NATO RTG SAS-045
on
Computer Based Decision Support Tool for Helicopter Mission Planning in Disaster Relief and Military Operations

Annex C – TECHNICAL REPORT 3: OVERVIEW OF GEOGRAPHICAL INFORMATION SYSTEMS, DIGITAL MAPS AND MISSION DATA COMPILATION

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C.1 INTRODUCTION

This document is prepared to fulfill the requirements of the Programme of Work (POW) of NATO SAS-045 RTG on "Computer Based Decision Support Tool for Helicopter Mission Planning in Disaster Relief and Military Operations".

The POW dictates to provide an a-priori analysis of Geographical Information Systems (GIS), digital maps, and mission data compilation that are anticipated to support the development of NATO SAS-045 project. As it is stated in the Terms of Reference (TOR) of the afore-mentioned project, the main goal of the research is to provide the basis for developing a generic and flexible decision support tool for effective management of helicopter missions by conducting the problem analysis, investigating the concept of solutions and determining relevant technical requirements.

It is foreseen that different models, technologies and solution approaches will be utilized concurrently, and integration and interfacing will pose itself as an important technical issue within the scope of maintaining interoperability and standardization in NATO practices.

Thus, the POW states that during the Analysis Phase of the project technology surveys should be carried out on modeling, computer and software engineering and data collection technologies; geographical information systems, digital maps, mission data compilation systems; model, data, and knowledge management repositories in NATO nations. Then, the technology mapping and capability matrix can be developed using the identified current needs and capability gaps.

In this document, it is intended to provide a broad overview that will guide any potential research dealing with the design and development of a generic decision support tool within a similar NATO context, not limited to helicopter operations.

The aim of this document is not to cover the subject matter in detail, but rather to give a general idea of techniques and products. In this report, we provide information on GIS, digital maps, mission data compilation systems in order to determine the design requirements for the helicopter mission planning decision support system.

In the next section, we provide information on GIS. Digital maps are discussed in Section 3. In Section 4, we summarize the mission data compilation systems in NATO and NATO nations. This report ends with a conclusion section.

C.2 GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

Geographical Information System (GIS) is a "computer system for capturing, managing, integrating, manipulating, analysing and displaying data which is spatially referenced to the Earth." (McDonnell and Kemp, 1995). GIS is an information system that is composed of hardware, software, data and personnel. The current generation of GIS products support data integration and manipulation, query, thematic and overlay analysis, and visualization in two and three dimensions. Geographic information technology has emerged as an important operations research tool for exploiting increasingly available amounts of valuable geographic data in a form easily comprehended by analysts and decision makers (Hanigan, 1989).

What distinguishes GIS from other forms of information systems, such as databases and spreadsheets, is that GIS deals with spatial information. GIS has the capability to relate layers of data for the same points in space (see Figure C.1), combining, analyzing and, finally, mapping out the results. Spatial information uses location, within a coordinate system, as its reference base. The most common representation of spatial information is a map on which the location of any point could be given using latitude and longitude, or other grid references.

Figure C.1: Layers of Data in GIS.

Some applications of GIS are obvious, for example water supply companies use GIS as a spatial database of pipes and manholes; local governments can use GIS to manage and update property boundaries, emergency operations and environmental resources. GIS may also be used to map out the provision of services, such as health care and primary education, taking into account population distribution and access to facilities. Increasingly, GIS is being used to assist businesses in identifying their potential markets and maintaining a spatial database of their customers (see Figure C.2).

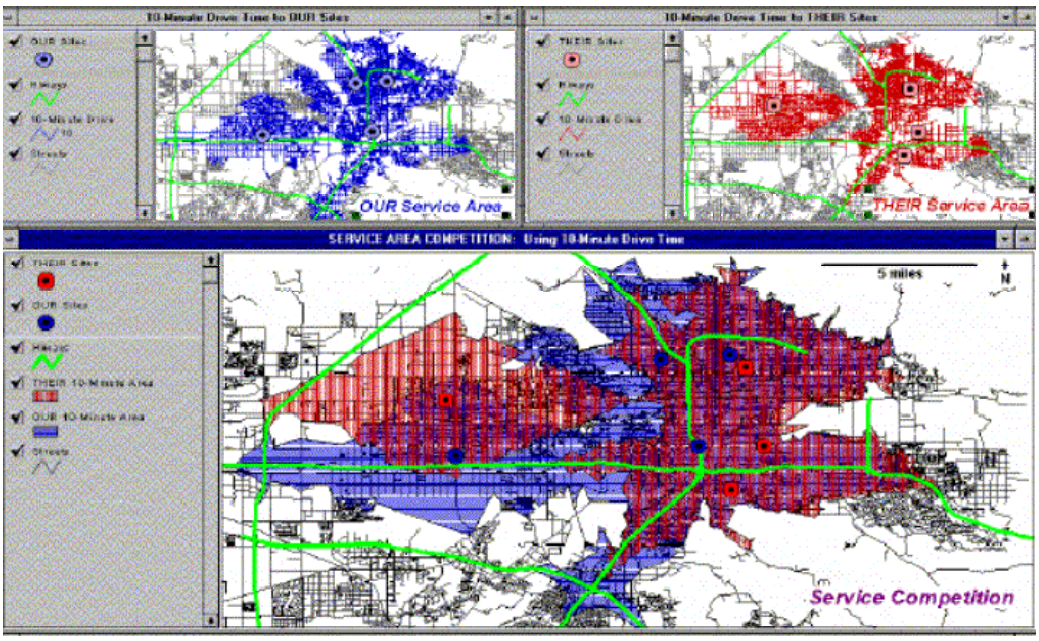

Figure C.2: Example of a Customer Relationship Management Application.

Geospatial information plays a key role in defence. Knowing what is, where is the key to mastering the battlefield, the installations, and deployed areas that support the warfighter. Military leaders must have a common tool with rapid access to relevant and accurate geospatial information for mission-critical

operations. To provide this geospatial information, the decision maker's ability to use, manage, analyze, and disseminate information is a vital component for command planning and operations. Broad ranges of challenges require the deployment of flexible and scalable technology to assist the decision makers.

GIS systems can visualize, manage, analyze and present geospatial data. Intelligent maps can be created by relating organizational databases with digital maps. Thus enabling quick and efficient decision making and instant data integration between the organizations.

GIS database is created via combining data from different sources. Scanned and digitized maps, data in tables, correct location information, information from land study and remote sensing and air photos provide data for GIS.

Spatial data may be represented in GIS in one (or both) of the two following formats (see Figure C.3):

- Vector model, as geometric objects: points, lines, polygons.
- Raster model, as image files composed of grid-cells known as pixels.

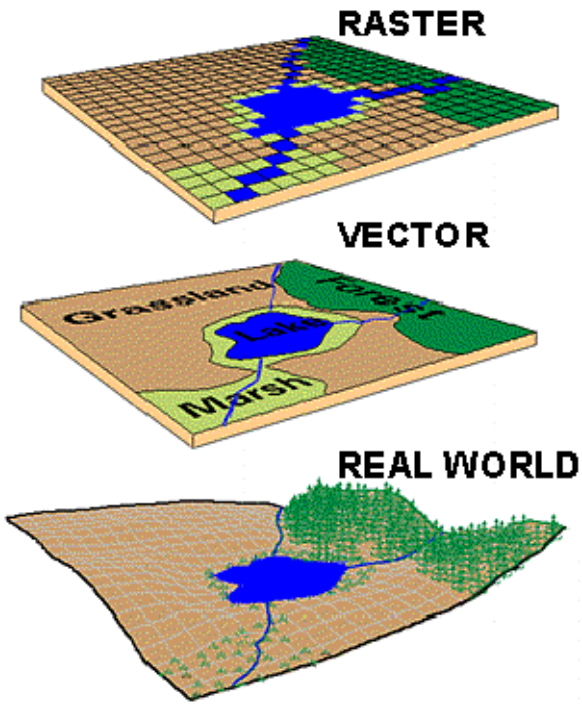

Figure C.3: Spatial Data Representation in GIS.

Geographic data have four major components. These are geographic position (location of geographic data recorded in a coordinate system), attributes (characteristics of geographic features such as "what it is"), relationships (the relationships between the geographic features), and time (geographic data may be referenced to a point in time or a period of time).

Relationships between data can be put into two categories: Spatial relationships (either topological relationships that are independent on coordinates (e.g. next to, inside) or metric relationships that are dependent on coordinates (e.g. 10 km away)) and non-spatial relationships (e.g. owner of, builder of).

Raster data can be represented using three different encoding schemes. Those are traditional raster encoding, run-length raster encoding, and quad tree raster encoding.

In vector representation, geographical features are organized as points, lines and areas called polygons. There are two different vector data models. In spaghetti model, the paper map is translated line-for-line into a list of x,y coordinates and in topological model, spatial relationships among entities are retained by explicitly recording adjacency information.

Comparison of vector and raster data models:

- Vector model is a more complex data structures and generally more compact;
- Raster model provides less explicit topological relationships;
- Some operations, such as overlay, are easier using vector data;
- Some operations, such as finding a shortest path, are easier using vector data;
- Boundaries are more accurately defined in vector model;
- Some input data, such as satellite imageries, are raster based;
- Some output devices, such as laser printers, are raster based; and
- Some output devices, such as pen plotters, are vector based.

Each data model has particular strengths and weaknesses, and the type of model used is to be determined by the nature of the work being undertaken and the data available.

The main advantage of the vector data format is that it allows precise representation of points, boundaries, and linear features. This makes it particularly useful for analysis tasks that require accurate positioning, for example in engineering or cadastral boundary databases. It is also possible in a vector-based GIS to define the spatial relationship (i.e. the connectivity and adjacency) between coverage features. This aspect of GIS is known as topology, and is important for such purposes as network analysis (for example to find an optimal path between two nodes in a complex transport network). By contrast, raster-based GIS defines the position of features in terms of x,y coordinates where topological associations are more difficult to represent. However, the main disadvantage of vector data is that the boundaries of the resulting map polygons are discrete (enclosed by well-defined boundary lines), whereas in reality the map polygons may represent continuous gradation or gradual change, as in soil maps.

Raster Data Models use a raster matrix (a grid of image cells) to represent information. The resolution (visual definition) of the raster depends on its pixel (cell) size. In other words, pixel resolution represents the size of the ground area covered by each pixel in the image. The smaller the cell size, the higher the resolution. The raster data model is, therefore, good for representing indistinct boundaries, such as thematic information on soil types, soil moisture, vegetation, ground temperatures, and so on. Furthermore, as reconnaissance satellites and aerial surveys use raster-based scanners, the information (i.e. scanned images) can be directly incorporated into GIS programs capable of working with raster data. However, the higher the grid resolution, the larger the data file is going to be. This is the main limitation of raster based GIS.

The question of which data model to use in GIS depends on the nature and objective of the GIS project. Primarily the model type will depend on the nature of the data. Issues of concern are the volume of the data generated, ease of analysis and accuracy. Generally, vector data sets are economical in terms of file size, and have a high level of positional precision, but are relatively difficult to use in mathematical computations. On the other hand, grid data sets tend to take up more file space and have a coarser resolution, but are easier to work with mathematically.

Standard hardware for GIS includes computers, scanners, digitizers, printers and line plotters. Hardware such as remote sensing units, global positioning systems (GPS) and software may be included in GIS system depending on the application.

Architecture of GIS may be client/server (distributed and simultaneous operation) or stand-alone (independent application on a PC).

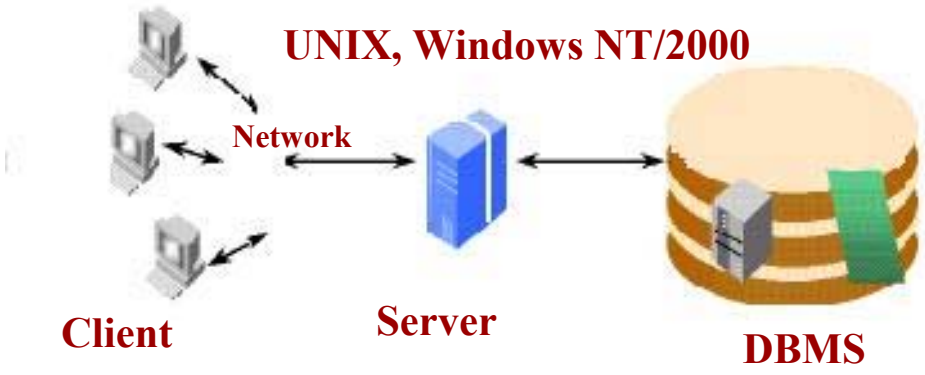

Figure C.4: Client/Server Architecture for GIS.

There are more than 300 GIS software in market. Several of those are:

- ArcInfo (www.esri.com);
- MapInfo (www.mapinfo.com);
- Idrisi (www.clarklabs.org);
- GeoMedia (www.intergraph.com/gis/geomedia);
- IlogViews (www.ilog.com); and
- Autodesk (www.autodesk.com).

GIS and data base management system (DBMS), which is a complex set of programs that control the organization, storage, retrieval and security of data for users can be integrated. Storing, querying and replication of geospatial data, and creating intelligent information by integrating data at the DBMS and geospatial data are important features of such integration. IBM Informix Spatial DataBlade, IBM DB2 Spatial Extender and Oracle Spatial Database Engine are examples of those kinds of software.

GIS applications require decisions on; required data types, database structure (relation between data), base maps and their scales and required expertise on different areas.

C.3 DIGITAL MAPS

Representation of the terrain is very important. Maps were very much used in military environments. The last decade digital maps become more used also in a military environment. Geographical data exists in many appearances. The complete world is now available on digital maps. In determining geographical data requirements the following aspects are of importance:

- Format of the file; and
- Co-ordinate reference system.

Format: The format is the way the digital data is captured. There are many formats such as usual formats of pictures like “BMP”, “TIF” and “JPG”, DLMS (consisting of DTED (terrain information) and DFAD (features)), Modsaf CTDB, INDIA/MARS, VMAP1 in combination with Vector Product Format (VPF), MilGeo-PCMAP, Geotif in combination with Shapefiles and DXF.

Co-ordinate reference system: The coordinate reference system is the system that uses coordinates to establish the position on the earth. Each system uses a projection method in order to transform a position on the globe to a 2D position. There are also many co-ordination systems that use different projections methods of the earth, e.g. UTM, UTM MGRS, WGS84, Gauss Kruger, Lambert, Geographic Coordinate System (Lat/Lon), Rijksdriehoeks (Dutch).

Digital maps have specific formats and coordinate systems in which they have been produced. Each format and co-ordinate system has some features and drawbacks depending on the application. In the absence of a universal standard, conversion between formats and coordinate systems are problematic.

In the USA the National Mapping Program (NMP) has introduced a number of standards (see also http://mapping.usgs.gov/standards/). The standards are essential for efficient sharing of products and to provide information about geospatial data. The NMP produces the following five basic types of digital geospatial data:

- **Digital Elevation Model Standards:** Standards, which define a digital file consisting of terrain elevations for ground positions at regularly spaced intervals. A Digital Elevation Model is often referred to as a DEM.
- **Digital Line Graph Standards:** Standards, which define digital vector files containing line data, such as roads or streams, digitized from quadrangle maps. A Digital Line Graph is often referred to as a DLG. The standards cover both DLG-3 and DLG-F series.
- **Digital Orthophoto Standards:** Standards, which define a digital image of an aerial photograph in which displacements caused by the camera and the terrain have been removed. A Digital Orthophoto is often referred to as a DOQ. A DOQ combines the image characteristics of a photograph with the geometric qualities of a map.
- **Digital Raster Graphic Standards:** Standards, which define a digital image, which is scanned from a USGS quadrangle map. A Digital Raster Graphic is often referred to as a DRG. A DRG is georeferenced to the surface of the Earth, inside the map neat line.
- **National Hydrography Dataset Standards:** The USGS and the Environmental Protection Agency (EPA) are jointly preparing standards for the National Hydrography Dataset (NHD) and the National Hydrography Dataset – High Resolution (NHD – HR). Both the NHD and NHD – HR are digital vector files of cataloging units which uniquely identify and interconnect the stream segments or "reaches" that comprise the country's surface water drainage system.

Other geospatial standards and specifications can be found at the following website: http:/164.214.2.59/publications/specs/index.html.

NATO also tries to standardize digital maps used in GIS applications as much as possible in order achieve interoperability between different national systems. The list of NATO standards on collecting, using and exchanging geospatial information are as follows:

STANAG 2215-Evaluation of Land Maps, Aeronautical Charts and Digital Topographic Data (Edition 6): The aim of this STANAG is to enable producers of geographic material to standardize the system of evaluation of land maps, aeronautical charts and digital topographic data to be used by NATO armed forces.

STANAG 3809-Digital Terrain Elevation Data (DTED) Exchange Format (Edition 4): Participating nations agree to use US Performance Specification 89020B as a manual for defining the requirements within a DTED database. DTED supports various weapon and training systems. The purpose of this specification is to assure uniformity of treatment among all mapping and charting elements engaged in a coordinated production and maintenance program for this product.

STANAG 4387-ARC Standard Raster Product (ASRP)-AGeoP-5.

STANAG 7072-Vector Map (VMap) Level 0 (Edition 2): Participating nations of this STANAG agree to use US MIL-PRF-89039 Vector Map (VMap) Level 0 as a manual for military planners at the operational and, to a limited extent the tactical level of operations. This product will support Geographic Information Systems (GIS) applications. VMap0 data is suitable for use by both ground and air commanders.

STANAG 7074-Digital Geographic Information Exchange Standard (DIGEST): The aim of this agreement is to provide interoperability and compatibility among NATO systems and users for the exchange and provision of digital geographical information.

STANAG 7098-Compressed ARC Digitized Raster Graphics (CADRG): CADRG is a general-purpose product, comprising computer readable digital map and chart images. CADRG files are physically formatted within a National Imagery Transmission Format (NITF). CADRG uses WGS-84 coordinates as coordinate reference system.

STANAG 7108-ARC Digitized Raster Graphics (ADRG) (Edition 1): The aim of this agreement is to standardize ADRG produced by participating nations. Participating nations agree to produce and use ADRG products in accordance with the specifications given in this STANAG. The ARC System is a special grid system covering the entire ellipsoid of the World Geodetic System 1984. It provides a rectangular coordinate system based on 18 latitudinal zones. These allow a relative coordinate system to be used with individual raster images.

STANAG 7136 Identification of Land Maps, Aeronautical Charts, Digital Geographic Datasets and Media Containing Datasets (Edition 1): The aim of this Agreement is to establish a standard method of uniquely identifying land maps, aeronautical charts, digital geographic datasets and media containing geographic datasets, which are produced and exchanged by NATO members. Hydrographic products are excluded from this STANAG.

STANAG 7173: The Arc System (The Equal Arc-Second Raster Chart/Map System) (Edition 1): The aim of this agreement is to enable a common understanding of the Equal Arc-Second Raster Chart/Map System amongst nations exchanging digital geographical information.

C.4 MISSION DATA COMPILATION

In this section, we provide brief information on automatic data capture, remote sensing and tactical data link systems.

C.4.1 Automatic Data Capture

The traditional way of entering planning and manufacturing data into a computer system has involved manually keying it in after the data has been gathered on sheets of paper. Studies show that with this technique there is likely to be 1 error for every 300 characters entered (Lindau and Lumsden, 1999). The traditional way is error prone, non-real time, and risky in emergency situations. Whereas, automatic data capture techniques make it possible to enter a stream of data automatically in a single operation.

By expressing the data, e.g. part number, with a machine-readable code; this information can be entered into the computer system with an automatic code-reading device. The decoded data can either be transmitted directly to an attached computer, be stored locally for later transmission, or interact with a resident application program in the reading device. Data entered by such techniques has a lower error rate than manual methods, 1 error for every 3 million characters entered (Lindau and Lumsden, 1999) and data is available in real-time. Vehicle monitoring systems using GPS and SMS cellular phone technology, and meteorological sensors are two examples of automatic data capture systems.

C.4.2 Remote Sensing

Remote sensing involves the use of sensors to "capture" the spectral and spatial relations of objects and materials observable at a distance – typically from above them. (http://rst.gsfc.nasa.gov) An aerial photograph is a common example of a remotely sensed product. Determining the status of a growing crop, defining urban patterns, delineating the extent of flooding, recognizing rock types, pinpointing areas of deforestation are typical application areas.

Remote sensing data, from vegetation and climatic data to outlines of manmade structures, can form much of the information that is entered into a GIS. The technologies of remote sensing and GIS are distinct, but complimentary. Different equipment and technical skills are needed for each, but in both cases the user must have a string grasp on the information that is collected, be it forestry, geology, man-made structures, etc. Remote sensing technology focuses on sensor systems and image processing, whereas GIS requires expertise with the principles of spatial analysis, map projections and databases (Aronof, 1995).

C.4.3 Tactical Data Links

Tactical Data Links (TDLs) are the means of providing real time encrypted communications to achieve total situational awareness through use of advanced information technology. TDLs involve transmissions of bit-oriented digital information, which are exchanged via data links. Within NATO, ADatP-33 provides the procedures for operators who employ tactical data links, for planning, initializing, controlling, and terminating the exchange of real-time and near real-time tactical data between tactical data systems, and defines responsibilities for these functions.

TDL systems used in NATO and NATO nations are briefly explained below. (See http://www.fas.org/irp/program/disseminate/tadil.htm for further information on TDLs.)

C.4.3.1 Link-1

Link 1 is a duplex digital data link primarily used by NATO's Air Defence Ground Environment (NADGE). It was designed in the late 1950s to cater for point-to-point data communication. Link 1 mainly provides for exchange of air surveillance data between Control and Reporting Centres (CRCs) and Combined Air Operation Centers (CAOCs)/Sector Operation Centers (SOCs) and has a data rate of 1200/2400 bit per second (bps). It is not crypto secure and has a message set (S-series) limited to air surveillance and link management data.

C.4.3.2 Link-4A

Link 4 is a non-secure data link used for providing vector commands to fighters. It is a netted, time division link operating in the UHF band. There are 2 separate "Link 4s": Link 4A and Link 4C. Link-4A provides digital surface-to-air, air-to-surface, and air-to-air tactical communications. Link 4C is a fighter-to-fighter data link which is intended to complement Link 4A although the two links do not communicate directly with each other.

C.4.3.3 Link-11

Link-11 employs netted communication techniques and a standard message format for exchanging digital information among airborne, land-based and shipboard tactical data systems. Link-11 data communications must be capable of operation in either the high-frequency (HF) or ultra-high-frequency (UHF) bands.

C.4.3.4 Link-14

Link 14 is a broadcast HF teletype link for maritime units designed to transfer surveillance information from ships with a tactical data processing capability to non-tactical data processing ships. The Link can be either HF, VHF or UHF dependent on unit-communication fits.

C.4.3.5 Link-16

Link-16 is a relatively new tactical data link, which is being employed by several nations of NATO and Japan. Link-16 does not significantly change the basic concepts of tactical data link information exchange supported for many years by Link-11 and Link-4A. Rather, Link-16 provides certain technical and operational improvements to existing tactical data link capabilities and provides some data exchange elements, which the other data links lack. It provides significant improvements as well, such as jam resistance; improved security; increased data rate (throughput); increased amounts/granularity of information exchange; reduced data terminal size, which allows installation in fighter and attack aircraft; digitized, jam-resistant, secure voice capability; relative navigation; precise participant location and identification and increased numbers of participants.

C.4.3.6 Link-22

Link 22 is the next-generation NATO Tactical Data Link, and is also referred to as the NATO Improved Link Eleven (NILE). Link 22 is a multi-national development program that will produce a “J” series message standard in Time Domain Multiple Access architecture over extended ranges.

C.5 CONCLUSION

A generic decision support system (DSS) is expected to interact with the analyst and the decision maker for exploiting different course of actions and present the current status and the results of the actions in a form easily comprehended by analysts and decision makers. Geographic information systems and mission data compilation systems can help to fulfill this requirement.

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