CHAPTER 57

The Role of GIS in Military Strategy, Operations and Tactics

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57.1 Introduction

The United States military has used geospatial information in every conflict throughout its history of warfare. Until the last quarter century, geospatial information used by commanders on the battlefield was in the form of paper maps. Of note, these maps played pivotal roles on the littoral battlegrounds of Normandy, Tarawa and Iwo Jima (Greiss 1984; Ballendorf 2003). Digital geospatial data were employed *extensively* for the first time during military actions on Grenada in 1983 (Cole 1998). Since then, our military has conducted numerous operations while preparing for many like contingencies (Cole 1998; Krulak 1999). US forces have and will continue to depend on maps—both analog and digital—as baseline planning tools for military operations that employ both Legacy and Objective Forces (Murray and O'Leary 2002).

Important catalysts involved in transitioning the US military from dependency on analog to digital products include: (1) the Global Positioning System (GPS); (2) unmanned aerial vehicles (UAVs); (3) high-resolution satellite imagery; and (4) geographic information systems (GISs) (NIMA 2003). In addressing these four important catalysts, this review is first structured to include a summary of geospatial data collection technologies, traditional and state-of-the-art, relevant to military operations and, second, to examine GIS integration of these data for use in military applications. The application that will be addressed is the development and analysis of littoral warfare (LW) databases used to assess maneuvers in coastal zones (Fleming et al. 2008).

57.2 Geospatial Data Collection Technologies

Three major data collection categories used in populating GIS databases include: (1) field data collection and GPS; (2) aerial reconnaissance; and (3) satellite reconnaissance. Discussed here, these collection methods provide a complementary mix of platforms and technologies for gathering information about operational areas.

57.2.1 Field Data Collection and GPS

There are numerous methods of collecting raw data in the field for direct input into geospatial databases. These methods are most often used when the required data do not exist in any other readily available format, such as maps, photographs or satellite images. Field data also are frequently collected when "ground truthing" of remotely sensed data is required. Traditional manual surveying techniques make use of levels and theodolites for directly collecting field measurements. Modern digital equivalents of these manual techniques have been developed so that data collected are stored in digital format ready for direct input into a GIS. Examples here include total stations (high-precision theodolites with electronic distance measurement [EDM] and data logger capabilities), hand-held laser range finders and digital compasses. A universal military locating system, GPS, was designed and fully introduced to the military by the late 1980s. During this time, global missions for US forces expanded dramatically, often requiring immediate information about "place" anywhere on Earth. Joint operations between services became the norm for how America's military planned and executed tasks. A common system for providing key location data for friendly units, enemy targets and critical terrain was required.

Joint US combat operations in Grenada (1983) demonstrated the need for improved positioning technology. Although US forces prevailed as a result of large amounts of non-standard geospatial data between services, the conflict was not an efficient, well-coordinated effort by any measure of warfighting (Cole 1998). Since then, GPS integration and employment has accelerated, becoming the answer to many location-based challenges brought about by mission and interoperability changes.

The GPS, including satellites and monitoring equipment, undergoes constant improvement cycles to increase accuracy, reliability and capability. Currently, military GPS receivers reliably provide position accuracies to within one meter (GPS JPO 2000). These receivers have been made smaller, more accurate and easier to use. Microelectronics have made them very affordable so that every individual, weapon system and command post can share the technology, making available the benefits of a reliable, accurate worldwide navigation and positioning system (Huybrechts 2004).

The user-equipment segment of GPS consists of the military receivers, antennae and other GPS-related equipment. Global positioning system receivers are used on aircraft, ships at sea, ground vehicles or hand-carried by individuals. They convert satellite signals into position, velocity and time estimates for navigation, positioning and time dissemination. Most of the user equipment is employed by more than one branch of military service with very few (if any) having utility for just one.

System devices and GPS-aided weapons have been employed in numerous warfighting applications including navigation and positioning, weapon guidance, targeting and fire control, intelligence and imagery, attack coordination, search and rescue, force location, communication network timing and force deployment/logistics (NAVSTAR 2001). Major benefits of GPS realized in these applications include: (1) improved position accuracy; (2) more accurate weapon placement; (3) enhanced systems performance; and (4) time synchronization (GPS JPO 2000). Table 57-1 provides a detailed listing of benefits derived from GPS employment.

The GPS has a bright future; it is being improved to preserve the advantages it brings to the battlefield and to prevent its vulnerability to attack (GISDevelopment 2004). The vulnerability of the GPS includes terrorist use as demonstrated by the tragic events of 11 September 2001 where al Qaeda loyalists exploited GPS technology in guiding airliners into their targets on the US mainland.

Changes designed to better support the warfighter in an evolving threat environment are planned. They will provide more flexibility through more portable systems as well as military anti-jam capability, meaning that GPS accuracy will be maintained closer to the target in a high-jamming environment. In this, the GPS has recently been linked to commercial laptop computers and personal data assistants. Overall, GPS will provide a more secure, robust military signal service, assuring acquisition of the GPS signal when needed in a hostile electronic environment (Kimble and Veit 2000). Ongoing changes will deny an enemy the military advantage of GPS, thereby protecting friendly force operations and preserving peaceful GPS use outside areas of operations (SPAWAR 2001).

Table 57-1 Military benefits resulting from employing GPS.

Improved Position Accuracy	Accurate Weapon Placement
Mine Countermeasures	Saved Ordnance
Search and Rescue	Improved "Kill Ratios"
Special and Night Operations	Increased Efficiency
Intelligence Assessments	Demoralized Enemy
Logistics Support & Tanker Ops	Reduced Exposure to Hostile Fires
Enhanced Systems Performance	**Time Synchronization**
Standoff Land Attack Missile	Command and Control
Patriot	Secure Communications
Artillery and Armored Vehicles	Coordinated Operations
Sensors	Joint Operations
Attack Aircraft	Special Operations

57.2.2 Aerial Reconnaissance

There are numerous methods of collecting data via aerial reconnaissance for use in military operations. Some methods have been used for many years, while others make use of relatively new technologies. Included here is a discussion of two primary methods of employing airborne reconnaissance platforms to populate military geospatial databases: (1) air photos and digital images; and (2) sensor data obtained with UAVs.

57.2.2.1 Air Photographs and Digital Images

Aerial photographs have been traditionally used for over 75 years in mapping littoral regions (NOAA 1997). Taken from specially designed aerial camera systems, several different types of aerial photographs have been used routinely by military intelligence sources. These include simple black-and-white (panchromatic), color and color infrared. Color-infrared systems assist military analysts in camouflage detection mandates.

Current aerial photographs show changes that have taken place since the making of a map. For this reason, in military operations, maps and aerial photographs complement each other. More information can be gained by using the two together than by using either alone. Detailed in Table 57-2, aerial photographs (or digital images) provide many advantages over an analog map for military applications.

Over the past decade, digital images have been used increasingly in populating military databases. Scanning analog photographs or collecting scenes with digital cameras mounted on aircraft are the two primary means of generating digital images. In the latter use, digital cameras for collecting panchromatic, color and color-infrared images are designed around a matrix (array) of charge-coupled device (CCD) imaging elements. Camera features such as completely electronic forward motion compensation (FMC) and 12-bit per pixel radiometric resolution ensure image quality (Intergraph Corporation 2006). Significant advances in sensor technology have stemmed from subdividing spectral ranges of radiation into bands (intervals of continuous wavelengths), allowing digital camera sensors in several bands to form multispectral (MS) images. For multispectral data, the total spectral range is normally between 0.4 and 0.9 μm for visual and near infrared (IR). An advantage over aerial photos, digital images enable rapid image enhancement, zoom viewing and classification via supervised or unsupervised methods.

Table 57-2 Advantages of aerial photographs over analog maps (Department of the Army 2001).

Photos provide a current pictorial view of the ground that no map can equal.
Photos are more readily obtained; they may be in the hands of the user within a few hours after they are taken. A map may take months to prepare.
Photos may be taken of places that are inaccessible to ground soldiers.
Photos show military features that do not appear on maps.
Photos provide a day-to-day comparison of selected areas, permitting evaluations to be made of enemy activity.
Photos provide a permanent and objective record of the day-to-day changes with the area.
Photos are often used to obtain data not available from other secondary sources, such as location and the extent of certain areas of interest.

Another popular technology, imaging spectroscopy (also known as hyperspectral remote sensing) allows a sensor on a moving platform to gather reflected radiation from ground targets where a special detector system records up to 200+ narrow spectral channels simultaneously over a range from 0.38 to 2.50 µm (JPL 2004). With such detail, the ability to detect and identify individual materials or classes greatly improves. Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), one such hyperspectral sensor operated since 1987, consists of four spectrometers with a total of 224 individual bands, each with a spectral bandwidth of 10 nm and a spatial resolution of 20 m (Lillesand et al. 2007).

A new form of digital imagery, **l**ight **d**etection and **r**anging (lidar) is a very powerful and versatile remote sensing tool. It has a broad range of applications and is extremely well suited for monitoring combat zones. One noteworthy application of lidar technology is the Scanning Hydrographic **O**perational **A**irborne Lidar Survey (SHOALS) system (Guenther et al. 1998). This bathymetric mapping application uses a technique known as airborne lidar bathymetry (ALB) or airborne lidar hydrography (ALH) where lidar is employed to rapidly and accurately measure seabed depths and topographic elevations, surveying large areas and far exceeding the capabilities and efficiency of traditional survey methods (Guenther et al.1998). Other uses of lidar include terrestrial data collections, which further detail the context and elevation of terrain. When aerial lidar data and electro-optical imagery are merged, accurate and current terrain modeling products are possible.

In addition to these digital technologies, thermal remote sensing, operating primarily in the 8-14 µm but also in the 3–5 µm wavelength region of the spectrum, produces data that aid in identifying materials by their thermal properties. Finally, radio detection and ranging (radar), an active microwave system, has been flown on both military and civilian platforms because of its ability (for certain wavelengths) to penetrate clouds. Aircraft-mounted synthetic aperture radar (SAR) is the most popular radar device used in military mapping operations.

57.2.2.2 Sensor Data Obtained with UAVs

Although the use of aerial photographs and digital images for military applications has seen modest increase over the past few years, UAV exploitation has grown tremendously. The ability to provide real-time or near real-time data about the terrain they fight on and the enemy they face has always been a goal of the military intelligence community (Mahnken 1995). Unmanned aerial vehicles have made that goal a reality at many levels of war, becoming a valuable tool for ground commanders in preparation and execution of missions. With increasingly more UAVs populating the littoral battlespace, coupled with robust communications systems for distribution of the information they gather, these data may soon be available to every soldier and marine.

Unmanned aerial vehicles are remotely piloted or self-piloted aircraft that carry cameras, sensors, communications equipment or other payloads (Reinhardt et al. 1999). Not a new idea, the UAV has been employed by military units since the late 1950s (Pike 2003). Until the last 15 years, however, their usefulness was viewed as limited because the analog data they collected were not accessible (in most all cases) until after they returned from their missions. Digital technology changed this paradigm. As a result, since the early 1990s, the Department of Defense (DoD) has employed UAVs to satisfy surveillance requirements in close range, short range and endurance categories. Initially, close range was defined to be within 50 km, short range was defined as within 200 km, and endurance range was set as anything beyond. By the late 1990s, the close and short range categories were combined. The current classes of these vehicles are the tactical UAV and the endurance category.

Numerous digital multispectral, hyperspectral and radar sensor platforms are used on-board both tactical and endurance UAVs for military applications in a variety of regions. As the ability to move data more quickly and in greater volume improves, military commanders now receive current details of battlefield events like never before. Commanders are trained warfighters; they have a basic understanding of aerial photos/video, but typically are *not* trained in the interpretation of IR and radar data. For simple utility purposes, much of the tactical data gathered for military use by these systems are high-resolution multispectral images, predominantly from the visual portion of the electromagnetic spectrum. Average spatial ground resolutions now routinely achieved by these systems are on the order of 1 m. Systems collecting IR, thermal and radar data are quickly approaching similar resolutions (FAS 1996).

In all cases of UAV employment, tactical control stations (TCS) are used to control the vehicles and their on-board systems. The TCS is the hub where all software and communications links reside as well as connectivity links to other battlefield command, control, communication, computers and intelligence (C4I) systems (FAS 1999b).

Tactical commanders routinely control UAVs from within their command posts. Three tactical UAVs (TUAVs) are discussed here. The Pioneer was procured beginning in 1985 as an initial UAV capability to provide imagery intelligence for tactical commanders on land and sea at ranges out to 185 km. Used temporarily by the Army, it is currently only used by the US Navy (FAS 2000a). The Outrider was designed to provide follow-on, interim support to Army tactical commanders with near real-time imagery intelligence at ranges up to 200 km. This system, still in limited use, helped developers create the systems' capabilities requirement for future TUAV design (FAS 2000b). The resulting product, now in extensive use, was the Joint Tactical UAV or Hunter. This system was developed to provide ground and maritime forces with real-time and near real-time imagery intelligence at ranges up to 200 km and extensible to 300+ km by using another Hunter as an airborne relay (FAS 2001a).

Complementing TUAVs, Endurance UAVs have seen tremendous application and experienced great success over the past five years for military commanders, particularly in Afghanistan and Iraq. The medium altitude endurance UAV is called the Predator. This vehicle provides imagery intelligence to satisfy Joint Task Force and Theater commanders at ranges out to 830 km (FAS 2001b). Global Hawk and Darkstar are high-altitude endurance UAVs. These latter two vehicles are used for missions requiring long-range deployment, wide-area surveillance or prolonged acquisition over the target area. They are both directly deployable from the continental United States to any theater of operations (FAS 1999a; FAS 2001c).

Micro unmanned aerial vehicles (MAV) are currently under development. Experiments are being conducted to explore the military relevance of MAVs for future operations and to develop and demonstrate flight-enabling technologies for very small aircraft (less than 15 cm in any dimension) (FAS 2000c). As portable systems capable of receiving and utilizing image data proliferate the littoral battlefield, data volume will continue to be a challenge. Communication systems designed to monitor, control and filter bandwidth at different levels of warfighting (strategic, operational or tactical) will play critical roles in “moving” the data. When combined, the aerial reconnaissance data collection methods provide an important resource for populating military databases. These technological benefits offered by the various systems are a tremendous improvement to the intelligence assets available to military forces only a few years ago.

57.2.3 Satellite Reconnaissance

There are a growing number of satellites orbiting the earth, collecting valuable military data and returning these data to ground stations all over the world. Satellite remote sensing has the ability to provide complete, cost-effective, repetitive spatial and temporal data coverage. Tasks such as the assessment and monitoring of various conditions can be carried out over large regions. Classified and, increasingly, unclassified systems have and continue to be successfully used by intelligence organizations to provide critical information to military units.

57.2.3.1 Classified Systems

Satellite imaging systems have long been the workhorse of the military intelligence community. Classified satellite systems are primarily used for the collection of intelligence information about military activities of foreign countries. These satellites can detect missile launches or nuclear explosions in space and acquire/record radio and radar transmissions while passing over other nations. There are four basic types of reconnaissance satellites: (1) optical-imaging satellites that have light sensors designed to detect enemy weapons on the ground; (2) radar-imaging satellites that are able to observe the Earth through cloud cover; (3) signals-intelligence or ferret satellites that are sophisticated radio receivers capturing the radio and microwave transmissions emitted from any country on Earth; and (4) relay satellites that make military satellite communications around the globe much faster by transmitting data from spy satellites to stations on Earth (Galactics 1997). The first two will be discussed in detail as part of this review.

Starting in the 1960s, the US began launching reconnaissance satellites with the first series called Discoverer. As these satellites circled the Earth in polar orbits, on-board cameras recorded photographs (Pike 2000). The next series of US spy satellites was given the code name Keyhole, or KH for short. They mostly performed routine surveillance or weapons targeting. Traveling in elliptical orbits at low altitudes of 140 km at perigee, they either took wide-area photographs of large land masses or close-up photos of special interest objects (McDonald 1995; Pike 2000). The early KH satellites—*Corona, Argon,* and *Lanyard*—were used through the early 1970s to assess the former Soviet Union’s long-range bombers and ballistic missile production and deployment (McDonald 1995; Pike 2000). The resulting photographs were used to produce maps and charts for DoD and other US government mapping programs.

In June 1971, the KH-9 satellite deployed. Weighing 30,000 pounds and placed in an orbit that at times came within 150 km of the Earth, it was nicknamed Big Bird because of its extraordinarily large size. Big Bird employed two cameras to obtain both area-surveillance images and close-up photos. On the latter photos, it was reported that objects as small as 20 cm could be distinguished (McDonald 1995; Pike 2000). The Big Bird satellites were launched at the rate of about two a year from 1971 to 1984; 19 successful launches were followed by one failure, on 18 April 1986, in which the booster exploded after takeoff. The Big Bird’s major limitation was its relatively short life span, which started out at some 52 days. By 1978, it was extended to 179 days and the average orbital life was 138 days with a maximum of 275 days achieved in 1983 (McDonald 1995; Pike 2000).

In the early 1970s, another major US classified initiative, the Defense Satellite Program (DSP), was established. The satellites from this program, a key part of North America's early warning system, detect missile launches, space launches and nuclear detonations. Operated by Air Force Space Command, the satellites feed warning data to North American Aerospace Defense Command (NORAD) and US Space Command early warning centers at Cheyenne Mountain Air Force Base, Colorado. The first launch of a DSP satellite took place in the early 1970s, and, since that time, they have provided an uninterrupted early warning capability to the US. The system's capability was demonstrated during Desert Shield/Storm when the satellites detected the launch of Iraqi SCUD missiles, providing warning to civilian populations and coalition forces in Israel and Saudi Arabia (USAF 2004).

In December of 1988, the National Aeronautical and Space Administration (NASA) launched the $500 million *Lacrosse* satellite. *Lacrosse's* main attribute, like most spy satellites, is its image sensor. *Lacrosse* uses SAR technology to detect objects only 1 m across, the level of detail necessary to identify military hardware. Instead of providing a constant stream of images like most radars, *Lacrosse* records a series of snapshots as it arcs over the Earth (Pike 2000). *Lacrosse* also actively beams microwave energy to the ground and reads the weak return signals reflected into space. This allows the satellite to "see" objects on Earth that would otherwise be obscured by cloud cover and darkness. In order to send out these signals, however, *Lacrosse* has very substantial power needs that are met with solar panels larger than would be found on most satellites its size. *Lacrosse* uses a rectangular antenna, 15 m long and 3 m wide, which is very different from the standard mechanical antenna (Pike 2000). This antenna is covered by rows and columns of small transmitting and receiving elements that help *Lacrosse* pick up the faint return signals bouncing back from the Earth. Today, the National Reconnaissance Office continues to design, build, launch and operate classified satellites. Its future looks promising with over $25 billion planned for the next two decades (USAF 2004).

57.2.3.2 Unclassified Satellite Systems Producing High-resolution Images

Although the military has had and continues to have its share of classified satellite programs, commercial systems are now producing data with comparably high spatial resolution (Behling and McGruther 1998). Historically, remote sensor data with spatial resolutions corresponding to 0.5–10 m are required to adequately define the high-frequency detail that characterizes the urban scene (Welch 1982). Military databases demand similar detail, as many of the features found in the urban scene are common to LW data sets. Because of their ability to provide high-resolution spatial data, these systems are useful in most military mapping applications at large scale (examples provided in Table 57-3).

Table 57-3 Commercial high-resolution satellites and their sensor systems (Wilson and Davis 1998; DigitalGlobe 2004 and 2008; Orbital Sciences 2006; and GeoEye 2008).

SYSTEM	Ikonos	QuickBird	OrbView-3	WorldView-1
Date of Launch	September 1999	October 2001	June 2003	September 2007
Orbital Parameters	Altitude: 681 km Orbit type: sun-sync. Orbit time: 98 min	Altitude: 450 km Orbit type: sun-sync. Orbit time: 93.4 min	Altitude: 470 km Orbit type: sun-sync. Orbit time: 98 min	Altitude: 496 km Orbit type: sun-sync. Orbit time: 94.6 min
Sensor Parameters	Spatial Resolution 1m (pan) 4 m (XS) Spectral Resolution Panchromatic 0.45 - 0.90 μm Multispectral #1: Blue 0.45 - 0.52 #2: Green 0.52 - 0.60 #3: Red 0.63 - 0.69 #4: Near IR 0.76 - 0.90 Radiometric Resolution: 11 - bit Swath Width: 11 km at nadir	Spatial Resolution 0.61 m (pan) 2.5 m (XS) Spectral Resolution Panchromatic 0.445 - 0.90 μm Multispectral #1: Blue 0.45 - 0.52 #2: Green 0.52 - 0.60 #3: Red 0.63 - 0.69 #4: Near IR 0.76 - 0.89 Radiometric Resolution: 11 - bit Swath Width: 2.12 degrees (nominal 16.5 km at nadir – can be 14 – 34 km; altitude dependent)	Spatial Resolution 1m (pan) 4 m (XS) Spectral Resolution Panchromatic 0.45 - 0.90 μm Multispectral #1: Blue 0.45 - 0.52 #2: Green 0.52 - 0.60 #3: Red 0.625 - 0.695 #4: Near IR 0.76 - 0.90 Radiometric Resolution: 11 - bit Swath Width: 8 km at nadir	Spatial Resolution 0.55 m (pan) Spectral Resolution Panchromatic 0.45 - 0.90 μm Radiometric Resolution: 11 - bit Swath Width: 17.6 km at nadir
Data Parameters	Scene Size: 13 km by 13 km	Scene Size: 16.5 km by 16.5 km in-orbit stereo pairs	Scene Size: User defined	Scene Size: 17.6 km by 14 km at nadir

Commercial satellite images are primarily characterized by significant *spatial* resolution improvements over the well-known Landsat and SPOT satellite images and are useful for mapping applications at large scale. Three noteworthy high-resolution systems—*Ikonos, QuickBird* and *OrbView-3*—have some unique qualities (GeoEye 2008; DigitalGlobe 2004; Orbital Sciences 2006). In September 1999, with the successful launch and deployment of *Ikonos* by Space Imaging (now GeoEye, Inc.), high-resolution satellite images exploded onto the commercial market scene (GeoEye 2008). Just over two years later (October 2001), DigitalGlobe launched the *QuickBird* satellite (DigitalGlobe 2004). *Ikonos* provides panchromatic and 4-band multispectral images of 1 and 4-m resolutions, respectively, whereas QuickBird generates panchromatic images of 0.61 m and multispectral images of 2.44-m pixel resolutions. *OrbView-3,* launched in June 2003, has very similar technical capabilities as the *Ikonos* and *QuickBird* satellites. The greatest advantage is its repeat cycle, re-visiting (through sensor "pointability") ground tracks every one to three days to provide extraordinary temporal resolution required for assessing rapidly occurring changes on the Earth's surface (such as flooding or volcanic activity). All of these systems provide high-resolution multispectral data that are suitable for military mapping, change detection and the assessment of threats. Stereo images suitable for generating digital elevation models (DEMs) and large-scale mapping also can be obtained by these systems (Dial and Grodecki 2003; Haverkamp and Poulsen 2003). Other commercial satellite systems that provide high-resolution images (e.g., WorldView-1, GeoEye-1) have been and are continuing to be launched, providing additional resources to military organizations.

57.3 Data Integration and GIS Applications in Military Environments

GIS technology allows for the use of digital data in developing and employing tailored, current battlefield information to military commanders. In the 1990s, DoD performed work in GIS that focused primarily on database design/population and software development (Satyanarayana and Yogendran 2001). Numerous digital data formats are available for incorporation into large-scale military mapping projects. Previously discussed, many of these are the result of various data collection methods currently in use and they facilitate military and civilian organizations supporting DoD.

GIS analysis has been effectively demonstrated for military base (also known as garrison) operations. This affords installation personnel from multiple organizations with the impressive capability to successfully answer questions related to geographic inventory, analysis and modeling (GISO 2001). Although garrison operations are important, this example does not demonstrate the possible applications of GIS for military commanders. The remainder of this review will focus on the relevant GIS functions for use in combat operations followed by a discussion of current and planned developments of GIS technology for our armed services.

57.3.1 GIS and Its Role in Military Applications

Two major components of a GIS include a geographic database and software that includes different types of analysis functions. These spatial analysis functions distinguish a GIS from other information systems (Peuquet and Marble 1990; Mcguire et al. 1991). The use of spatial and non-spatial attributes in the database to answer questions about the changing world facilitates the study of real-world processes by developing and applying models (Burrough and McDonnell 1998). Such models often illuminate underlying trends in geographic data, making new information available and accessible through digital maps. The organization of databases into map layers provides rapid access to data elements required for geographic analysis.

There are four major groups of analytical functions: (1) data query; (2) overlay operations; (3) neighborhood analysis; and (4) connectivity operations (Aronoff 1991; Maguire et al. 1991; Lo and Yeung 2002). Critical to military operations, the rapid and selective retrieval, display, measurement and reclassification of information from a database (data query) are fundamental to every GIS. Overlay operations are important as well to military decision makers. Just as plastic acetate attached to a map has been historically used to show different components of the battlefield, overlay functions efficiently integrate layers of geospatial data and result in the creation of new spatial elements.

Neighborhood analysis involves the search and assessment of geospatial data surrounding a target location followed by calculation and/or assignment of a value. The generation of DEMs—the interpolation of a continuous surface from discrete points of elevation for terrain analysis—is an example of a neighborhood analysis that is important in military applications. The DEMs provide realistic terrain shape necessary for accurate visualization of the battlefield. Finally, connectivity operations are based on interconnecting logical components of a process or model. Those important to military operations include intervisibility (line-of-sight), seek (or stream) functions, buffering and spread analysis.

Buffers, calculated circular or square areas from a given point or series of points, are frequently required in combat planning/execution to establish radii or zones around critical locations and key terrain (e.g., weapon impact areas or search and rescue zones) (ESRI 1998; ESRI 2002). Spread functions evaluate phenomena that accumulate with distance (Aronoff 1991). One final military application of this type of analysis is terrain trafficability—predicting the time needed to traverse terrain with variable conditions. The trafficability, or ease and speed of movement, varies with the type of ground cover, topography, mode of transport and season of travel (Aronoff 1991; Fleming et al. 2008).

GIS technology is rapidly moving from its historic niche usage of installation inventory and monitoring within defense organizations to becoming a critical defense-wide infrastructure. The importance of GIS is based on the fact that defense operations depend on battlespace awareness—and the battlespace is geographic. This involves more than an understanding of location—geography is a science that creates a framework for understanding the relationships between all battlespace entities. This, in turn, develops knowledge from the flood of data. Defense-wide spatial infrastructures break down the divisional "stovepipes" of the separate military services—Army, Navy, Air Force and Marines—to provide a common framework for handling mapping, charting, geodesy and imagery across all defense systems. This is important because it avoids having the government pay time and time again for the same core functions to be developed for each system. Defense-wide spatial infrastructures also ensure that the warfighter receives the latest capabilities from the commercial off-the-shelf (COTS) community where information technology (IT) innovation occurs.

The idea of delivering interoperability is only part of the rationale of creating a defense-wide infrastructure. Far more important is the contribution that this spatial information infrastructure contributes to network-centric operations that represent a revolution in military affairs that is affecting every nation in the world. Such an infrastructure fundamentally reengineers defense organizations, doctrines, and systems to take full advantage of the capabilities of modern information technology. A GIS is the critical infrastructure that connects the three concepts of network-centric operations: 1) situational awareness (intelligence, surveillance and reconnaissance, or ISR); 2) command, control, computers, communications and intelligence assessment, or C4I; and 3) precision engagement. Sensors in the ISR domain are being directly coupled to geodatabases that are then distributed and replicated into the C4I domain to support decision making. They are then, in turn, distributed and replicated into the precision engagement domain to coordinate and target weapon systems. GIS is the COTS technology that makes all of this possible and affordable. ArcGIS, for example, supports the very scalable and rich geodatabases that are populated from a wide range of sensors, distributed and replicated across low to high-bandwidth networks. The advanced analysis and dissemination of information supports precision engagement, thus permitting the more effective employment of existing weapon systems. Numerous products are now being created for military use, such as assessments of cross country mobility, mobility corridors, zones of entry, aerial concealment, line-of-sight and fields-of-fire, as well as perspective views and fly-throughs of 3D terrain (Fleming et al. 2008).

The Cross Country Mobility (CCM) product demonstrates the off-road speed for a vehicle as determined by the terrain scenario and vehicle type (Figure 57-1). The makeup of the CCM includes surface traction and resistance, slope, vehicle dynamics, obstacles and vegetation. The CCM is used to develop the best axis of advance for a particular course of action or development of an engagement area.

The aerial concealment overlays describe the most suitable areas to conceal a force from overhead detection. This overlay is important to judge where enemies may be located, especially in areas where guerilla forces may be operating. This overlay also may be used by friendly forces to develop concealed movement routes and staging areas. Concealment may be provided by woods, underbrush, tall grass or cultivated vegetation. This product is predicated on canopy closure information within the vegetation layer. Line-of-Sight Profiles show an area of direct observation possible from one location to another based on digital elevation data or a digital surface model (DSM), if available. This line-of-sight analysis is used to anticipate enemy positions, plan locations for communications platforms and develop engagement areas (Figure 57-2); obviously, the higher the resolution of the DEM (or DSM), the more accurate the results.

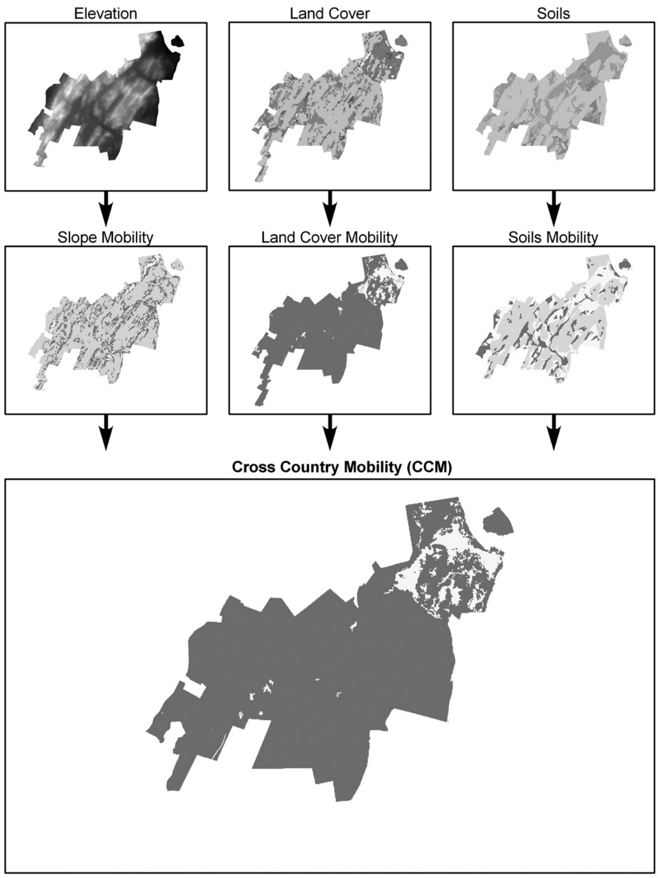

Figure 57-1 Example of a cross-country mobility product. See included DVD for color version.

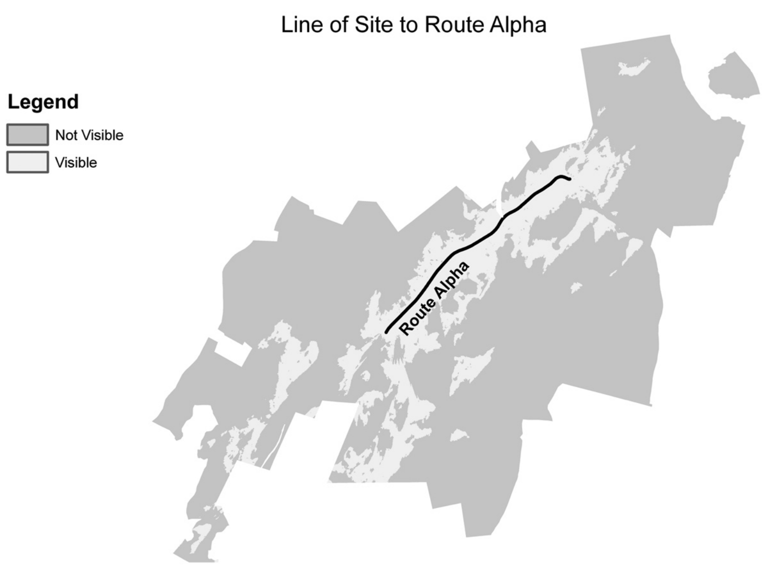

Figure 57-2 Example of a line-of-sight analysis. See included DVD for color version.

A virtual representation of a view of an area or target at a specified altitude, azimuth or angle of attack from a point position is called a perspective view. This product replicates a photograph of an area of battlespace (Figure 57-3). A perspective view can be used in many aspects of the military. Typically it is used to visualize an objective area or important battlefield terrain. A visual preview of an area of interest along a specified flight line at a specified altitude and angle viewed from inside the aircraft is called a fly-through. This product is used by commanders to visualize maneuver areas and plan operations. Operators can display roads, rivers, operational graphics and a text to enhance the visualization of the terrain.

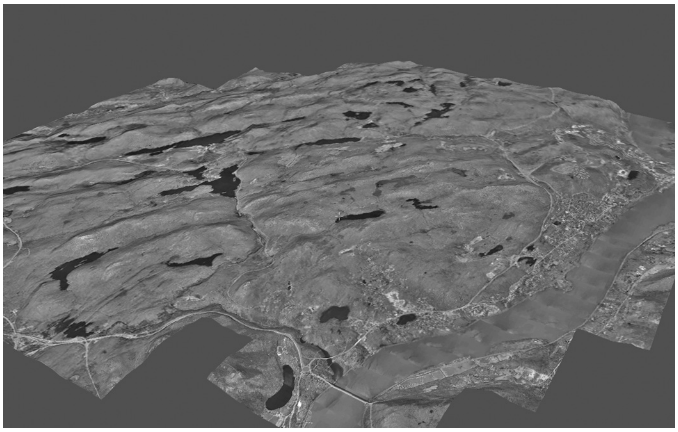

Figure 57-3 Example of a perspective view for battlefield assessment. See included DVD for color version.

57.3.2 Current and Future Military Applications in the Armed Services

Substantial ongoing research efforts by each service employ digitization and GIS analysis to aid in combat decision making by commanders and their staffs. Full digitization of the battlefield, however, will demand an extensive technological leap—the complete embracing of digital geospatial data and the means of exploiting it with GIS at all levels of war. This condition is, arguably, still some time from now. For the foreseeable future, paper maps and GIS will be complementary. The defense community has been using digital data in training and combats for about a decade, primarily confined to strategic and air systems (JCS 1997). Its use on the battlefield, long predicted, has also been leveraged at the tactical level of war by deployable systems (PEO-C3S 1997). Tremendous growth is now being realized as the importance of GIS technology on the battlefield is recognized. GIS allows for efficient representation of the ever-changing battlespace and provides for rapid transmission of that information over their robust communications infrastructure.

As discussed earlier, paper maps have two major limitations. First, they often do not adequately provide relevant information to individual commanders leading diverse organizations on complex missions, and, second, they quickly become out of date and therefore inaccurate. In addition, every paper map represents a compromise between the needs of differing users, none of whom receive the ideal product. Employing GIS, users are able to create (or have created) timely custom products that depict information that they need (Evans et al. 2000). The modern battlefield changes rapidly; the analog map product cannot. This is a critical limitation on today's fast-moving battlefield where weapon systems are capable of significant alteration of the real world. A GIS can help solve this problem, but only if the problem is clearly acknowledged and effectively addressed. To accomplish this, three things must happen. First, proper GIS models of the real world must be developed, validated and implemented. Second, data must be properly maintained. Finally, human intervention must apply a "sanity check" after each step in the decision process; where problems are determined, inspections of the models and/or data are required.

At the direction of the US National Geospatial-Intelligence Agency (NGA), an effort to leverage and consolidate GIS technology for military commanders (in all services) is now being developed. Northrop Grumman is the prime contractor for NGA's Commercial/Joint Mapping Tool Kit (C/JMTK) Program. The C/JMTK will be a standardized, commercial, comprehensive tool kit of software components for the management, analysis and visualization of map and map-related information (Northrop Grumman 2002). The commercial software companies involved in this plan include the Environmental Systems Research Institute, Inc. (ESRI), ERDAS, Inc., Analytical Graphics, Inc. (AGI), and Great- Circle Technologies. The developing foundation of the C/JMTK is ESRI's ArcGIS framework, which includes Spatial Analyst, 3D Analyst, and Military Overlay Editor (MOLE), extended by the ArcSDE database engine and distributed by the ArcIMS Internet server. These products provide a seamless package that give unprecedented capabilities in viewing map and map-related information along with tools to support the analysis and storage of map data (Birdwell et. al 2004). The program integrates the best of government and industry into a common, long-term solution that will advance operational mission application development into the next generation of interoperable systems for the warfighter (ESRI 2003).

Taking full advantage of such inventions as the C/JMTK, it is envisioned that the Objective Force—the planned future combat systems for 2020 and beyond—will operate on four war-fighting tenets: (1) see first; (2) understand first; (3) act first; and (4) finish decisively (JCS 1997). Unprecedented intelligence, surveillance and reconnaissance capabilities, coupled with other ground, air and space sensors networked into a common integrated operational picture, will enable forces to accurately see individual components of enemy units, friendly units and the terrain. Data integration systems will enable decision makers to have a synthesized Common Operational Picture (COP) (JCS 1997). Using the COP, Objective Force commanders will be able to leverage the intellect, experience and tactical intuition of leaders at multiple levels in order to identify enemy strengths and conceptualize future plans. As commanders decide on a course of action, they will be able to instantaneously disseminate their intent to all appropriate levels, affording maximum time for subordinate levels to conduct requisite troop-leading procedures. The time gained through effective use of these information technologies should permit Objective Force units to seize and retain the initiative, building momentum quickly for decisive outcomes.

Seeing and understanding first gives commanders and their units the situational awareness to engage at times and places with methods of their own choosing. Objective Force units will be able to move, shoot and reengage faster than the enemy. It is planned that target acquisition systems will see farther than the enemy in all conditions and environments. The intent, here, is to deny the enemy any respite or opportunity to regain the initiative. Objective Force units will be able to understand the impact of events and synchronize their own actions. Finally, Objective Force units should finish decisively by quickly destroying the enemy's ability to continue the fight. Units will be able to maneuver by both ground and air to assume tactical and operational positions of advantage through which they will continue to fight the enemy and pursue subsequent military objectives.

Although these advances will not eliminate battlefield confusion, the resulting battlespace awareness should improve situational knowledge, decrease response time, and make the battlefield considerably more transparent to those who achieve it. The integration of geospatial technologies and GIS will likely provide an improvement in warfighting success. Commanders will be able to attack targets successfully with fewer platforms and less ordnance while achieving objectives more rapidly and with reduced risk. Strategically, this improvement will enable more rapid power projection. Operationally, within the theater, these capabilities will mean a more rapid transition from deployment to full operational capability. Tactically, individual warfighters will be empowered as never before, with an array of detection, targeting and communications equipment that will greatly magnify the power of small units. As a result, US forces will improve their capability for rapid worldwide deployment.

57.4 Conclusions

There are numerous critical and advanced image data collection technologies that now define unprecedented military intelligence, surveillance and reconnaissance capabilities. These advances enhance the detectability of features and targets across the littoral battlespace, improving distance ranging, "turning" night into day for some classes of operations, reducing the risk of friendly fire incidents (fratricide) and further accelerating operational tempo (JCS 1997). On the horizon, improvements in information and systems integration technologies will significantly impact future military operations by providing decision makers with accurate information in a timely manner. The fusion of information with the integration of sensors, platforms and command organizations will allow operational tasks to be accomplished rapidly, efficiently and effectively.

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