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Military applications of GIS

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This chapter is concerned with military applications of GIS. It contrasts the considerable differences between military and civilian applications and highlights some of the key areas that have been exploited to date, namely base plant, barrack, and battlefield applications. In spite of the very real challenges of needing large (fine) scale data, for large areas of the Earth, in near real-time, there have been some notably successful military GIS applications. In the future, as technology continues to improve, many of the current technical difficulties are expected to reduce in importance.

1 INTRODUCTION

GIS is an increasingly important technology to the military. Spatial information has always been important to military commanders; an understanding of terrain, for example, is an essential military skill. Maps have been the principal mechanism for disseminating this knowledge and the ability to interpret a map the essence of understanding. The military is always seeking to improve capabilities in order to maintain a credible deterrent and increasingly to ensure efficient participation in peace-keeping missions. In the post-Cold War situation a key driver for international defence mapping agencies is their vastly increased area of interest. Forces can be deployed into almost any part of the world, yet prior knowledge of the terrain is unlikely. GIS have a key role to play in creating, editing, analysing, querying, and displaying geographical data in order to help the commander understand the influence of terrain on the conduct of the battle.

Why then has the take up of GIS technology been so slow and confined to very specific areas within the military? While base-plant activities have closely followed (and in some cases led) civilian GIS evolution, the same cannot be said of battlefield systems. This chapter will expose the very real challenges that face military GIS developers.

At the outset, it is worth defining some terms and setting the limits to this chapter. All that is discussed here is necessarily unclassified. That does not limit the scope as much as might be imagined since classification is mainly reserved for the use rather than design of systems. Notwithstanding classification, it can be extremely difficult to cite specific examples since the release mechanisms to publicise work can be unduly cumbersome. This necessitates a more generic discussion of military applications.

The chapter centres on 'western' technology and therefore 'western' defence. While this is partially a reflection on the difficulties of gaining access to information from other nations, it is an accurate reflection of the uptake of GIS. There may be several reasons for this. The first is that the use of GIS must be preceded by widespread use of Information Technology (IT). The use of IT on the battlefield is largely confined to technology-rich military environments. This precludes many nations with low-technology military requirements.

The setting for this chapter is therefore post-Cold War defence. The main drivers in this context are a shrinking resource, an increasingly unpredictable threat, and wider areas of interest. These drivers are of course well supported by the introduction of GIS. It is also worth explaining the use of the words 'defence' and 'military'. Although they can be used interchangeably in some contexts, the formal differentiation is that 'military' refers to uniformed members of the airforce, army, and navy while 'defence' includes all components including politicians, civil servants, and contractors.

GIS can be applied to a wide range of military applications. These can be broken into three overlapping categories of Base-plant, Barrack, and Battlefield, as shown in Table 1.

What might be surprising is that the ubiquitous application of GIS has been so slow in defence organisations. To date, the use of GIS has been confined mainly to certain specialist support areas such as base-plant mapping activities and some limited facilities management applications. Each of the key application areas is now examined in order to expose the challenges and potential benefit of GIS implementation

2 APPLICATION AREAS

2.1 Base-plant

Defence organisations require mapping and related products in order to support operations, planning, and training. Demands for geographical coverage and resolution increase constantly as does the range of products. These demands have to be met by defence geographical agencies.

The fundamental problem is that the amount of effort required to produce a map or equivalent digital geographical product is far greater than that required to reproduce it. It takes little more effort to produce 100 000 maps than 1000. Thus geographical support is not proportional to the size of a force but to its area of interest.

Defence geographical agencies are therefore faced with a requirements gap. Demand is growing as resource shrinks, or at best remains static. In order to bridge this requirements gap a number of strategies can be adopted. Burden sharing, development of more efficient production techniques, and work to impose realism on requirements are described below. Unfortunately, each of these strategies has some largely unforeseen effects on the implementation of GIS.

2.1.1 Burden sharing

Burden sharing spreads the production activity across a wide range of allied nations. To initiate such activity, considerable effort has to be applied to the negotiation of bilateral and multilateral agreements covering the exchange of geographical products and services. In the digital era this has two main effects: rapid adoption of international standardisation and problems with the release of data.

The former is positive in that the free exchange of digital geographical data demands, and indeed has achieved, strong international standards. In some respects international defence standards for the exchange of digital geographical products are many years ahead of civilian equivalents. The work of creating and maintaining these standards is

Table 1 Classification of major military applications.

Base-plant		
	Digital Geographical Information (DGI) management	DGI production
	Mapping production	Map catalogue production
	The management of geographical requirements	Map stock control
Barrack		
	Range management	Range control systems
	Natural resource management	Facilities management
	Environmental management	Hydrology
	Barrack reorganisation and closure	Emergency response
	Wildlife management	Airfield damage repair
Battlefield		
	Situation mapping	Terrain analysis
	Air space management	Track management
	Command, control, and communications	Simulation
	Map distribution and supply	Terrain visualisation
	The production of military situation overlays	Targeting
	Maintaining battle records	War gaming

undertaken by the Digital Geographical Information Working Group (DGIWG – pronounced *dijeewig*) on behalf of the NATO Geographic Committee (Salgé, Chapter 50). The efforts of this working group manifest themselves in an exchange standard for digital geographical information. This exchange standard is known as the Digital Geographic Information Exchange Standard (DIGEST).

DIGEST is an excellent framework for the exchange of raster, matrix (e.g. digital terrain models), and vector data. It can be implemented at a number of different levels: for example, vector data can be exchanged using either a feature-oriented or relational data structure (see Worboys, Chapter 26). On top of the basic framework, specific products can be built to supply to end-users. This greatly assists in distributing data in a user-oriented form. DIGEST is not, however, compliant with any vendor's binary data structure. This has enormous implications for GIS developers since defence agencies in many countries are moving to commercial-off-the-shelf (COTS) solutions (see Maguire, Chapter 25). No longer will developers (in-house or external) create one-off systems built from the ground up. The intention instead is to maximise the use of up-to-date, widely supported COTS solutions. This can create a problem for defence users because of the intimate linkage between algorithms and data structures in COTS GIS packages as shown in Figure 1.

Figure 1 illustrates in a generalised way the relationship between GIS algorithms and data structures. One important consequence of the increasing use of COTS GIS algorithms is that application algorithms are required to translate DIGEST data into an internal GIS data structure.

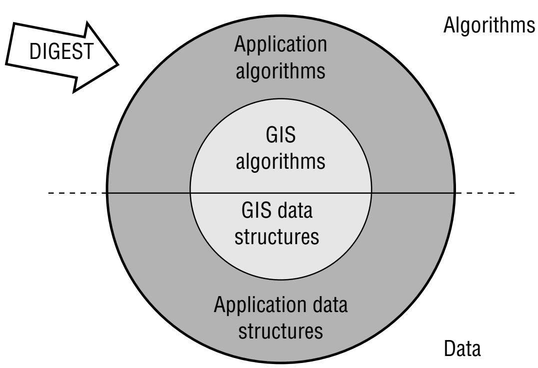

Fig 1. Relationship between GIS algorithms and data structures.

This conversion, particularly for raster data, is time consuming, processor intensive, and demands considerable data storage capacity. A key question is 'who should be responsible for performing this conversion?' If the task is distributed to users, the infrastructure required increases alarmingly, the user requires considerable geographical expertise and a centralised common picture of data creation and usage is in danger of being lost.

The alternative is for the conversion to be done at base-plant. The problem here is that vendors' data structures are different and incompatible not least because each area in defence has different requirements that may demand more or less capable GIS. It is highly unlikely that the whole of defence will choose a single COTS GIS package. Thus the result of base plant conversion would be a plethora of different data formats that would complicate the distribution process.

The outcome will probably be, as is often the case, a compromise. It is likely that attempts will be made to standardise on as few GIS software packages as possible. Base-plant GIS specialists will undertake a considerable amount of data reformatting and users will come to rely on geographical data servers operated by geographical specialists that reformat data for a cluster of local clients.

2.1.2 Making production more efficient

Early GIS work focused on automating manual cartographic techniques. Military developments in automated cartography often led the commercial world.

Feature extraction, that is creation of specific features (e.g. drainage features, houses, and roads) is perhaps the slowest part of the cartographic process (see Weibel and Dutton, Chapter 10). The fact that different scales of mapping have traditionally demanded separate extraction has resulted in research and development to facilitate automatic generalisation. This allows multi product operations (MPO) where features are extracted once at the largest scale demanded and then automatically generalised to create smaller-scale products. True MPO remains very difficult to achieve since the considerable amount of operator intervention necessary demands highly skilled technicians working at expensive workstations.

Auto-stereo correlation is now widely used to extract elevation data from stereo pairs of imagery and operator intervention is typically reduced to less than ten per cent. In this case though, capability drives demand and battlefield commanders are increasing their aspirations from 100 m to 1 m spatial sampling interval elevation models. In terms of effort, ten per cent operator intervention on a 1 m model represents 1000 times more work than 100 per cent manual effort to create a 100 m model!

At the present time, fully automatic feature extraction continues to elude developers. Whilst many research projects show much promise, there is considerable difference between research and production.

2.1.3 Requirements realism

In defence, as in any business, a line must be drawn between what is desirable, highly desirable, and essential. This discrimination must be made in terms of what is affordable. It would be a considerable advantage for defence planners if every part of the Earth's surface were mapped at 1:1000 resolution. Yet this is clearly unaffordable given current technology and requirements. At the other extreme it would be very cheap but clearly unacceptable to only hold worldwide products at scales greater than 1:1 000 000.

In between these two extremes can be found the balance between affordability and acceptable risk. Maintaining that balance is a key function of defence geographical agencies. On the one hand, data are needed to support defence activities. At the same time, operational staff, planners, and developers must be educated to be realistic in stating their demands for geographical data of all kinds.

There is an additional problem concerning the resolution of data required to support GIS use at different levels of command. The correspondence between map area, map scale, and type of defence user is summarised in Table 2. A strategic planning headquarters will be able to meet most of its requirements using small (coarse) scale data and only require limited amounts of 1:250 000 scale data. A high level tactical headquarters such as a divisional headquarter will require an absolute minimum specification of 1:250 000 scale data and large swaths of 1:50 000 data. A brigade commander at the next level down will demand 1:50 000 data and need down to large (fine) scale 1:10 000 data for target areas of interest. The battle-group commander one level lower really needs 1:10 000 data to support GIS requirements. This is unrealistic and the unpleasant message that must be distributed is that the user's functional requirements cannot be met and that the developer's aspiration is technically not feasible.

Table 2 Military data requirements.

Geographical extent	*User*	*Map scale*
1000km × 1000km	Strategic planning	> 1:250k
400km × 400km	Divisional HQ planning	1:250k – 1:50k
150km × 150km	Brigade HQ planning	1:50 – 1:10k
50km × 50km	Battle group planning	< 1:10k

Both user and developer are likely to react angrily to this news and may seek contractors to demonstrate their wares. The contractor will be able to demonstrate the functionality on a small part of a training area that has the required data available. There is a real danger at this point that the vested interest of the contractor, the needs of the user, and the ambition of the developer will conspire to introduce a system that cannot be supported in operations where wide area coverage of digital geographical information is required.

2.2 Barrack

The term barrack is used to encompass a wide range of asset management, training, and infrastructure activities that are required to support the military in their peacetime locations.

The infrastructure required to support defence is typically huge. The ending of the Cold War has forced many countries' military organisations to emerge blinking into the harsh realities of downsizing, rationalisation, competition, and environmental assessments: all the issues that most commercial businesses have been grappling with for years (see Birkin et al, Chapter 51).

The application of GIS to assist in these problems is not new (see, for example, Conry and Goldberg 1994; Lamb et al 1994), and for that reason this section is the shortest of the three. For further discussion of similar civilian infrastructure applications, see Meyers (Chapter 57) and Fry (Chapter 58). The military-specific issues that are worthy of note concern the scale of the problem, the availability of data, and the potential need to migrate to Command Control and Communication Information (C3I) functionality.

The scale of the problem is enormous. The number of buildings, the length of roads, complexity of infrastructure, and area of land involved are similar to that of a large local government user, but the assets are dispersed nationally and, often, internationally. The quality of available hard copy map data is typically poor and the numbers of staff engaged in production often inadequate. Finally, the problem is often most pressing whilst the resources to solve the problem are difficult to acquire.

Data availability is tied to the paucity of trained technical personnel. Inevitably, military priorities focus on the ‘front line’. It can be difficult to attract sufficient investment to acquire the GIS hardware and software, much less the data required to populate a GIS. Defence mapping agencies are focused on acquiring and producing data to support operations: they are frequently not resourced to collect the very large scale data required to support facility management. This is an important issue since military developers and procurement staff are rarely confronted with the true costs of geographical data. When a barrack or training area GIS project submits a bill for the procurement of large-scale geographical data, disbelief and refusal are typical reactions.

Even when data are acquired, the problems continue. The data are likely to be acquired from national civilian mapping agencies whose data standards may not conform with DIGEST. Furthermore, where data are acquired for more than one country, the data specification and transfer formats are likely to differ (see Smith and Rhind, Chapter 47; Salgé, Chapter 50). The result is that facility managers are likely to encounter different data structures across their area of responsibility.

The final issue concerns the need to have commonality between the facility management GIS and ‘battlefield’, or to be more precise, ‘battle management’ GIS. This problem is most acute when facilities are located in a different country to the agency’s base GIS capability. It can especially be a problem in the case of an operational airfield. If the facility is attacked, the need to integrate facility management data into the command and control system is very real. For example, ‘what damage has been caused by that bomb? How long before the airfield is operational again? What units are within 5 km that could assist?’

This requires liaison between developers at the two extremes of the military spectrum: the facility manager and the operational commander. This rarely happens because development activity for the operational commander is often focused on the battlefield while the facility manager is rarely confronted with C3I system requirements. Cova (Chapter 60) provides a review of emergency management using GIS.

2.3 Battlefield

This section focuses on the specific use of GIS on the battlefield, and highlights the particular challenges that are faced by developers in this area. The military are beginning a process of moving from reliance upon paper products to using maps and digital geographical products in tandem. Note, however, that a switch from paper maps and manual methods of interpretation during field use, to digital geographical data and GIS is not being advocated. This is unlikely to occur in the near future for good practical reasons. When a US$10 GIS is developed that can be folded into a pocket, display 10km × 10km at 600 dpi even when the batteries have failed, and will still be usable with a bullet hole in it, then look to a switch from maps to GIS!

The military always strives for improvement because there is an ever pressing incentive for continuous change. Military agencies must continue to provide an effective deterrent and, if required, win in battle against constantly improving threats. This ever-present driver for change is being supplemented by the growing need to support operations short of war. Increasingly, the military are called to make or keep the peace. In these situations very small actions can have key strategic consequences and there is therefore the need for high-level headquarters to have an increasingly fine resolution view of the situation. These politically sensitive situations also require very careful media handling and the need to get information to commanders ahead of television companies is very pressing!

Much of the work of the military is currently supported by paper maps. Before seeking to improve on the map it is necessary to understand exactly what a paper map has been providing the military with for hundreds of years.

It is easy to take maps for granted because they are such common commodities. Maps are of course extremely expensive commodities to make and maintain. Accurate mapping demands a sophisticated national infrastructure that takes considerable time and effort to put in place. Military deployments are becoming increasingly unpredictable as peace-making and peace-keeping operations become the norm. As a consequence of this, ensuring the availability of 1:50 000 topographic mapping demanded by military commanders has become a challenge for defence mapping organisations around the world. GIS have contributed to the process of meeting the paper map requirement by automating map production systems. Now that GIS are migrating onto the battlefield and digital geographical data are being required for battlefield applications, that base plant burden is set to increase many-fold.

When attempting to project what GIS is likely to be used for on the battlefield it does not suffice to look at the uses of a paper map and then automate those manual processes. GIS is likely to revolutionise command and control procedures on the battlefield in the same way that commercial businesses have been revolutionised by IT. The disadvantage faced by developers on the battlefield is that there has been very little use of any IT to date; IT is being introduced into headquarters at the same time as GIS. This, not surprisingly, is revolutionising the way military agencies operate.

Most military IT development effort in the UK, for example, is currently focused on the development of C3I systems. These C3I systems will be used by staff officers from the Defence Ministry to the front line. Since the essence of command and control on the battlefield is an understanding of terrain it is logical that GIS will form an essential foundation of these bigger systems.

There is a significant difference between a team of GIS specialists building a GIS with a range of applications built on top, and a team of C3I developers trying to implement a GIS at the heart of a C3I system. C3I developers have traditionally had a wide range of communication system skills but have not seen GIS as a core skill. That is slowly changing as the importance of the geographical infrastructure is understood.

It is useful to divide battlefield GIS use into two broad categories, based on the spatial data manipulated. High end GIS will be required to manipulate the background geographical data that are the equivalent of the paper map. Lower specification GIS will suffice to view the background data and manipulate the digital battle information that is analogous to an overlay trace. This overlay trace contains military-specific information traditionally drawn on transparent film overlain on the paper map. This separation of background and overlay data is essential for data management purposes; users will manage their own layer of the overlay whilst management of the background data should be left to geographical specialists. The overlay will probably be split into layers based on functional divides within the headquarters: operational staff managing the friendly force picture; intelligence staff, the enemy picture; engineers, the obstacles; artillery, the guns, and so on. This model of a multi-purpose database is well known in multi-department civilian organisations such as local government and large private agencies.

Each component of a GIS demands special consideration in the military environment. Table 3 highlights five components: hardware; software; data; the human resource; and the target management structure. This latter component refers to the need for the GIS to take its place within the structure of an existing organisation; in this case a military headquarters. This table lists some of the factors that must be considered when introducing GIS into the military environment.

These factors represent a small proportion of those that need considering and may help us to understand why there are so few GIS on the battlefield today. Further discussion of the critical, but often overlooked, organisational issues is given in Peuquet and Bacastow (1991).

2.4 Examples of current military GIS

Currently there are very few military C3I systems, although a number of systems with embedded GIS are nearing their in-service dates. These tend to use a geographical client–server architecture as is illustrated in Figure 2.

This allows the C3I system to embed a lower-end GIS (OPGEOCLIENT), while leaving the high-end GIS functionality to a separate system (OPGEOSERVER) operated by geographical specialists. It is this latter system that manipulates and manages background geographical data in order to provide the C3I system with a managed picture of the terrain. These high-end systems are already in service. For example, operational connection has been made to the NATO Crisis and RESponse Prototype (CRESP) and Prototype Allied Command Europe Intelligence System (PAIS) in Bosnia Herzegovina. A trial connection has also been established to the Battlefield Management System (BMS), a prototype command and control system in service in the UK.

Table 3 GIS components in a military environment.

Component	*Consideration*
Hardware	Protection to some extent against: Water, dust, temperature, shock, vibration, etc. Very low overheads: Low maintenance, hot-swap modules, user serviceable GIS-ready: Good display resolution, multi-gigabyte data storage, powerful graphics architecture Future-proof: Modular, latest technology, commercial-off-the-shelf (COTS) Affordability: COTS, low unit cost, low maintenance cost
Software	Usability: Intuitive, low training overhead, standard interface Security: Compatible with secure operating systems Data: Ability to handle any format with variable coverage and resolution Cost: COTS, reusable application code, low maintenance cost
Data	Coverage: Small scale worldwide, large scale provided on warning for localised area Resolution: Low resolution worldwide, resolution improves with targeting and time Format: Data will be provided in DIGEST format; a worldwide military standard Timeliness: Commanders require an up-to-date picture of the battlefield
Human resource	The situation: Operator is tired, cold, under immense pressure, mistakes kill! Training burden: The user is a soldier, sailor, or airman first, then a specialist, then a GIS operator Tool, not system: The system should allow the user to complete tasks faster and better
Target management structure	Situation: A military HQ is lean, under pressure, and very conservative The system must fit into existing procedures: The tested procedures in a military HQ will only change after the introduction of a new system Evolution: The procedures will change to take advantage of the new system The system will need to evolve

Geographical specialists are also using these high-end systems to undertake some specialist tasks in support of high level decision-making. Terrain analysis, for example, demands a very powerful GIS capability to help a commander to understand how terrain is likely to influence the conduct of a battle. This analysis requires use of every component of the GIS described in Table 3 and as such is likely to remain a specialist task. Indeed, at present terrain analysis is restricted to problems where there is a specific question that can be satisfied with limited data and an explicit answer. When fuzziness enters any element, computer-based terrain analysis becomes increasingly difficult, and users must revert to manual methods of terrain analysis.

Terrain visualisation is being used as an achievable alternative to pure terrain analysis. This involves presenting terrain information in a 'flyable

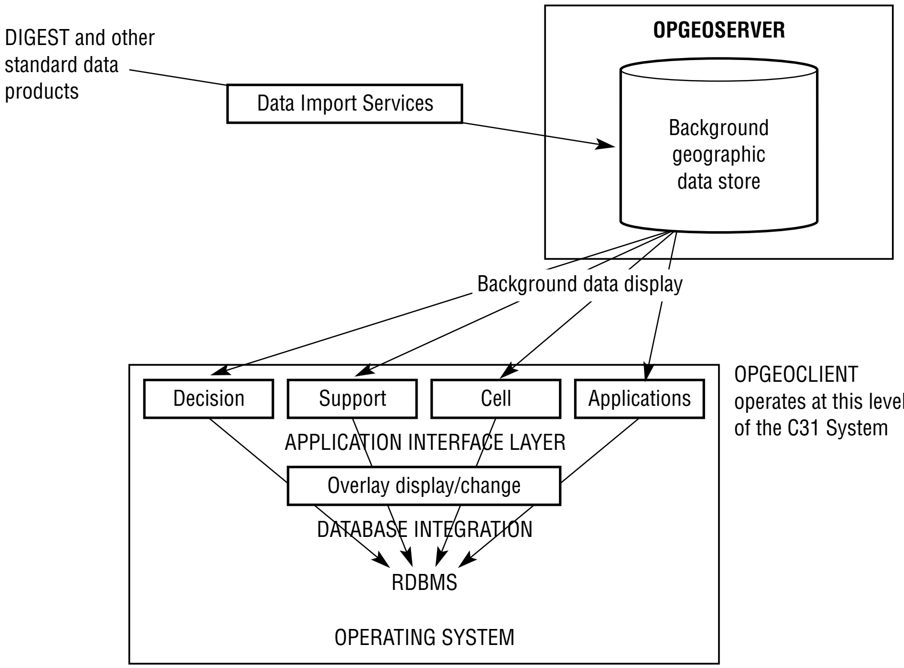

Fig 2. The embedding of GIS into a C31 system.

3-dimensional model space that allows very intuitive understanding. Limited terrain analysis results can be presented in this model space to allow a commander or other user to assimilate the impact of the information and thus assist in the decision-making process.

Plate 55 illustrates a typical model space with georeferenced imagery draped over an elevation matrix. This example integrates the line-of-sight analysis of a weapon platform and a correctly scaled attack platform into the model space. It is emphasised that this is a snapshot of a dynamic model space. It is the dynamism that adds considerably to the interpretability.

3 THE FUTURE

It is always difficult to predict the future, especially in the IT arena where things move quickly. For this reason only a vision of the future is described; others can guess the timeframe in which the events will occur. One certainty is that the timeframe will be much shorter than could be expected in almost any other discipline except IT!

Possibly the most important aspiration must be to remove any differentiation between base-plant, barrack, and battlefield GIS. Although the applications will be different and tailored to the specific requirements of each area, they should be based on a common view of the world. This demands common data, preferably manipulated using a common GIS interface. This is not the same as advocating a single vendor's GIS software package, but does recognise the training and operational advantage of having a common user interface. Despite setting unification as a major goal, each current application area will be assessed separately here in order to allow easy comparison with the current situation described above.

3.1 Base-plant

Automatic feature extraction offers the greatest promise for base-plant GIS. This, allied to the increasing availability of high resolution commercial satellite imagery (Barnsley, Chapter 32; Estes and Loveland, Chapter 48), is likely to have a radical impact on the activities of base-plant mapping organisations. When the sources and means to exploit them enter the public domain, competition is likely to enter the closed world of defence geographical organisations. Why produce base-maps in-house when you can out-source?

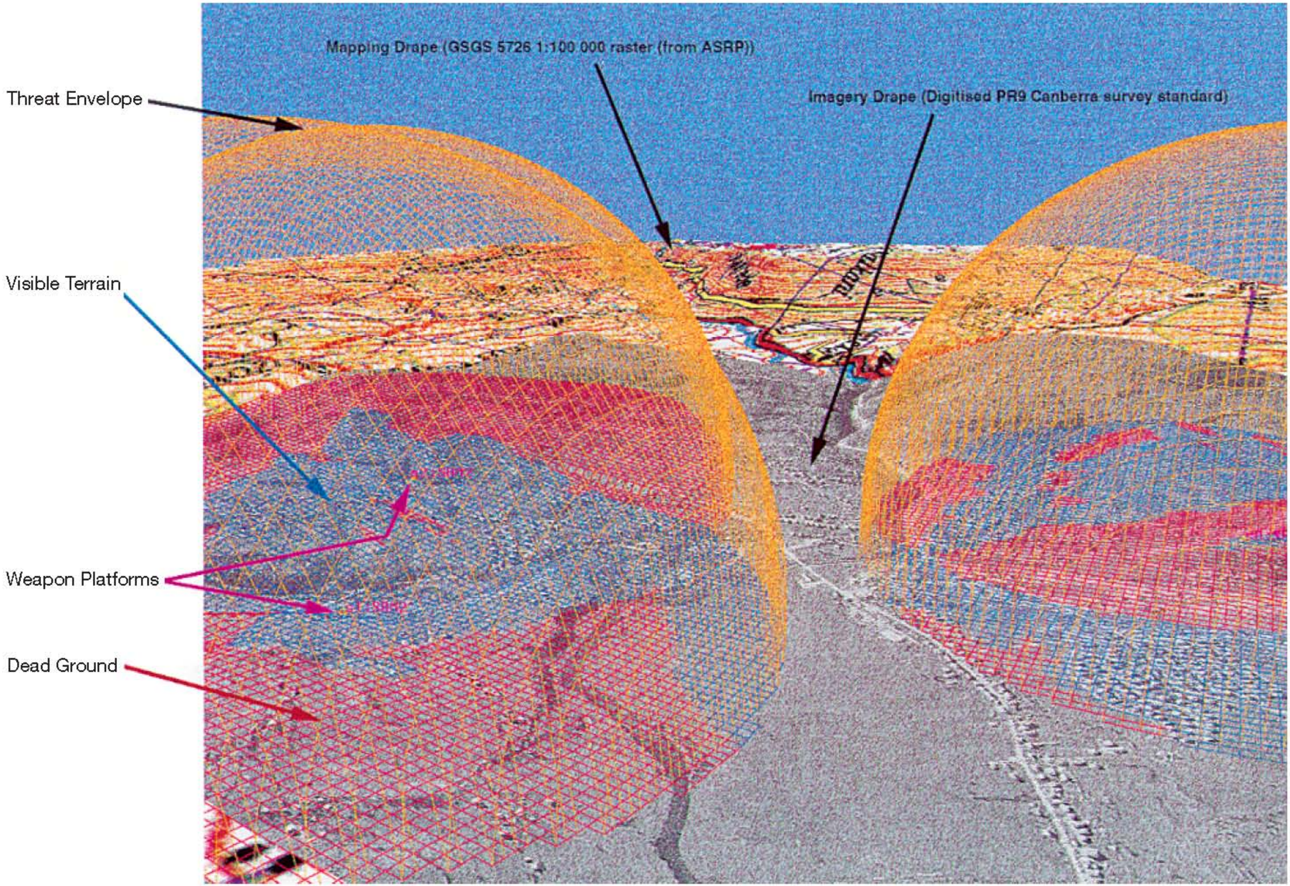

Plate 55 Example output from a GIS-based terrain visualisation system.

There are likely to be enormous political impacts as countries whose 1:50 000 topographic mapping is classified suddenly find neighbours exploiting imagery and extracting features at a resolution equivalent to 1:2 500 scale mapping and better. Equally, civilian mapping agencies will see threats to existing pricing structures as competition drives spatial data prices sharply downwards (but see Rhind, Chapter 56). This is likely to be exacerbated as international competition, perhaps using extremely cheap labour, has access to high resolution imagery over national territory.

The requirement for a common view of the battlefield demands standards for data and rapid data capture (Lange and Gilbert, Chapter 33; Salgé, Chapter 50; Smith and Rhind, Chapter 47). As features are captured at base-plant they should immediately be seen by end-users. Similarly, change being reported from any source should immediately be promulgated to all users. There are enormous quality control and validation issues to be addressed here, but to a large extent these can be resolved by comparing change from different sources. In turn this demands more complicated data structures that allow time and quality information to be added to individual data elements such as points, lines, or polygons (Bédard, Chapter 29; Goodchild and Longley, Chapter 40).

3.2 Battlefield

Commanders at all levels need a common view of the battlespace that is capable of integrating all information into an easily interpretable user interface. They need to be able to rewind the battle picture to re-examine past information in the light of newly received reports. More importantly they need to be able to fast-forward the battle picture for war game scenarios of future operations.

The need to integrate information from a variety of sources, sent at different times and of different qualities, demands very specialist GIS tools. Naval systems, for example, have used track management software to produce a record of ships' tracks on navigational displays. This involves extrapolating positions and speed and direction information reported at different times in order to provide predicted current positions of vessels in the vicinity. This functionality now needs to migrate to battlefield systems where the unpredictability of position, speed, and direction is much greater, the situation more complex, and the terrain itself subject to change.

All of this activity demands advanced, knowledge-based GIS processing. This must be based on a common, high resolution representation of the battlespace, presented using widely distributed visualisation tools (e.g. see Neves and Câmara, Chapter 39).

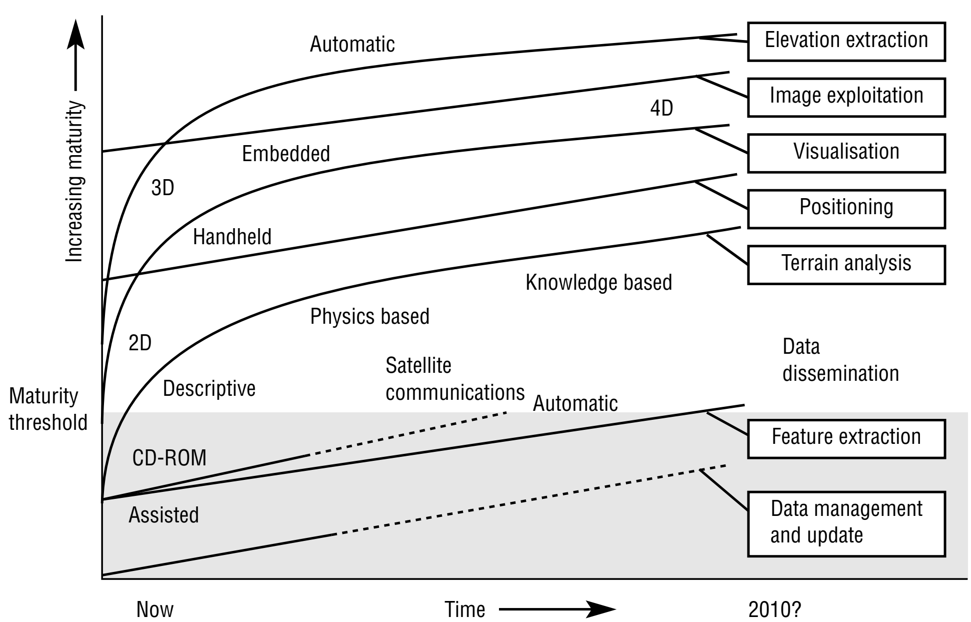

Fig 3. Maturity of GIS technologies.

Table 4 Some hopes and fears for military GIS development.

Component	*Aspiration*	*Challenges*	Hopes/*fears*
Hardware	Visualisation capability down to platoon level	Affordability	New games platforms offer.affordable visualisation.
		Training burden	Increasingly intuitive interfaces.
	Palmtop size	Display	Portable display technology emerging rapidly.
		Voice input, instead of keyboard	Voice recognition improving rapidly.
	Group decision display – 2 m x 2 m @ 600 dpi that can be rolled into a kit bag, retaining display without power	Immense!	*The type of display that could replace the paper map as a group decision aid (the 'Bird Table') presents enormous technological challenges.*
	1 m resolution across the battlefield	Data storage > 1 terabyte (TB)	Data storage continues to fall in cost. *Demand continues to outstrip supply.*
Software	Full terrain analysis	Knowledge-based processing	*Progress with knowledge-based GIS remains slow.*
		Data availability	*Automatic data extraction some way off.*
	Battlespace visualisation	Integration of GIS and visualisation	Rapid progress in COTS packages.
	Data management	Change detection	Change detection routines available.
		Automatic feature extraction	*Automatic feature extraction a long way off.*
		Update management	*Doctrine yet to be established, routines must follow doctrine.*
Data	High resolution geographical data (1 m imagery, elevation and feature data)	Data volumes	Decreasing storage costs.
		Data communications	*Bandwidth improvements not keeping pace.*
		Increased rate of change	Improving change detection routines.
		Data management	*Immature doctrine.*
		Image interpretation	Increasingly sophisticated classification tools.
	High resolution vector data	Extraction from imagery	*Fully automatic extraction some way off.*
	Common view of the data From division to platoon	Data dissemination	*Wireless bandwidths inadequate.*
		Data standardisation	*Data formats remain tied to vendor's GIS.*

Several elements of this vision are closely related. There is, for example, a link between resolution and commonality that demands attention. A low resolution representation can be made common to all users with comparatively low bandwidth communications. An increase in resolution demands an increase in bandwidth. To share a 1 m resolution picture of a typical battlespace (often 10 000 km^2 and with activity up to 10 000 m) to all the widely dispersed users would demand a bandwidth in excess of 1 Gb/s (1 Gigabit per second). This is not technically feasible at present for wireless communication networks.

It may be possible to focus effort on geographical data maintenance by ensuring that all users deploy from barracks with a full geographical data coverage. This could be provided using a high bandwidth network infrastructure linking all static peacetime locations. Bandwidth requirements could also be dramatically reduced by only sending changes to the distributed dataset to deployed users. Thus automatic change detection algorithms could be applied to imagery at base-plant and the changes in the imagery automatically extracted to create vector changes. The combined imagery and vector changes would then be the only components sent to deployed users.

The hypothesis of a drawing together of GIS technologies in different areas of defence is supported by this vision of automatically extracted base-plant data being distributed to an in-barrack infrastructure prior to deployment.

3.3 Trends

One way of attempting to predict the future is to examine trends. Figure 3 shows the maturing of various geospatial technologies over time and attempts to project them into the future.

This illustrates the challenge facing battlefield GIS developers: whilst a number of key technologies have only just become mature enough to deploy onto the battlefield (crossing the maturity threshold in the diagram), a number of foundation issues have yet to be resolved. Of these, it is data management and update that cause most concern. There is little point in developing tools to enhance a commander's decision-making if those decisions are going to be based on poorly managed or maintained data.

The maturity threshold is also important in terms of COTS development. Technologies that appear to have developed beyond the threshold generally have commercial applications that offer the potential for return on investment. Those below the line demand considerable investment before a commercial return is likely. For an example of how COTS software can be used to create a military terrain information system see Graff and Visone (1996).

Some predictions about the future of GIS technology and their impact on military systems are summarised in Table 4.

4 CONCLUSIONS

GIS present considerable challenges for military developers. Many of the problems are unique to the military and demand innovative solutions. Increasingly, those solutions are relevant to the civilian world, particularly the efforts to turn specialist GIS into transparent, user-oriented tools.

Many challenges lie ahead but, given the incredible pace of change, there can be few doubts that they will be met, and more before the next edition of this book is published!

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