Integrating Geospatial Decision Support into C2 Decision Making

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Abstract

Geographical awareness will be critical to many Command and Control (C2) decisions. Geospatial Decision Support (GDS) allows geographical analysis to be embedded into decision making cycles where specialist tools are provided to the decision maker. GDS provides the framework for integrating database management systems with analytical models, graphical display, tabular reporting capabilities with the expert knowledge of a decision maker.

C2 planning problems often require complex spatial decision making and contain well defined elements that can be modelled as well as semi-structured components that cannot. A GDS environment provides a framework within which specialist models approach the well defined aspects of the problem while a contingency planning structure enables the user to store multiple courses of action. This allows the flexibility to incorporate 'what if…' style solutions to the decision making process which this author believes is the most suitable way of dealing with the intangible, semi-structured elements of a C2 planning problem.

Introduction

Maps are a familiar and easy-to-interpret vehicle for the organisation of complex spatial information. They are integral to all Command and Control (C2) decision making processes and provide the starting point for geographical analysis. C2 decision making can be further enhanced by combining such maps with other symbolic and graphical representations of data.

Geographical Information Systems (GIS) allow the computer-based visualisation and manipulation of geographical or 'spatial' data through this mechanism. The creation of geo-referenced overlays referenced to a traditional map table allows powerful comparison analyses. This 'where is what?' and 'what is where?' approach can yield useful results, but falls a long way short of fully exploiting the potential of GIS technologies.

Currently, the level of expertise required in geographical data manipulation limits access to GIS. The increase in the power of desktop and laptop computing, the recent rise in functionality of Browser-based GIS (Intra/ Internet), and the advent of more advanced spatial analytical functions all exacerbate this skills shortage. As such, many staff who make critical geographical-based decisions in a C2 context have been unable to benefit from GIS. QinetiQ has developed the concept of Geospatial Decision Support (GDS) to place the power of GIS into the hands of a wider range of C2 decision makers.

SPATIAL PROBLEMS AND THE DECISION MAKING PROCESS

To fully understand our GDS approach, it is important to first investigate the nature of C2 decision making itself.

In general battlespace planning involves dynamic situations that consist of complex systems of changing problems that interact with each other. Commanders are rarely confronted with isolated problems that are independent of other aspects of the battlespace. It is not possible to sum the optimal solutions to individual problems to find an optimal solution to the whole problem. To find the best solution to individual problems within the context of the whole battlespace, the wider picture needs to be considered and de-conflicted subject to specific constraints.

In many cases the constraints are extremely restrictive. Generally each decision situation is unique with respect to both spatial and temporal elements. Consequently, alternative courses of action need to be judged in relation to the threats and opportunities over different time scales - now, tomorrow and next week. In such circumstances it becomes very difficult to structure the problem completely (i.e. define and precisely measure the objective for every possible solution), by formal analysis. The consequence is that a significant element of C2 planning is an inherently intuitive process, relying on value judgements of the C2 decision maker.

At this point it is valuable to highlight the difference between well-structured and semi-structured problems.

Well-Structured Problems

Well-structured problems have unambiguous objectives, firm constraints and clearly identified relationships between causes and effects. There is usually one clear solution that can be found analytically. Such problem solving can often be automated, with IT systems able to quickly assess the firm constraints to find the best solution.

Semi-Structured Problems

Semi-structured problems contain some (often intangible) elements that cannot be rigorously defined, measured, or represented. Solutions to semi-structured problems are usually obtained by generating a set of alternatives and using intuitive discretion to select from among the viable options. Exploiting IT systems to solve such problems requires a flexible problem-solving environment that will adopt an intuitive approach.

To illustrate the ideas outlined here we use an example of a typical C2 spatial problem – the assignment of a location for an artillery unit. Solving this problem requires consideration of many geographical, temporal and situation dependencies such as:

- Terrain
  - Is flat terrain required or will rugged terrain provide better camouflage?
  - Can urban areas be considered or excluded ?
  - Will areas with severe gradients cause problems?
- Connectivity and communication
  - Is access to roads or isolation a priority ?
  - How will the road network and off-road conditions affect deployment timings?
- Visibility and threat
  - Can the location be detected by radar ?
  - Will the terrain provide adequate muzzle flash cover?
- Exclusion zones
  - Do we need to stay a certain distance from a particular location, physical feature or danger zone ?
  - Do we have a preference in location relative to other previously selected locations (e.g. for other associated units) ?
  - Do we need to de-conflict with active air corridors and fire missions ?
- Weather conditions
  - Will the conditions for surveillance assets be favourable ?
  - Will off-road transportation be hindered by flooding or marsh conditions ?

Clearly the scope of dependencies considered within the problem can be as simple or as complex as the C2 decision maker wishes. For many of the examples above, different options may be an advantage or disadvantage depending on the exact situation.

We can see that many spatial problems are semi-structured involving intuitive decisions (that may change over time), as well as intangible issues that could include, for example, gaps in data availability, unknown behaviour of threat, and ill-defined dimensions of possible outcomes. However, embedded within the wider problem are elements that have an impact on the wider semi-structured problem that can themselves be considered well-structured problems. One example above is the issue of visibility – once a location and a candidate view-point is selected, the question "am I visible from here?" is a well-defined problem.

Our view is that C2 decision makers should not attempt to 'solve' individual problems. Instead, the emphasis of C2 decision making should be on contingency planning and the development of 'what if…' scenario evaluation in order to structure and wargame the decision making process.

Our concept of Geospatial Decision Support has been developed to exploit the power of IT systems to support semi-structured problem solving that is inherent to C2 planning and decision making processes.

GEOSPATIAL DECISION SUPPORT

To assist decision makers with complex semi-structured spatial problems, geographical processing systems must support a *decision research process*, rather than a more narrowly defined decision making process. As such, our GDS systems are designed to provide C2 decision makers with a problem solving environment within which they can explore, structure and understand complex spatial problems. This allows the user to evaluate alternative solutions to investigate the possible trade-offs between conflicting objectives.

A well-designed GDS should enable the user to explore the solution space (the options available to them) without the need for advanced understanding of GIS technologies or spatial data management techniques. It should support a variety of decision-making styles, and easily adapt to provide new capabilities as the needs of the user evolve. In addition, it should give the user access to analytical models to help research the well-defined subsections of the overall problem in a rapid manner, so that a series of feasible alternatives can be evaluated through multiple passes rather than a single linear decision making path. Note that GDS are primary designed to improve effectiveness rather than efficiency of decision making – the overall system supports a more thorough decision research process, but the embedded analytical models also improve the efficiency of solving the well-defined elements of the problem.

We can illustrate the concept of GDS with the following example. A user wishes to plan a "best route" from A to B. GIS systems currently contain routing algorithms to give you a "solution" subject to fixed criteria. However, for most C2 decisions, there is a significant element of intuition required to weigh up different optimal "solutions" (each of which corresponds to a set of fixed criteria).

If we now know that the user is concerned with route time, direction, distance travelled, petrol consumed as well as information on terrain suitability (gradient, terrain type,…) and radar detection threat at each section of the route, we can design an appropriate GDS solution. The user would enter a route directly onto a map display while information on his key criteria above is dynamically calculated in the background and returned in an intuitive manner. In addition, automatic rules for "failure" (gradient too steep, radar visibility too high,…) can be defined by the user and automatically highlighted or excluded from the problem solving process. This sort of dynamic information can be relayed by a combination of coloured graphics, split-screen information bars or control panel type indicators and gauges.

We can see from this example how GDS can answer a wider semi-structured problem while exploiting analytical models to solve *user-defined* subsections of the problem. The applications for our GDS concept to C2 decision making are almost limitless.

In conclusion, integrating GDS concepts into a C2 environment provides a high level of human-computer interaction that can provide dynamic and well-informed decision making during the planning or 'brainstorming' process.

DESIGNING A FLEXIBLE GDS ENVIRONMENT

Our goal is to design and develop an IT environment that can answer all of the key requirements for our GDS concept outlined above. It must support a decision research process for semi-structured problems without the need for advanced understanding of

GIS technologies or spatial data management techniques. It should be highly interactive, intuitive to use and give access to appropriate data and analytical models.

Our view is that the system design process must mirror the decision-making process itself and is therefore required to be *iterative, integrated* and *participatory.*

- *Iterative* - because a set of alternative solutions can be generated which the decision-maker evaluates, and insights gained are input to, and used to define, further analysis.
- *Integrated* - because value judgements that materially affect the final outcome are made by decision-makers who have expert knowledge that must be integrated with the quantitative data in models. This means that user input into the system design is crucial.
- *Participatory* - because the decision-maker plays an active role in defining the problem, carrying out analysis and evaluating the outcomes.

Each of our GDS tools is designed to focus on a particular aspect of problem solving and is tailored for use by the decision maker (not a geographic or IT specialist that is one step removed from the problem). As such, GDS tools considerably advance the exploitation of the expert knowledge of C2 decision makers.

On a system level, GDS provide a framework for integrating database management systems with analytical models, graphical display and tabular reporting capabilities, to which is added the expert knowledge of decision makers themselves. Our PC-based solutions can provide instant analysis and information to the decision-maker through interaction of the user with the system. This interaction is currently achieved using a mouse but could involve other input methods such as touch-screen and pen-based technologies which will allow the user to ‘write' directly on the screen.

We have identified a number of key requirements to support the performance of a GDS environment for C2 decision making as follows:

- Appropriate spatial data to support the model
- Support for temporal multi-path planning
- Incorporation of flexible decision making processes
- Analytical modelling focused on well-defined elements of C2 problems
- The decision-maker’s expert knowledge

We will now discuss each of these in turn.

Spatial Data

To remove the requirement for the user to have detailed understanding of spatial data, GDS requires such data to be embedded into the system. The decision maker should not be required to input or manipulate the raw data and this should be done by geospatial specialists during system design (or upgrade). To support most models a combination of geographical data is required and should include:

- Raster data

  Data is stored in a grid system. These digital representations of existing paper maps provide an excellent interface for GDS.
- Vector data

  Data is stored as point, line and polygon representations of features. Highly effective for describing certain features, such as urban areas and road networks.
- Digital Elevation Models (DEM)

  A 3D representation of terrain, essential for analytical models such as Line-of-Sight analysis, gradient and terrain analysis and artillery cresting models.
- Imagery

  Can enhance the visualisation aspects of GDS although currently none of our GDS models work directly from image analysis. Future systems could extract features using multi- or hyper-spectral analysis and potentially DEMs could be computed 'on-the-fly' from raw satellite imagery.

Temporal Multi-Path Planning

Multi-path planning should be designed to allow contingency planning over time. This supports the 'what if…' analysis central to GDS. Limitless theoretical Courses of Action can therefore be wargamed alongside any other influences, such as enemy intention, mission analysis, real estate reservation, airspace co-ordination and targeting sequences. All C2 plans are inherently time dependent so a GDS system needs to provide a database that allows each plan to be saved against a Date, Time Group (DTG). Within each plan or Course of Action the user should have the option to commit a 'save as…' action at any point as illustrated in figure 1. This allows recording of the user's conclusions, as well as providing a starting point for anther contingency.

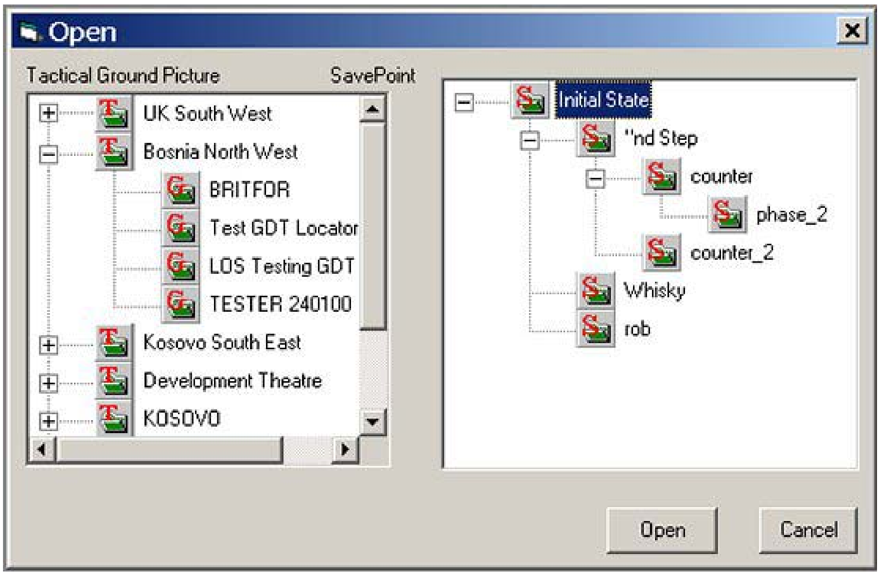

Figure 1: Structure for saving multiple course of action. The options on the left provide the available Theatre of Operations. Bosnia North West is selected and includes four previously planned scenarios. One of these scenarios is selected and on the right we see that it has an initial start state followed by a collection

of plans following multiple paths representing separate plans for the same moments in time as well as plans for different periods of time.

Analytical Modelling

Models can be applied to many aspects of C2 decision making to tackle well-defined elements of the problem. The bespoke nature of GDS requires carefully constructed, tested and focused models that can be adapted to a decision making environment. However, although each GDS tool is unique, embedded analytical models can often be exploited in multiple tools.

An example of a generic model used within C2 decision support is the line-of-sight (LOS) algorithm that operates on Digital Elevation Models (DEM) to provide an overlay of areas that are visible from an observation position placed on the map. The LOS algorithm is the start point for other, focused GDS functionality as required and can be embedded into models to provide for example:

- Linear LOS
  'which areas can see what parts of a route?' or 'which areas can you see from certain parts of a route?'
- UAV planning
  'where can a UAV fly while maintaining constant LOS with the ground control station?'
- Radar coverage
  'what are the optimal locations for Radar to cover targets and areas of interest?'
- Direct fire
  'where can units engage with direct fire?' and 'where can we combine engagement from several units?'
- Dynamic LOS
  This can allow an instant trace of LOS as the mouse is moved across the screen

Such an approach to generic algorithms can also be applied to other models that could focus on radar propagation parameters, ballistic trajectories or 'shortest path' type algorithms based on road network data.

Expert Decisions Maker's Knowledge

GDS is aimed at expert users. The user is not expected to be an expert in geographical data nor an expert in computer simulation and modelling. The aim of GDS is to provide support to user by relieving them of the skilled knowledge required for standard GIS operations. The end result is that the decision maker is free to apply their particular knowledge to solving the problem in hand using easy-to-use 'point and click' methods on a map based environment.

Flexible Decision Making Processes

Understanding how the end user makes decisions is critical to GDS. The models, data and Graphical User Interface (GUI) have to be designed *with the decision maker* to ensure the success of the system. For C2 processes it is better to adopt a 'feet in the mud' policy where as much feedback as possible is supplied from prototypes used in a realistic situation. Building a GDS system with the end user is the only feasible way to validate and customise the models for a decision making environment where the user is constantly appraising alternative courses of action and making 'trade-off' type decisions.

CONCLUSIONS

Most C2 decision making involves semi-structured problems that are likely change in the immediate future. Providing a GDS environment can greatly enhance the quality of rapid decision making by placing well designed analytical tools into the hands of an expert decision maker. The tools are well designed because the decision maker is allowed to participate and dictate not only what they want but also how this achieved.

The ability to save and store multiple courses of action enables decision makers to break down complex problems and structure a response to dynamic situations that maybe about to occur. The combination of this structure and focused modelling support will provide significant benefit to C2 decision makers especially under conditions of competition and time pressure.

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