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System Choice for Data Processing, Analysis & Applications in Defence

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ABSTRACT

The design of a suitable system for image data processing, analysis and applications in Defence is governed by users' requirements during peace time and prehostility/hostility period. The users need timely information and image products for decision-making. The product specifications in terms of their scale, geometrical accuracy, information content, and turnaround time among other things are crucial for the design of systems. The systems are not complete without efficient software for information extraction and analysis and for aiding decision-making process. Usually, the base data is from high resolution remote sensing systems, both airborne and spaceborne, and also from conventional sources, like topomap and other intelligence gathering mechanisms. The database thus evolved is basic and vital for a decision support system.

The sensors providing input to the database creation could be airborne high resolution camera systems, high resolution synthetic aperture radar systems and thermal imaging systems operating from a stand-off range of 50 to 100 km, or from high resolution spaceborne panchromatic optical and synthetic aperture radar imagery. High resolution stereo data from airborne and spaceborne sensors are also increasingly needed for image interpretation and analysis.

The digital elevation data is another important information, derived from either existing topographic maps or high resolution space stereo imagery. The system also should cater to a large information archival/retrieval system and data dissemination system for the users spread far and wide. This may call for to and fro traffic between central operational system and units spread over different locations, preferably, through high speed satellite communication channels. Finally, the total system should have reliability, data security, adequate redundancy, user-friendliness and be efficient enough to provide timely information transfer for the decision makers.

This paper discusses the various application requirements, data sources, software and packages for interpretation, approach to analysis, applications, database needs and hardware systems.

INTRODUCTION

From various developments that have taken place all over the world in imaging system for Defence applications (particularly after the Gulf war), the importance of remote sensing data in gathering strategic information during peace time, prehostility/hostility period and its integration with decision support systems has been realised by most of the Defence agencies. The intelligence gathering is strongly supplemented by spatial data derived from high resolution airborne and spaceborne sensors. Such data is integrated with the data from other sources, including maps, electronic intelligence gathering systems and conventional intelligence gathering mechanisms, and restructured to derive useful information in a format immediately digestible and of direct relevance to the task in hand. These are normally stored in a large database and analysis is carried out through integration of various data sources by various geographical information

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systems to aid applications, such as optimal route planning, training of pilots before carrying out missions, troop deployment and for planning various offensive and defensive strategies. The strategic data collected, if suitably made available in a user-friendly form and in a timely fashion, will make the job of Defence planners a lot more comfortable and will enable them to take appropriate decisions.

Data integration is thus a crucial element in Defence applications. For various functions discussed above, different types of hardware and software systems are required, which are elaborated in the following sections.

2. SYSTEM REQUIREMENTS

2.1 Map Database Related

Currently, many Defence agencies use photographic imagery and paper maps as the basic inputs for interpretation and analysis for strategic information extraction. Worldover, the trend is to go in for digital database for information derived from remote sensing data and for map-derived information. The advantages are that the digital data is flexible and can be easily manipulated. For example, when the map data is in digital form it is possible to extract only the relevant information, say, communication and transportation network, and compare with the latest available information from image data and update the information content in the database, without having necessarily to 'clutter' all other data which is in a paper map. Similarly, change detection during peace time and hostile period can be easily done by comparing earlier information from the database and the latest information obtained from the corrected map, like imagery by bringing both the data sets by an interpreter onto a single image display system in near real-time. Once the change is detected, the cause for the change can be analysed by regressing the change variable against the probable cause variables; and the effect of the change can also be studied using various GIS tools. This analysis would help one to understand enemy's intentions and his capabilities. Further, the digital data can be easily transmitted over a long distance and visualised by advanced display system for local use. It is also possible to integrate the information gathered from different locations at a central place once the data exchange formats are standardised. One need not worry about information leakages through communication as powerful data encryption techniques are available though they are not discussed in detail.

2.2 Decision Support System Related

This way the advent of instantly accessible computer databases and associated graphics hardware and software could drastically alter the way battles are fought. Personal reconnaissance of a proposed battlefield may never be entirely superseded; however, the use of purpose-designed information systems coupled with expert knowledge and analytical modelling capabilities will allow many important strategic and tactical decisions to be made out of the intelligence information, before even seeing the proposed area of operations. This calls for a spatial decision support system (SDSS) that embraces problems with spatial or geographic aspects, and processes transactions and interacts with other parts of the overall system and support the decision-making activities related to Defence applications.

The software components of an SDSS typically include a database management system, analysis procedures, a display and report generator, a user interface and an expert system that can guide even an inexperienced or 'naive' user through the analysis and decision-making. Geographic information systems (GIS) normally provide database management, graphical display and tabular reporting capabilities - and the addition of analytical modelling capabilities and the decision maker's expert knowledge creates an SDSS. The analysis procedures and expert system provide knowledge bases, mathematical models and algorithms that can be applied to spatial analysis, and this renders the SDSS more powerful than traditional TTGIS.

Remote sensing represents a powerful technology for providing input data for measurement, mapping, monitoring, and modelling within an SDSS context. Integrating remote sensing, GIS, expert system and analytical modelling capabilities within an SDSS framework can result in a tremendous increase in information for Defence personnel.

2.3 Data Related

The requirements on data can be classified as

(a) Terrain mapping

(b) Target area mapping and identification.

For the later applications, the spatial resolution requirements of the space sensor will have to be of the order of 1 m or better, preferably in digital form and will have a repetivity of 12 hr during prehostile and hostile periods. During peace time the repetivity could be of the order of two weeks.

With regard to peace time applications, the system will have to cater to long-term strategic intelligence, namely, monitoring of large industrial and military installations/establishments, communication and transportation networks, terrain elevation, detection and monitoring of sensitive targets and it may also include monitoring of terraincover, economy intelligence, including agricultural and industrial production. This calls for both multispectral medium resolution data and panchromatic high resolution (1 to 3 m) data. However, the repetivity of data acquisition can be from 2-4 weeks.

Suitable airborne imaging sensors (photographic and electronic) are also required to acquire very high resolution imagery to serve as ground truth as well as to complement the space sensors.

2.4 Electronic Intelligence Related

For any mission planning activity, it is essential to know the deployment pattern of the radars and other electronic Defence mechanisms on the enemy territory. This pattern which is dynamic in nature needs continuous monitoring and updation. This becomes an essential input to GIS for various military applications, like planning for air interdiction mission.

2.5 System Related

The system for Defence applications relating to image data will have the following facilities (Fig. 1) :

(a) Preprocessing functions to prepare the data for map level accuracy geometrically and information contentwise. The best product would be geocoded orthoimages which will exactly match with standard maps in the scales of 1:50,000 to 1:25,000. Larger scales may be possible with very high resolution imagery. The preprocessing functions will be different for aerial and satellite sensor imagery.

(b) The facility for acquiring data, including contour information from standard maps and statistical information based on other intelligence sources, such as ELINT.

(c) Suitable information extraction techniques which are as automatic as possible. (It cannot yet be fully automatic and minimal interactive component is still essential).

(d) A large database system for storing map, image and statistical information in digital form.

(e) Geographical information system for manipulating data for analysis, information extraction and applications. It should have tools, like network modelling for carrying out applications, such as route planning, flight path simulation, mission planning and tools for spatial data modelling, such as cross-country trafficability, flood inundation, facility siting for military training area, airport, ammunition dump, etc.

(f) A report generation system, including a photo facility.

(g) Communication systems, computer networking schemes, etc, for acquiring and disseminating extracted information to a large number of users spread out over vast areas.

3. POSSIBLE SYSTEM CONFIGURATIONS

As discussed before, the systems configuration can be broadly divided into the following segments.

(a) Image preprocessing functions and related systems.

(b) Systems for extraction of auxiliary information and database creation.

(c) Database and GIS systems.

(d) System integration elements.

(e) Software packages and methodologies for data analysis to meet the needs of applications.

(f) Suitable data security arrangement (software locks), data compression and related communication network.

3.1 Image Preprocessing

This is the most crucial step in the proper utilisation of image data, namely, preprocessing the image data to bring it to the level of map standards. This includes the following steps :

(a) Image downloading and creating auxiliary files of ephemeris data.

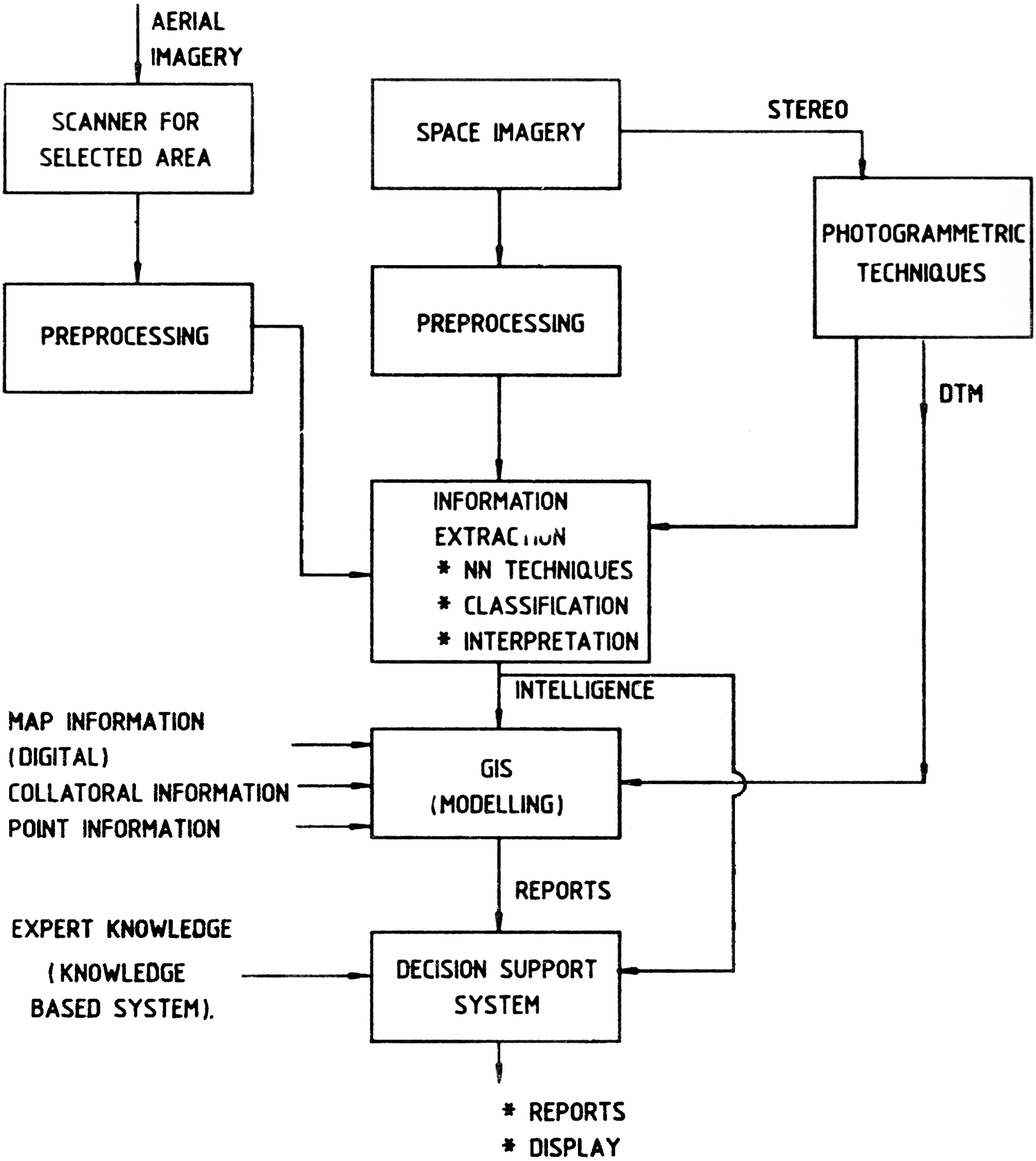

Figure 1.

(b) Geometrical corrections leading to the generation of geocoded orthoimagery to match with map standards. This step involves the use of DTM for correcting data to generate orthoimage. If DTM is available from map, it can be extracted and used. However, in the absence of the availability of maps, if stereo space or aerial imagery is available, then suitable photogrammetric systems can be utilised to extract DTM.

For the photographic products, the digital data creation needs a programmable photoscan system to digitise image transparencies at as high a sampling pixel as 4 to 5 micron at desirable locations of the photograph. An analytical plotter or a soft copy photogrammetric system also will be useful for interpretation and stereo modelling DTM extraction and mapping.

3.2 Auxiliary Information and Related Facilities

The auxiliary information include topographic information available in standard maps (for DTM computation), electronic intelligence data and other statistical and spatial information available from various other sources.

For extracting the map information, the facility will include a map scanner at a reasonable resolution (300-600 dpi), character recognition software (to recognise, extract and store names of places, locations, groundcover details, etc.), vectorisation software to convert the digitised raster map data into vector data for easy storage and retrieval, facilities for incorporating ELINT and other spatial/point information into the database and management information on data acquired from space and aerial platforms.

The extraction of auxiliary information and database creation aims at automatic information extraction as far as possible since it would help in standardising information, avoiding excessive dependence on operator expertise. This includes:

(a) Image classification for terraincover or landcover identification using multispectral satellite data.

(b) Image segmentation for segmenting the image into object and background for extracting the object of interest in an image.

(c) Automatic extraction of linear features, like roads, canals, drainage lines, etc. This avoids the tedious job of tracing and digitisation for database creation.

(d) Neural network for pattern classification and pattern recognition. Neural networks are more advantageous than conventional image classifiers because they are much faster and require almost no human expertise. Neural networks perform very well in target recognition. They can search and pick out the target from very large dataset and classify them according to their type. Automatically extracted image information can be converted into vector data, which directly goes into the database. One cannot totally do away with manual digitisation since some data would be available in a map form and has to be necessarily digitised or scanned for on-screen digitisation using a video display system.

3.3 Database and GIS

Every new information generated in the data processing and analysis system would be used for updating data in the database. The database may be organised on the basis of toposheet military zone. At any stage one could retrieve all the information related to a particular area and a tabular reporting of the information would be provided. Determination of the terrain conditions in inaccessible areas can be done by comparing with the terrain conditions in analogous accessible areas by querying the database.

The GIS system is the nerve centre of the spatial data analysis system which is capable of manipulating, merging, sorting various datasets stored in different layers for convenience and case of operations. The GIS is linked to a standard relational database system and the data are tightly coupled.

3.4 System Integration Elements

The decision-making process in an SDSS for Defence applications can be envisaged as:

Data → Information → Intelligence → Decision

The first three aspects involve technical issues while the fourth one coupled with the first three requires Defence knowledge/military intelligence. The data collected and stored in the database management system must be collated and integrated into 'military intelligence' by image processing, analysis and applications software. A decision maker makes use of the intelligence information to make important strategic and tactical decisions.

The ultimate user of an SDSS would be a Defence person who would have specialised knowledge in his domain. It is quite unfair to expect him to know the technical issues involved in solving the problem, which includes data processing and analysis procedures. An SDSS architecture can assist the user by providing a problem-solving environment, without exposing the technical issues involved in solving the problem. A novice who does not have any knowledge on the issues related to the scientific/analytical techniques can use the system to make decisions.

The expert system guides the user by providing knowledge on the type of data required and on what GIS/analytical function has to be fired/invoked to solve a specific problem. This way the system would be made totally transparent to the user.

3.5 Software Packages & Methodologies for Data Analysis

The solution to an application problem will never be straight forward. It could involve a set of operations which in turn has to be attempted using a variety of decision-making tools, like GIS, neural network, expert system and analytical models, etc. The existing GIS software should have to be customised for solving application problems. This point is illustrated below with a hypothetical problem.

3.5.1 Terrain Evaluation for Defence Applications

The objectives of the problem are:

(a) To ascertain according to the terrain, the size, type and location of forces to be deployed and plan rapid deployment routes.

(b) To determine the factors which maximise our own and minimise an adversary's use of equipment and tactics.

(c) To predict an adversary's advance rates by the terrain to be covered.

A study on terrain evaluation must be oriented to provide answers to the following:

(a) Cross-country vehicle performance to determine the going condition, avoiding forest and dense vegetation and moving over soils which has got good bearing capacity and over land which has got maximum camouflaging capability and planning for a route that is out of adversary's sight.

(b) Determining going condition for land troops preferably through dense vegetation.

(c) Determining the land capability for laying communication lines, roads, tunnels, and ditch cum bunds.

(d) Evaluating the suitability of site location for temporary structures, camps, aircraft drop zones and landing zones.

(e) Assessing the availability of logistic requirements, like water.

(f) Estimating the deployment capacity of the ground by finding out the amount of camouflaging cover available.

(g) Assessing the possibility of occurrence of natural hazards, like landslides, snow avalanches, earthquakes; and flooding which could be either natural or deliberate.

3.6 Data Security and Data Compression

Considering the sensitive nature of data, a suitable mechanism should be built around the systems to ensure access to data only by authorised personnel. Data encryption is an important element in the data security output. Since the data volumes are enormous, the storage requirements for online archival/retrieval could pose problems unless suitable data compression techniques are adapted. Such facilities are available as firmware to minimise overheads. A suitable configuration for such a system is given in Fig. 2. With the availability of powerful workstations with in-built display systems and networking capabilities, a client/server-based distributed computing system is proposed with UNIX as the standard operating system for easy upgradability and for proper software maintenance.

4. APPLICATIONS

There are several specific applications which relate to Defence planning and operations. These include:

4.1 Antenna Siting (Visibility Analysis)

This problem involves selection of an ideal location for an antenna or watch tower to have a maximum coverage in a hilly terrain or maximum view of the adversary's land.

4.2 Flight Path Planning

This involves determination of an optimal flying height to cover various targets in the adversary's territory, particularly a hilly one, based on visibility and to determine a cost-effective path for flight operations.

4.3 Selection of Suitable Site for Military Training Area

This involves selection of area for military training activities avoiding severely degraded and highly sensitive areas.

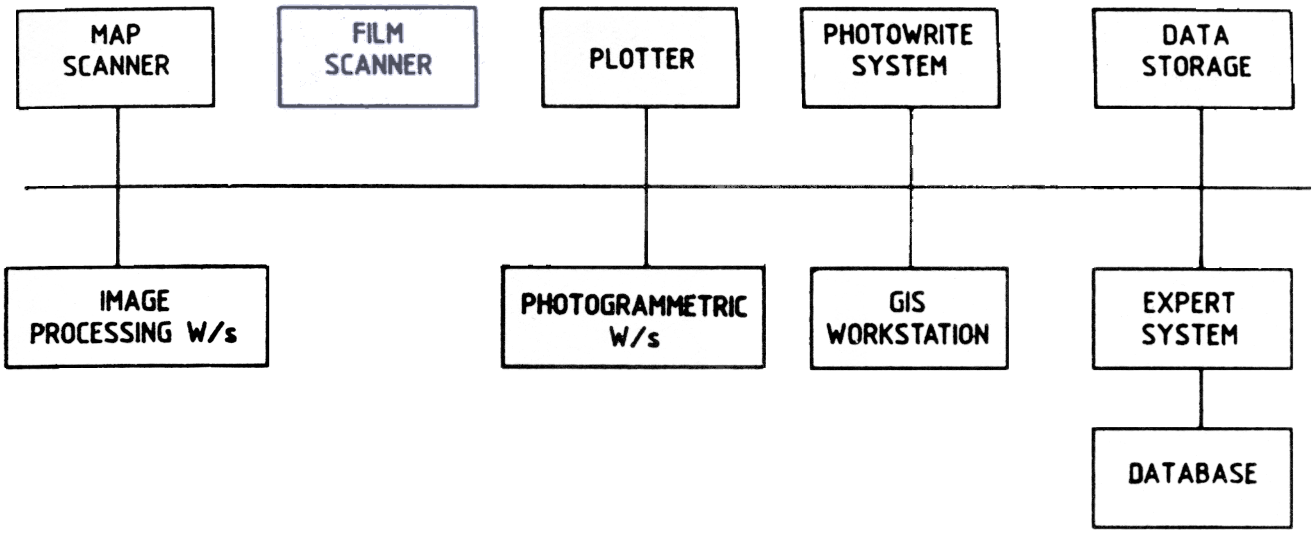

Figure 2. Possible system configuration.

NOTE:

1 IT IS A DISTRIBUTED SYSTEM CONFIGURATION WITH CLIENT-SERVER APPROACH

2 IMAGE PROCESSING SYSTEM FOR INFORMATION EXTRACTION CAN BE CONVENTIONAL OR NEURAL NETWORK BASED

3 FOR EACH FUNCTION, A CLUSTER OF WORKSTATIONS CAN BE CONFIGURED WHICH IN TURN CAN BE NETWORKED TO THE NEXT RELATED FUNCTION

4 THE PERIPHERALS CAN WORK IN OFFLINE MODE

5 DATA STORAGE ALSO CAN BE OFFLINE

6 THE SYSTEM IS UNIX BASED AND HENCE SYSTEM UPGRADATION WILL NOT AFFECT APPLICATIONS S/w

4.4 Change Modelling

This analysis may be done to understand the intentions of the adversary — recent change that has occurred in adversary's land, like emergence of a new canal or road or an industry could be detected, cause for the change can be inferred and the effect of the change can also be studied.

4.5 Landuse Modelling

This is to suggest a suitable change in the landcover to maximise the tank movement, troop movement, or to maximise the camouflaging capability of the land.

4.6 Landslide/Snow Avalanche Modelling

This is to predict and prevent the occurrence of land slides/snow avalanches. This activity involves identification of slopes which are potentially more dangerous and classify certain slopes that are less likely to slide or avalanche. This could help the troops operating in snow-bound landslide-prone mountainous terrain to select routes which are comparatively safer from avalanches or slides. Suitable control technique for the landslide-prone area can be found out based on the nature of the terrain

4.7 Disruption Analysis

Disruption analysis may be done to determine the alternate shortest route in case one or some of the routes are disrupted.

4.8 Selection of Aircraft/Helicopter Landing Ground

This can be done through the GIS-based analysis under facility siting model. Facility siting involves selection of favourable sites for landing of aircraft/helicopter.

4.9 Air Interdiction Model

Air interdiction mission objectives are to delay, neutralise or destroy the military potential of the adversary before it can be effectively used against our own forces. Target destruction and force survival are the measure of success of an operational mission. This involves planning of an air route for the aircraft which enables him to destroy the target and come back safely escaping from the threats caused by surface-to-air missiles, antiaircarft artillery, adversary fighters, etc. Also, geophysical constraints, like weather, nature of the terrain (mountainous or flat), presence or absence of landmarks, become critical in planning a route.

The selection of location of attack should consider all these factors for successful completion of the air interdiction mission.

4.10 Economic Intelligence

Study of economic intelligence would enable one to assess the potentiality of the adversary and would give an idea on where to attack so that the adversary's economy is disturbed.

4.11 Cross-country Trafficability

The cross-country trafficability analysis is performed to find the least impedance/resistance, safest and shortest route for tracked vehicle movement/land troop movement from the place where the tanks are unloaded by the tank carriers to the forward end of the battle area or into an enemy territory. Impedance maps of the enemy territory would help one to predict their advance rate when their mode of transport is known. This work will need 1:25,000 or 1:50,000 scale maps and point information collected from other intelligence sources.

4.12 Flood Inundation Model

This involves the selection of appropriate breach location in the canal or river so as to cause purposeful flooding in the adversary's land to delay their movement and activities. The extent of the area that would be inundated, depth of standing water, the direction of flood route and the time that would be taken to inundate the area can be predicted by the model. This activity requires aerial photographs at a scale of 1:10,000 to derive 1 m or better contour information.

5. CONCLUSION

The most characteristic feature of the present day warfare is its rapidly changing technology and unusual mobility. The troops have to be deployed at short notices over extensive areas and have to be moved from one sector to another. It is of paramount importance to supply with the same expediency the specific data related to the conditions of terrain and its attributes, and the limitations which these conditions impose on operations. Equally important is the prior provision of data to the troops on terrain of inaccessible areas so as to enable them to maintain the momentum of their advance.

A scientific evaluation of the effect of terrain and its various attributes on military operations is of vital importance to derive intelligence information which would aid in decision-making for present day warfare.

With the present day computer systems and software tools/expertise available, it is possible to design a suitable image analysis system for Defence applications with a provision for upgrades in future.