Spatial Query for Decision Support of Cross-Country Movement

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ABSTRACT: This paper discusses the use and evaluation of a query language processor (IDQUERY) for decision support of cross-country movement (CCM) in an image-based geographic information system (VICAR-IBIS). Queries are based on Boolean, arithmetic, and logical operators that interrogate the GIS data layers on a pixel by pixel basis for immediate display. Data layers consisting of soils, surface configuration, and vegetation data are queried for analyses related to cross-country movement. These analyses include the determination and display of areas where slopes limit mobility, vegetation acts as a barrier, and soil areas are prone to decreased load-carrying capacity under conditions of increased soil moisture. Query processing yields results comparable to those obtained using conventional CCM techniques and analysis. In addition, it provides a flexibility of information extraction and rapid display unavailable using current methodology. Query processing in the CCM application can provide flexible decision support in time-critical, limited data situations. This performance exceeds current methods and is not likely to be available in expert systems or other AI approaches in the near future.

INTRODUCTION

Capabilities for data acquisition and rapid computation are surpassing advancements in the methodologies for processing the data into information usable for problem resolution (Hepner, 1984). Advancements in the transformation of geographic data to information useful for decision support are crucial to the future development of geographic information systems (Bedard, 1987). This research examines the utility of spatial query methodology applied to a terrain features database in support of decisions related to cross-country movement (CCM). Cross-country movement information has application to facility routing, emergency services purveyance, and tactical battlefield management problems. The research has two principal objectives:

- To compare the query approach using IDQUERY software to current procedures for the acquisition of terrain and cross-country movement information in terms of accuracy, flexibility of use, and adaptability to an updated database; and
- To examine the present and future position of spatial query in the methodological and technological milieu of expert systems and AI for real-time CCM decision support.

Among the current approaches to geographic information processing and decision support, query processing is becoming increasingly important. Query processing is the interactive retrieval of data from a database using a statement of logical and mathematical operators. In effect, the query process provides a question and answer context in which the data becomes information. The ability to query a database using logical, symbolic, and even natural language expressions is a development of the 1970s. Only recently has the approach been applied to geographical/spatial databases (Frank, 1982; Ingram, 1987; Manola, 1987; Pullar, 1987). In these systems the spatial attributes and associations of the data can be determined by means of the query processor along with the nonspatial information. The adoption of query processing has been stimulated by technical developments in data storage, graphics presentation, and data structures, such as relational databases (Peuquet, 1985; Waugh and Healey, 1985). At the policy level, managers appear to be less willing to rely on the intermediate layers of technical staff in the decision-making process (Bennett, 1983). They now are able to interrogate the database directly using a query approach without advanced programming skills. Such flexibility is allowing the decision-maker to tailor the extraction of spatial information from a continually updated database to a specific problem in real time.

BACKGROUND

Existing techniques using a terrain features database for cross-country movement analysis are relatively non-automated and inflexible to a dynamic situation (Wynn, 1985). Analysts prepare detailed map overlays for surface materials, surface configuration, vegetation characteristics, and soil capabilities. These comprise the terrain features database. The translation of these data into information specifying the mobility limitations on the mapped area is accomplished by the processing of the data through a series of equations to yield mobility factor values (F factors). The F1 factor represents the maximum off-road speed for a specified vehicle as modified by slope conditions. Each of the other mobility factor values represents a percentage of the maximum off-road speed for a specified vehicle based on the other soil, slope, and vegetation factors. The multiplicative product of these F factors equals the average cross-country speed for the composited map area (Table 1). A composite CCM map is produced with speed ranges presented as general classes of movement (DMA, 1983). The production of this final map involves the manual compilation of the map overlays for identification of the unique areas formed by the intersection of the terrain factor areas (Figure 1). It is important to note that several

TABLE 1. DETERMINATION OF CCM USING F FACTOR CALCULATIONS

Predicted Average CCM Speed = F1 × F2 × F3 × F4 × F5
where F1 = maximum off-road speed based on ground slope and vehicle gradeability.
F2 = percentage of maximum vehicle speed relative to vegetation characteristics (roughness, stem diameter, spacing),
F3 = percentage of maximum vehicle speed relative to soil load-bearing capacity,
F4 = percentage of maximum vehicle speed relative to surface roughness (micro-relief, scarplets, rocks), and
F5 = percentage of maximum vehicle speed relative to localized variability in slope (slope intercept frequency).

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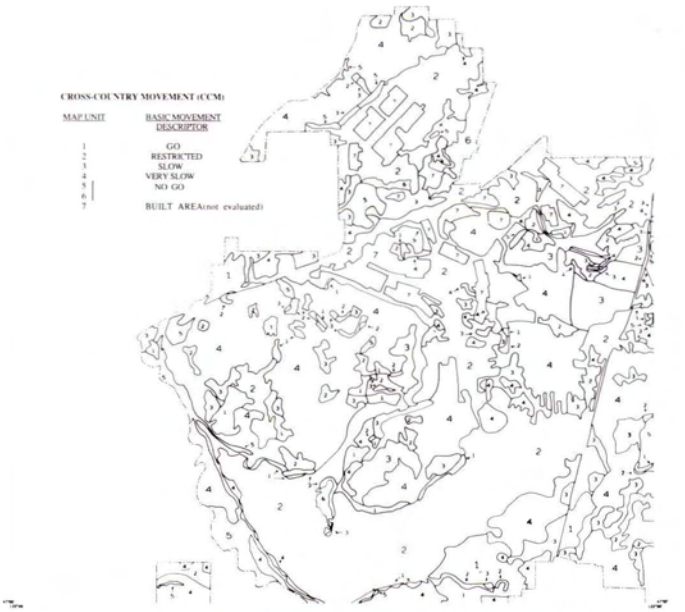

FIG. 1. Conventional composite CCM map indicating the classes of movement possible. It is based on the product of F factor calculations (see Table 1).

of the F factor values are dependent upon specific vehicles characteristics, such as weight and width. A unique set of overlays and composite maps must be prepared for each type of vehicle. The process is becoming more automated as many of the data acquisition, map compilation, and overlay processing tasks are computerized (Šocher, 1982). However, reliance on the mobility factor approach based on manually processed map overlays limits its response in situations not prescribed in the standardized procedures, such as rapidly changing weather conditions, vegetation modifications, etc.

QUERY PROCESSING FOR CROSS-COUNTRY MOVEMENT

This study attempts to replicate important facets of the existing approach to CCM analysis using interactive spatial query processing of the terrain features database in digital form. The query software is used to generate preliminary and final F factors and to display those areas satisfying the query statements. The results of the query sequences are compared with the manual map overlay products as a means of evaluating the utility of query processing in CCM analysis. Queries are designed to extract information from the database with flexibility and detail beyond the scope of the information available using the conventional CCM methodology.

IDQUERY is a query processing software system operating in the VICAR-IBIS image-based information system environment. The system is implemented on a VAX computer with a De Anza display processor. The user can structure logical, Boolean, and arithmetic queries for the interactive interrogation of one or more raster image files and associated attribute files (Friedman, 1986). The image files can be maps or classified satellite images. The attribute files are structured in a relational framework of data categories and values related to polygons on the image files. Query statements are formulated using logical and arithmetic operators, as opposed to natural language operators. In operation, the software uses the column labels (variable operands) of the attribute files to identify the data values to be examined to satisfy the query. IDQUERY evaluates each pixel within each polygon of the images to determine if it meets the specifications of the query. The resultant pixels are retained in a specified raster bit plane for immediate display.

APPLICATION

A terrain features database consisting of detailed terrain characteristics for the Ft. Lewis, Washington area (Anderson Island Quadrangle, 1:50,000 scale) was used to test IDQUERY (Figure 2). The database was manually compiled by the Terrain Analysis Branch at the Defense Mapping Agency. The map overlays were processed into digital raster form at the Jet Propulsion Laboratory (JPL). The raster database contains three image files portraying vegetation, slope, and soil classes, respectively. These files are linked to detailed attribute files for each for the classes shown on the images.

The manually produced map overlay of vegetation is shown in Figure 3. The raster form of this overlay is shown in Figure 4. Each pattern variation represents a vegetation class. The class code identifiers link image polygons to attribute files containing data on vegetation characteristics for that code, such as height, canopy closure, roughness, stem spacing, and stem diameter. Similar files exist for surface configuration (slope) and soils (Wynn, 1985).

A number of tests were conducted to indicate the capability of spatial query processing to enhance CCM decision support. V_t is defined as the minimum number of trees that could impede a vehicle of a specified width at one time. Figure 5 shows those areas where V_t is greater than or equal to one. The critical query statements to achieve this display are

FIG. 2. Reference map showing the Ft. Lewis study area.

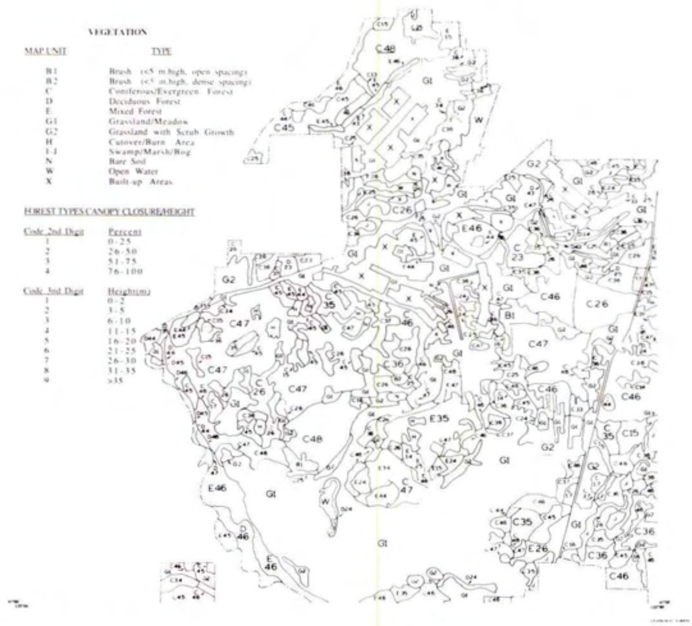

FIG. 3. Map overlay of vegetation classes produced by manual compilation.

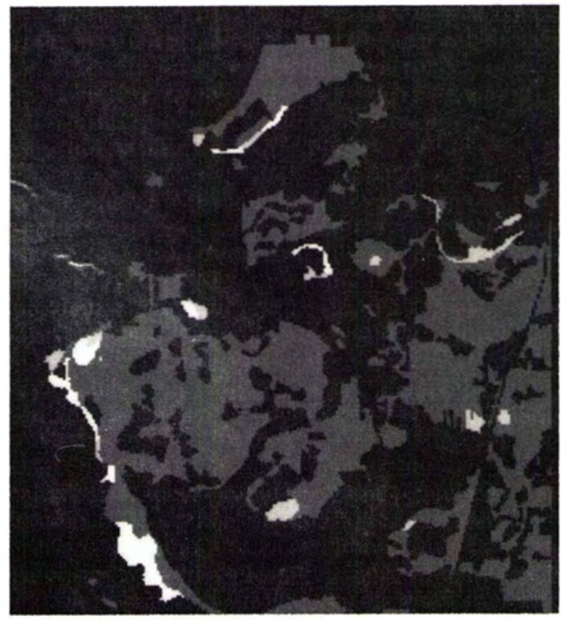

FIG. 5. Resultant query image of the parameter V_t which is based on tree spacing and trunk diameter. Those pixels in white satisfy the final query statement.

FIG. 4. Raster image of vegetation classes used in IDQUERY processing. Each class is a separate gray (DN) value.

FIG. 6. Map overlay of surface configuration (slope) produced by manual compilation.

(1) STEMDIM >0.25 (shown in gray in Figure 5)

(2) $\dfrac{(3.65 + \text{STEMDIM})}{\text{STEMSPAC}} \geq 1$ (shown in white in Figure 5)

where (1) STEMDIM is the variable, tree stem diameter, and 0.25 is the maximum tree diameter (in metres) that can be overridden by the vehicle; and (2) 3.65 metres is the vehicle width and STEMSPAC is the variable, tree stem spacing.

The display indicates those areas the vehicle cannot cross due to the size and spacing of the trees relative to the vehicle width and override capability. As might be expected, Figure 5 corresponds to areas of large forest vegetation. In conventional CCM analysis, V_t is a preliminary calculation used only to specify the final F2 percentage. The actual value of V_t could be very useful in certain situations. However, it is not mapped, nor is it available to the conventional CCM user. IDQUERY processing expands the range of terrain information available to the decision-maker for supplemental analysis.

Surface configuration (slope) for the study area is shown on the map overlay (Figure 6). The F1 factor for slope is defined as the maximum off-road vehicle speed relative to the slope and the capability of the vehicle for traversing sloped areas. In conventional CCM analysis this speed becomes embedded in the calculations of the composite CCM map. Using the map products, one cannot acquire more detailed information on the interaction of slope constraints on speed. Figure 7 shows those areas having an F1 speed of less than 40 kph due to slope. The query statement generating this display is

$$\frac{(54 - \text{slope } \%)}{68.7/71} < 40$$

where 54 is the maximum off-road slope that can be climbed by the vehicle (gradeability), slope % is the mapped variable, ground slope, the maximum road gradeability for the vehicles is 68.7, and the maximum road speed of the vehicle is 71. Visual comparison of Figure 7 to the map overlay of the surface configuration (Figure 6) indicates that IDQUERY is portraying those areas of steep slope which will limit vehicle speed to less than 40 kph. Significant barriers exist across the southwestern and northern portions of the mapped area. As with the previous example, query processing is replicating accurately the fundamentals of the standard slope class and CCM speed range maps. However, query processing allows the specification of constraints that increase the precision of the information extraction.

The previous two examples are designed to replicate facets of the standard CCM calculations and results. If desired, the entire CCM process using the F factors (Table 1) can be replicated using query statements. Figure 8 indicates the potential for interrogation of the database to yield information beyond the scope of standard CCM parameters and methodology.

The rating cone index (RCI) is a measure of soil strength and load-bearing capacity. It is used to calculate the F3 movement factor. RCI values range from 0 for open water to 165 for rock outcrops. The RCI for a given soil can change dramatically depending upon available soil moisture. The relationship between RCI and soil moisture is not linear in all cases. Many soils actually have a greater RCI with some moisture available to bind the soil particles. The RCI may decline from either an increase or a decrease in moisture. Standard CCM maps indicate movement only under generalized conditions of dry or wet. They do not provide for intermediate conditions of moisture or for variability across the mapped area. The query approach can assist routing and movement decisions in realtime relative to changing weather conditions and predictions. Figure 8 shows those

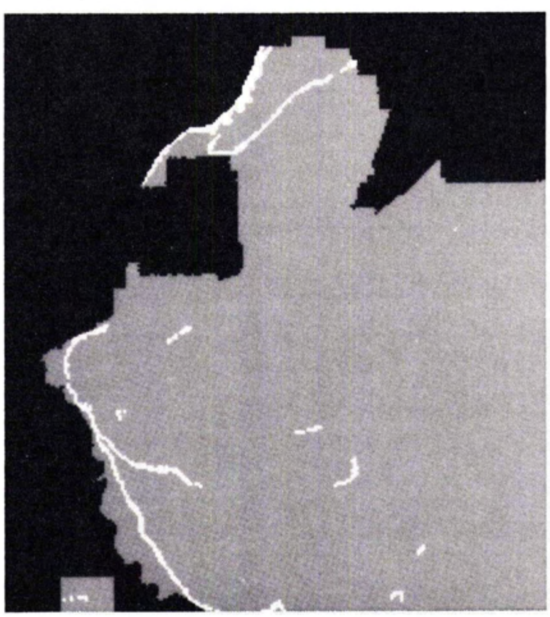

FIG. 7. Resultant query image indicating (in white) those areas where the vehicle speed is limited to less than 40 kph due to slope.

FIG. 8. Resultant query image indicating (in white) those areas prone to a large decrease in load-bearing capacity when wet. Areas in gray are less prone.

areas that experience a large decline in their load-bearing capacity after a rainfall. The query statement used to generate this display is

(1) RCIDRY – RCIWET <90 (gray on Figure 8)

(2) RCIDRY – RCIWET >90 (white on Figure 8)

The areas shown in white have sandy-silt and organic silt soils which accounts for the large decline in their RCI when wet. The query image can be used to define routes across the area that will avoid the areas affected most by moisture. The constraints of the query can be modified depending on the amount of precipitation and the vehicle characteristics. Queries on soils can be combined with queries on vegetation and slope features. This type of interactive decision support is not possible by other means. Interactive query provides insights into CCM problems unobtainable using any of the conventional CCM parameter calculations or map products.

CONCLUSIONS

These examples demonstrate that query processing can not only replicate conventional CCM processing, but can also be more flexible. Given the same level of database development, query's rapid display capabilities can deliver information beyond that available using standard CCM methodology. Queries can be tailored to meet the dynamic uncertainties of changing weather, vehicle specifications, and logistical and tactical situations.

Visual evaluation of the map overlays and the query images indicates that IDQUERY is correctly processing the image and attribute data and providing an accurate display of the results. The IDQUERY software has been shown to possess several powerful features:

- the ability to rapidly extract information and display areas satisfying queries,
- a raster graphics data structure to allow rapid processing of large areas with rapid update from remote sensing and other sources,
- a formalized syntax and grammar in the query language to minimize fuzziness common in map and spatial phenomena and vocabulary.
- the ability to use the query language to build specialized modeling and computational macros, and

- the relational data structure for flexible access to the attribute data.

IDQUERY is part of a prototyping effort in geographic information systems at JPL directed toward the development of advanced GIS software and workstations. As a result, the user interface and the graphic output are very operational, but inadequate by commercial product standards. Other limitations include a significant amount of image and attribute data file preparation, and confinement of the software to the VICAR-IBIS environment.

Many of the impediments to real-time GIS processing appear to be theoretical and methodological rather than technical. Spatial query provides an entree for the human decision-maker into the processing loop of the envisioned real-time GIS support for cross-country movement. Unique occurrences will hamper any automated system in providing reliable decision support. Questions arise as to the efficacy of expert systems and artificial intelligence (AI) in coping with all of the possible scenarios of a rapidly changing, complex CCM situation (Rose, 1987). The use of an expert system to replace the current very structured, semi-automated procedures for the production of cross-country movement map products is possible and desirable. This is a topic for further research. Expert systems depend on the development of a structured rule base to guide operation. It appears unlikely that such a system can be comprehensive and adaptable enough for the rapid, critical routing of emergency vehicles and battlefield management support under a broad spectrum of conditions. Presupposing the eventual development of operational AI and related technologies, such as artificial neural networks, system learning and adaptation may not be sufficiently rapid, or reliable in limited data situations, to handle the need for decisions in real time. Spatial query within a GIS provides a robust alternative for decision support in many applications for the foreseeable future.

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The following schedule lists the deadlines for articles/events that you wish to have published in the Newsletter, GIS News, Calendar, or Classifieds sections of a particular issue of *PE&RS*. We have advanced our publication date for 1989 so that the issue will be off press between the 20th and 24th of the previous month. This means that the February issue would be off press 23 January 1989, etc.

Material received after these dates would be used in the next available issue.

ISSUE	SUBMISSION DATE
January	28 October
February	25 November
March	23 December
April	20 January
May	24 February
June	24 March
July	28 April
August	26 May
September	23 June
October	21 July
November	25 August
December	29 September

For your information, we have planned the following editorial calendar for 1989:

January — Membership promotion
February — Annual Preconvention issue
April — Annual Convention issue
May — Directory issue
June — Geosciences issue
July — Yearbook/Fall Preconvention issue
September — Image Processing/Fall Convention/GIS '89 Preconvention issue
November — GIS/GIS '89 Convention issue
December — Index issue

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