Comparison of Manually Produced and Automated Cross Country Movement Maps Using Digital Image Processing Techniques

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ABSTRACT

The Image-Based Information System (IBIS) at the Jet Propulsion Laboratory was used to automate the cross-country movement (CCM) mapping model developed by the Defense Mapping Agency (DMA). Existing terrain factor overlays and a CCM map, produced by DMA for the Fort Lewis, Washington area, were digitized and reformatted into geometrically registered images. Terrain factor data from Slope, Soils, and Vegetation overlays were entered into IBIS, and were then combined utilizing IBIS-programmed equations to implement the DMA CCM model. The resulting IBIS-generated CCM map was then compared with the digitized manually produced map to test similarity.

The numbers of pixels comprising each CCM region were compared between the two map images, and percent agreement between each two regional counts was computed. The mean percent agreement equalled 86.21%, with an areally weighted standard deviation of 11.11%. Calculation of Pearson's correlation coefficient yielded +0.997. In some cases the IBIS-calculated map code differed from the DMA codes: analysis revealed that IBIS had calculated the codes correctly. These highly positive results demonstrate the power and accuracy of IBIS in automating models which synthesize a variety of thematic geographic data.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

vi

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Military geographic intelligence provides commanders with nec-
essary data about terrain and weather conditions for the purposes of
planning and executing combat missions. Assimilating geographic
intelligence of the terrain involves analyzing what effects natural
surface features, transportation and communication networks, re-
sources of urban and rural areas, climate, and weather could have
upon the activities of friendly and enemy operations.[1] Such factors
are evaluated through interpretation of aerial photography and col-
lateral sources in the process of terrain analysis.

Results of terrain analysis studies support planning of both
strategic and tactical operations. Strategic planning covers a
large area of interest and may require information on an entire
nation's waterways, gross geologic features and soil types, and
major geographic regions. Tactical planning, covering a smaller,
localized area, requires much more detailed information regarding
the local weather, soils, rock types, vegetation, roads, obstacles,
and any other terrain features of importance.[2]

Thematic maps portraying relevant information about terrain
factors may be produced on transparent acetate for comparison with
other maps. These "terrain factor overlays," as they are called,

are overlaid on standard printed topographic maps for comparison of a selected factor with the surrounding region. This combination of overlay plus topographic map, however, allows analysis of only one terrain factor at a time. Analyses of factor combinations and their effects upon military operations are also necessary, but much more complicated functions performed by terrain analysts. For instance, analysis of the effect of rainfall on the ability of a particular soil type to support tank movement would be accomplished by studying soil and climate maps for the area of interest. A common method of analyzing factor combinations involves stacking overlays on top of each other with a light table beneath, enabling the analyst to see intersections of terrain factors of interest. A new overlay may then be drawn which portrays these areas of factor combinations.

An important type of terrain analysis study calculates the effects of soil type, vegetation types and heights, vegetation roughness, tree spacing, percent slope, and surface roughness on the ability of vehicles to move off-road. This is the analysis of cross country movement, or CCM, and the product of a CCM study is a map showing predicted speeds of vehicles of interest over various areas.[3] Speeds may be depicted qualitatively, showing "GO," "SLOW GO," or "NO GO" areas, or they may be quantitative, with mapped areas depicting speed ranges, such as 15-30 kph.

Terrain Analysis Modeling

In order to evaluate factor combination maps which have been compiled from stacked terrain factor overlays, the data portrayed on

those overlays must be quantified and processed using algorithms appropriate to the type of factors being combined. Equations which process these data are models; terrain analysis modeling involves developing such equations to evaluate varying combinations of terrain factors for military planning. The CCM model, for instance, multiplies speed reduction factors (ranging from 0-100%) attributed to soil, vegetation, and slope characteristics, against the maximum vehicle speed, resulting in a speed value between 0 and the maximum vehicle speed for each area with a unique combination of soils, slope, and vegetation.[4] The equations described here, which comprise the Defense Mapping Agency (DMA) CCM model, will be presented in Chapter II.

Purpose of the Study

The purpose of this study is to automate and test the CCM model used by the Terrain Analysis Branch at the Defense Mapping Agency Hydrographic/Topographic Center in Washington, DC. The automated model will be used to generate a CCM map in digital form, using as source data a currently existing terrain analysis study, including a CCM map, produced by DMA. The automated CCM map will be compared with the manually produced map to see if there are significant differences between the two. The degree of similarity between the two maps will serve as an indicator of the utility of one type of automated terrain analysis model.

Currently, most terrain analysis modeling is accomplished manually. Manual modeling involves reading map codes from overlays,

cross-referencing those codes with precalculated numerical values, entering those values into the model's equations, and solving those equations. This process is repeated for each unique combination of terrain factors detected from the stacked overlays. Since numerous repetitive mathematical calculations are required, several government agencies are developing automated routines, mostly to support their own workstations, such as the Digital Terrain Analysis Station (DTAS) at U.S. Army Engineer Topographic Laboratories (ETL).[5] Automated modeling simplifies the process since numerical map data exist in digital form, and the cross-referencing and equation solving are accomplished by computer.

Hypothesis to be Tested

The hypothesis of this research is that raster-based automated mapping procedures can produce maps of complex, secondary relationships that equal those of conventional manual methods--hopefully in a more efficient manner. The Image-Based Information System (IBIS) developed at the Jet Propulsion Laboratory (JPL) in Pasadena, California is a raster-based system that will be used to produce two versions of a DMA cross-country movement map: an automated version, using programmed equations to implement the CCM model and generate a new map, and a digitized version of the original manually produced map. The test hypothesis will be that the area comprising each mapped region on the automated map is not significantly different from the area comprising each corresponding region on the digitized version of the DMA map. This hypothesis will be tested by statis-

tically comparing the numbers of pixels covering each polygon on the digitized versions of both maps. The DMA terrain analysis study of the Fort Lewis, Washington Military Reservation will provide the terrain factor overlays and the CCM map compiled manually from those overlays. Details of the testing methodology will be discussed in Chapter IV.

The IBIS system is a geographic information system which can merge and process digital map, imagery, and tabular data stored in raster (pixel), rather than vector (graphical), format.[6] Maps initially digitized in vector format are converted into raster data and stored as raster graphics files having the same gridded, or pixel, format as digital imagery such as Landsat. For this reason, maps stored in raster format are referred to as "image planes," a term later useful when referring to overlaying several maps, or image planes, on top of one another using IBIS routines.

Justification of the Study

Automated terrain analysis is urgently needed by today's armed forces who require fast, accurate, and up-to-date information about the battlefield. This study will be a step toward perfecting the methods used to supply that information. In the civilian world there are currently no equivalents to CCM maps; however, partici- pants in the sports of orienteering, cross-country hiking and skiing, and any other off-road recreation would be logical customers for such maps if it were shown that they could be easily developed. Such "civilian CCM maps" could show conditions of off-road movement

based on the type of sport involved. Map scale would also vary accordingly.

There is already great demand in the civilian world, however, for the type of geographic analysis performed in this study. The IBIS system, with its capabilities of storing and merging remotely sensed data, maps, and tabular information in image format, is in use at several NASA research centers, state agencies, and university research centers. There have been several IBIS studies carried out at JPL and other research institutions for the civilian community with applications such as correlating land cover distributions with cultural boundaries, modeling debris slide potential in mountainous terrain, and monitoring rural-to-urban land cover transitions.[7] This study, by merging and analyzing data from several thematic maps, will enhance and expand the analysis capabilities of geographic information systems such as IBIS.

Base Maps and Source Data

The Fort Lewis Military Reservation is located approximately 20 kilometers southwest of Tacoma, Washington. The 1:50,000 scale topographic map covering the area, as seen in Figure 1, is _Anderson Island_, Sheet 1478II, Series V791, Edition 9-DMAHTC, 1979. This sheet contains the study area, which is defined by the Fort Lewis boundaries.

The Prototype Tactical Terrain Analysis Data Base (or PTTADB) for Fort Lewis, Washington, produced by the Terrain Analysis Branch at Defense Mapping Agency Hydrographic/Topographic Center (DMAHTC)

Fig. 1. The Fort Lewis, Washington Study Area

8
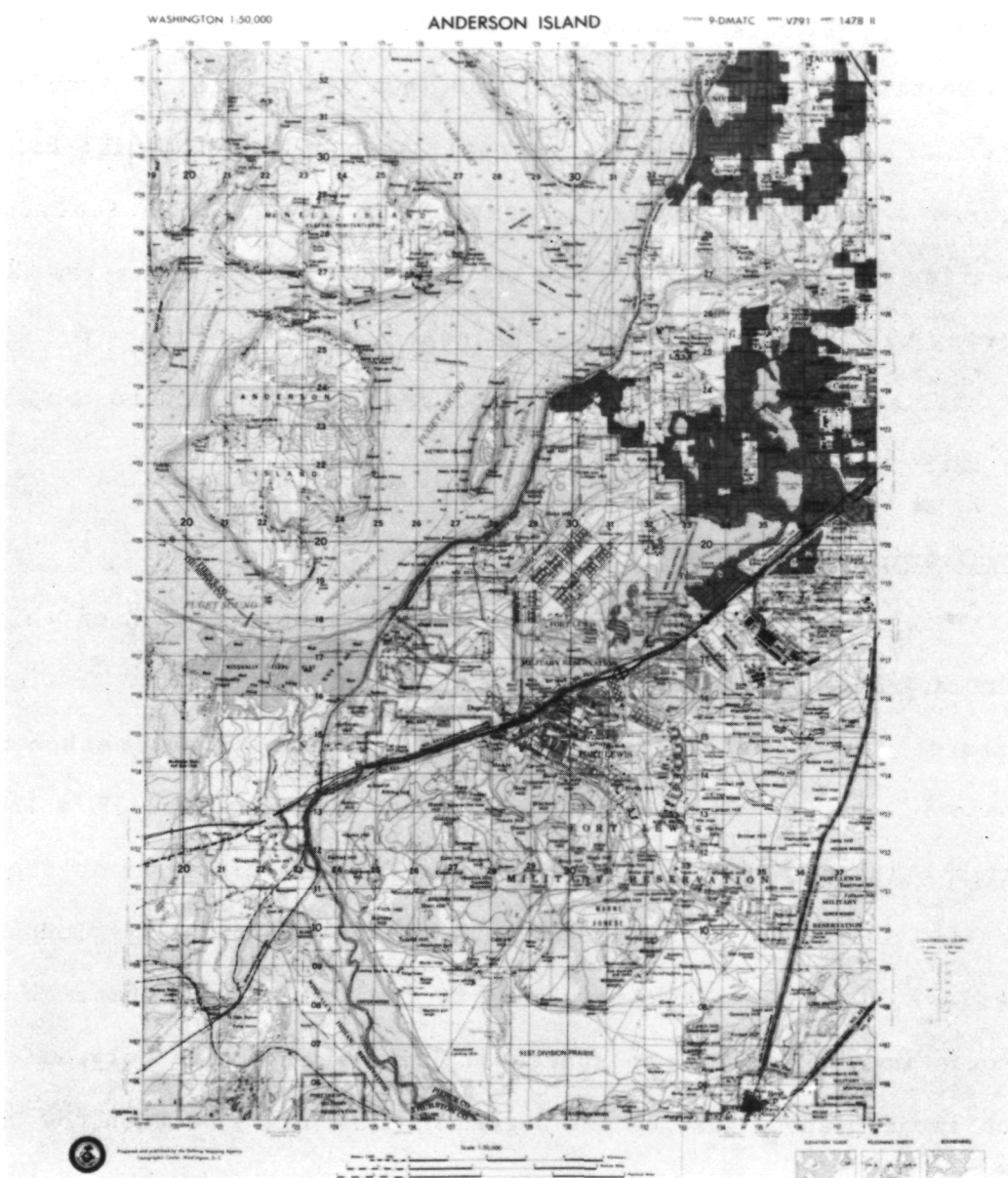
contains the terrain factor overlays to be used in this study. This data base consists of manually compiled terrain factor overlays at the 1:50,000 scale, depicting six types of features: slope, soils, vegetation, hydrology, obstacles, and transportation. These overlays do not exist in lithographic form, but are printed on 4 millimeter-thick Cronaflex, a translucent, stable-base drafting film. Figures 2 through 5 show the Vegetation, Slope, Soils, and CCM Cronaflex overlays which will be used in this study. From the CCM overlay the printed CCM map was produced, shown in Figure 6. The CCM overlay will serve as the control map against which to compare the IBIS-produced CCM map.

Organization of the Study

This study is organized into four basic sections, each of which comprises a chapter in the thesis. Chapter II will discuss previous research on automated terrain analysis, DMA's current method of production of terrain analysis overlays and CCM maps, and JPL's IBIS system. The preparation of the test map will be discussed in Chapter III, including the process of converting the manually produced overlays into digital format, and the creation of interface files associating the proper map codes with their respective polygons in each image plane. Testing the degree of similarity between the DMA and IBIS maps will be discussed in Chapter IV, which will include explanations of any observed discrepancies between the two maps. The impact of these findings and recommendations for further research will be covered in Chapter V.

Fig. 2. Vegetation Cronoflex Overlay

10

SURFACE CONFIGURATION
WASHINGTON 1:50,000

ANDERSON ISLAND

1478 II
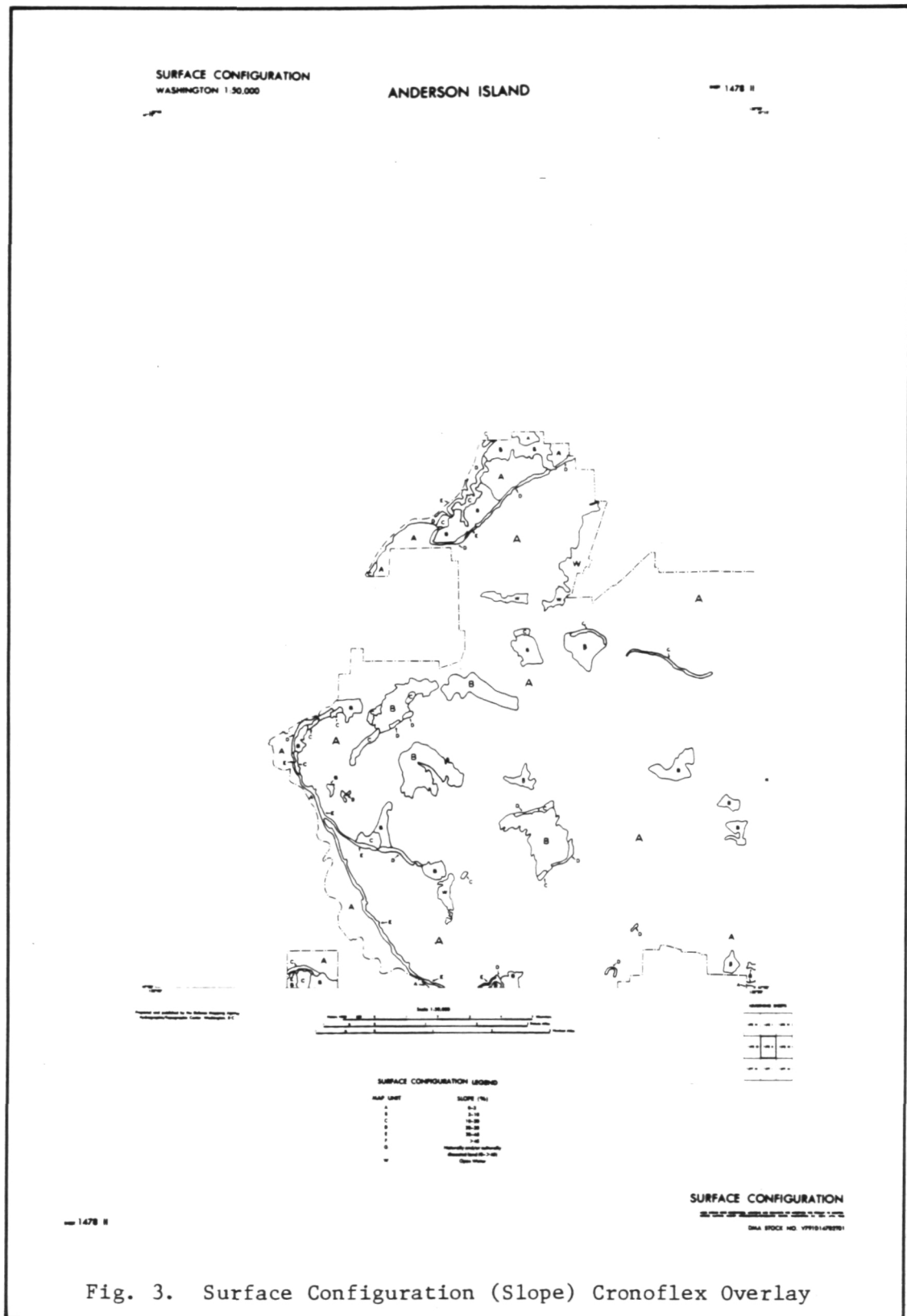
Fig. 3. Surface Configuration (Slope) Cronoflex Overlay

SURFACE MATERIALS (Soils)
WASHINGTON 1:50,000

ANDERSON ISLAND

— 1478 II
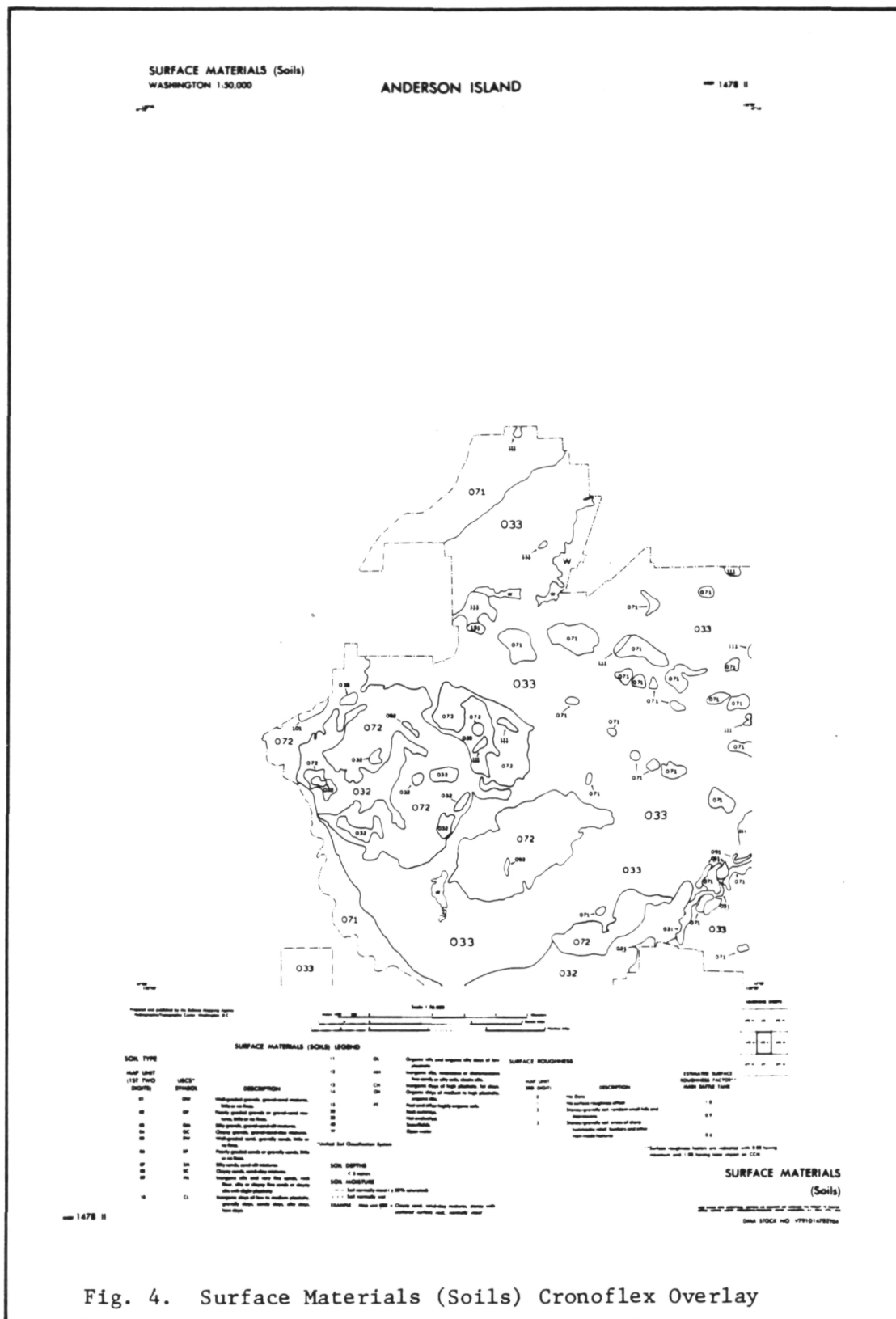
Fig. 4.   Surface Materials (Soils) Cronoflex Overlay

12

CCM - MAIN BATTLE TANK
WASHINGTON 1:50,000

ANDERSON ISLAND

1478 II
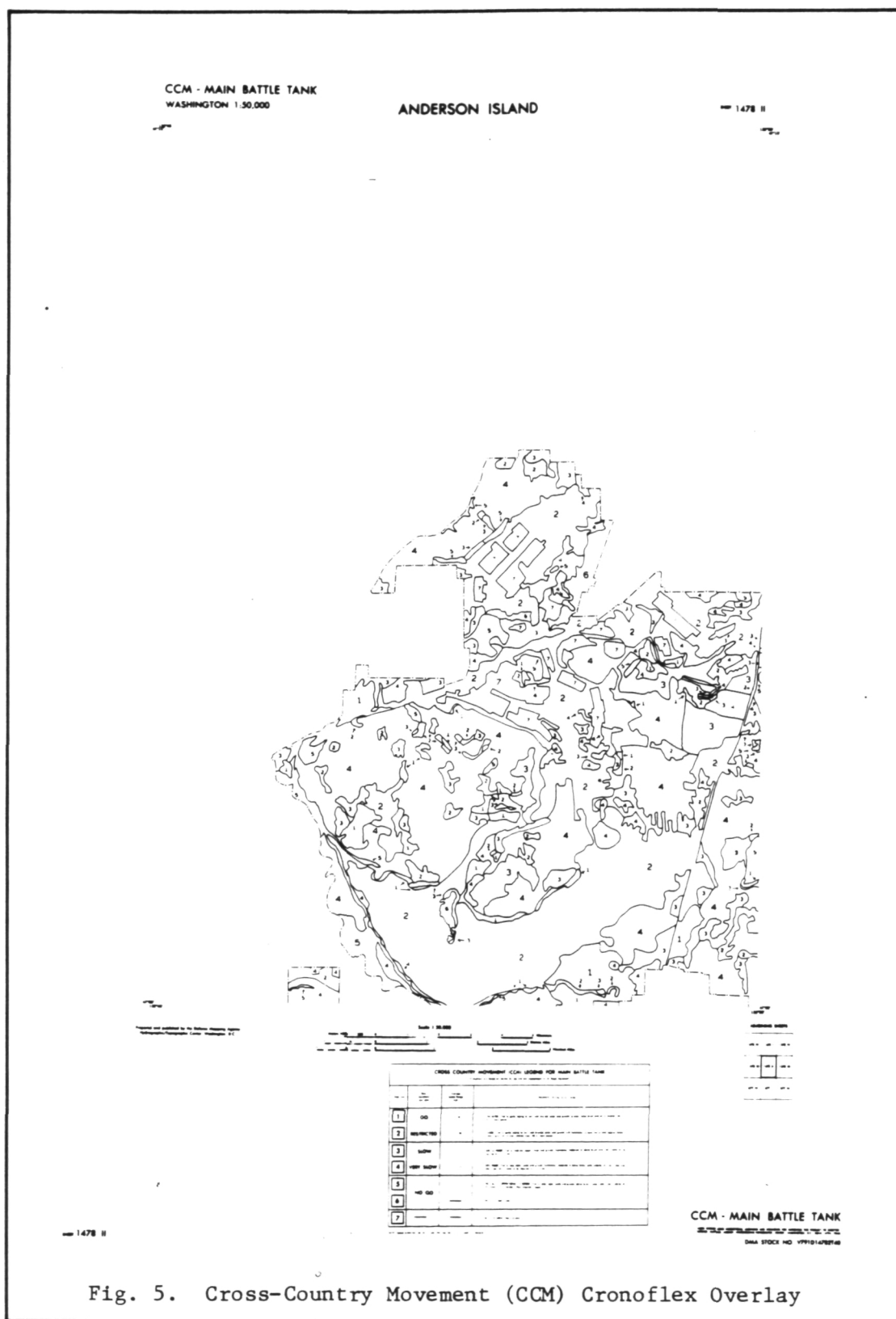
Fig. 5.   Cross-Country Movement (CCM) Cronoflex Overlay
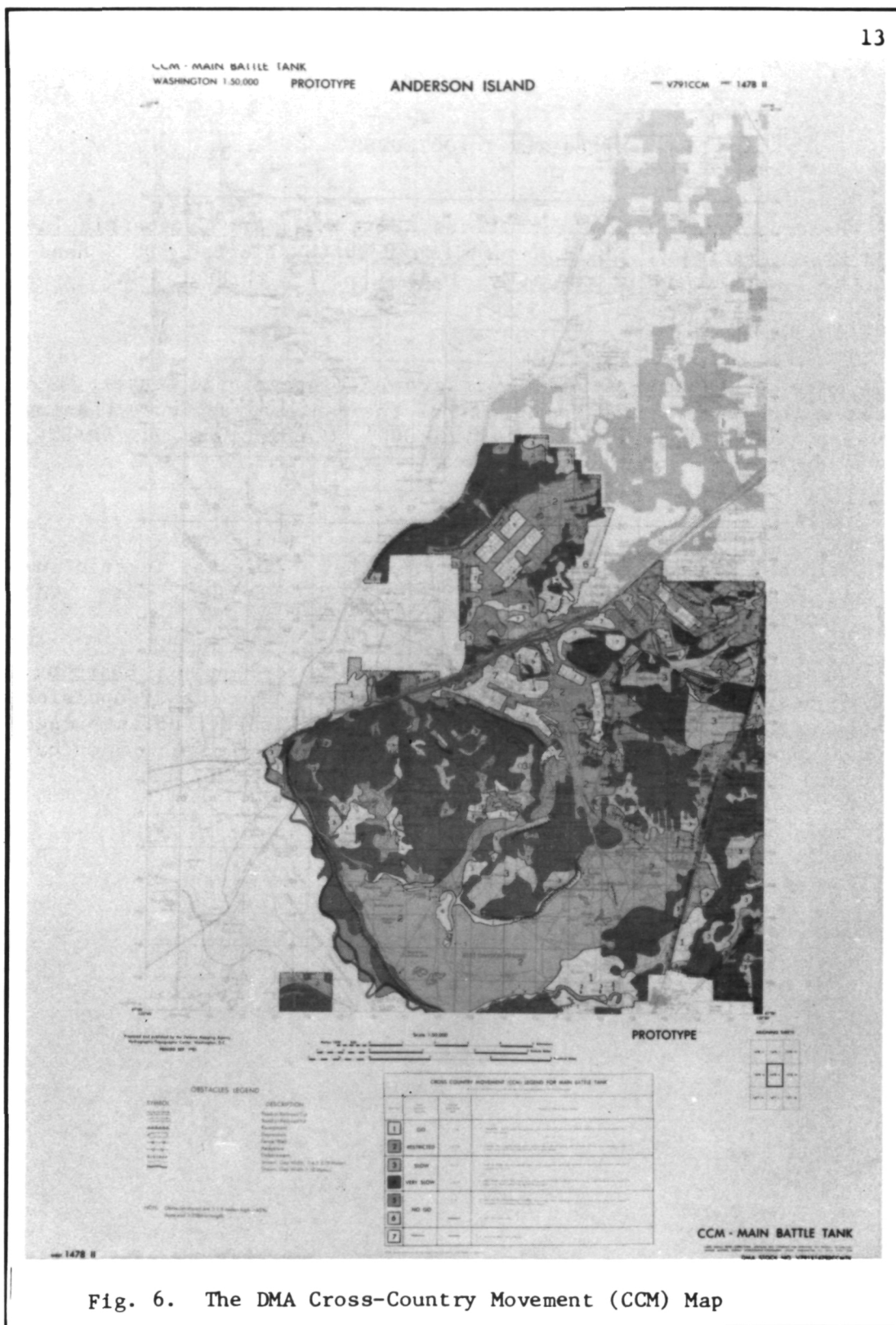
Fig. 6.   The DMA Cross-Country Movement (CCM) Map

CHAPTER I FOOTNOTES

1

Headquarters, Department of the Army, <u>Military Geographic Intelligence (Terrain)</u>, Field Manual FM 30-10 (Washington, DC: Headquarters, Department of the Army, 1972), pp. 1-1 through 1-2.

2

Ibid., p. 1-2.

3

Defense Mapping Agency Hydrographic/Topographic Center, "DMA Procedural Guide for the Production of the Synthesized Cross-Country Movement (CCM) Overlay(s), Scale 1:50,000" (Washington, DC: DMAHTC, 1982), p.1.

4

Ibid.

5

Michael R. Thompson and Robert M. Socher, "Digital Terrain Analysis Station," <u>Proceedings, Auto-Carto V</u> (Crystal City, VA: n.p., 1982), p. 649.

6

Steven Z. Friedman, <u>Image-Based Approach to Mapping, Charting, and Geodesy</u>, JPL Publication 715-153 (Pasadena, CA.: Jet Propulsion Laboratory, [1982]), pp. 1-2 and A-5. IBIS is a subset of the image processing system used at JPL called VICAR (Video Image Communication and Retrieval).

7

Ibid., pp. 1-1 through 1-3.

CHAPTER II

TERRAIN ANALYSIS TECHNIQUES

Military terrain analysis is carried out within several Department of Defense (DOD) agencies, on military bases, and at sites of DOD contractors who conduct research and development on new terrain analysis methods. The majority of terrain analysis map products is produced manually, with the Defense Mapping Agency holding the charter for standardizing and producing such maps for all branches of the military. Some production mapping is also being done by DOD contractors.

Compilation of Terrain Factor Overlays

The Defense Mapping Agency currently produces terrain factor overlays through the manual processes of aerial photointerpretation and cartographic drafting. The types and contents of these overlays have been standardized by DMA into two general data bases: the 1:250,000 scale Planning Terrain Analysis Data Base (PTADB), and the 1:50,000 scale Tactical Terrain Analysis Data Base (TTADB). Both data bases consist of overlays which include Surface Configuration (Slope), Vegetation, Surface Materials (Soils), Surface Drainage, Transportation, and Obstacles. This study will operate under the constraints of the specifications for compilation of the TTADB and for the CCM map, to be discussed later, under which all source

materials for this study were produced.[1]

Terrain factor overlays are thematic maps derived from interpretation of aerial photography and are keyed to a base topographic map. The overlays carry the same sheet numbers as the base maps, standard DMA 1:50,000-series topographic maps. Sheets of translucent drafting acetate are taped to the base map, upon which the initial pencil overlay is compiled. The final inked version is drafted on stable-base material, with pre-printed neatlines and titles, which is registered to the base map.

The analyst uses a stereoscope, such as a Bausch and Lomb Zoom 500 Stereoscope, and stereopairs of the best available photography to derive terrain information for the particular type of overlay being compiled. Guided by the TTADB specifications as to what information to pick up, analysts transfer the data interpreted from the photos onto the drafting acetate in colored pencil. The base map controls the positioning of the compiled terrain information. When the sheet is completed and edited by the analyst, the final version is inked on heavy stable-base drafting material. Pre-printed legends and other marginal notes are applied. Final reproductions are created via graphic arts printing processes.

Efforts are underway to develop computer-aided photointerpretation systems, which will allow analysts to view photography and enter the interpreted data directly onto digital tape. An analytical plotter will capture such data as elevation, road characteristics, and other terrain information straight from the aerial photography.

The Terrain Analysis Workstation (TAWS) and Digital Terrain Analysis Station (DTAS) projects at ETL involve developing such automated capabilities.[2]

An intermediate step in the development of a fully automated terrain analysis data base is to digitize the overlays already produced manually. Selected overlays have been digitized by DMA to support various simulator programs and exist in both raster-scanned and vector-digitized formats.[3] The simulator programs required specific types of map information in formats which did not match DMA's production specifications, so these digitized overlays by no means represent a suitable core upon which to build a standardized digital terrain analysis data base. A study is being carried out by ETL to determine digital terrain analysis requirements of all four service branches in order that specifications may be developed by DMA for standardized digital products.[4]

The DMA Cross-Country Movement Map

Defense Mapping Agency Cross-Country Movement maps are compiled from the Surface Materials, Vegetation, and Surface Configuration terrain factor overlays, according to DMA specifications.[5] The CCM model converts the data from these overlays into mappable speed ranges, which are then drawn as a new map--the CCM map. The manual procedure for CCM modeling and map compilation will be described in detail here so that it may later be compared with the slightly different automated procedure.

CCM modeling. The three overlays contain specific information used in the CCM model, either portrayed by the map codes themselves or printed in auxiliary tables. The Surface Materials overlay map codes depict soil type, moisture content, depth, and surface roughness. The Vegetation map codes describe vegetation type, canopy closure, and height. Auxiliary tables printed on the Vegetation overlay include vegetation roughness factors, stem diameter, and tree spacing. The Surface Configuration overlay simply encodes percent slope and areas of naturally or culturally dissected land. All overlays show areas of open water; the Vegetation overlay also shows built-up areas (urbanized), which are not evaluated in the CCM model.

As described in Chapter I, the CCM model is a set of equations which evaluates the terrain data according to the type of vehicle of interest, and predicts speed ranges for that vehicle based on the terrain of a particular area of interest. The set of equations is consolidated into five "factor values," which, when multiplied together, yield CCM speed. Each factor value in itself is a set of equations, as shown in Figure 7. The five factor values are: F1 (slope), from the Surface Configuration Overlay; F2 (vegetation), from Vegetation; F3 and F4 (soil and surface roughness factors), from Surface Materials; and F5 (slope intercept frequency), derived independently from a topograhic contour map of the area. The calculation of these factor values will be described in Chapter III.

As seen in Figure 7, the slope, vegetation, and soil factor

GENERAL CASE CCM MODEL
FACTORS FOR SPEED ADJUSTMENT

MODULE

1. Slope

F_1 = $\dfrac{\text{Maximum Off-Road Gradeability (\%) - Ground Slope (\%)}}{\text{Maximum Road Gradeability (\%)}} \div \text{Maximum Road Speed (kph)}$

= $\dfrac{MOG - GS}{MRG} \div MS$

2. Vegetation

F_2 = $V_R(V_M$ or $V_0)$; use the greater of V_M or V_0

V_R = Vegetation Roughness Factor

V_M = Vegetation Maneuverability Factor = $(V_F)(V_C)$

V_F = Vegetation Vehicle Factor (0.2 for wheeled and tracked vehicles without towed trailers and 0.2 for foot troops)

V_C = Vegetation Clearance Factor

= $\dfrac{\text{Stem spacing - Stem Diameter}}{\text{Vehicle Width}} = \dfrac{SS-SD}{VW}$

If V_C is less than (1.0), use V_0 only.

If V_C is greater than five (5.0), use V_C = 5.0.

V_0 = Vegetation Override Factor

= $1 - (V_T) \left(\dfrac{\text{Stem Diameter}}{\text{Maximum Tree Override Diameter}}\right)^2 = 1 - (V_T)\left(\dfrac{SD}{MOD}\right)^2$

V_T = Minimum number of trees vehicle can hit at one time.

= $\dfrac{\text{Vehicle Width + Stem Diameter}}{\text{Stem Spacing}} = \dfrac{VW+SD}{SS}$

Fig.7. General case CCM model: factors for speed adjustment.

GENERAL CASE CCM MODEL
FACTORS FOR SPEED ADJUSTMENT

MODULE

If V_T is less than one (1.0), use $V_T = 1.0$.
If Stem Diameter is greater than Maximum Tree Override Diameter (SD > MOD), use V_M only.

Negative values indicate a standstill or "No Go" situation; Use V_M only.

NOTE: (1) F_2 cannot exceed a value of one (1.0); if it does, use $F_2 = 1.0$.

(2) Where both V_M and V_0 say to use the other, in effect the vehicle cannot maneuver ("No Go" situation); use $F_2 = 0.0$.

(3) Where no Stem Diameter (SD) or Stem Spacing (SS) is given, use $V_C = 5.0$. Therefore, $V_M = (V_F)(V_C) = (0.2)(5.0) = 1.0$; in effect, $F_2 = V_R$ for these vegetation classes.

3. Soil
$F_3 = \dfrac{\text{Rating Code Index} - \text{Vehicle Cone Index, One Pass}}{\text{Vehicle Cone Index, 50 Passes} - \text{Vehicle Cone Index, One Pass}}$

$= \dfrac{RCI - VCI_1}{VCI_{50} - VCI_1}$

NOTE: (1) Negative F_3 values indicate a standstill or "No Go" situation; use $F_3 = 0.0$.

(2) F_3 cannot exceed a value of one (1.0); if it does, use $F_3 = 1.0$.

Fig. 7 (continued). General case CCM model: factors for speed adjustment.

GENERAL CASE CCM MODEL
FACTORS FOR SPEED ADJUSTMENT

MODULE

4. Surface Roughness (Micro-relief; rocks, sumps, scarplets, broken surfaces, etc.)

$$F_4 = \frac{100-2 \; (\text{Obstacle Height (cm)} + \text{Vehicle Approach Angle (°)})}{\text{Obstacle Spacing (meters)}}$$

100

or

Use the estimted F_4 as given on the Surface Materials O/L.

NOTE: (1) Negative F_4 values indicate a standstill or "No Go" situation; use $F_4 = 0.0$.

(2) F_4 cannot exceed a value of one (1.0); if it does, use $F_4 = 1.0$.

(3) This is the last item for Foot Troops; F_5 is not applied to Foot Troops.

5. Slope Intercept Frequency (Positive-Negative Slope Changes over a 1 km distance)

$$F_5 = \frac{280 - \text{Use Count (Frequency/km)}}{280}$$

$$\text{Use Count} = \frac{(\text{SIF} \; (C_U \div C_S))}{(L_U \div L_S)}$$

SIF = Slope Intercept Frequency Count

C_U = Contour Interval on Map or Plate Used for SIF

C_S = Standard Contour Interval = 20 meters

L_U = Side Length of Square Used for SIF

L_S = Standard Side Length Used for SIF=1km

Fig.7 (continued). General case CCM model: factors for speed adjustment.

GENERAL CASE CCM MODEL
FACTORS FOR SPEED ADJUSTMENT

MODULE

NOTE: (1) If standard 1:50,000 map is used; Use Count = SIF

(2) Do not use F_5 for Foot Troops

6. Predicted Average S(Personnel, Animal, or Vehicle) = $(F_1 \times F_2 \times F_3 \times F_4 \times F_5)$
   CCM Speed

Fig.7 (continued). General case CCM model: factors for speed adjustment.

SOURCE: Defense Mapping Agency Hydrographic/Topographic Center, "Defense Mapping Agency Procedural Guide for the Production of the Synthesized Cross-Country Movement Compilation Overlay(s), Scale 1:50,000" (Washington, D.C.: DMAHTC, 1982), pp. 10-11. (Photocopied.)

equations require data from sources outside the terrain factor overlays. For these factors gradeability, road speed, vehicle width, tree override diameter, and vehicle cone index data come from Table 1. The rating cone index for soils is found in Table 2. The surface roughness factor F4 is normally estimated by the soils analyst during compilation of the Surface Materials overlay and appears as the third digit in each map code in that overlay. Its value is included in the legend. Both Tables 1 and 2 are adapted from DMA's Procedural Guide.[6] These tables contain data for many different vehicles and for different soil moisture states; as this implies, CCM models may be developed for any vehicle or group of vehicles, as well as for different weather conditions.

Slope factor F1 yields an average off-road speed on a firm, smooth surface with a specified slope. Factors F2 through F5 yield values ranging from 0.0 to 1.0, which modify the speed value of F1 according to the following equation:

$$\text{Average CCM speed} = F1 \times F2 \times F3 \times F4 \times F5 \qquad (1)$$

Factor values for F2 through F5 of 1.0 indicate maximum possible speed, while values of 0.0 indicate no movement possible.[7]

Once the factor values are calculated they are grouped logically into "model units" for each overlay. This is done to reduce the thousands of calculations that would have to be performed as each individual factor value changes when the terrain factors from the three overlays are combined. (With an automated system the computer

TABLE 1

PERSONNEL, ANIMAL, AND VEHICLE CHARACTERISTICS AND TERRAIN CLEARANCES FOR CCM CALCULATIONS

Personnel, Animal or Vehicle	Max. Off-Road Gradeability (%)	Max. Road Gradeability (%)	Max. Road Speed (kph,mph)	Max. Off-Road Speed (kph,mph)	Vehicle Width (m)	Max. Tree Override Diameter(dbh,m)	Vehicle Cone Index (VCI$_1$/VCI$_{50}$)	Max. Vehicle Approach Angle (°)
Foot Troop	100	100	6.4(4)	6.4(4) (calculated)	0.45	.01	5/60	90+
Mule (Packed)	100	100	8(5)	8(5) (calculated)	1.00	.02		45
M-1, Abrams Tank	54 (calculated)	68.7	71(44)	55.8(35) (given)	3.65	.25	24/56	22.5
M-2, Inf.Ft.Veh.		60	66(41)		3.20			
M-3, Cal. Ft. Veh.		60	66(41)		3.20			
M-29c, Weasel	95	100	58(36)	55(34.2) (calculated)	1.71	.05	13/25	45+
M-35, Truck	30	64	97(60)	45.2(28.1) (calculated)	2.43	.06	35/69	48
M-48, Tank	45 (assumed)	60	48(30)	36.2(22.5) (calculated)	3.63	.15	26/58	45
M-60, Tank	45 (assumed)	60	48(30)	36.2(22.5) (calculated)	3.63	.15	22/52	45 (43)
M-109, SP 155	45	60	56(34.8)		3.10	.12	25/57	
M-113, APC	45 (assumed)	60	64(40)	48.3(30) (calculated)	2.69	.10	24/47	70
M-151, Jeep	28	60	106(66)	49.6(30.8) (calculated)	1.63	.04	30/60	66
M-274, Mule	25	60	40(25)	17.4(10.8) (calculated)	1.24	.03	24/48	41
T-62, Tank	45 (assumed)	62.5	50(31.2)	36(22.5) (calculated)	3.37	.15 (assumed)	22/58 (averaged)	
T-72, Tank	45 (assumed)	62.5	60(37.5)	43.6(27.1) (calculated)	3.38	.18	25/60 (assumed)	32.5

TABLE 1

PERSONNEL, ANIMAL AND VEHICLE CHARACTERISTICS AND TERRAIN CLEARANCES FOR CCM CALCULATIONS (CONTINUED)

Personnel Animal or Vehicle	Vehicle Length Hull(w/Gun Forward) (m)	Vehicle Height (m)	Wheel Base (m)	Max. Vertical Obstacle Climb Height (cm)	Max. Trench Crossing Width (m)	Fording Depth w/o Kit (m)	Fording Depth with Kit (m)	Max. Stream Velocity Vehicle can Cross or Swimming Speed (if Amphibious) (m/s)
Foot Troop				220+	1.25	Amphibious	Amphibious	0.22
Mule (Packed)				30	.75	Amphibious	Amphibious	0.45
M-1 Abrams Tank	7.90(9.78)	3.00		124.5	2.77	1.22	2.34 & 4.11	3.5
M-2 Inf. Ft. Veh.	6.22	2.97	2.97	91	2.54			2.0
M-3 Inf. Ft. Veh.	6.22	2.97	2.97	91	2.54			2.0
M-29c, Wessel			1.98	25	.91	Amphibious	Amphibious	1.79
M-35, Truck	8.19	3.16	3.91	30 (35)	.55	.76	1.83	0.46
M-48, Tank	6.87	3.09		91.4	2.6	1.22	2.43	
M-60, Tank	6.95(9.31)	3.26	4.23	91	2.59	1.22	2.44	3.4
M-109, SP 155				53	1.80	1.10		2.8
M-113, APC	4.86	2.50	2.67	61	1.68	Amphibious	Amphibious	2.10
M-151, Jeep	3.52	1.85	2.16	18	.35	.53	1.52	
M-274, Mule			1.45	18	.30	.46		
T-62, Tank	6.71	2.40		80	2.85	1.4	5.48	3.4
T-72, Tank	6.95	2.37		100	2.8	1.4	5.48	3.4

SOURCE: Defense Mapping Agency Hydrographic/Topographic Center, "Defense Mapping Agency Procedural Guide for the Production of tne Synthesized Cross-Country Movement Compilation Overlay(s), Scale 1:50,000" (Washington, D.C.:DMAHTC, 1982), pp. 12-13, (Photocopied.)

TABLE 2

RATING CONE INDEX (RCI) VALUES FOR SOILS UNDER THE
UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

USCS CODE	SOILS CATEGORY ON O/L	SOIL TYPE	RCI VALUES DRY	MOIST	WET
GW	01	Gravel or sandy gravel, well graded	163	123	83
GP	02	Gravel or sandy gravel, poorly graded	160	120	81
GM	03	Gravel, silty	120	76	32
GC	04	Gravel or sand gravel, clayey	130	91	52
SW	05	Sand, well graded	155	116	78
SP	06	Sand, poorly graded	145	109	73
SM	07	Sand, silty	119	72	25
SC	08	Sand, clayey	126	86	46
ML	09	Silts	118	69	20
CL	10	Clays	123	81	40
CL-ML		Clay-Silt mixtures	116	65	14
OL	11	Organic silts	111	57	3
MH	12	Inorganic elastic silts	114	61	8
CH	13	Fat clays	136	99	62
OH	14	Fat organic clays	107	54	1
PT	15	Highly organic soils or peat	106	52	0
RK	20	Rock outcrops	165	165	165
X	30	Not evaluated	–	–	–
W	W	Open water	0	0	0

SOURCE: Defense Mapping Agency Hydrographic/Topographic Center, "Defense Mapping Agency Procedural Guide for the Production of the Synthesized Cross-Country Movement Compilation Overlay(s), Scale 1:50,000." (Washington, D.C.:DMAHTC, 1982), p.29. (Photocopied.)

performs the calculations, eliminating the need for any grouping of map codes and factor values.) For example, Table 3 shows how the Vegetation map codes for the Anderson Island sheet and their factor values were grouped into eight model units, each including groups of F2 values within 0.20 of each other. Similarly, F1 (slope) values were grouped into six model units, F3 (soil) values were reduced to seven units, and F4 (surface roughness) values were reduced to three. The F5 values correspond to the number of F1 values. With this reduction in factors the number of combinations of model units, and thus calculations, is kept below 300.

After the model units are prepared the actual calculations of CCM speed are carried out according to Equation 1 above. A table, the Factor Map Units (FMU) Table (Table 4), is set up so that the map compiler can see at a glance which combinations of model units correspond with which speed categories, usually numbering between five and seven on the map legend. Another table, the "Terrain Factor Grouping Table" (Table 5), lists original overlay codes and their corresponding model unit, and is used in conjunction with the FMU table during compilation.[8]

At this point the data have been converted from codes on the three overlays into speed ranges for the vehicle of interest. This completes the preparation of the CCM model. Next comes the actual compilation of the final CCM map.

CCM map compilation. The first step is to have inked copies of the three overlays reproduced in different colors on stable-base

TABLE 3

GROUPING OF VEGETATION FACTOR (F_2) VALUES

Project Fort Lewis   Map Sheet(s) Anderson Island

Vehicle M-1 Abrams Tank

VEGETATION O/L CODES	F_2 VALUE	LOGICAL GROUPING VALUE	ASSIGNED CCM VEGETATION MODEL UNIT
N	.95	.92	1
B1, G1	.90		
B2	.80	.80	2
G2	.70		
D23	.67		
C18	.63	.60	3
C17	.55		
C23	.53		
C16, E43	.51		
C13, H	.50		
C43	.48		
C15	.47		
E15	.45		
C14	.44		
D24	.41		
D34	.40	.39	4
C28	.39		
C27, E24, E34	.35		
C26	.31		

TABLE 3

GROUPING OF VEGETATION FACTOR (F_2) VALUES (CONTINUED)

Project __Fort Lewis__   Map Sheet(s) __Anderson Island__

Vehicle __M-1 Abrams Tank__

VEGETATION O/L CODES	F_2 VALUE	LOGICAL GROUPING VALUE	ASSIGNED CCM VEGETATION MODEL UNIT
C24, C25, C34, E25	.30	.39	5
C38	.28		
E44	.25		
C44, D44	.24		
C37	.22		
J	.20		
C48	.19		
C36	.18		
C35, E35	.16	.19	
C47, D35, D48	.15		
C46	.14		
E46	.13		
C45	.12		
I	.10		
D45, D46, D47, E45	-0-	-0-	6
W	-0-	-0-	7
X	NE	NE	8

SOURCE: Defense Mapping Agency Hydrographic/Topographic Center, "Defense Mapping Agency Procedural Guide for the Production of the Synthesized Cross-Country Movement Compilation Overlay(s), Scale 1:50,000." (Washington, D.C.:DMAHTC, 1982), pp.42-43. (Photocopied.)

TABLE 4

FACTOR MAP UNITS TABLE

Factor Map Units	Terrain Factor Grouping Model Units				Computed Average CCM Speed(kph)	CCM Map Unit or M-1 Abrams Speed Grouping
	Veg	Slope	Soils	SR		
	CCM in Dry, Moist, and Wet Conditions					
1	8	All	All	All	Built-up Area, CCM Not Evaluated	7
2	7	All	All	All	Open Water, Speed=0	6
3	6	All	All	All	0.0	5
4	All except 8 & 7	6	All	All	0.0	5
5	All except 8 & 7	All	3	All	0.0	5
	CCM in Dry Conditions Only					
6	1	1	1	1	49.79	1
7				2	44.81	1
8				3	29.87	2
9		2	1	1	44.60	1
10				2	40.14	1
11				3	26.76	2
12		3	1	1	36.26	1
13				2	32.63	1
14				3	21.75	2
15		4	1	1	26.14	2
16				2	23.52	2
17				3	15.68	2
18		5	1	1	14.55	3
19				2	13.10	3
20				3	8.73	3
21	2	1	1	1	43.30	1
22				2	38.97	1
23				3	25.98	2
24		2	1	1	38.78	1
25				2	34.91	1
26				3	23.27	2
27		3	1	1	31.53	1
28				2	28.38	2
29				3	18.92	2
30		4	1	1	22.73	2
31				2	20.46	2
32				3	13.64	3
33		5	1	1	12.66	3

TABLE 4

FACTOR MAP UNITS TABLE (CONTINUED)

Factor Map Units	Terrain Factor Grouping Model Units				Computed Average	CCM Map Unit or M-1 Abrams
	Veg	Slope	Soils	SR	CCM Speed(kph)	Speed Grouping

CCM in Dry Conditions Only

Factor Map Units	Veg	Slope	Soils	SR	CCM Speed(kph)	Speed Grouping
34				2	11.39	3
35				3	7.59	3
36	3	1	1	1	32.47	1
37				2	29.22	2
38				3	19.48	2
39		2	1	1	29.09	2
40				2	26.18	2
41				3	17.45	2
42		3	1	1	23.65	2
43				2	21.28	2
44				3	14.19	3
45		4	1	1	17.05	2
46				2	15.34	2
47				3	10.23	3
48		5	1	1	9.49	3
49				2	8.54	3
50				3	5.70	3
51	4	1	1	1	21.11	2
52				2	19.00	2
53				3	12.66	3
54		2	1	1	18.91	2
55				2	17.02	2
56				3	11.34	3
57		3	1	1	15.37	2
58				2	13.83	3
59				3	9.22	3
60		4	1	1	11.08	3
61				2	9.97	3
62				3	6.65	3
63		5	1	1	6.17	3
64				2	5.55	3
65				3	3.70	4
66	5	1	1	1	10.28	3
67				2	9.25	3
68				3	6.17	3
69		2	1	1	9.21	3
70				2	8.29	3
71				3	5.53	3
72		3	1	1	7.49	3

TABLE 4

FACTOR MAP UNITS TABLE (CONTINUED)

Factor Map Units	Veg	Slope	Soils	SR	Computed Average CCM Speed(kph)	CCM Map Unit or M-1 Abrams Speed Grouping
CCM in Dry Conditions Only						
73				2	6.74	3
74				3	4.49	4
75		4	1	1	5.40	3
76				2	4.86	4
77				3	3.24	4
78		5	1	1	3.01	4
79				2	2.71	4
80				3	1.80	4
CCM in Wet Conditions Only						
81	5	1	2	1	2.57	4

SOURCE: Defense Mapping Agency Hydrographic/Topographic Center, "Defense Mapping Agency Procedural Guide for the Production of the Synthesized Cross-Country Movement Compilation Overlay(s), Scale 1:50,000." (Washington, D.C.:DMAHTC, 1982), pp.62-63. (Photocopied.)

TABLE 5

TERRAIN FACTORS GROUPING TABLE

Project **Fort Lewis**   Map Sheet(s) **Anderson Island**

Vehicle **M-1 Abrams Tank**

MODEL UNITS	CODE FROM OVERLAY
1. Vegetation Factors	
1	B1, G1, N
2	B2
3	C13, C16, C17, C18, C23, C33, D23, E43, G2, H
4	C14, C15, C24, C25, C26, C27, C28, C34, C43, D24, D34, E15, E24, E25, E34
5	C33, C35, C36, C37, C38, C44, C45, C46, C47, C48, D35, D44, D48, E35, E44, E45, I, J
6	D45, D46, D47, E45
7	W=Open Water
8	X=Built-up Areas, CCM Not Evaluated
2. Slope (including SIF) Factors	
1	A=0-3%
2	B=3-10%
3	C=10-20%
4	D=20-30%
5	E=30-45%, G=0->45%
6	F=>45%, W=Open Water

TABLE 5

TERRAIN FACTORS GROUPING TABLE (CONTINUED)

Project __Fort Lewis__   Map Sheet(s) __Anderson Island__

Vehicle __M-1 Abrams Tank__

MODEL UNITS	CODE FROM OVERLAY
3. Soil Factors	
1	All soils in dry state, and not evaluated areas
2	03=GM in wet (saturated) state
3	11=OL and 15=PT in wet (saturated) state, W=Open Water
4	
4. Surface Roughness Factors (Microrelief)	
1	1-No SR effect, (1.00)
2	2-Stoney/gravelly, random small hills (0.90)
3	3-Stoney/gravelly, hummocky, man-made features (0.60)
4	

transparent film. Vegetation is printed in green, Surface Configuration in red, and Surface Materials in brown. These three colored overlays are then stacked and punch registered, and are treated as a unit during compilation. Next a sheet of stable-base drafting film is registered on top, and the stack is laid on a light table so the compiler may easily see the red, brown, and green outlines on the overlays.

The compiler must now outline in pencil on the drafting film every unique area formed by the intersection of terrain factors, which produces a unique CCM speed range. Because overlay codes were grouped into model units, not every individual code translates into a unique speed range. The compiler uses the terrain factor grouping table to translate the overlay codes into model units, and uses the FMU table to translate combinations of model units into CCM speed ranges.

It is easiest to map "knockout" areas first--those areas which are automatically no-go or not evaluated, such as open water or urban areas. The next areas to be outlined are dense forests, steep slopes, and wet soils, all areas which effectively stop tanks no matter how favorable the other factors.

The rest of the combinations are mapped using Tables 4 and 5. This proceeds until all areas of the CCM map are filled in with speed range numbers. There may be other factor combinations which generate no-go codes: if these occur adjacent to an identical no-go code the areas are run together. No two adjacent areas may have the

same code; they must be joined. Similarly, all outlined areas must have a code, since blank areas are not allowed. Minimum sizes for each outlined area, at the 1:50,000 scale, are a square 5mm (250m ground distance) on a side, or a rectangle less than 5mm wide and at least 10mm (500m ground distance) long.

The completed pencil copy of the CCM map must be edited for internal and edge match errors. Internal errors include areas without codes and identical codes adjacent to each other. The map must also be checked against the original overlays by the terrain analyst for logical errors, such as an area of maximum speed occurring over a swamp. Once all errors are corrected the map may be converted to final form.

The CCM pencil copy may be scribed on scribecoat or inked on a stable-base inking shell. Depending on the customer's needs the final form of the map may be an inked overlay or a lithographed paper copy reproduced with color screens. For the paper product, the Obstacles and Surface Drainage overlays may be used, their linear features appearing as magenta overprints on the CCM map. When these features are shown, the speed ranges do not include time required to cross or go around them. For a comparison of the two formats of the final CCM map--the inked overlay or the printed paper map--refer again to Figures 5 and 6.

Automated CCM Modeling

The current Digital Terrain Analysis Station project at ETL is a prototype system designed to compile digital terrain factor over-

lays, store overlay data in a format easily accessible by a data base management system, process the data using any of several applications programs, and provide output in hardcopy and digital form. The DTAS was supported by the Department of Defense Electromagnetic Compatibility Analysis Center (ECAC), developer of the software called the Tactical Terrain Information System which performs these functions. One of the applications programs available is the Cross-Country Mobility Model, which utilizes DMA's CCM model equations, excluding slope and slope—intercept frequency factors, in its polygon processing routines. The terrain data used for input are DMA terrain factor overlays, digitized in graphical (vector) format. Terrain attribute values are attached directly to the elements in the graphical files and are easily retrievable and modifiable. The output of the CCM model consists of a combined—polygon file, for use in subsequent mobility modeling, and the display of the mobility map and its legend which conforms to DMA specifications.[9]

The degree of similarity of the DTAS-produced CCM map and DMA's original CCM map will be statistically evaluated by ETL as part of the research and development of DTAS. The final report on this has not yet been released. Further research related to this thesis will be to study the ETL evaluation of the automated CCM map, and compare those results with the results obtained in this study. The major point of interest will be to determine which, if either, data format--raster or vector--is more suitable for CCM modeling.[10]

The IBIS Geographic Information System

The IBIS system was developed out of a growing need at JPL to be able to merge graphical map data and tabular data with remotely-sensed imagery, used extensively by JPL researchers involved in earth-resource monitoring applications. Experience with existing geographic information systems (GIS), with their constraints on interfacing image with map and tabular data, convinced developers Bryant and Zobrist that an _image-based_ information system would provide the solution. Image processing technology would be required, but the advantages of high spatial resolution, independence of scale and data formats, and ease of updating the interfaces between data types were attractive bonuses.

IBIS stores information in raster format, a line-by-sample grid of digital data values where each value corresponds to one pixel in the image.[12] Digital imagery is stored and processed in raster format, so all map data must be converted into raster (image) format before being processed by IBIS. VICAR routines convert the graphical map files to raster by geometrically registering the map (using appropriate tiepoints) to a suitable planimetric base, and converting vector graphics into gridded data of a given array size, thus creating an _image plane._ All maps to be used in a particular project must undergo the same process, and must be registered to the same base, so that the same pixels in each plane represent the same geographic location.

Tabular data may be entered into the IBIS data base via a

logical interface, resulting in <u>interface files.</u> These files are
linked to at least one of the image planes by associating each
pixel's digital value (gray tone) with its corresponding tabular
data. Usually there are regions in the images made up of many
contiguous pixels: the tabular data (e.g., statistics or region
identification codes) would be assigned to all pixels making up each
unique region.[13]

There are four basic data manipulation procedures available in
IBIS. Data manipulation between image planes results in new image
planes through such functions as image addition and subtraction, or
more complex mathematical functions. Data may be manipulated within
an interface file to produce new tabular data to be associated with
the image. For example, population may be divided by area to derive
poulation density of a region. The last two data manipulation
procedures involve transforming image into tabular data, and vice-
versa. The former accomplishes such region identification tasks as
histogramming, which assigns tabular codes to pixel gray values.
Transforming tabular data into image data produces output resulting
from all previous manipulations. New, synthesized maps may be
generated from the tabular data, and such new images may be stored
in the IBIS data base for subsequent operations.[14]

Summary of Relevant Literature

Specifications for producing terrain factor overlays are pub-
lished by two agencies: Defense Mapping Agency and Engineer Topo-
graphic Laboratories. The DMA specifications were discussed under

"Compilation of Terrain Factor Overlays," above; ETL has produced approximately twelve Terrain Analysis Procedural Guides, describing the compilation of various overlays such as Vegetation, Climate, and Roads and Related Structures. These guides are published as ETL reports, and are available from ETL. The process of terrain analysis is described in the Army's Terrain Analysis and Military Geographic Intelligence (Terrain) field manuals, including photointerpretation techniques. Colin Mitchell's Terrain Evaluation includes civilian applications of terrain analysis as well as early military studies on mobility. Douglas Way's Terrain Analysis serves as the authority on civil engineering applications of terrain analysis.[15]

Cross-country movement modeling, or mobility modeling in general, has been investigated by various Army organizations for a number of years. The models on which DMA's are based were first developed by the Army Engineer Waterways Experiment Station at Vicksburg, Mississippi, which has carried out extensive research dealing with terrain effects on mobility. DMA's model was discussed under "The DMA Cross-Country Movement Map" above. Schreier and Lavkulich investigated terrain trafficability in the Canadian North to aid exploration of undeveloped areas in the region.[16]

Development of IBIS was pioneered by Bryant and Zobrist as discussed above. Friedman's 1982 study is the most extensive report describing the implementation of IBIS for mapping applications. Edwards and Batson utilized raster-digitized maps for investigating relative seismic and volcanic activity in the United States; their

report includes several algorithms used in developing their data base. Leberl and Olson describe in detail the process of digitizing maps, converting vector to raster data, and establishing topological relationships among digital data elements, utilizing the SysScan system. Sharpley et al. describe topological data bases in detail, emphasizing the vector-based ODYSSEY GIS.[17] Since this study does not deal with vector-based GIS, the full range of literature on this type of digital mapping was not researched. As might be expected, the references described here represent only a _selection_ of the broad range of literature available on all of these topics.

CHAPTER II FOOTNOTES

1

Defense Mapping Agency Hydrographic/Topographic Center, <u>Defense Mapping Agency Product Specifications for the Hard Copy Tactical Terrain Analysis Data Base (TTADB), Scale 1:50,000</u> (Washington, DC: DMAHTC, 1982), p. 1.

2

Interview with Larry Wright, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA, 17 November 1983.

3

Edwin E. Neel, Jr., Suzanne J. Stultz, and Robert J. Tyszka, "Digital Terrain Analysis Data," <u>Signal</u> 36 (March 1982): 52.

4

A. C. Elser, Memorandum on Prototype Digital Terrain Analysis Data Base (DTADB) Evaluation, 27 July 1983, U.S. Army Engineer Topographic Laboratories, Geographic Sciences Laboratory, Ft. Belvoir, VA, p. 1.

5

Defense Mapping Agency Hydrographic/Topographic Center, "DMA Procedural Guide for the Production of the Synthesized Cross-Country Movement (CCM) Overlay(s), Scale 1:50,000" (Washington, DC: DMAHTC, 1982), p. 10. (Photocopied.)

6

Ibid., pp. 13 and 29.

7

Ibid., p. 10.

8

Ibid., pp. 42, 62, and 66.

9

R. Socher, <u>Tactical Terrain Information System (TTIS) User's Manual</u> (Annapolis, MD: Dept. of Defense Electromagnetic Compatibility Analysis Center, 1982), pp. 1-1 and 3-3.

10

Interview with Larry Wright, U.S. Army Engineer Topographic Laboratories, Ft. Belvoir, VA, 17 November 1983.

11

Nevin A. Bryant and Albert L. Zobrist, "IBIS: A Geographic Information System Based on Digital Image Processing and Image Raster Data Type," <u>Geoscience Electronics</u> 15 (July 1977): 153-158.

12

A pixel, or picture element, is a grid cell corresponding to the intersection of a line (row) and sample (column) within the raster.

13

Albert L. Zobrist, et al., "Image-Based Information System (IBIS) System Guide," Internal Report No. 900-909 (Pasadena, CA: Jet Propulsion Laboratory, California Institute of Technology, [n.d.]), pp. 5-6.

14

Ibid., pp. 8-9.

15

J. A. Messmore et al., Terrain Analysis Procedural Guide For Vegetation, (Ft. Belvoir, VA: U. S. Army Engineer Topographic Laboratories, 1979);   R. J. Frodigh, Terrain Analysis Procedural Guide For Climate, (Ft. Belvoir, VA: U. S. Army Engineer Topographic Laboratories, 1980); T. C. Vogel, Terrain Analysis Procedural Guide for Roads and Related Structures, (Ft. Belvoir, VA: U. S. Army Engineer Topographic Laboratories, 1979); Headquarters, Dept. of the Army, Terrain Analysis, Field Manual 21-33 (Washington, DC: U. S. Government Printing Office, 1978), and Military Geographic Intelligence (Terrain), Field Manual 30-10 (Washington, DC: U. S. Government Printing Office, 1972); Colin W. Mitchell, Terrain Evaluation (London: Longman Group Limited, 1973); and Douglas S. Way, Terrain Analysis, 2nd ed. (New York: Mc Graw-Hill Book Co., 1978).

16

John H. Shamburger and Warren E. Grabau, Mobility Environmental Research Study: A Quantitative Method for Describing Terrain for Ground Mobility, vols. I-VIII, Technical Report No. 3-726 (Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, 1968); Marvin P. Meyer, A Bibliography with Abstracts of U.S. Army Engineer Waterways Experiment Station Publications Related to Vehicle Mobility (Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, 1976); and H. Schreier and L. M. Lavkulich, "A Numerical Approach to Terrain Analysis for Off-Road Trafficability," Photogrammetric Engineering and Remote Sensing 45 (May 1979): 635-642.

17

Steven Z. Friedman, Image-Based Approach to Mapping, Charting, and Geodesy (Pasadena, CA: Jet Propulsion Laboratory, California Institute of Technology, 1982); Kathleen Edwards and R. M. Batson, "Preparation and Presentation of Digital Maps in Raster Format," American Cartographer 7 (1980): 39-49; Franz W. Leberl and Dale Olson, "Raster Scanning for Operational Digitizing of Graphical Data," Photogrammetric Engineering and Remote Sensing 48 (April, 1982): 615-627; and W. K. Sharpley et al., A Unified Approach to Mapping, Charting and Geodesy (MC&G) Data Base Structure Design, (Reading, MA: The Analytic Sciences Corp., 1978).

CHAPTER III

PREPARATION OF THE TEST MAP

Testing the IBIS capabilities for producing a cross-country movement map required converting the Ft. Lewis terrain factor overlays into digital format, associating the map codes with their appropriate speed reduction factors in interface files, programming the CCM model equations, and applying the model to the digital overlays and map information to produce a new, digital CCM map. The original Ft. Lewis CCM map was also digitized for later comparison with the new CCM map using automated techniques. Figure 8 shows the steps involved in preparing the final test map. All overlay digitizing and data processing were carried out within the Image Processing Laboratory at the Jet Propulsion Laboratory in Pasadena, California.

Digitizing the Terrain Factor Overlays

The Vegetation, Soils, Slope, and CCM overlays of the Ft. Lewis terrain analysis study were digitized using a Bendix coordinate digitizer. Using point-mode digitization, the X-Y coordinates of the vector strings comprising the map polygons were recorded on magnetic tape. The northwest, northeast, and southeast corners of each overlay were digitized as tiepoints, which would be used later to register the overlays together as well as to help define the
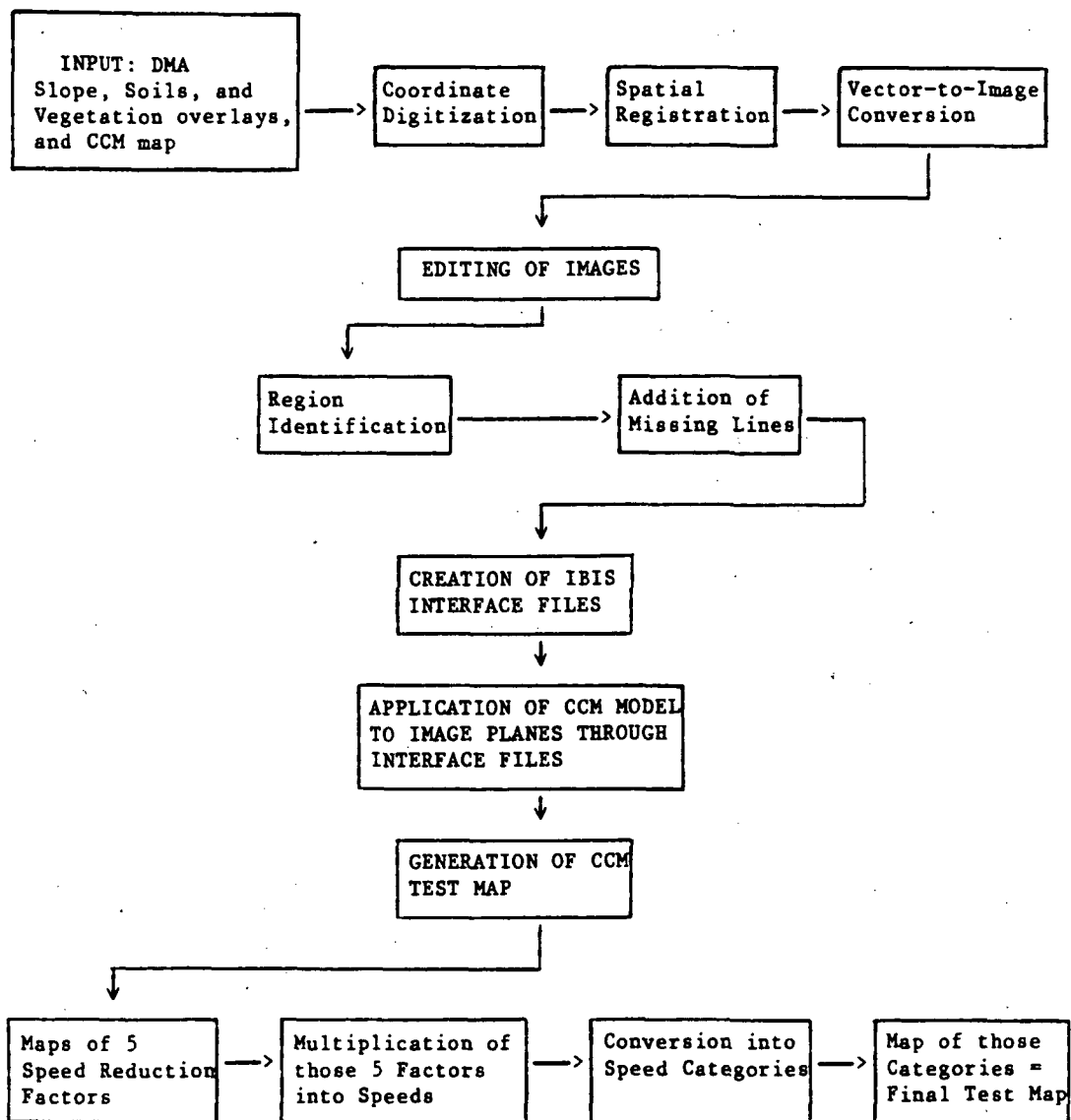
Fig. 8. Preparation of the test map.

numbers of lines and samples in the raster. The coordinate data recorded on the digitizer were then converted into a format readable by VICAR routines, which would perform the vector-to-raster conversions. The VICAR program DIG2 was used to perform this reformatting. Next, the program V2POLY was employed to convert the vector data into IBIS graphics files of 1200-byte blocks.

Performing Spatial Registration and Image Formation

The four overlay data sets were registered together using the digitized corner tiepoints from each overlay. These tiepoints were matched to the desired line-sample coordinates of the image to be created, as shown in Figure 9. The program POLYREG transforms a polygon data set from vector coordinates to line-sample coordinates, correcting for size, rotation, or skew differences between data sets. In this case two POLYREG transformations were performed, since the final output image was to consist of only a subset of the original map area. The program POLYSCRB was employed to transform the polygon vectors generated through V2POLY and POLYREG into an image file of polygon borders, with the desired number of lines and samples. Figure 10 shows the outlines of the polygons on the digitized CCM overlay, in image form.

Calculating numbers of lines and samples. The numbers of lines and samples were calculated to result in a pixel resolution of 15m x 15m on the ground. This value was chosen to match the ground resolution of the minimum line width of a polygon outline on a 1:50,000

Line-Sample coordinates*
of map image

Digitized x,y coordinates*
of tiepoints of data sets

(1,1)   (1,1266.14)

(30838,12930)

(15935,12952)   14.903"

Image Origin

(475.88,161.64)

(475.88,
1266.14)

(1,1) (1,1104.5)
Subset Image
Origin

MAP SUBSET
IMAGE

(1377.12,
1104.50)

(1853,1266.14)

map width

13"

MAP SUBSET
AREA

16.25"

map length

21.851"

Digitizer Origin   (30923,34781)

VECTOR-TO-IMAGE
TRANSFORMATION

*Coordinates are based on 15m
ground resolution per pixel.

*Coordinates are in units of .0001 inch,
and vary slightly between data sets.

Fig. 9. Conversion of digitizer coordinates into line-sample coordinates.

Fig. 10. Polygon outlines of the digitized DMA CCM overlay.
These outlines correspond to the coded regions on the printed CCM
map (see Fig. 6).
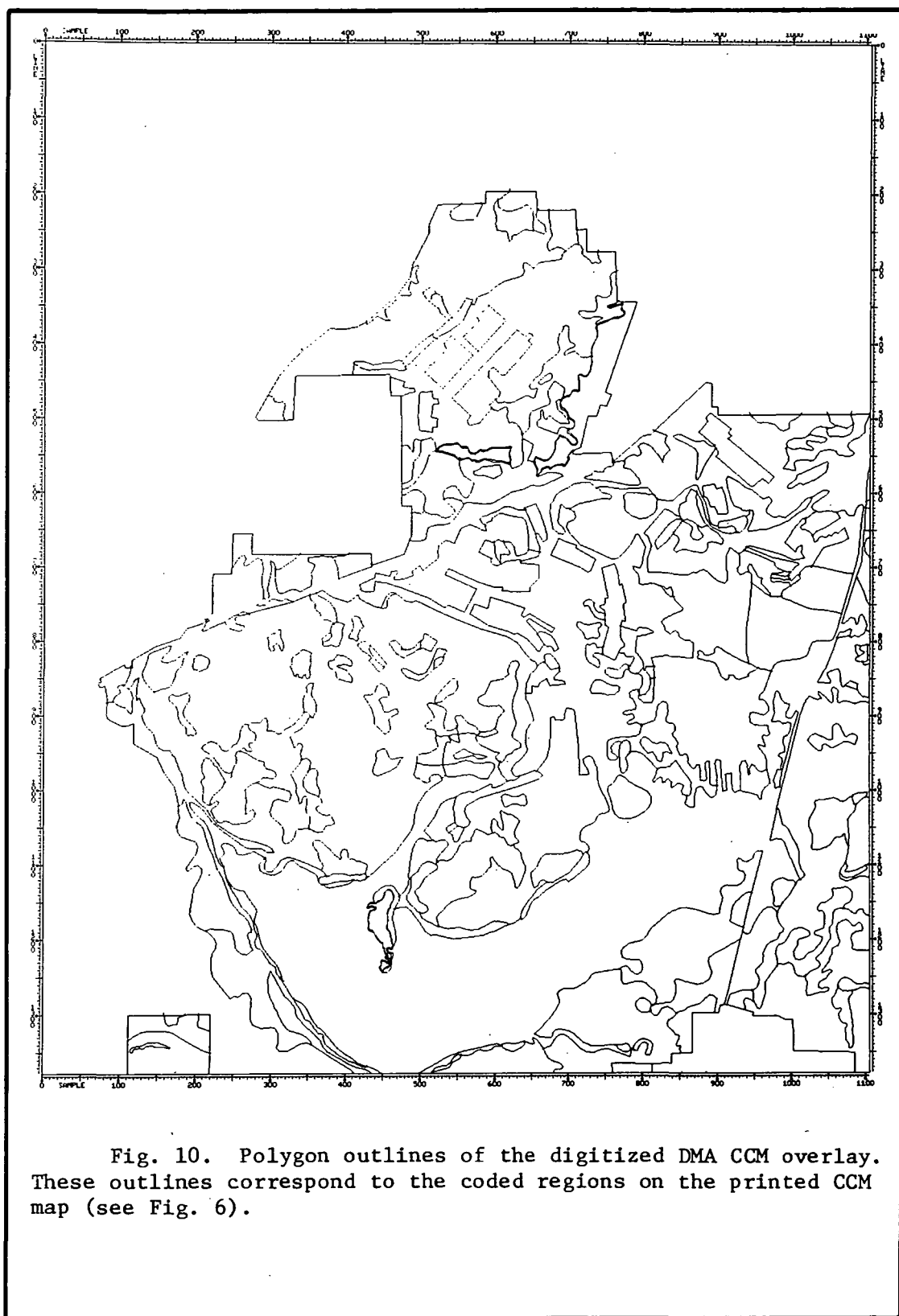
scale map, as defined in the DMA Product Specifications:

Minimum line width = 0.30mm = 15m ground distance

To derive the numbers of lines and samples which would cover
the map subset image at 15m per pixel, the actual geographic ground
distance represented in the mapped subset was determined. Taking
the center coordinate of this subset to be 47° 3' 45" North latitude
by 122° 33' 45" West longitude: one degree of meridian (north-south
direction) is equal to 111,180.200m and one degree of parallel
(east-west direction) equals 75,968.625m.[1] The entire map covers
15' latitude by 15' longitude, or 27,795m north-south by 18,992m
east-west, also equivalent to 21.870 inches by 14.903 inches in map
dimensions (calculated from digitizer coordinates). The desired map
subset area was 16.25 by 13.00 inches, or 20,652m by 16,567m. The
resultant number of lines and samples covering this image area,
maintaining 15m pixel resolution, was:

$$\text{Number of lines} = 20,652m \times \frac{1 \text{ line}}{15 \text{ m}} = 1377 \text{ lines}$$

$$\text{Number of samples} = 16,567m \times \frac{1 \text{ sample}}{15 \text{ m}} = 1105 \text{ samples}$$

The 16.25 by 13.00-inch subset area was chosen to maintain an 8:10
image ratio for the purpose of later obtaining photographic prints
of the images, and to include slightly more of the map than was
actually mapped for CCM.

At this point, all four data sets had been converted to map
images of 1377 lines by 1105 samples, and all four images were in

precise geographic registration. Next, those images were edited for

digitizing errors, after which all the mapped areas were assigned

their proper map code. Generating the IBIS cross-country movement

map from the three appropriate image planes was the final step in

preparation of the test map.

Editing the Digitized Overlays

The overlays, now in image form, were edited for missing or

unconnected lines and "pinched polygons," very narrow polygons which

became divided in two during the vector-to-image conversion rou-

tines. The first step in this editing process is region identifica-

tion, accomplished with a routine called "PAINT." This program

converts the images of polygon borders into images of unique re-

gions, whose pixels are identified by darkness values called "DN

values," ranging from DN=0 (black) to DN=255 (white).[2] The first DN

value is assigned to the upper left-most region, and the rest of the

DN values are assigned in ascending order proceeding right and

downward across the image. Figure 11 shows the PAINT image created

from the digitized CCM overlay. Since DN values increase from a

value of 0 in the upper-left to maximum value for the lower-right

polygon, the PAINT images are typically dark at the top and light at

the bottom. Once these regions are assigned unique DN values the

image may be displayed on a display processor, and each polygon

highlighted individually according to its DN value. Comparing the

screen image with the original hardcopy map, any missing or pinched

polygons or improperly digitized lines may be identified. In this

Fig. 11. PAINT image of CCM overlay. The unmapped back-
ground appears white. Mapped polygons are assigned region numbers
(DN values) ranging from 0 (black) at upper left to 231 (nearly
white) at the lower right. The PAINT region numbers are the
keys to the IBIS interface files.
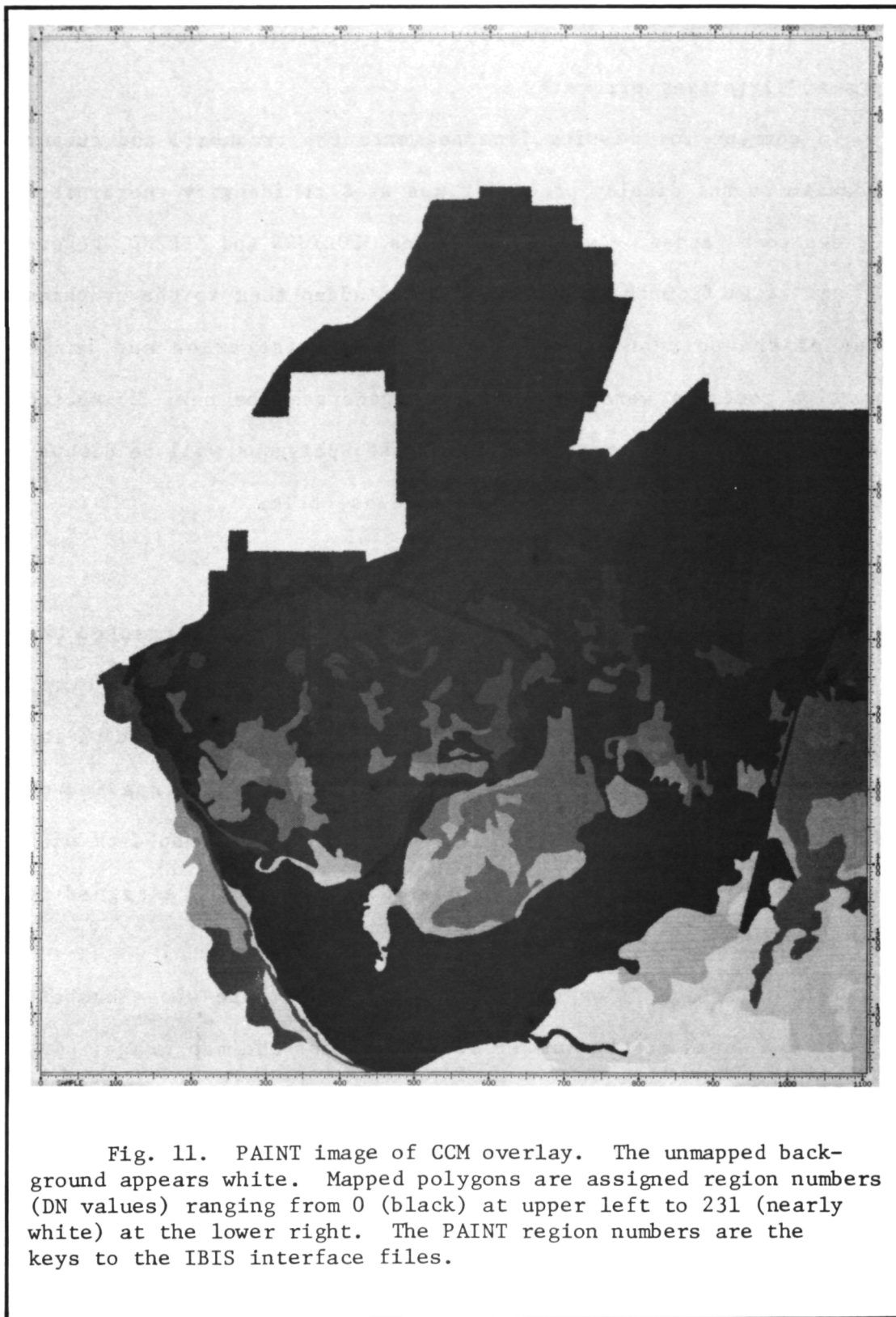
study, three of the four overlays contained one or more of these types of digitizing errors.

To correct for missing line segments the trackball and cursor mechanism on the display processor was used to identify coordinates of lines to be added. Two IBIS routines, POLYGEN and APPEND, generated new lines from these coordinates and added them to the graphics files of the polygon outlines. Spatial registration and image formation routines were then rerun to generate the new, corrected images. The method for correcting pinched polygons will be discussed under the topic of IBIS interface files, below.

Generating IBIS Interface Files

After the overlay image planes were edited and corrected the resulting images contained polygons with DN values only. No map codes or CCM speed-reduction factors had yet been assigned to the polygons. Assigning the codes was performed through creation of IBIS interface files, which associate various types of map data with their proper polygons via the unique DN value already assigned to each polygon.

IBIS interface files consist of columns of data whose numbers of rows are equal to the number of polygons on the map image. Any type of thematic or tabular data may be assigned to polygons by entering these data in up to 50 columns. The data value in each row corresponds to its associated polygon. These columns may also be manipulated mathematically to produce new columns of data. In this manner the CCM model was applied to soils, slope, and vegetation

data in their respective interface files, generating speed-reduction factors as new columns in each file.

Setting up the interface files. The program IGENER was run to generate the interface files of DN values, map codes, and their CCM-related data values. Within this program data values or map codes are entered as columns in the file corresponding to their appropriate DN values (map regions). For example, the Slope map codes were entered in the Slope interface file by keying in pairs of DN numbers with their respective map codes, for all 75 mapped Slope regions.

Interface files may be merged together. This allows all data values to be entered in a separate, short file and later merged with their appropriate map codes in the master interface file. For instance, slope data (percent slope) associated with the Slope map codes were entered in a file only 8 rows long, since there are only 8 unique slope codes on the map. These 8 values were later merged with the 75-row long master interface file, so that every mapped region was assigned its proper slope data value.

Some data values must be generated by mathematical operations performed on the various columns. Columns may be manipulated mathematically through use of the MF program, which allows the user to create FORTRAN-like mathematical and logical expressions to combine columns and generate new ones. In this way the five CCM factor values were generated according to the five CCM model equations. For example, the Slope factor value, F1, is calculated according to

the equation:

$$F_1 = \frac{MOG - GS}{MG - RS} \tag{2}$$

where MOG = Maximum Off-Road Gradeability, GS = Ground Slope, MG = Maximum Road Gradeability, and RS = Maximum Road Speed (refer again to Figure 7). The value of Fl is derived by performing the required mathematical operations between the columns of the interface file containing the required data. The Fl values are then stored in a new column in the master interface file. (See below for a detailed discussion of the building of the individual interface files.)

Assigning map codes to polygons. The first step for each image plane was to make a list of DN values of polygons and the map code each DN represents. This was accomplished using the display processor, highlighting each polygon in DN order and manually listing the map code for each DN. As an additional aid, a photographic copy of each PAINT image was made, and the DN numbers written on the photographs. The numbers of mapped regions in each image plane, and thus polygons with DN numbers, were as follows: Slope=75; Soils=71; Vegetation=320; and CCM=231.

Next, the IGENER program was used to match map codes to polygons. A column number was specified into which all the map codes were entered from the manually compiled list, in ascending DN number order. The number of map codes for each image plane was, of course, equal to the number of polygons in each image. The DN numbers also had to be entered into a column, since these data are used as keys

for all subsequent mathematical operations between columns in the interface files. An indexing routine automatically entered sequential numbers into a specified column, eliminating the need for manually keying in the DN numbers. Pinched polygons were corrected in this step by encoding each separate piece of a split-up polygon with the proper map code for the whole polygon. This ensured that the proper CCM data would be assigned to those regions.

Applying the CCM Model

In addition to the map codes, numerical and textual data relevant to CCM calculations had to be entered in the interface files as well. Figures 2 through 5 show the map legends for each overlay and the CCM data values associated with each map code. Data such as vegetation roughness, stem spacing and diameter, slope percentages, surface roughness, soil rating cone index, and vehicle cone index were entered in short, temporary files according to their map code; these files were later merged with the master files by matching map codes in the two files and transferring the appropriate data to new columns in the master files. The resulting interface files contained map codes and all CCM-related data for each map code, all in DN-number order.

Three interface files were built, within which the five CCM speed factors were calculated. A fourth file listed the DMA CCM map codes with their respective region numbers. The four files included Slope, Vegetation, Soils, and CCM data, shown in Tables 6 through 9. These files implemented the equations shown in Figure 7, Gener-

al Case CCM Model: Factors For Speed Adjustment. Note that the Fl values in the Slope file are the resulting CCM speeds after the effects of ground slope are taken into account, in kilometers per hour (kph). These speeds were later multiplied by the four speed-reducing factors, namely: vegetation, soils, surface roughness, and slope intercept frequency. These four factors are values in percent and reflect the _percentage_ of maximum possible speed at which the vehicle may move after the effects of each particular terrain factor are taken into account. Note that no grouping of data values is needed to reduce calculations, as in the manual method of CCM map compilation.

Slope interface file. The Slope interface file (Table 6) implemented the equations contained in the Slope and Slope Intercept Frequency modules in Figure 7. The Slope equation calculates the maximum speed a vehicle may attain given the effects of percent ground slope as measured from the contour lines on a topographic map. For the Fl (Slope) calculations the values for maximum off-road and road gradeabilities and maximum road speed for the vehicle of interest (in this case, the M1 Abrams tank) were obtained from Table 1, Personnel, Animal, and Vehicle Characteristics and Terrain Clearances for CCM Calculations.[3] Ground slope values were obtained from the map legend itself, and the midpoints of those slope ranges were stored in column 3. The MF program performed the necessary arithmetic and stored the resulting Fl values in column 5 in the interface file.

57

TABLE 6

SLOPE INTERFACE FILE

C1	C2	C3	C4	C5	C6	C7
1.		0.0	0.00	0.00	0.	0.
2.	A	1.5	1.00	54.12	100.	54.
3.	B	6.5	0.99	48.97	99.	49.
4.	C	15.0	0.98	40.21	98.	40.
5.	D	25.0	0.95	29.90	95.	30.
6.	A	1.5	1.00	54.12	100.	54.
7.	A	1.5	1.00	54.12	100.	54.
8.	D	25.0	0.95	29.90	95.	30.
9.	C	15.0	0.98	40.21	98.	40.
10.	A	1.5	1.00	54.12	100.	54.
11.	D	25.0	0.95	29.90	95.	30.
12.	E	37.5	0.93	17.01	93.	17.
13.	B	6.5	0.99	48.97	99.	49.
14.	W	54.0	1.00	0.00	100.	0.
15.	D	25.0	0.95	29.90	95.	30.
16.	C	15.0	0.98	40.21	98.	40.
17.	E	37.5	0.93	17.01	93.	17.
18.	D	25.0	0.95	29.90	95.	30.
19.	C	15.0	0.98	40.21	98.	40.
20.	W	54.0	1.00	0.00	100.	0.
21.	C	15.0	0.98	40.21	98.	40.
22.	C	15.0	0.98	40.21	98.	40.
23.	B	6.5	0.99	48.97	99.	49.
24.	B	6.5	0.99	48.97	99.	49.
25.	C	15.0	0.98	40.21	98.	40.
26.	B	6.5	0.99	48.97	99.	49.
27.	B	6.5	0.99	48.97	99.	49.
28.	C	15.0	0.98	40.21	98.	40.
29.	B	6.5	0.99	48.97	99.	49.
30.	C	15.0	0.98	40.21	98.	40.

C1 = PAINT number

C2 = Slope map code

C3 = % ground slope

C4 = F5 values (Slope Intercept Frequency)

C5 = F1 values (Slope module factors)

C6 = F5 values converted to integers ranging 0-100%

C7 = F1 values converted to integers ranging 0-54 kph

TABLE 6 (continued)

SLOPE INTERFACE FILE

C1	C2	C3	C4	C5	C6	C7
31.	C	15.0	0.98	40.21	98.	40.
32.	D	25.0	0.95	29.90	95.	30.
33.	D	25.0	0.95	29.90	95.	30.
34.	C	15.0	0.98	40.21	98.	40.
35.	A	1.5	1.00	54.12	100.	54.
36.	D	25.0	0.95	29.90	95.	30.
37.	B	6.5	0.99	48.97	99.	49.
38.	C	15.0	0.98	40.21	98.	40.
39.	B	6.5	0.99	48.97	99.	49.
40.	B	6.5	0.99	48.97	99.	49.
41.	C	15.0	0.98	40.21	98.	40.
42.	E	37.5	0.93	17.01	93.	17.
43.	B	6.5	0.99	48.97	99.	49.
44.	B	6.5	0.99	48.97	99.	49.
45.	D	25.0	0.95	29.90	95.	30.
46.	B	6.5	0.99	48.97	99.	49.
47.	C	15.0	0.98	40.21	98.	40.
48.	B	6.5	0.99	48.97	99.	49.
49.	B	6.5	0.99	48.97	99.	49.
50.	D	25.0	0.95	29.90	95.	30.
51.	B	6.5	0.99	48.97	99.	49.
52.	C	15.0	0.98	40.21	98.	40.
53.	D	25.0	0.95	29.90	95.	30.
54.	D	25.0	0.95	29.90	95.	30.
55.	B	6.5	0.99	48.97	99.	49.
56.	C	15.0	0.98	40.21	98.	40.
57.	C	15.0	0.98	40.21	98.	40.
58.	W	54.0	1.00	0.00	100.	0.
59.	D	25.0	0.95	29.90	95.	30.
60.		0.0	0.00	0.00	0.	0.
61.	B	6.5	0.99	48.97	99.	49.
62.	A	1.5	1.00	54.12	100.	54.
63.	B	6.5	0.99	48.97	99.	49.
64.	C	15.0	0.98	40.21	98.	40.
65.	D	25.0	0.95	29.90	95.	30.
66.	E	37.5	0.93	17.01	93.	17.
67.	C	15.0	0.98	40.21	98.	40.
68.	B	6.5	0.99	48.97	99.	49.
69.	B	6.5	0.99	48.97	99.	49.
70.	B	6.5	0.99	48.97	99.	49.
71.	D	25.0	0.95	29.90	95.	30.
72.	E	37.5	0.93	17.01	93.	17.
73.	B	6.5	0.99	48.97	99.	49.
74.	B	6.5	0.99	48.97	99.	49.
75.	A	1.5	1.00	54.12	100.	54.

The Slope Intercept Frequency (SIF) values represent the number of times the ground slope changes from positive to negative over a one kilometer distance. These values were stored as F5 values in column 4 of the Slope interface file. The F5 equations appearing in Figure 7 show how SIF is calculated from contour lines on a topographic map. For purposes of this thesis these values were taken directly from the CCM Procedural Guide table on CCM Slope Intercept Frequency Values For The Fort Lewis Overlays.[4]

Columns 6 and 7 of the Slope file represent the integer values of columns 4 and 5, with SIF values multiplied by 100 to give values between 0 and 100. These values were stored this way so that they could later be mapped digitally, which would require integer data values ranging from 0 to 255 in byte format. Columns 1 and 2 contain the PAINT region numbers and map codes to which all other data were matched during the MF calculations.

Vegetation interface file. The Vegetation interface file (Table 7) shows the results of calculating the equations in the Vegetation module of Figure 7. As can be seen in Figure 7, there are several properties of vegetation which affect cross-country movement. The vegetation roughness factor (VRF) accounts for slowing of vehicles by vegetation characteristics other than tree stems; e.g., plowed fields, slippery grass, and bushy undergrowth. The vegetation maneuverability factor (VM) reflects how well the vehicle can maneuver between trees. If the opening between trees (stem spacing less stem diameter) is less than the vehicle width (3.65m for the M1

TABLE 7

VEGETATION INTERFACE FILE (COMPRESSED)

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	0.00	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
B1	0.90	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.90	90.
B2	0.80	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.00	0.80	80.
C13	0.40	0.134	8.5	2.29	0.46	0.45	0.00	0.00	0.29	0.00	0.00	0.71	0.29	29.
C14	0.40	0.198	10.2	2.74	0.55	0.38	0.00	0.22	0.00	0.00	0.00	0.37	0.22	22.
C15	0.40	0.275	11.0	2.94	0.59	0.36	0.00	0.24	0.00	0.00	0.00	-0.21	0.24	24.
C16	0.40	0.363	12.0	3.19	0.64	0.33	0.00	0.26	0.00	0.00	0.00	-1.11	0.26	26.
C17	0.40	0.475	13.0	3.43	0.69	0.32	0.00	0.27	0.00	0.00	0.00	-2.61	0.27	27.
C23	0.30	0.124	5.0	1.34	0.27	0.75	0.00	0.00	0.23	0.00	0.00	0.75	0.23	23.
C24	0.30	0.188	6.8	1.81	0.36	0.56	0.00	0.00	0.13	0.00	0.00	0.43	0.13	13.
C25	0.30	0.260	8.0	2.12	0.42	0.49	0.00	0.13	0.00	0.00	0.00	-0.08	0.13	13.
C26	0.30	0.348	8.5	2.23	0.45	0.47	0.00	0.13	0.00	0.00	0.00	-0.94	0.13	13.
C28	0.30	0.579	10.8	2.80	0.56	0.39	0.00	0.17	0.00	0.00	0.00	-4.36	0.17	17.
C33	0.30	0.114	3.2	0.85	0.17	1.18	0.76	0.00	0.23	0.00	0.00	0.00	0.23	23.
C34	0.20	0.178	4.2	1.10	0.22	0.91	0.00	0.00	0.10	0.00	0.00	0.49	0.10	10.
C35	0.20	0.246	5.2	1.36	0.27	0.75	0.00	0.05	0.00	0.00	0.00	0.03	0.05	5.
C36	0.20	0.333	5.8	1.50	0.30	0.69	0.00	0.06	0.00	0.00	0.00	-0.77	0.06	6.
C37	0.20	0.445	7.0	1.80	0.36	0.59	0.00	0.07	0.00	0.00	0.00	-2.17	0.07	7.
C38	0.20	0.559	7.8	1.98	0.40	0.54	0.00	0.08	0.00	0.00	0.00	-4.00	0.08	8.
C44	0.20	0.178	3.2	0.83	0.17	1.20	0.39	0.00	0.08	0.00	0.00	0.00	0.08	8.
C45	0.20	0.246	4.0	1.03	0.21	0.97	0.00	0.04	0.00	0.00	0.00	0.03	0.04	4.
C46	0.20	0.333	4.5	1.14	0.23	0.89	0.00	0.05	0.00	0.00	0.00	-0.77	0.05	5.
C47	0.20	0.445	5.0	1.25	0.25	0.82	0.00	0.05	0.00	0.00	0.00	-2.17	0.05	5.
C48	0.20	0.559	5.5	1.35	0.27	0.77	0.00	0.05	0.00	0.00	0.00	-4.00	0.05	5.
D23	0.60	0.100	4.5	1.21	0.24	0.83	0.00	0.00	0.50	0.00	0.00	0.84	0.50	50.
D24	0.60	0.175	6.0	1.60	0.32	0.64	0.00	0.00	0.31	0.00	0.00	0.51	0.31	31.
D25	0.60	0.275	7.0	1.84	0.37	0.56	0.00	0.22	0.00	0.00	0.00	-0.21	0.22	22.
D34	0.50	0.164	3.5	0.91	0.18	1.09	0.53	0.00	0.27	0.00	0.00	0.00	0.27	27.
D35	0.50	0.262	4.2	1.08	0.22	0.93	0.00	0.11	0.00	0.00	0.00	-0.10	0.11	11.
D43	0.50	0.091	2.0	0.52	0.10	1.87	0.75	0.00	0.38	0.00	0.00	0.00	0.38	38.
D44	0.50	0.164	2.5	0.64	0.13	1.53	0.34	0.00	0.17	0.00	0.00	0.00	0.17	17.
D45	0.50	0.262	3.0	0.75	0.15	1.30	-0.43	0.08	0.00	0.00	0.00	0.00	0.08	8.
D46	0.50	0.358	3.5	0.86	0.17	1.15	-1.35	0.09	0.00	0.00	0.00	0.00	0.09	9.
D47	0.50	0.495	4.0	0.96	0.19	1.04	-3.06	0.10	0.00	0.00	0.00	0.00	0.10	10.
D48	0.50	0.640	4.5	1.06	0.21	0.95	0.00	0.11	0.00	0.00	0.00	-5.55	0.11	11.
E15	0.50	0.275	10.5	2.80	0.56	0.37	0.00	0.28	0.00	0.00	0.00	-0.21	0.28	28.
E24	0.45	0.182	6.4	1.70	0.34	0.60	0.00	0.00	0.21	0.00	0.00	0.47	0.21	21.
E25	0.45	0.268	7.5	1.98	0.40	0.52	0.00	0.18	0.00	0.00	0.00	-0.15	0.18	18.
E26	0.45	0.359	8.0	2.09	0.42	0.50	0.00	0.19	0.00	0.00	0.00	-1.06	0.19	19.
E34	0.30	0.171	3.9	1.02	0.20	0.98	0.00	0.00	0.16	0.00	0.00	0.53	0.16	16.
E35	0.30	0.254	4.8	1.25	0.25	0.81	0.00	0.07	0.00	0.00	0.00	-0.03	0.07	7.
E43	0.40	0.103	2.3	0.60	0.12	1.63	0.72	0.00	0.29	0.00	0.00	0.00	0.29	29.
E44	0.30	0.171	2.9	0.75	0.15	1.32	0.38	0.00	0.12	0.00	0.00	0.00	0.12	12.
E45	0.30	0.254	3.5	0.89	0.18	1.12	-0.15	0.05	0.00	0.00	0.00	0.00	0.05	5.
E46	0.30	0.346	4.0	1.00	0.20	1.00	0.00	0.06	0.00	0.00	0.00	-0.92	0.06	6.
G1	0.90	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	0.00	0.90	90.
G2	0.70	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.70	70.
H	0.30	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.30	30.
J	0.20	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.20	20.
N	0.95	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95	0.00	0.95	95.
W	0.00	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.
X	0.00	0.000	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.

TABLE 7

VEGETATION INTERFACE FILE (COMPRESSED)

<u>LEGEND</u>

C1 = Vegetation map code

C2 = Vegetation roughness factor (VRF)

C3 = Stem diameter (SD)

C4 = Stem spacing (SS)

C5 = Vegetation clearance factor (VC)

C6 = Vegetation maneuverability factor (VM)

C7 = Minimum number of trees vehicle can hit at one time (VT)

C8 = Vegetation override factor (VO) where $VT \geq 1.0$

C9 = F2 values (Vegetation module factors) where $VM > VO$

C10 = F2 values where $VO > VM$

C11 = F2 values where $VM = VO$

C12 = F2 values if no trees are present (equals VRF)

C13 = VO where $VT < 1.0$

C14 = Sum of C9 through C12: equals final computed F2 value
      as a percentage 0.0 - 1.0

C15 = F2 values from C14 converted to integers ranging 0-100%

Abrams tank), the vehicle cannot move between the trees (VM=0) and must override the trees if it is to move forward at all. The vegetation override factor (VO) calculates the ability of the vehicle to move forward after it has knocked down the trees in its path. If the vehicle cannot move between the trees (VM $\leq$ 0) it must override them; if it cannot knock them down (VO $\leq$ 0) it must move between them. If it can do neither (both VM and VO $\leq$ 0) the vegetation speed factor (F2) is set equal to 0: in this case, the vegetation of the area effectively precludes any cross-country movement.

The complexity of the Vegetation interface file reflects the many conditions imposed in the vegetation module of the CCM model. The entire file contains 320 regions, too large to include here. The file has been compressed, instead, to show relevant data for each of the 52 Vegetation map codes. Column 1 contains the map codes of all the polygons in the Vegetation image. Columns 2, 3, and 4 contain the vegetation roughness factor (VRF), stem diameter (SD), and stem spacing (SS) associated with each map code. Columns 5 and 6 calculate the data needed for determining whether the M1 Abrams tank can move between the trees (VM). If column 5 (vegetation clearance factor) is less than 0, the tank cannot move between trees; it must be able to override them in order to move. Columns 7, 8, and 13 calculate this override ability (VO) subject to the conditions listed in Figure 7. Column 7 calculates VT, or the minimum number of trees the tank can hit at one time. Column 13 shows VO results where VT is less than 1.0; column 8 shows VO where

VT is greater than or equal to 1.0. Any negative VO values indicate the tank cannot override the trees. Columns 9 through 12 represent different calculations of F2 (vegetation factor) values based on the greater of the VM or VO values, and whether there are trees present or not. These columns are mutually exclusive: conditions generating data values in one column generate zeroes in the other columns, so that only one of the four columns contains an F2 value for that map code. These columns are summed up in column 14, the final F2 value for each map code. Column 15 converts these percentages into values between 1 and 100, used in generating a map of the final F2 values.

In programming the equations for calculating the Vegetation F2 values the author followed several examples provided in the DMA Procedural Guide. During this process it was noted that the DMA F2 results listed in the table, "CCM Vegetation Module Factor (F2) Values for the M1 Abrams Tank at Fort Lewis" in the Guide differed from results obtained by the author following the same calculation steps. Later discrepancies between the IBIS-generated CCM map and the DMA map may perhaps be explained by these differences in F2 values. This problem will be analyzed in full in Chapter IV.

Soils interface file. The Soils interface file (Table 8) calculated both F3 (soils module) and F4 (surface roughness) values as shown in Figure 7. The soil module factors depend on several variables. The rating cone index represents the supportive strength of a particular soil type under dry, moist, or wet conditions. Some

TABLE 8

SOILS INTERFACE FILE

C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13
1.	0	0	0.	0.	0.	0.0	-0.75	0.00	-0.75	0.	0.00	0.
2.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
3.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
4.	3	3	0.	120.	32.	0.6	3.00	0.00	3.00	60.	1.00	100.
5.	99	9	1.	0.	0.	0.0	0.00	-0.75	-0.75	0.	0.00	0.
6.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
7.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
8.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
9.	99	9	1.	0.	0.	0.0	0.00	-0.75	-0.75	0.	0.00	0.
10.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
11.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
12.	99	9	1.	0.	0.	0.0	0.00	-0.75	-0.75	0.	0.00	0.
13.	15	1	1.	106.	0.	1.0	0.00	-0.75	-0.75	100.	0.00	0.
14.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
15.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
16.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
17.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
18.	7	2	0.	119.	25.	0.9	2.97	0.00	2.97	90.	1.00	100.
19.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
20.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
21.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
22.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
23.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
24.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
25.	3	3	0.	120.	32.	0.6	3.00	0.00	3.00	60.	1.00	100.

C1 = PAINT number
C2 and C3 = Soils map code
C4 = Wet (1) or dry (0) soil indicator
C5 = RCI (dry) values
C6 = RCI (wet) values
C7 = F4 values (surface roughness factors)
C8 = F3 values for dry soils
C9 = F3 values for wet soils
C10 = Final F3 value (sum of C8 + C9)
C11 = F4 values converted to integers ranging 0-100%
C12 = F3 values from C10 converted to integers ranging 0.00 - 1.00
C13 = Final F3 mappable values, ranging 0-100%

TABLE 8 (continued)   65

SOILS INTERFACE FILE

C 1	C 2	C 3	C 4	C 5	C 6	C 7	C 8	C 9	C 10	C 11	C 12	C 13
26.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
27.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
28.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
29.	10	1	0.	123.	40.	1.0	3.09	0.00	3.09	100.	1.00	100.
30.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
31.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
32.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
33.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
34.	9	2	0.	118.	20.	0.9	2.94	0.00	2.94	90.	1.00	100.
35.	7	2	0.	119.	25.	0.9	2.97	0.00	2.97	90.	1.00	100.
36.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
37.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
38.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
39.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
40.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
41.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
42.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
43.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
44.	7	2	0.	119.	25.	0.9	2.97	0.00	2.97	90.	1.00	100.
45.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
46.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
47.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
48.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
49.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
50.	7	2	0.	119.	25.	0.9	2.97	0.00	2.97	90.	1.00	100.
51.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
52.	11	1	1.	111.	3.	1.0	0.00	-0.66	-0.66	100.	0.00	0.
53.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
54.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
55.	9	1	0.	118.	20.	1.0	2.94	0.00	2.94	100.	1.00	100.
56.	9	2	0.	118.	20.	0.9	2.94	0.00	2.94	90.	1.00	100.
57.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
58.	3	1	1.	120.	32.	1.0	0.00	0.25	0.25	100.	0.25	25.
59.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
60.	3	1	1.	120.	32.	1.0	0.00	0.25	0.25	100.	0.25	25.
61.	3	3	0.	120.	32.	0.6	3.00	0.00	3.00	60.	1.00	100.
62.	99	9	1.	0.	0.	0.0	0.00	-0.75	-0.75	0.	0.00	0.
63.	3	2	0.	120.	32.	0.9	3.00	0.00	3.00	90.	1.00	100.
64.	3	1	1.	120.	32.	1.0	0.00	0.25	0.25	100.	0.25	25.
65.	7	2	0.	119.	25.	0.9	2.97	0.00	2.97	90.	1.00	100.
66.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
67.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
68.	3	1	1.	120.	32.	1.0	0.00	0.25	0.25	100.	0.25	25.
69.	0	0	0.	0.	0.	0.0	-0.75	0.00	-0.75	0.	0.00	0.
70.	7	1	0.	119.	25.	1.0	2.97	0.00	2.97	100.	1.00	100.
71.	3	3	0.	120.	32.	0.6	3.00	0.00	3.00	60.	1.00	100.

soils, dry sands in particular, may increase in strength when partially wet but lose strength as they approach saturation. The RCI values for various soil types are listed in Table 2 in Chapter II. The RCI values for the Fort Lewis soils were stored in columns 5 (RCI-dry) and 6 (RCI-wet) of the Soils interface file. The vehicle cone index (VCI) for one and fifty passes represents the effects of vehicle compaction of the soil after one pass and fifty passes, respectively. The VCI values are listed in Table 1. Since these values are constant per vehicle they were inserted into the F3 equation as constants rather than storing them in the file.

Surface roughness (F4) values may be calculated using the equation in Figure 7 or may be estimated by the soils analyst for the various categories of surface materials appearing on the map. The latter was the case for the Fort Lewis study, so the F4 values were simply taken from the Soils overlay legend. They were stored in column 7 of the interface file, having been matched with the map codes for surface roughness listed in column 3.

Column 1 lists the PAINT region numbers for the 71 regions on the Soils overlay. Columns 2 and 3 hold the map code for the soil occurring in each region, and column 4 indicates whether the soil is a wet soil (1) or dry (0). Columns 8 and 9 resulted from calculating F3 for the dry soil and wet soil cases, respectively, and are mutually exclusive: if the soil is dry, column 8 will hold the F3 value while column 9 will equal 0, and vice-versa. Column 10 sums columns 8 and 9, resulting in the final F3 value for that soil.

Column 11 shows F4 values converted to mappable percentages between 0 and 100. Column 12 involved checking F3 values in column 10 to convert values greater than 1 to 1.00 and values less than 0 to 0.00, since F3 must be a value between 0 and 1. Column 13 shows mappable F3 values as percentages ranging from 0 to 100.

CCM interface file. This file was the simplest to generate because the speed codes had already been calculated. As Table 9 shows, the file simply contains the PAINT numbers of each map region on the DMA CCM map and the speed code ranging from 1 to 7, associated with each region. (The unmapped background region #1 was coded 0, to be later dropped from interface file calculations.)[5] This image and interface file act as the controls to which the IBIS data were later compared.

At this point all five CCM speed-factor values had been calculated, ready for input into equation 1, the CCM speed calculation described in Chapter II. The five speed factors were multiplied together as five images, yielding a "product image" of raw CCM speeds. Various classification routines were applied to these speeds within the product image and within interface files to generate regions of the seven possible CCM codes as shown on the DMA map. Comparison of data within those interface files comprised the final testing of the DMA and IBIS maps.

TABLE 9

CCM INTERFACE FILE

DMA Region	DMA Code	DMA Region	DMA Code	DMA Region	DMA Code	DMA Region	DMA Code	DMA Region	DMA Code
1.	0.	51.	3.	101.	5.	151.	2.	201.	2.
2.	4.	52.	3.	102.	7.	152.	4.	202.	1.
3.	3.	53.	7.	103.	4.	153.	2.	203.	2.
4.	2.	54.	3.	104.	2.	154.	1.	204.	4.
5.	2.	55.	7.	105.	2.	155.	3.	205.	4.
6.	3.	56.	3.	106.	2.	156.	3.	206.	2.
7.	4.	57.	4.	107.	1.	157.	2.	207.	3.
8.	2.	58.	7.	108.	2.	158.	3.	208.	3.
9.	5.	59.	7.	109.	3.	159.	1.	209.	3.
10.	4.	60.	4.	110.	4.	160.	4.	210.	6.
11.	2.	61.	2.	111.	3.	161.	4.	211.	1.
12.	3.	62.	3.	112.	2.	162.	2.	212.	4.
13.	5.	63.	3.	113.	4.	163.	3.	213.	2.
14.	6.	64.	7.	114.	3.	164.	1.	214.	3.
15.	7.	65.	4.	115.	3.	165.	3.	215.	3.
16.	4.	66.	4.	116.	3.	166.	1.	216.	4.
17.	4.	67.	7.	117.	2.	167.	1.	217.	4.
18.	4.	68.	3.	118.	3.	168.	4.	218.	4.
19.	7.	69.	5.	119.	2.	169.	3.	219.	0.
20.	3.	70.	3.	120.	4.	170.	3.	220.	2.
21.	7.	71.	4.	121.	3.	171.	3.	221.	4.
22.	5.	72.	7.	122.	5.	172.	3.	222.	4.
23.	5.	73.	1.	123.	3.	173.	4.	223.	4.
24.	3.	74.	2.	124.	5.	174.	2.	224.	4.
25.	7.	75.	5.	125.	1.	175.	2.	225.	2.
26.	2.	76.	1.	126.	2.	176.	3.	226.	5.
27.	7.	77.	4.	127.	3.	177.	5.	227.	1.
28.	3.	78.	4.	128.	3.	178.	4.	228.	1.
29.	4.	79.	3.	129.	4.	179.	3.	229.	3.
30.	4.	80.	5.	130.	2.	180.	2.	230.	5.
31.	4.	81.	7.	131.	1.	181.	2.	231.	4.
32.	7.	82.	1.	132.	2.	182.	1.		
33.	3.	83.	2.	133.	3.	183.	3.		
34.	4.	84.	4.	134.	7.	184.	1.		
35.	5.	85.	4.	135.	3.	185.	2.		
36.	4.	86.	2.	136.	3.	186.	3.		
37.	7.	87.	3.	137.	1.	187.	4.		
38.	3.	88.	1.	138.	3.	188.	1.		
39.	3.	89.	4.	139.	5.	189.	1.		
40.	4.	90.	7.	140.	5.	190.	4.		
41.	3.	91.	1.	141.	2.	191.	1.		
42.	4.	92.	4.	142.	4.	192.	2.		
43.	3.	93.	3.	143.	3.	193.	3.		
44.	2.	94.	4.	144.	1.	194.	3.		
45.	6.	95.	3.	145.	3.	195.	1.		
46.	6.	96.	3.	146.	1.	196.	4.		
47.	6.	97.	3.	147.	4.	197.	3.		
48.	2.	98.	1.	148.	4.	198.	3.		
49.	5.	99.	4.	149.	2.	199.	6.		
50.	5.	100.	1.	150.	3.	200.	3.		

Creating the Product Image

In order to multiply the five speed factors together as images, those five factors had to be extracted from the columns in their respective interface files and converted into images. The IBIS program MAPGEN accomplishes this conversion by merging a PAINT image of region boundaries with the appropriate interface file column containing the data to map into the PAINT regions. The F1 and F5 images, of slope module factor values and slope intercept frequency values, respectively, were created by merging the Slope PAINT image with Slope interface file columns 6 and 7 which contain the F5 data values in mappable percentages ranging from 0 to 100, and F1 values as speeds in kph ranging from 0 to 54 kph. The vegetation module factor values, F2, were converted into an image by merging the Vegetation PAINT image with column 16 of the Vegetation interface file, containing percentage values from 0 to 100. The F3 and F4 values, soil module factors and surface roughness factors, were converted into images by merging the Soils PAINT image with columns 13 and 11, respectively, to create images of F3 and F4 values ranging from 0 to 100 percent. Each of these five MAPGEN images now contained pixels representing percentages from 0 to 100, or, in the case of the F1 image, speed values ranging from 0 to 54. These five images could now be combined by multiplying their individual pixel values together. A new image would be created, containing the products of this pixelwise multiplication.

The IBIS program F2 (not to be confused with the vegetation

module "F2" designation) performs logical and arithmetic operations on input images on a pixel-by-pixel basis. The simple function applied to these five speed-factor images was:

$$FUNC = \frac{(F1\ image) \times (F2\ image) \times (F3\ image) \times (F4\ image) \times (F5\ image)}{10^8} \qquad (3)$$

Since the F2 through F5 values range from 0-100, their maximum product would be 10^8; therefore, division by 10^8 was necessary to cancel out the (0-100) percentage ranges in their values, producing a simple speed value, in kph, from the F1 (slope factor) image.

The resultant "product image" contained pixel values in absolute speeds in kph--not CCM map categories from 1-7. Further manipulation of this image and interface file data was required to generate an image with comparable map categories to the DMA map. The speed-product image would be very useful, however, to anyone requiring a map of absolute speeds rather than grouped speed ranges, and is evidence of the power of the IBIS method of generating maps from tabular data.

Formatting the IBIS Map into DMA-Format Speed Codes

With the product image containing pixel values in speeds ranging 0-54 kph, those values needed to be grouped into the same speed ranges (thus, map codes) as used by DMA, specifically:

Speed Range		Map Code
>30	kph	1 - GO
>15 ≤ 30	kph	2 - RESTRICTED
> 5 ≤ 15	kph	3 - SLOW
>1.5 ≤ 5	kph	4 - VERY SLOW
≤ 1.5	kph	5 - NO GO
"	"	6 - NO GO--
		Open Water
-------		7 - Not Evaluated--
		Built-Up Area

The pixel values were converted into their proper map codes by running program STRETCH, within which the table stretch mode allows ranges of values to be "mapped" or transformed into other specified values. In this manner pixel values ranging from 31-54 were transformed via table stretch to a value of 1, speeds from 16-30 kph were transformed into 2s, etc. Open water and built-up areas were identified and coded 6 and 7, respectively. This new thematic image (Figure 12) now contained pixels with values ranging 1 through 7, representing the same CCM speed ranges as occur in the DMA map, and was ready for direct comparison with the digitized version of the DMA CCM map.

Preparing the Final DMA CCM Map

Before the DMA map could be compared with the IBIS map the CCM PAINT image (containing CCM regions numbered from 1 to 231) had to be transformed into an image of regions numbered with their proper speed codes. The program MAPGEN was run to match PAINT regions with speed codes contained in column 2 of the CCM interface file. The output image (Figure 13) contained properly coded regions, ready for comparison with the IBIS map.

Fig. 12. The IBIS CCM map (product image).

LEGEND

Unmapped background
Code 1 - Go
Code 2 - Restricted
Code 3 - Slow Go

Code 4 - Very Slow
Code 5 - No Go
Code 6 - Open Water
Code 7 - Built-up area;
        not evaluated
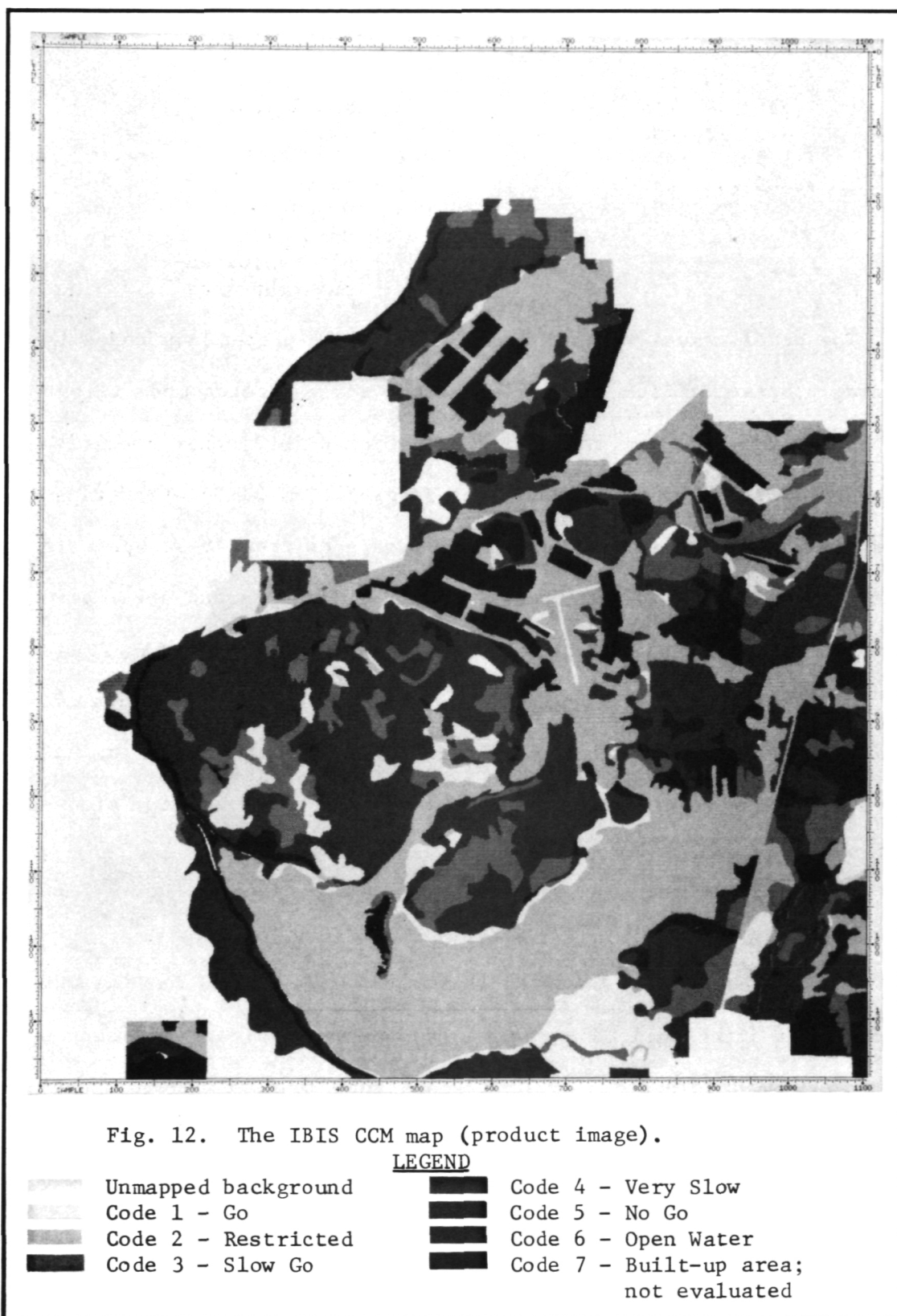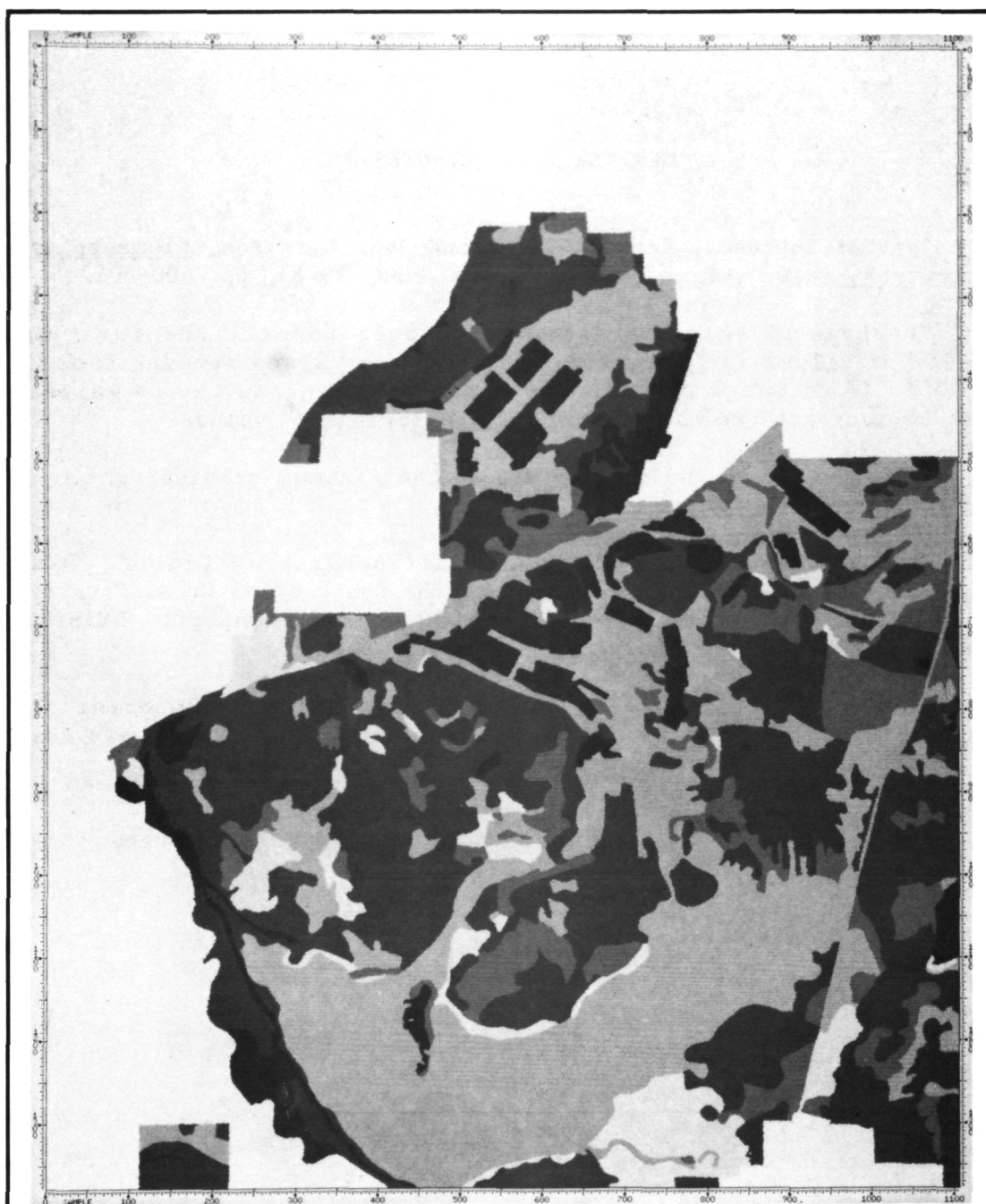
Fig. 13. The DMA CCM map.

LEGEND

Unmapped background
Code 1 - Go
Code 2 - Restricted
Code 3 - Slow Go

Code 4 - Very Slow
Code 5 - No Go
Code 6 - Open Water
Code 7 - Built-up area;
not evaluated

CHAPTER III FOOTNOTES

[1]Arthur Robinson, Randall Sale, and Joel Morrison, <u>Elements of Cartography</u> (New York: John Wiley and Sons, 1978), pp. 400–401.

[2]Because DN values are stored in byte format, the maximum number of values is 2^8, or 256, allowing for <u>values</u> ranging from 0 to 255. If an image contains more than 256 regions the DN values must be converted to halfword format, allowing 2^{16} values.

[3]The term "gradeability" refers to the maximum gradient which a particular vehicle or animal can ascend.

[4]Defense Mapping Agency Hydrographic/Topographic Center, "DMA Procedural Guide for the Production of the Synthesized Cross-Country Movement (CCM) Overlay(s), Scale 1:50,000" (Washington, DC: DMAHTC, 1982), p. 39. (Photocopied).

[5]Region #1 lies outside the Ft. Lewis Military Reservation boundaries, which is the only portion of the topographic map for which cross-country movement was computed in the DMA study.

CHAPTER IV

COMPARISON OF THE IBIS AND DMA CCM MAPS

The hypothesis of this research, as stated in Chapter I, is that the cross country movement map produced using the IBIS system at JPL is not significantly different from the map produced manually at DMA: specifically, that the areas comprising each mapped region do not differ significantly between the two maps. This hypothesis was tested using two general types of comparison: 1) visual, wherein a "difference image" was produced, highlighting all areas where the two map images contained different map codes; and 2) statistical, in which numbers of pixels contained in each mapped region for both maps were tabulated and regional percentages of correspondence between the IBIS and DMA maps were calculated and compared by calculating mean agreement percentages, areally-weighted standard deviations, and the Pearson product correlation coefficient. The visual comparison was strictly a subjective, non-quantifiable comparison, which, nevertheless, gave an immediate assessment of any spatial patterns associated with the variations between maps. The statistical comparison gave an objective, numerical measure of region-by-region agreement between the two maps, but provided no means of detecting spatial patterns of disagreement. For a geographical study such as this, both types of comparison are needed.

Overlaying the DMA and IBIS CCM Maps

The data necessary for map-to-map comparison were contained in the digital images of the IBIS product map and the DMA CCM map. These two images needed to be merged, or overlaid, in order to generate the tabular data needed for statistical comparison. The VICAR program MULTOVLY performs such overlaying of images of encoded polygons, with up to ten input images, and produces a tabular report listing possible combinations of DN values (map codes) and the numbers of pixels (pixel counts) occurring in each of those combinations. The tabular report is actually in IBIS interface file format, allowing the same types of mathematical manipulations of the file columns as discussed previously.

Since the DMA CCM map was to serve as the control map, the pixel counts per coded map region were counted first on that map. The program MULTOVLY overlaid the CCM PAINT image, containing region numbers 1-231 and region boundaries, and the CCM MAPGEN image, containing the proper speed codes for each region. The result was a table of three columns of data showing PAINT region number, map code, and pixel count for each region.

The IBIS map, resulting from combining three map overlays (Soils, Slope, and Vegetation) via five columns of interface file data (the five speed-reduction factors), contained no outlined regions; rather, every pixel in the 1377-line-by-1105-sample image contained its own unique map code. There is no program which draws outlines around areas of identical map codes (DN values) and stores

those as consolidated regions. Therefore, IBIS must overlay this type of product image with a PAINT image containing region boundaries via MULTOVLY, and tabulate the pixel counts of each map code on the product image falling within each region defined by the PAINT image.

The MULTOVLY program was run with the DMA CCM PAINT image and the IBIS product map image as inputs, with the output being a table containing the DMA region number in column 1, columns 2 and 3 containing the DMA map code and pixel count for that region, and columns 4 and 5 containing each IBIS map code and its pixel count occurring within that DMA region. (See Table 10, which shows only the first ten DMA regions: the entire table contains over 800 rows.) For instance, DMA region number 1, the large unmapped background portion of the image coded 0 for later removal, ended up containing a few IBIS pixels with all possible CCM codes except code 7, and 678,446 pixels coded 0, matching the DMA code. The small regions with erroneous codes are due to various factors as will be explained in the difference image discussion, below. In some cases, however, the largest group of IBIS pixels did not match the DMA code for that region (see region 4): the region's _shape_ was almost identical to the DMA outline, but the computed _speed code_ was different.

These features of the MULTOVLY output table give rise to two ways of combining data upon which to run tests: 1) to pull out the largest IBIS pixel count occurring within each DMA region and assume

TABLE 10

IBIS OVERLAY FILE

DMA Region #	DMA CCM Code	DMA Pixel Count	IBIS CCM Code	IBIS Pixel Count
1.	0.	678683.	0.	678446.
1.	0.	678683.	1.	8.
1.	0.	678683.	2.	27.
1.	0.	678683.	3.	19.
1.	0.	678683.	4.	98.
1.	0.	678683.	5.	18.
1.	0.	678683.	6.	67.
2.	4.	29426.	0.	188.
2.	4.	29426.	1.	25.
2.	4.	29426.	2.	44.
2.	4.	29426.	3.	311.
2.	4.	29426.	4.	26067.
2.	4.	29426.	5.	2791.
3.	3.	1447.	0.	322.
3.	3.	1447.	3.	1106.
3.	3.	1447.	4.	19.
4.	2.	1633.	3.	1586.
4.	2.	1633.	4.	47.
5.	2.	733.	0.	9.
5.	2.	733.	3.	701.
5.	2.	733.	4.	23.
6.	3.	1846.	0.	27.
6.	3.	1846.	1.	3.
6.	3.	1846.	2.	1.
6.	3.	1846.	3.	1802.
6.	3.	1846.	4.	13.
7.	4.	552.	0.	23.
7.	4.	552.	2.	21.
7.	4.	552.	3.	2.
7.	4.	552.	4.	431.
7.	4.	552.	5.	75.
8.	2.	33680.	0.	85.
8.	2.	33680.	1.	1342.
8.	2.	33680.	2.	29054.
8.	2.	33680.	3.	2016.
8.	2.	33680.	4.	517.
8.	2.	33680.	5.	40.
8.	2.	33680.	6.	12.
8.	2.	33680.	7.	614.
9.	5.	674.	0.	28.
9.	5.	674.	4.	113.
9.	5.	674.	5.	533.
10.	4.	1419.	0.	20.
10.	4.	1419.	2.	29.
10.	4.	1419.	4.	1332.
10.	4.	1419.	6.	38.

that to be the same spatial region as on the DMA map, no matter what code it has; and 2) to pull out the CCM code which matches the DMA code within each DMA region, and use the corresponding IBIS pixel count to define that IBIS map region, no matter how small. The first method tests the spatial accuracy of the IBIS map; the second tests how well the codes correspond between the two maps. Both types of accuracy are vital if the automated mapping procedure is to be successful.
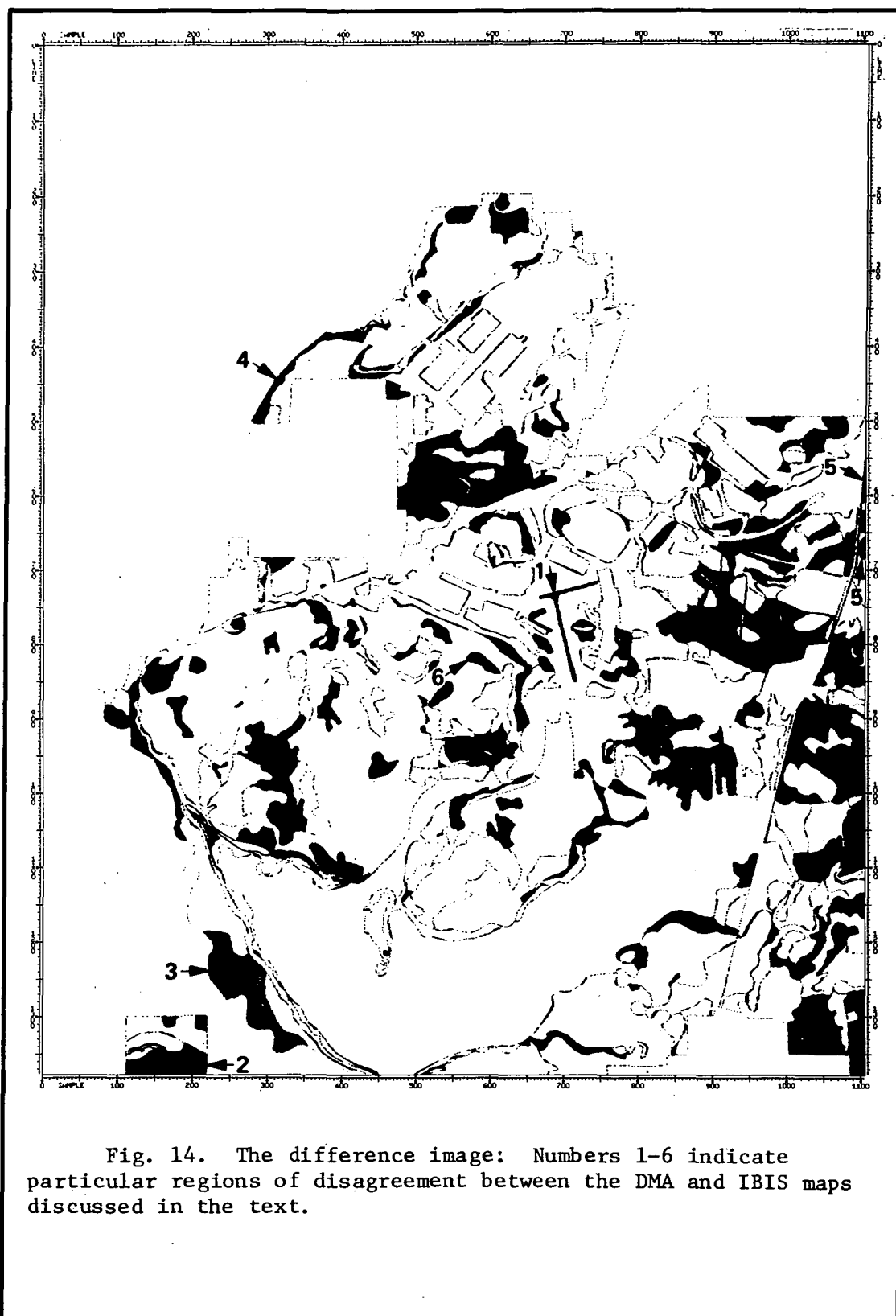
Visual Comparison: The Difference Image

The difference image, Figure 14, shows the result of comparing the pixel values between the DMA and IBIS maps and highlighting in black all pixels whose values disagree. The program F2 was used to subtract the IBIS map from the DMA map and added a constant to avoid negative values:

$$FUNC = (DMA \ map - IBIS \ map) + 10 \qquad (4)$$

This function resulted in values 3-9 indicating DMA pixel values less than IBIS values, values 11-17 indicating IBIS values greater than DMA values, and value 10 indicating equality between the two maps. For mapping purposes, all values of 10 were converted to DN 255 (white), and all other values, indicating disagreement, were converted to DN 0 (black).

Careful study of this difference map turns up four types of "errors," or areas of disagreement. First, very narrow (1 or 2 pixels wide) black lines, such as those showing up on the outer

Fig. 14. The difference image: Numbers 1-6 indicate particular regions of disagreement between the DMA and IBIS maps discussed in the text.

border of the mapped area, are due to program PAINT. Early on, when PAINT was used to define region numbers, it assigned border pixels (the original digitized outlines) randomly to neighboring regions. Therefore, each overlay's outside boundaries contained pixels randomly assigned to adjacent regions, causing different CCM codes to be computed at those sites. This error is unimportant, as the drafted ink lines on the manual map cover the same ground distance as these narrow borders on the IBIS map, and are the product of cartographic generalization.

The second type of error resulted from the coordinate digitizing process. Several water bodies were accidentally digitized more than once, since they occurred on all four overlays. This resulted in many small "false regions" showing up around those water bodies when several images were overlaid, and resulted in erroneous CCM codes being calculated. This error could be eliminated in the future by not double-digitizing common features in the first place, or by running a digital "smoothing filter" (known as a box filter) over the image afterward to average out pixel values within a small box-shaped region. This would be a type of digital cartographic generalization.

The third type of error shows up as many small black spots, unique polygons formed from the overlaying of three images whose region outlines almost overlap in some places. For instance, often a soils region will coincide with a vegetation region since soils are often mapped based on the prevailing vegetation; in this case,

the two overlays contain the same outline, and when these are digi-
tized it causes the same problem as digitizing common features.
These are legitimate areas; however, the minimum size requirement
specified by the DMA compilation guide is a square area 250m on a
side, or an elongated, narrow area < 250m on one side and ≥ 500m on
the other. On the product image those areas would have to cover
278 pixels to meet the minimum size, at 15m per pixel. The terrain
analysts are experienced at incorporating such undersized areas into
larger neighboring regions; the automated procedure did not elimi-
nate these tiny polygons from being formed. Again, a box (modal)
filter could be run to average these areas' values, assigning them
to a larger neighboring region. Still, this procedure would lack
the benefit of analyst expertise in deciding where to blend these
small areas with adjacent regions.

The fourth error is the most important type, and shows up as
entire regions highlighted in black. These are areas where the
computed CCM codes were completely different between the two maps.
The large number of these areas precludes manually re-calculating
all of their codes in this thesis to verify the IBIS procedure, but
a few selected examples (numbered 1-6 on Figure 14) might provide
clues as to the accuracy of the automated CCM model. (It must be
stated that these six regions were chosen for their ease of refer-
ence on the difference image, and for no other reason.)

Region 1. This T-shaped feature is an airfield, and, as shown

in Figure 13, was not coded separately on the DMA map. A manual re-calculation of the F values necessary for computing CCM speed reveal the following values: F1=54 kph, F2=.95, F3=1.00, F4=.6, and F5=1.00. The resulting CCM speed is 30.78 kph, putting it in the Code 1=GO category. The IBIS map (Figure 12) is correctly coded.

Region 2. This black region is derived from several small regions on the various overlays, as seen in Figures 2-5. In one case, Slope code B, Vegetation code C45, and Soils code 033 values are F1=49 kph, F2=.04, F3=1.00, F4=.6, and F5=.99, to produce a CCM speed of 1.16 kph, or Code 5=NO GO. Another small region combines Slope code C, Vegetation code C45, and Soils code 033 to produce a CCM speed of 0.94 kph, also Code 5. The third small region combines B Slope, C46 Vegetation, and 033 Soils to yield 1.45 kph, also Code 5. This entire black region is coded 4 on the DMA map, and Code 5 on the IBIS map, which is correct.

Region 3. Here again, three small regions formed by overlaying the three terrain factor overlays combined to produce this region. Vegetation was the only factor that varied: Slope was coded A, and Soils, 071. Therefore, F1=54 kph, F5=1.00, F3=1.00, and F4=1.00. Where Vegetation was coded D45, F2=.09, and CCM speed = 4.86 kph (Code 4). Vegetation code E45 (F2=.05) yielded a speed of 2.7 kph (Code 4), and E46 Vegetation (F2=.06) yielded a speed of 3.24 kph, also Code 4. This entire region was correctly coded CCM Code 4 = VERY SLOW by IBIS, and incorrectly coded Code 5 by DMA.

Region 4. This is a complex case, and referring back to the Cronaflex overlays is necessary to see the individual terrain factor regions causing the final CCM shapes. To the right of this error region is a small area coded 3 on both maps. This is correct, and the DMA map is also correct in its coding the whole corner as Code 3 (SLOW GO). The IBIS computed speed for C25 Vegetation, C Slope, and 071 Soils is 5.096, which should be Code 3. The IBIS routine erred, however, in performing integer rounding off, to yield 5.00, result-ing in a CCM Code 4. The computed speed was correct; rounding-off errors yielded a faulty code.

The rest of this region follows the narrow region coded as Code 5 by IBIS, and Code 4 by DMA. Here, Vegetation code C45 combines with a D Slope and 071 Soils to yield a speed of 1.14 kph, correctly coded as Code 5 by IBIS. So part of this region's discrepancies were due to IBIS incorrectly rounding off a speed value, and part were due to incorrect coding by DMA.

Region 5. This region includes the three black regions indi-cated at the upper-right edge of the image. The upper two black areas were coded as Code 3 by DMA and Code 4 by IBIS. The upper-most area combines C25 Vegetation, 033 Soils, and A Slope values to yield 4.212 kph, or Code 4. The middle area's computed speed was 1.94 kph (Code 4), derived from C36 Vegetation, 033 Soils, and A Slope speed-reduction factors. IBIS had correctly coded these features; they were incorrect on the DMA map.

The bottom, semi-circular area appears to be coded as 0 or

"unmapped background" by IBIS, since it is mapped as white. This interesting problem arises because the computed CCM speed is indeed exactly 0.00 kph, correctly coded as Code 5 by DMA. The IBIS routines, incorrectly, did not discriminate between this 0.00 DN value and the background 0.00 DN value, so it mapped it with white and assigned no code, the same as for the background. This error must be corrected in future models, but for now all white areas on the IBIS map may be assumed to be Code 5 areas where the speed exactly equalled 0.00 kph.

Region 6. This area shows up as white on the IBIS map, which we now know means Code 5. It is not broken out on the DMA map. This area corresponds to an area of wet organic soils, code 111 on the Soils overlay. All areas of wet soils automatically generate a Soils module F3 value of 0.00, resulting in a CCM speed of 0.00 kph, or Code 5 = NO GO. Notwithstanding the IBIS mapping error, the IBIS computed speed and CCM code were correct in this case.

These six examples show the general accuracy of the IBIS model and the incorrect coding by DMA. If all black "error regions" on the difference image were checked as these six were, it would probably demonstrate even further the superiority of the IBIS computation and coding routines. The two major faults of the IBIS method were the integer rounding of speeds which yielded faulty CCM codes, and the interpretation of 0.00 kph speeds as "unmapped background" areas. Both faults will be corrected before future applications of this model.

Statistical Comparison: The IBIS Overlay File

Table 10, as mentioned previously, shows a small portion of the raw data used in the statistical comparisons of the DMA and IBIS maps. The DMA data were the control data: the DMA pixel counts for each region were assumed to comprise the accurate spatial area of that region, and the DMA CCM codes were assumed to be accurate. This assumption is made for purposes of control and is suspect, considering results of the previous analysis. From the tabulated IBIS data one could either match up CCM codes or pixel counts, or could do both in separate trials. This research compared the maps using both methods.

For both the pixel-matched and code-matched cases, three statistics were computed: the mean percent agreement between the IBIS and DMA pixel counts for each region, the areally weighted standard deviation of the regional pixel agreements, and the Pearson product correlation coefficient. The mean percent agreement simply computed the average of the agreement percentages of all 230 regions, without adjusting for region size. In reality, a large region having a high agreement percentage would be more significant than a small region having a low agreement, but these cases were given equal weight in this test. The areally weighted standard deviation measured the deviation from the mean agreement, adjusted for areal extent of each region, of those regional agreement percentages. The Pearson correlation coefficient measured the simple correlation (a type of covariance) between the two sets of pixel counts.[1] Since this measure-

ment is made directly on pixel counts the effect of different-sized regions is taken into account. Naturally, a higher mean agreement percentage and correlation would be expected for the pixel-matched case than for the code-matched case: where the codes _do not_ match, the IBIS pixel count is 0, which would lower the mean agreement percentage and total IBIS pixel count.

Mean agreement percentage, pixel-matched case. From the complete file of which Table 10 is a portion, pixel counts had to be matched between the DMA and IBIS counts. Within each DMA region the maximum pixel count in the IBIS column and its corresponding CCM code were extracted, since it was assumed that the largest group of pixels must comprise the area most closely resembling the DMA area. A new table only 230 rows long (the unmapped background area was eliminated from these computations) was constructed containing the DMA data and extracted IBIS data. A new column was then calculated by dividing the IBIS pixel count by the DMA pixel count for each region and multiplying by 100 to give a percentage of agreement between the two counts. The mean percent agreement was computed by summing all 230 regional agreement percentages and dividing by 230. The resulting mean percent agreement was 86.21%.

As an additional measure the areally weighted standard deviation was computed for these agreement percentages. The areal extent of each region was adjusted for in the formula as follows:[2]

$$S = \sqrt{\frac{\sum aZ^2}{A} - \left(\frac{\sum aZ}{A}\right)^2} \qquad (5)$$

The variable "a" represents each IBIS pixel count, "Z" represents each agreement percentage, and "A" is the sum of all IBIS pixels contained in all 230 regions. The computed term $\frac{\sum aZ^2}{A}$ equalled 7914.84; the term $\left(\frac{\sum aZ}{A}\right)^2$ equalled 7791.40. The standard deviation result equalled $\sqrt{7914.84 - 7791.40}$, or $\sqrt{123.44}$ = 11.11%. Therefore, the mean percent agreement between the IBIS and DMA regional pixel counts was 86.21%, with an areally weighted standard deviation of 11.11%.

Pearson product correlation coefficient, pixel-matched case.
The Pearson correlation coefficient is a type of covariance measured between data sets, and in this case is measured on the pixel counts of both the DMA and IBIS maps. The equation to be calculated is:

$$r = \frac{\sum(y-\bar{y})(x-\bar{x})}{\sqrt{\sum(y-\bar{y})^2 \sum(x-\bar{x})^2}} \qquad (6)$$

The variable "y" represents the IBIS pixel count for each region, "$\bar{y}$" is the mean of IBIS pixel counts for all 230 regions, "x" is the DMA pixel count per region, and "$\bar{x}$" is the mean DMA pixel count for the 230 regions. The computed values for terms in equation 6 are:

$$\sum(y-\bar{y})(x-\bar{x}) = 6.102524 \times 10^{10}$$
$$\sum(y-\bar{y})^2 = 5.617250 \times 10^{10}$$
$$\sum(x-\bar{x})^2 = 6.668261 \times 10^{10}$$
$$\sqrt{\sum(y-\bar{y})^2 \sum(x-\bar{x})^2} = 6.120236 \times 10^{10}$$

This computation of r results in:

$$r = \frac{6.102524 \times 10^{10}}{6.120236 \times 10^{10}} = + 0.997$$

Values of r range between ± 1.00, with a value of +1.00 indicating perfect positive correlation, or complete correspondence between two data sets. A -1.00 value indicates a perfect negative relationship between two data sets--that one varies with the inverse of the other. A 0.00 value indicates that there is no relationship whatsoever between the two data sets--that they are completely independent.

The +0.997 Pearson correlation coefficient calculated here indicates almost perfect positive correlation between the DMA and IBIS pixel counts for the 230 regions, disregarding whether the CCM codes match. This result shows the accuracy of the IBIS system in generating CCM regions which almost perfectly match those outlined on the DMA map.

Mean agreement percentage, code-matched case. Data were extracted from Table 10 in a different manner to match CCM codes rather than pixel counts. The new file to be generated was formed by matching columns 2 (DMA code) and 4 (IBIS code), and extracting all other corresponding data from the rows where those two columns (codes) matched. The result was a file 230 rows long with five columns containing the DMA region number, DMA code, DMA pixel count, IBIS code (matching the DMA code), and IBIS pixel count for each

C - 2

region. There were many cases where there was <u>no</u> match between codes--IBIS had calculated different codes than DMA. In these cases the IBIS code and pixel count showed up as 0. Because of these cases where pixel counts were 0 one would expect a lower mean agreement percentage (and less correlation) between the two data sets. Where IBIS pixel counts were 0, the regional agreement percentage was also 0, lowering the overall mean agreement. In fact, the mean agreement between the two sets of pixel counts equalled only 59.66%.

The areally weighted standard deviation (equation 5) was also computed with the following results:

$$\frac{\sum a \ z^2}{A} = 7897.03$$

$$\left(\frac{\sum a \ z}{A}\right)^2 = 7699.44$$

The areally weighted standard deviation equalled $\sqrt{7897.03 - 7699.44}$, or a value of 14.06%. Therefore, the mean percent agreement between the IBIS and DMA regional pixel counts, on a code-matched basis, was 59.66% with an areally weighted standard deviation of 14.06%.

<u>Pearson product correlation coefficient, code-matched case.</u>
The terms necessary to compute the correlation coefficient were evaluated as follows:

$$\sum (y-\bar{y})(x-\bar{x}) = 6.094733 \times 10^{10}$$

$$\sum (y-\bar{y})^2 = 5.625912 \times 10^{10}$$

$$\sum (x-\bar{x})^2 = 6.668261 \times 10^{10}$$

$$\sqrt{\sum (y-\bar{y})^2 \sum (x-\bar{x})^2} = 6.124953 \times 10^{10}$$

The computation of r resulted in:

$$r = \frac{6.094733 \times 10^{10}}{6.124953 \times 10^{10}} = + 0.995$$

This high positive correlation between the DMA and IBIS pixel counts is somewhat surprising for the code-matched case, since there were many instances where codes did not match, producing 0 pixels for the IBIS pixel count. A tabulation of numbers of unmatched regions, however, shows that out of the 46 regions where codes did not match, 21 of those regions contained fewer than 278 pixels on the DMA map (the minimum size requirement for polygons). Considering the whole image contains 1.5 million pixels, the discrepancy in pixel counts where codes do not match must be so slight as to be insignificant. DMA polygons less than minimum size are due to two factors: double digitizing of features, and the map compilers actually having mapped features less than the minimum size.

Final Results

The results of computing the mean agreement percentages, areally weighted standard deviations, and Pearson product correlation coefficients are summarized in the following similarity matrix:

	Mean agree-ment %	Standard deviation	Correlation coefficient
Pixel-matched case	86.21%	11.11%	+ 0.997
Code-matched case	59.66%	14.06%	+ 0.995

The mean agreement percentages and their areally weighted standard deviations reflect the type of distribution characterizing those agreement percentages. If these were normal distributions, approximately 68% of the agreement percentages would fall within one standard deviation on either side of the mean. For the pixel-matched case, this would mean values should fall within the range 75.10% - 97.32%. It was tabulated, however, that 172 of the 230 agreement percentages, or 75%, fell within that range. Obviously this is _not_ a normal distribution: most of the percentages were high, as would be hoped. The deviation of 11.11% reflects the fact that the values of the other 58 agreement percentages fell far below the 86.21% mean value.

For the code-matched case, only 24 of the 230 agreement percentages, or 10%, fell within the one standard deviation range of 45.6% - 73.72%. Most of the percentages fell in the high 80s to high 90s, or were _very_ low, reflecting the fact that where codes matched the pixel counts often matched too, yielding high agreement percentages, and where codes didn't match, the IBIS pixel count was 0, yielding an agreement percentage of 0. The large deviation value

of 14.06% shows this high degree of spread about the mean.

Correlation coefficients showed the high correspondence of the areal extent of the DMA and IBIS CCM regions, irrespective of the computed code. Because these were computed on regional pixel counts rather than agreement percentages, the resulting correlations took region size into account. Large regions of similar pixel counts weighed more heavily than small regions. Even so, the IBIS method of combining digitized overlays resulted in a map whose polygon outlines almost exactly corresponded with the control DMA map.

The hypothesis of the research, that the area comprising each mapped region on the IBIS map is not significantly different from the DMA map, is confirmed by the correlation coefficients which show almost perfect positive correlation between the two maps, computed on a region-by-region basis. The high mean percentage of agreement between IBIS and DMA regional pixel counts, on a pixel-matched basis, is also very high. These statistics prove the accuracy of the IBIS system in synthesizing three overlays into a new map.

Another characteristic of IBIS which was proven by this research is the accuracy with which it implements a mobility model-- specifically, DMA's cross-country movement model. The visual comparison analysis turned up cases where the DMA computed CCM code was incorrect, while IBIS had computed the correct speed and CCM code. The accuracy of the automated system carries implications not only for production of military cross-country movement maps, but for civilian applications of a geographic information system as well.

CHAPTER IV FOOTNOTES

[1]Peter J. Taylor, <u>Quantitative Methods in Geography</u> (Boston: Houghton Mifflin Company, 1977), p. 186.

[2]Arthur Robinson, Randall Sale, and Joel Morrison, <u>Elements of Cartography</u> (New York: John Wiley and Sons, 1978), p. 142.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

The purpose of this research was to investigate whether a geographic information system such as IBIS could effectively implement the cross-country movement model developed by DMA. A computer program can easily set up the equations which are needed to calculate cross-country movement, requiring only the analyst's input of the relevant soils, slope, and vegetation data in order to compute the potential speed of the vehicle of interest. The analyst may obtain a concise printout of input data and calculated speeds. Portraying that information in the spatial domain, however, is the task (art) of the cartographer. Programming the computer to make the kinds of judgements a cartographer makes in deciding how to portray features on a map falls within the realm of artificial intelligence, or programming so many possible choices that the computer is nearly able to "think" for itself.

Within the IBIS system the CCM model equations were set up, speeds were calculated and translated into CCM map codes, and a CCM map was produced, all on computer. It was verified that the areal regions drawn by the IBIS system were not significantly different from those drawn on the DMA map, and was even discovered that some of the map codes appearing on the DMA map were incorrect—IBIS had

calculated the correct speed and code, which showed up on the dif-
ference image as black (different) regions. The accuracy of the
drawn regions and speed computations are evidence of the power of
IBIS in merging geographic data with their spatial distributions to
produce new, synthesized maps--a special function of geographic
information systems. As was to be expected, however, IBIS did not
reach the same <u>artistic</u> conclusions as the human cartographer.

The process of overlaying three data planes (map overlays,
images, etc.) and trying to combine those data in spatial form
produces many tiny areas too small to be mapped and therefore must
be incorporated within neighboring areas. The cartographer uses his
or her artistic skill in deciding which areas should be merged into
one, and this cartographic generalization produces a more readable,
pleasing map. Many of those small areas showed up on the IBIS map,
and could be smoothed out in the future by running box filters to
merge them with neighboring regions, performing some <u>digital</u> carto-
graphic generalization.

In solving the model equations to generate vehicle speeds, and
translating those speeds into map codes, the IBIS routines rounded
those results differently than an analyst would have, yielding a
slightly different speed which sometimes fell into a different map
category than what DMA had encoded. Rounding algorithms may be
easily changed to insure uniformity with the cartographer's results.
Areas which are unmapped for some reason and may be interpreted to
yield CCM speeds of 0 must be distinguished from areas where the

true, computed CCM speed does equal 0. This problem may be solved by simply assigning unmapped areas unique values, such as "999" or other unrealistic speeds, in the interface files. Map-drawing routines could draw both of these "0-speed" areas with different patterns or gray levels, allowing proper map interpretation.

These slight adjustments in the IBIS CCM model would make the final map closer artistically to a manually compiled map. The appearance of the map would reflect some of the generalization a human cartographer would employ. The accuracy of the calculated codes would remain high.

As development of IBIS as an automated cartographic system continues, an improvement would be to interface the IBIS image handling capabilities with sophisticated coordinate digitizing systems, allowing more accurate map digitization because of the editing capabilities. Interfacing IBIS with large-format, multi-color plotters would generate one-to-one plots of maps at various scales. A data base management system would store map codes and relevant geographic data such as terrain factor data in more easily accessible files. Models such as the CCM model could be written as stand-alone programs allowing input of soils, slope, and vegetation data (or other appropriate data) all at once, rather than requiring separate file manipulations as were used in this study.

An additional improvement, currently under development at JPL, is a method whereby an analyst can take an IBIS-synthesized map, choose a region on that map, and "query" the data base for the raw

data which were used to compile the map. For example, an analyst could choose a particular "NO GO" region on the IBIS CCM map and call out the data from the three terrain factor overlays used to produce that map. Those raw data would show why that region was "NO GO": perhaps it was a swampy area, or trees were too close together, or the soil was perennially wet. Perhaps one of these hindrances would be easier to work around than another, and the analyst would have the data to help make these decisions. This new IBIS methodology is called "QUERY," and its set of programs will greatly enhance the utility of this GIS.

With continuing development IBIS will evolve into a superior GIS able to handle coordinate-digitized maps, store map codes and data in a streamlined data base, manipulate the data in image format, and allow queries of the raw data used to synthesize new maps. Applications of this mapping capability will serve the civilian as well as military world. Under the guidance of the human cartographer the computer will produce maps which are pleasing to the eye, mathematically accurate, and endlessly manipulable because of their digital form. Because the nature of cartography lends itself so readily to computerization, the merging of computer science and cartography in this century marks a major milestone in the science of geography.

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102

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15. Supplementary Notes

16. Abstract

The Image-Based Information System (IBIS) at the Jet Propulsion Laboratory was used to automate the cross-country movement (CCM) mapping model developed by the Defense Mapping Agency (DMA). Existing terrain factor overlays and a CCM map, produced by DMA for the Fort Lewis, Washington area, were digitized and reformatted into geometrically registered images. Terrain factor data from Slope, Soils, and Vegetation overlays were entered into IBIS, and were then combined utilizing IBIS-programmed equations to implement the DMA CCM model. The resulting IBIS-genereated CCM map was then compared with the digitized manually produced map to test similarity.

The numbers of pixels comprising each CCM region were compared between the two map images, and percent agreement between each two regional counts was computed. The mean percent agreement equalled 86.21%, with an areally weighted standard deviation of 11.11%. Calculation of Pearson's correlation coefficient yielded +9.997. In some cases, the IBIS-calculated map code differed from the DMA codes: analysis revealed that IBIS had calculated the codes correctly. These highly positive results demonstrate the power and accuracy of IBIS in automating models which synthesize a variety of thematic geographic data.

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