a potential disadvantage if a digital map user does not understand that extreme care should be exercised when combining data from maps of different scales (e.g., overlaying 1:50,000-scale digital map data on a 1:250,000-scale digital map). Although it is fairly easy to electronically overlay map data, the result may be a digital map with conflicting information on roads, bridges, waterways and other features.

Because data from a 1:250,000-scale map is more generalized than data on a 1:50,000-scale map, map features will align poorly. Metadata review is important when comparing or combining maps because it lists map data accuracies, helps map users understand apparent data conflicts and helps determine the appropriate uses of map data.

(3) Spatial Metadata Example

Spatial Metadata Categories and Their Descriptions	
Identification information	Description of data set
Contact information	Organization to contact to obtain data
Transfer information	Details to obtain data
Status information	Completeness of the data
Coordinate system information	Data set coordinate and map projection
Source information	Description of the origin of the data set
Processing history information	Information about processing steps performed on the data set
Data quality information	Measures used to provide user information on which to judge if the quality of the data set is suitable for planned use
Feature/attribute information	A detailed description of the information about features, attributes, and attribute values

404. Command and Control Systems. GPS-derived data has a great potential to improve command and control if (a) it is not misused and (b) users understand that with GPS potential, proper planning is still be required to ensure the most important GPS data is collected. Consider two points:

a. Integrating GPS with Map Data. Users of GPS-generated location data in a headquarters must apply good judgment to the use of this information.

(1) Signal-blocking obstacles, satellite geometry, initial warm-up time for a GPS receiver to acquire adequate signals and determine its correct location and other factors discussed in Chapter 3 may adversely affect field use of a GPS receiver. These factors may also affect the use of GPS-derived data in command and control systems. Headquarters depend on battlefield information to develop situational awareness that is often aided by digital map displays. Automated GPS-generated digital data improves situational awareness because position data is relayed and displayed much faster than position information passed over voice circuits. This data may contribute to (a) assessing the flow of the battle, (b) deciding where to deliver fire missions, and (c) precluding fratricide. But, the same systems that automatically relay normally-accurate GPS positions may also relay inaccurate positions due to GPS obstacles or user actions (e.g., battery changes). Headquarters must understand that field conditions beyond a GPS user's control such as enemy fire, a need to keep moving or an advance up a hill to gain tactical surprise may force the user to position his GPS device where it produces inaccurate location data.

(2) Because GPS-generated data displayed in a headquarters may have a different accuracy than its base digital map (and perhaps a different datum), headquarters must understand the issues of map and data accuracy discussed in paragraph 403.

(3) Communications systems' latency (i.e., delays introduced in passing data through the communications system) can reduce the accuracy of map displays of GPS-generated data. Such latency is discussed in the next paragraph, but users must exercise judgment when determining if the data they are looking at is "real time."

b. Information Flow and Latency

(1) Communications architecture will influence the flow of GPS-generated data to command centers. Data that travels through several servers may be delayed at each server. These delays will affect the accurate display of icon locations on a computer map. When field units move rapidly, their location displays in headquarters may lag their actual ground positions. For example, if icons for vehicles at the end of a column move on a computer map display while icons for vehicles at the front do not, the problem may not be an actual vehicle movement delay but rather a delay of automated GPS-generated field data in the communications system.

(2) Since location data flow into databases, users of GPS-based data must understand when a location database is updated old positions are overwritten with new positions. Updating database positions on a time basis (e.g., every 5 minutes) or movement criteria (e.g., a units moves 100 meters) may cause varying accuracy for GPS-generated map displays. Due to the increasingly large volume of field data fed to command centers, some delay or latency is unavoidable.

c. Targeting

(1) Targeting focuses on the identification of potential targets and their locations. Highly accurate GPS-based devices are potentially very useful in determining the location of terrain features that may be used later as targets (e.g., a mountain pass through which an advancing enemy must travel). It is also possible to determine the location of inaccessible targets by using an offset from a fixed position determined using a GPS receiver.

(2) The increased capability to collect more targeting data of greater accuracy using GPS receivers can only be realized if such collection efforts continue to be planned carefully and if there is a good plan for processing the data collected by reconnaissance units.

d. Updating Maps

(1) Maps are images that show information as of a specific date. Because of the high labor and production costs required to make maps, revisions may be produced as infrequent as every ten years. Map representations of hills, rivers, and most major highways are changed infrequently because these features rarely change. Bridges, minor roads, buildings, towers and other features are added, changed or destroyed much more frequently than most maps are updated. Because of infrequent map updates, most maps provided by NIMA lack recent road and building construction and demolition.

(2) GPS and electronic mapping software can provide a means to update old and outdated maps. A GPS receiver can be used to collect current data on the location of features of interest (e.g., new buildings, bridges, towers and roads). Determining the location of the corners of a large building will define its shape and identify its location. Similarly, bridge location data can be collected. The collected GPS data can be entered and displayed as an electronic map overlay. The biggest challenge is data management - the naming and filing of GPS-generated data so it can be retrieved efficiently and used effectively. Data management includes creating a comprehensive system for the assembling and disseminating data on new map features.

e. Managing GPS Data. Providing everyone with GPS receivers that automatically report locations can potentially overload a C2 system with data. GPS receivers are usually widely distributed throughout combat, logistical and other units. GPS-generated data must be well managed to prevent information overload. Command guidance and detailed planning are required for generating, receiving, storing and using GPS data. These plans should include:

(1) Position Updates Based on Distance Moved or Time Passed. Location data is constantly generated and updated by a GPS receiver (i.e., every second or sooner). Most vehicles, equipment or individuals that carry GPS receivers do not move far in this short period. Although there is some immediate appeal to the notion of a "second-by-second" update of a situation, less frequent position updates require fewer C2 resources including bandwidth, data storage capability and processing power. There are two basic approaches for automatically reporting GPS-generated data into a C2 system to avoid overload:

(a) Position Updates at a Fixed Time Interval. For example, a GPS-device in a convoy can communicate its position once every minute over radio circuits to a C2 system. This feeds much less data into a C2 system than position updates every second. For a convoy, second by second reported positions are largely irrelevant for operational use. An update once a minute is probably sufficient for a convoy or a reconnaissance patrol moving by foot.

(b) Update after moving a fixed distance. For example, a GPS-device can communicate its position when it determines its location is 100 meters or more from its last position reported to a C2 system. Artillery batteries spend most of their time in fixed firing positions; duplicate reports generated at fixed time intervals by these units take communications bandwidth better used collecting reports from reconnaissance or tank units on the move. Knowing the exact locations of moving units are essential for fire support coordination and other activities that require quick and correct decisions.

(2) Compensating for GPS Receiver Failures. Because GPS receivers are complex electronic devices, they break occasionally and cannot determine positions. Similarly, if an obstacle blocks signal reception for a GPS receiver, it is unable to calculate new and accurate positions. Both problems render GPS receivers unusable. These inevitable problems can be solved by equipping every unit that automatically reports their location with GPS devices with at least two GPS devices that calculate and report positions.

Note: This technique is called forward error correction - providing redundant data to compensate for possible problems.

(3) Correlation of Data Collected with Units. Although a GPS receiver can automatically calculate its location, it cannot automatically determine the designation of the unit using it. A plan to collect GPS-generated data should ensure the data is associated with the proper unit. It is human nature to trust whatever is printed or appears on a computer screen. However, this trust may unwarranted with displays of automated positions using GPS-generated data. Authenticity of automated position data should be checked to ensure it correctly represents the proper unit.

(4) Select Data to Display. As automated GPS position reporting devices become more widely used, efforts to display all reported data received will produce digital map information overload. Cluttered map displays will obscure a situation rather than contribute to improved situational awareness. Planners should determine which GPS data they need and which should be automatically displayed in computer map displays and similar C2 information presentations.

(5) Collecting Required Data. Because it is impossible to display data that is not collected, provisions must be made to collect desired GPS-generated data. Historically, effective military forces plan and collect required data and information. GPS devices, though recently acquired and used in the military, should be integrated into planning for data and information collection.

(6) Constantly Updated and Accurate Maps. GPS devices can provide a means to collect the necessary data for constantly updated and accurate maps. Because a map shows only those relatively few features in an area that are important for the intended use of the map, GPS data can be collected and used to update map features. If an area has new buildings, bridges, towers, roads or features, units (a) can use GPS devices to trace these features, (b) collect their location information and (c) rapidly pass it to a C2 system. The amount of data required to report trace points is very small; locations of the corners of a building or bridge can be determined and reported with a very small amount of data. Road locations require considerably more data but far less than that required for aerial imagery. Data management of updated map feature locations is a big problem that must be addressed in planning.

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