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A RAND NOTE

Secondary Land Theater Model

Patrick D. Allen, Barry A. Wilson

July 1987

RAND

The research described in this report was sponsored by the Director of Net Assessment, Office of the Secretary of Defense (OSD), under RAND's National Defense Research Institute, an OSD-supported Federally Funded Research and Development Center, Contract No. MDA903-85-C-0030.

Published by The RAND Corporation
1700 Main Street, P O Box 2138, Santa Monica, CA 90406-2138

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER N-2625-NA	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Secondary Land Theater Model		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Patrick D. Allen, Barry A. Wilson		8. CONTRACT OR GRANT NUMBER(s) MDA903-85-C-0030
9. PERFORMING ORGANIZATION NAME AND ADDRESS The RAND Corporation 1700 Main Street Santa Monica, CA. 90406		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Director of Net Assessment Office of the Secretary of Defense Washington, DC. 20301		12. REPORT DATE July 1987
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

No Restrictions

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Land Combat
Models
Theater Level Operations
Battles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See reverse side

DD FORM 1 JAN 73 1473

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

This Note describes a new approach to combat modeling and an application of this approach to modeling selected theaters of operation in a global model--the RAND Strategy Assessment System. There are five important features of this new approach: (1) Using the model parallels the processes involved in developing a concept of operations or a game plan; (2) the model is rule-based rather than algorithm-based for both decision and assessment processes; (3) the model focuses on first defining a specific situation, and then selecting the most appropriate assessment process; (4) heavy emphasis is placed on the qualitative factors that determine the success or failure of operations, as well as the usual quantitative factors; and (5) the approach relies on the flexibility, clarity, structure, and speed of the RAND-ABEL programming language.

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A research publication from
The RAND Strategy Assessment Center

Distribution/
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Dist | Avail and/or Special
A-1

QUALITY INSPECTED 2

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PREFACE

This Note describes a new approach to combat modeling and an application of this approach to modeling selected theaters of operation in a global model. Additional theaters will be added throughout 1987 and 1988. The work described in this Note is part of the research program of the RAND Strategy Assessment Center and has been sponsored by the Director of Net Assessment in the Office of the Secretary of Defense (OSD) and by the Organization of the Joint Chiefs of Staff. The work has been done under the auspices of RAND's National Defense Research Institute, the OSD supported Federally Funded Research and Development Center at RAND. Comments are welcome and should be addressed to the author or to Dr. Paul K. Davis, Director of the RAND Strategy Assessment Center.

SUMMARY

This Note describes a new approach to modeling theater combat and illustrates the approach by representing operations in a particular theater as part of the global combat model of the RAND Strategy Assessment System (RSAS). Our approach or "model" has five important features. The first is that using the model parallels the same processes involved in setting up a concept of operations or a campaign plan. The second is that the model gives considerable emphasis to key discrete events and details of road networks (e.g., capture or denial of a major airport or road junction) and relegates the modeling of continuous processes such as attrition in a particular battle zone to a lower status of visibility. In using the approach, one tends to think in military terms rather than in the imagery of sliding pistons or Lanchester equations, even though model subcomponents may be piston-like and use Lanchester equations.

The third is that the approach depends heavily on *rules* (rather than algorithms alone) for modeling tactical and operational decisions and for adjudicating the outcomes of battles. Fourth, in adjudicating combat the approach pays particular attention to distinguishing among different types of battle so that different algorithms can be used for each if necessary. This is strongly preferable to the common tendency of modelers to apply some variant of Lanchester equations to all battles, even when the real-world nature of those battles is distinctly different (e.g., battles in narrow mountain passes or the pursuit phase subsequent to a breakthrough). Finally, the method depends heavily on the flexibility, clarity, structure, and speed of the RAND-ABEL™ programming language. RAND-ABEL is especially well suited to complex rule-based models in which there is a premium on the analyst's being able to understand and change interactively model details such as key decision rules or adjudication parameters.

In many respects, the approach is more a gaming system and model development tool than just another model. The design has emphasized transparency and flexibility of model parameters, assumptions, and logic

for the analyst. Great care has been taken to make sure that there are as few hidden assumptions as possible and that any otherwise obscure assumptions are well documented. The initial applications of the S-Land modeling approach have been to theaters such as Northern Norway and Turkey. Although the first-generation models are very simple in some respects, they are relatively sophisticated in others (e.g., the sides' plans include contingent branches dependent on the ability to achieve surprise at a key node). We are confident that the models can be made increasingly sophisticated within the current framework if particular users need additional resolution (e.g., to reflect detailed constraints on the availability of intratheater lift).

CONTENTS

PREFACE iii

SUMMARY v

FIGURES ix

TABLES xi

Section

I. OVERVIEW 1

II. A BRIEF DESCRIPTION OF THE MODEL 2

Modeling a Concept of Operations 2
Focusing on Discrete Events 3
A Rule-Based Approach for Combat Adjudication 3
New Opportunities Created by the RAND-ABEL Language 5
Model Scope 6
Model Features 9
Model Assessment 10
Analyst Tools 12

III. EXAMPLES OF MODEL USES 13

IV. ONE EXAMPLE IN DETAIL 18

How To Read RAND-ABEL Tables 18
Sample Airborne Landing Operation 21

V. CONCLUSIONS 28

REFERENCES 31

FIGURES

1. Annotated Flowchart of an Airborne Operation 4
2. The Scandinavian Theater 8
3. Distributed Landing Option 15
4. Focused Landing Option 16
5. Sample Decision Tree for Amphibious Options 17

TABLES

1. Sample RAND-ABEL Table 19
2. Air Drop Degree of Surprise 21
3. Air Drop Lift Losses 22
4. Point Terrain Effects Table 24
5. Point Combat Type Battle 24
6. Point Combat Loss Rates 25
7. Point Ground Combat Loss Seasonal Multipliers 26
8. Point Combat Damage Rates 27

I. OVERVIEW[1]

The Note begins with a description of the S-Land model and an examination of its unique features. In a sense, what is described is actually an *approach* to modeling--one that has been greatly assisted by recent developments in computer hardware and software. We then describe how this approach has been applied to represent all but two of the land theaters in the RAND Strategy Assessment System (RSAS) [Davis and Winnefeld, 1983; Davis, 1985]--a global model designed to study strategic- and operational-level issues.

Third, we present a simplified example of the types of issues that can be represented by the model. This examines tradeoffs between two hypothetical options available to a Red commander contemplating joint amphibious and airborne operations against Northern Norway.

Finally, we present a single example with actual computer code to demonstrate the ease and power of the modeling techniques. The example follows an airborne landing operation through the first day of battle.

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[1] This Note documents an address given at the 55th MORS Symposium. Full documentation on the S-Land model will be forthcoming late in 1987.

II. A BRIEF DESCRIPTION OF THE MODEL

Our approach or "model" has five important features. The first is that using the model parallels the same processes involved in setting up a concept of operations or a campaign plan. The second is that the model focuses on key discrete events to focus attention on the military operational issues, rather than on the combat attrition assessment processes. The third is that this rule-based approach is used to *adjudicate* simulated outcomes, in addition to being used in the side's decision processes. Fourth, an emphasis has been placed on defining the different types of battles and selecting the best algorithms to adjudicate results, as opposed to depending upon a single type of algorithm to assess all types of battle outcomes. Finally, the key to these new capabilities lies in the development of a new computer language--RAND-ABEL [Shapiro et al., 1985a]--and a hierarchical approach to analytically oriented rule-based modeling [Davis et al., 1986].[1]

MODELING A CONCEPT OF OPERATIONS

An important feature of the S-Land modeling process is that when using the model, one is paralleling the processes involved in developing a concept of operations or a campaign plan. This is important in making sure that the unique perceptions, decisions, and assumptions about an operation within a theater are included in the model.

One starts with a map of the region of conflict and identifies key features and objectives. These features include key terrain such as mountain passes, large port facilities, airbase complexes, and the lines of communication (LOCs) that are essential for sustaining operations and advancing large formations. These points may be combined with LOCs into a network or left as discrete points. For example, small islands may

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[1]An early version of the model was developed in 1985-1986 by Paul Olsen, Carl Jones, and Paul Davis. That version depended more on extrapolating results of scripted campaigns. In reviewing that work, it became clear that the most attractive features were those we emphasize and develop greatly here. The current model now supplants the earlier one.

each be represented as a single point for purposes of combat, rather than representing the movement of forces explicitly on each island.

The analyst must then define how the forces available in each side's order of battle will initially be used by defining one or more war plans for each side. A war plan defines when, where, and under what conditions the forces available will be used and the objectives of each concept of operation. Any special instructions or guidance to the local commander(s) are also specified.

FOCUSING ON DISCRETE EVENTS

The model *focuses* upon key issues and discrete events in a theater of operations--rather than on algorithms required to give average results (although it can use complex algorithms). This allows the analyst to *focus on studying the factors that cause or prevent a key event from occurring*, rather than on simply assuming the factors away in a perpetually average result.

For example, an airborne operation either succeeds or fails for various reasons, such as the local air control over the target, the degree of surprise achieved, the quantity of escort aircraft available versus the number of interceptors, the strength[2] of the surviving landed forces, and the strength of the defender (see Fig. 1). The model does not just have an average impact of a half-successful, half-failed operation, nor are the factors that contribute to its success or failure buried in a single probability. Any of the determining factors may be varied to find the sensitivity of the degree of success to any of the contributing factors.

A RULE-BASED APPROACH FOR COMBAT ADJUDICATION

The mechanism for focusing on discrete events is a rule-based approach used to adjudicate simulated processes as well as to make decisions. To expand on the previous airborne operation example, the

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[2]Aggregate ground force strength is measured in Equivalent Divisions (EDs). Ground force assets are tracked in the model by numbers of assets of each category, such as tanks, armored personnel carriers (APCs), and artillery. Therefore, one could also use more elaborate killer-victim scoreboard attrition algorithms if desired.

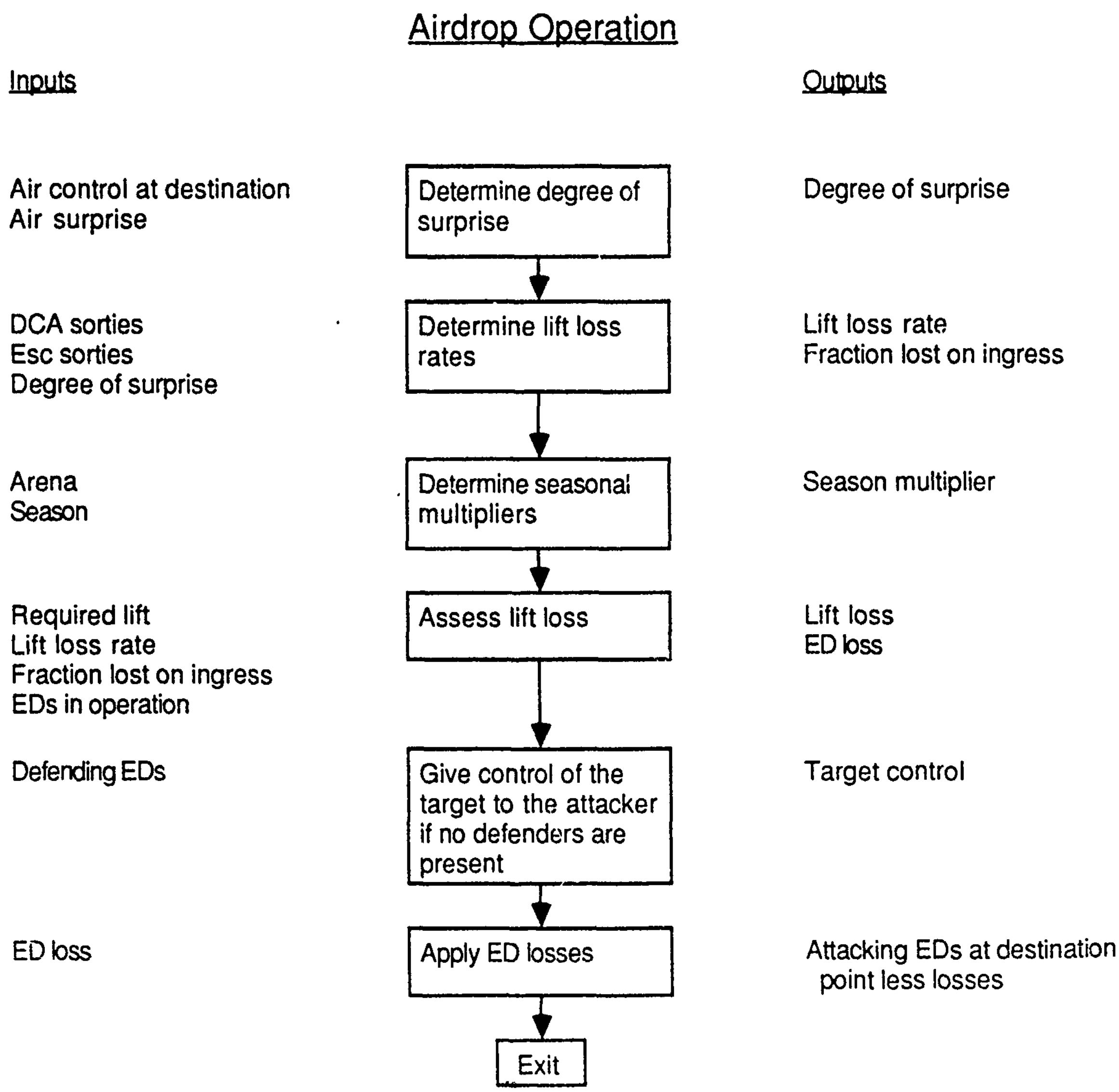

Fig. 1 -- Annotated Flowchart of an Airborne Operation

current air control over the target is determined through a series of rules. The current air control is one of the inputs to the rules that determines the degree of surprise obtained by this operation. The degree of surprise is one of the inputs to the rules determining the degree of success of the operation.

The rule-based approach encourages the analyst to write rules distinguishing situations that ought to be described by different algorithms. For example, Lanchester equations are highly inappropriate for describing battle in the pursuit phase after a breakthrough. Even so, most models do not even recognize this type or phase of battle as being different. For example, many combat models depend upon a single ground combat algorithm to assess all types of ground combat, regardless of how badly one must stretch the original algorithm to fit unusual situations.

Rules are also useful in representing the "soft" variables with which decisionmakers are familiar. For example, air control means something to military personnel and carries with it implications for making allocation decisions and setting goals. Furthermore, values such as "very-good," "good," "mixed," "poor," "very-poor," and "don't care" *can be defined as a function of the situation with respect to the current plan of action.*

NEW OPPORTUNITIES CREATED BY THE RAND-ABEL LANGUAGE

The approach we have developed owes a great deal to technology (the RAND-ABEL language) and to an earlier example of rule-based decision modeling that emphasized the importance of reducing key decision inputs to a few, often qualitative, variables in a decision table. These input variables are themselves determined by decision tables involving lower-level variables, and so on, in what is sometimes a four- or five-level hierarchy of variables [Davis, 1985; Davis et al., 1986]. For example, the concept of "air control over the target" is defined as a variable for each target in S-Land. The current value of air control is determined earlier in other tables in the model. The specifics of how the variable is defined, and what impact that variable has on the assessment process, are subject to debate, but the concept of air control is useful to the military planner and analyst.

The RAND-ABEL language is very fast because it translates into C (runtime is within a factor of three of C's speed). It can be quite understandable by subject area specialists who are not programmers. This is especially true of the language's decision tables.

It is important that the model assumptions and parameters are presented in tables that exist directly within the computer code. These decision tables are far more flexible than decision tables in data, because the analyst may view the rules in context and change *variables* as well as values (i.e., add or subtract rows and columns. Since RAND-ABEL is selectively interpretive (owing to recent work by colleague Ed Hall), the model code and tables may be modified *while the model is running*. In the event that decision tables become cumbersome, as in basic bookkeeping processes, one can always write a function in the C language to do the computationally intensive work, which need not be so transparent.

The decision-table-oriented modeling approach goes far in *allowing the analyst to view model assumptions and key parameters and in judging completeness of rules* (i.e., it is difficult for options to be accidently ignored and "fail through the cracks"). Multiple runs may also be set up for sensitivity analysis using the table structure.

MODEL SCOPE

The techniques described in the previous section have been applied to building the CAMPAIGN-ALT portion of the RSAS. The RSAS is a global model representing strategic- and operational-level conflict in various land, sea, and aerospace regions of interest. CAMPAIGN is the model that encompasses all of the combat assessment processes in the RSAS, including strategic mobility, strategic nuclear exchange, theater warfare, naval conflicts, and activities in space. The CAMPAIGN-MT model is a subset that portrays land and air theater warfare in Central Europe and Korea. The CAMPAIGN-ALT (other Air-Land Theater) portion of the model must handle all other non-ocean theaters of operation.

CAMPAIGN-ALT must use the general CAMPAIGN database of military forces worldwide, be sufficiently detailed to satisfactorily represent the important and unique operations in each theater, and perform these

CAMPAIGN-ALT must use the general CAMPAIGN database of military forces worldwide, be sufficiently detailed to satisfactorily represent the important and unique operations in each theater, and perform these functions quickly, flexibly, and without excessive memory requirements.[3] Furthermore, important interactions with other CAMPAIGN model functions, such as antisubmarine warfare (ASW) operations in adjacent sea regions, must also be included. Finally, the model must be understandable.

The theaters that currently exist in the 2.0 version of the RSAS include:

- The Scandinavian theater (Norway, Sweden, and Finland),
- The Baltic Islands,
- Turkey (both east and west), and
- Greece.

Theaters currently being modeled include:

- Iceland,
- Cuba,
- Italy and Yugoslavia,
- Iran,
- The Saudi Peninsula, and
- Pakistan.

The current version of the Scandinavian theater is shown in Fig. 2. The main avenue of approach is along the coast road from Kirkenes to Trondheim, then inland to Oslo. LOC axis 2 is the Finnish-wedge, while axis 4 is the Arctic Circle approach through northern Sweden. LOC axis 3 is used if the Soviets need to conquer Finland. Axis 5 follows the coast road down Sweden, connecting with axis 6 from Stockholm to Oslo. Eleven points are specifically identified.

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[3]A standalone version of the model also exists (i.e., one that is independent of the rest of CAMPAIGN and its database. It is faster but with less resolution of the forces represented. The standalone version was applied to support gaming operations at the National Defense University. It is also useful for model development and testing.

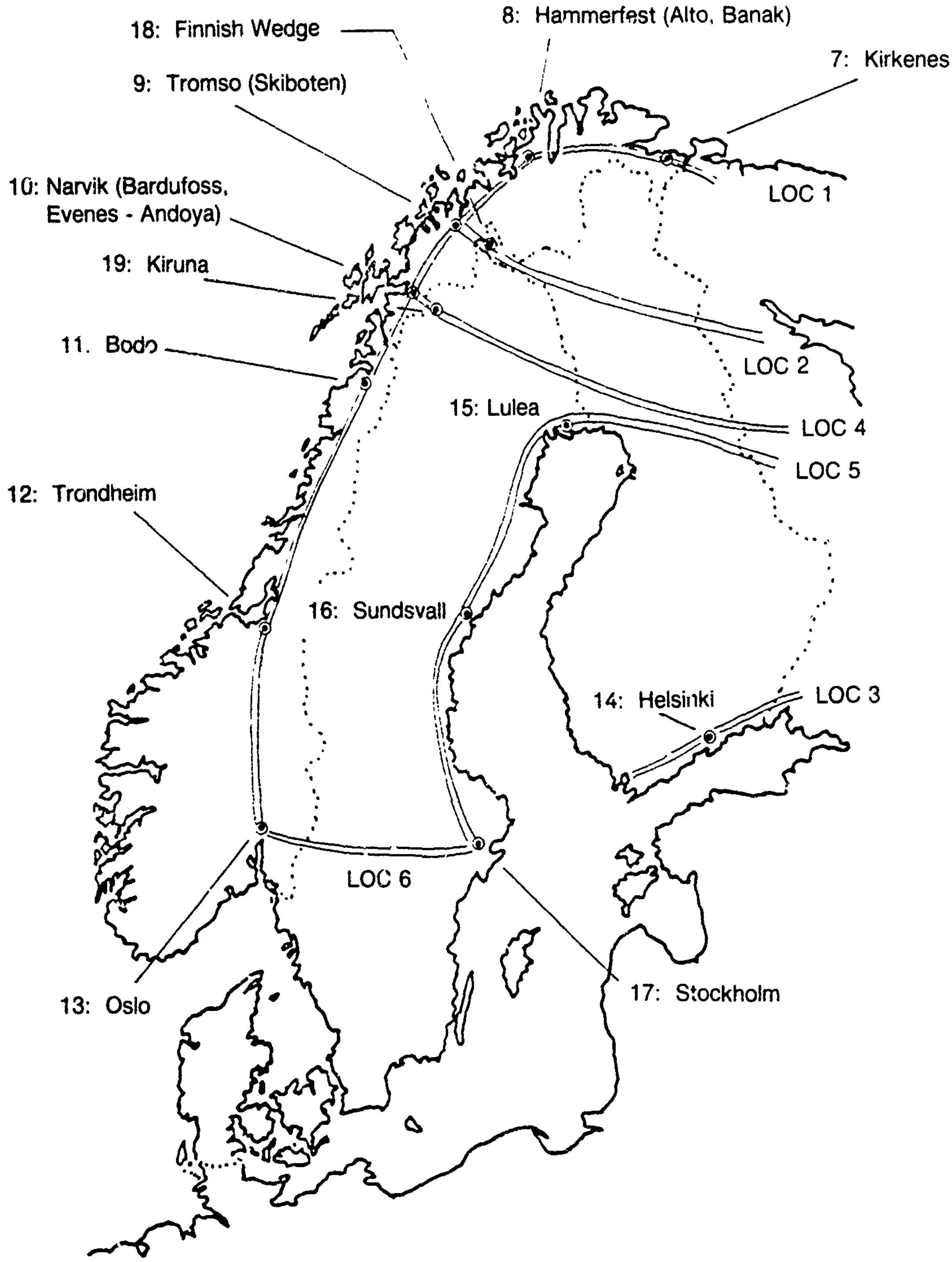

Fig. 2 -- The Scandinavian Theater

MODEL FEATURES

Points represent items such as one or more of:

- National capitals,
- Airfields,
- Ports,
- Key facilities (e.g., intelligence collection stations),
- LOC chokepoints (e.g., mountain passes), and
- Stockpiles (e.g., POMCUS).

In addition, the rear area behind the FLOT may also be targeted. Forces at the point may be allocated to each type of target. Each type of target, such as an airfield, may actually represent more than one airfield that is in the vicinity of that point. To distinguish damage and activities distinctly between two airfields at the same point in the model, a second point must be defined. Usually, however, multiple airfields at a given point is sufficient for the theater level of resolution in the model. Forces may be assigned missions of "occupy" or "deny" for any target at a point.

The types of operations represented in the model include:

- Airborne, heliborne, and air reinforcement,
- Amphibious, sea reinforcement,
- Unconventional warfare (UCW) operations, and
- Chemical strikes.

Chemical strikes and UCW operations can "deny" targets to the opponent by damaging the facilities. In addition, any ground force may be assigned to security duty at a target by being at the point and having a fraction of the force assigned to "occupy" that particular target.

Both the model and the RSAS are modular. To represent operations in a theater, five components must be prepared:

- The data for the theater, including a map with LOCs and points,
- The forces or order of battle (OOB) for each side,
- The analytic war plans (AWPs) or initial instructions to each side, with contingencies if desired,
- The operational command level (OCL) for each side. and
- The referee, or the part of the model that adjudicates results of each side's actions.

In most cases, the model has a default set of components for the war to "run itself" if the analyst does not want to change anything from the default case. For example, the four theaters built for the 2.0 version of the RSAS include all of the above components. The terrain and the basic concepts of operation are included in the map and associated network of LOCs and points. The CAMPAIGN database includes the OOB for each side (ground, sea, and air). The AWPs include specific instructions on when, where, and how forces will be used in the theater, including any contingency plans. The OCLs are used to make minor modifications to forces in the theater to better accomplish the plan and adapt to minor problems. An OCL is planned for each theater of operations, although a modular functional form similar to the CAMPAIGN-ALT will help keep the computer space requirements small.

MODEL ASSESSMENT

The referee is the heart of the assessments in the theater of operations. Conceptually, the referee compares Blue's plan and associated forces with Red's plan and associated forces and determines the outcomes of the war. This is not done instantaneously but as a simulation that is assessed day by day. At any time, Blue or Red may elect to implement a different plan, causing the referee to determine outcomes based on a new situation. The referee is not completely general but must be prepared with knowledge of Red and Blue plans.

Obviously, the referee must be rather robust to accomplish this task under many possible conditions. Fortunately, this is accomplished by making the referee modular by functional area. The functional areas currently represented in the model include:

- **Air sortie** generation for each side,
- **Air control** over each point and the FLOT on each LOC axis,
- **Air combat** in the theater and surviving offensive air support (OAS) sorties against FLOT,
- **Coastal control** at each coastal point and the FLOT on each coastal LOC axis,
- **Coastal combat** in each coastal sector (not including surge operations, which are handled separately),
- **Operations** including airborne and amphibious operations,
- **Land combat** including combat at points and at FLOTs on LOC axes,
- **Special events** such as the closing of maritime patrol aircraft (MPA) bases in the theater,
- **Deployments** of forces within the theater of operations.

The order in which these functional areas are listed is also the sequence in which they are calculated within the model. For example, air control over a point is calculated before coastal control is calculated, since control of the air influences control of the sea. This is assuming that any naval aircraft flying in the theater have been accounted for in the air control calculations.

Air control and coastal control in the theater are defined by air and sea sector. For example, air sector A in Norway parallels LOC axis NEUR-1 down the coast road.[4] Air control is a function of the range of aircraft flying out of the most forward operating airbase, and the quantity of aircraft flying. Air control over any point or FLOT may be defined as Blue, Red, Contested, or Neither. Coastal control is defined in a similar manner.

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[4]NEUR is the RSAS name for the northern European theater.

ANALYST TOOLS

For any functional area, the *user may override the simulation's calculations and specify the output of that functional area* for one or more days of assessment. This is accomplished through user-specified events, which bypass the normal assessment process for that functional area and insert the user-specified values. For example, the user may specify coastal control for all sectors over the course of the war on the basis of the results of a separate study.

As noted above, the RAND-ABEL language also has an interpreter, which allows the analyst to modify the code and implement the changes *while the model is running*. For example, the analyst may wish to modify one or more of the user-specified events during the game. The file that contains the user-specified events is edited and placed in a special directory of files that are executed instead of the baseline files. The game is then continued. All such modified files are placed in the same special directory for ease of use.

Batch runs for rapid sensitivity analysis will soon be available using the Run Number feature. Using the RAND-ABEL interpreter, all of the tables (or other code) that the analyst wishes to vary over this set of runs are edited to show the desired values. To any table is added a column that refers to the global variable named "Run-nbr." The rows of the table applying to that "Run-nbr" apply only to that excursion. For example, if the analyst wishes to vary helicopter effectiveness over ten values, the helicopter effectiveness table will have ten rows, each with a different "Run-nbr" in the new column. A different helicopter effectiveness value is placed in each row with a different "Run-nbr."

There is also a variety of displays for current status reports, histories, tableaus, and maps. The maps for each theater include the points and LOCs, the FLOT location on each LOC, point names, and the types of facilities at each point. Each feature allows a presentation of more information by selecting the feature with the electronic mouse. This additional information currently includes the target control and target damage and will include the forces present on each side. On the color SUN computers, ownership of a target is shown by the color of the symbol--blue and red for each side and magenta for contested.

III. EXAMPLES OF MODEL USES

There are many types of issues that this model may help analyze. The primary uses are to represent widely differing scenarios for purposes of analysis. For example, the closing of the operating bases of maritime patrol aircraft (MPA) in a theater may have a significant impact on the ASW capabilities in adjacent sea regions. In general, the types of issues that the model is designed to examine are different concepts of operation. Different concepts of operation may vary with actions or reactions by Pact and NATO allies or neutrals in the region of conflict, different degrees of strategic surprise, and so on. The mobilization times or levels of alert for each side will have a major impact in the degree of surprise achieved on land, sea, and in the air.

The model is not really designed to examine force-mix tradeoff issues, because it is part of a global model. However, more detail may be added to the model to examine a particular issue that may be bypassed during normal model operation. For example, the question of combined arms effects and explicit casualty distribution based upon force mix may be at the center of some issues, and optional submodels may be created to focus on these effects. Other analysts may wish to ignore that high degree of resolution for faster running time, depending on their own needs.

A concept of operations will include the objectives and timing of major operations in the theater. For example, a large-scale amphibious or airborne operation will most likely have a major impact on the success or failure of the whole campaign plan. In theaters such as Northern Norway, the overland avenues of approach are so poor that only an "end run" via an airborne or amphibious operation can avoid a slow war of attrition. However, deep operations of this sort are risky at best and difficult to maintain. Therefore, various options must be examined to find the combination that will give the highest probability of success.

In this example, two Soviet joint amphibious and airborne operations in support of land operations in Northern Norway will be examined. The first option will consist of three distributed landings at Narvik, Tromso, and Hammerfest (see Fig. 3). The second option is a focused landing only at Tromso (see Fig. 4). There are advantages and disadvantages to each option, depending upon the situation.

Factors to consider include the disruption of NATO air and MPA activity. If the main goal of these operations is to disrupt NATO's ability to generate sorties within a specified geographical location, then the distributed option is preferred. If the purpose of the operation is to seize, rather than deny, enemy port and airbase facilities, then the focused option is preferred. The distributed option poses NATO with multiple threats rather than a single threat, increasing the probability that NATO will delay in responding to the threats. However, forces farthest to the south are less likely to still be a coherent fighting unit by the time link-up is achieved. Fewer amphibious and airborne forces may be reconstituted in the distributed option.

All of these tradeoffs must be weighed in light of the objectives of the operation, as well as their chances of success. In addition, situational factors may dominate the final decision (see Fig. 5). For example, if the degree of strategic surprise is high, then the distributed option will probably have the highest payoff for the risks involved. If the degree of strategic surprise is not high, and there are no U.S. carrier battle groups or other major air or surface threats in the area, then the focused option may have the best payoff-to-risk value. If, instead, carrier battle groups are in the area of amphibious operation, then possibly no invasion is the best option. An AWP may be written with exactly these conditions so that these factors are actually considered in the execution of the concept of operations. Thus, one's plan is *contingent*--a longstanding goal in work by the RAND Strategy Assessment Center [Davis and Winnefeld, 1983].

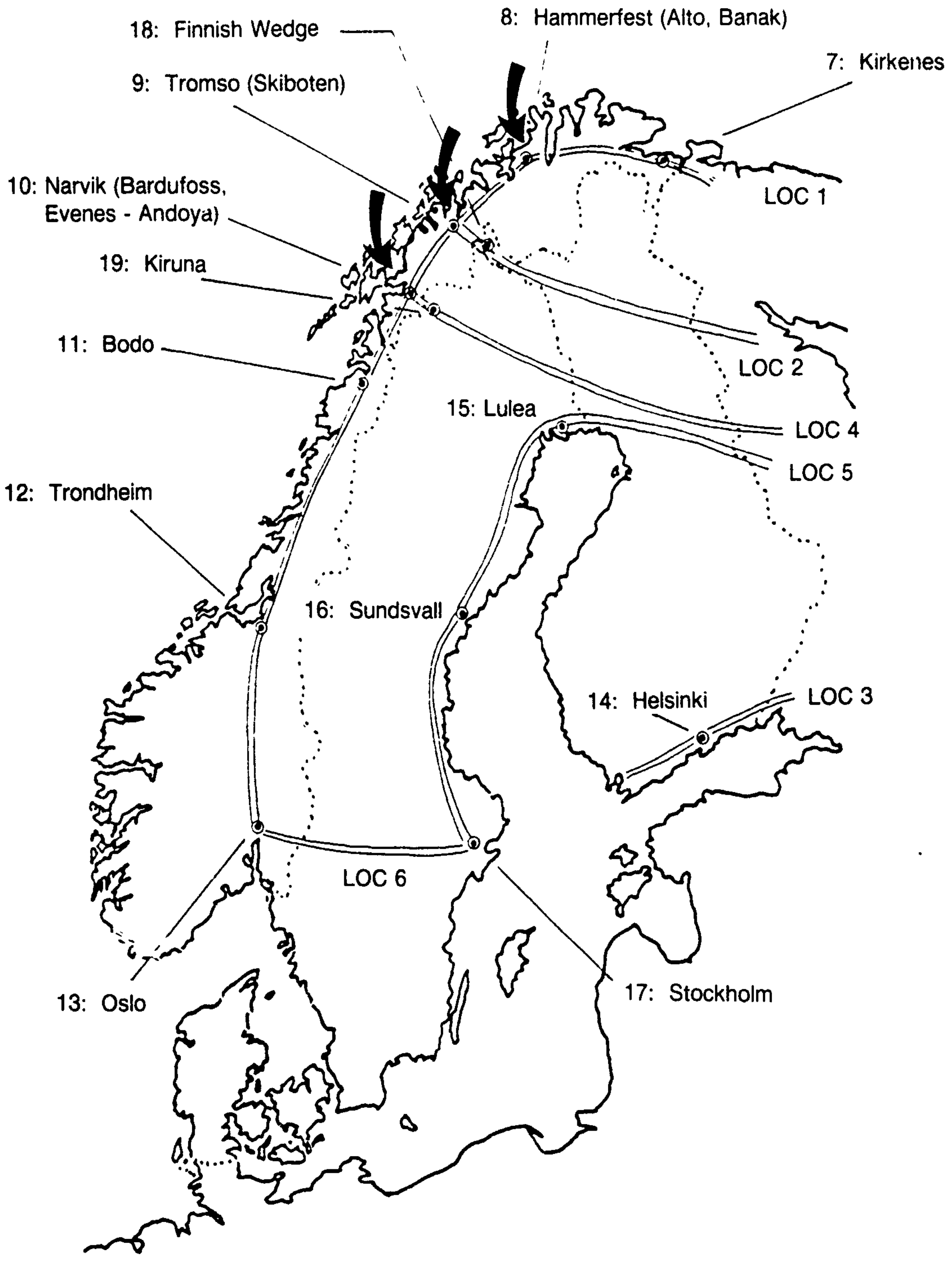

Fig. 3 -- Distributed Landing Option

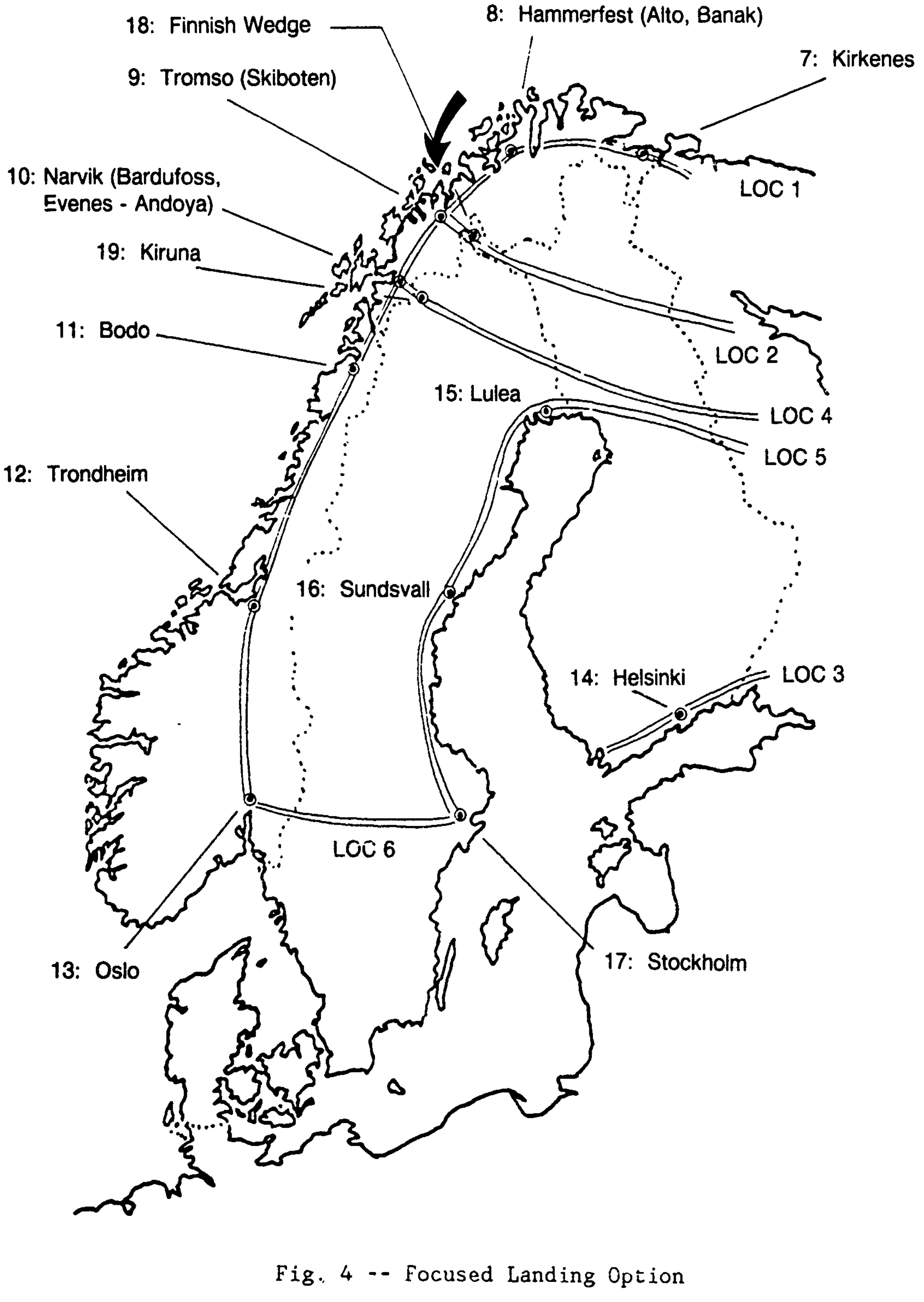

Fig. 4 -- Focused Landing Option

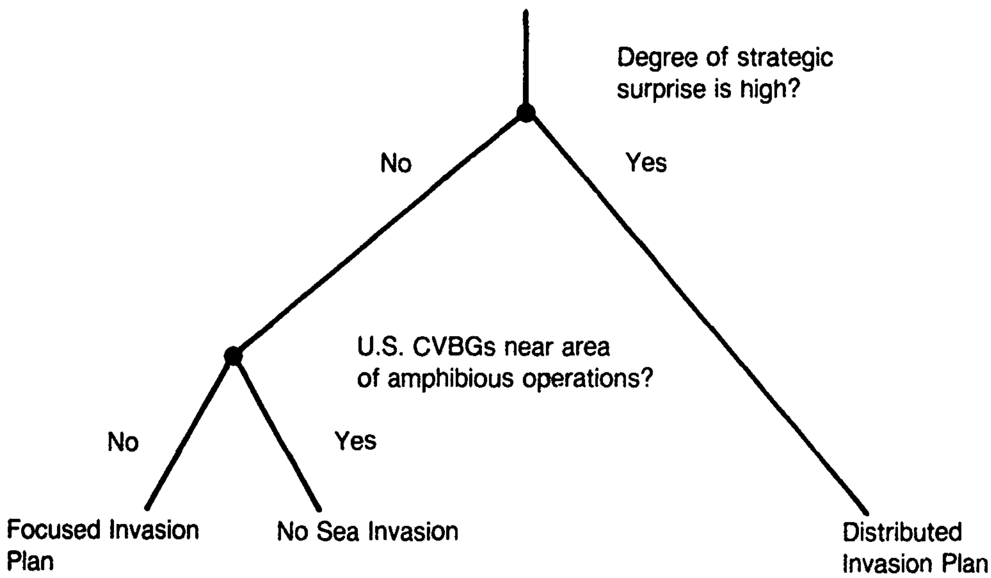

Fig. 5 -- Sample Decision Tree for Amphibious Options

IV. ONE EXAMPLE IN DETAIL

This section presents a sample airborne operation down to the details of the actual code. This airborne operation is assumed to be launched by the Soviets against Northern Norway. Only the RAND-ABEL tables and associated comments are shown. An example of how to read a RAND-ABEL table is presented first [Shapiro et al., 1985b].

HOW TO READ RAND-ABEL TABLES

RAND-ABEL tables usually consist of four elements. The first element is a comment, the second is a header, the third is the body of the table, and the last part is the end of the table statement. Anything between brackets [...] is considered to be comment and not executable code. These brackets may appear anywhere before, in the middle, or after a table (see Table 1).

The table header consists of the statement "Decision Table," followed by an optional table name comment and the required input and output variables to be used in this table. In the sample RAND-ABEL table, there are three input variables (A, B, and C), and two output variables (X and Y). Anything to the left of the slash marks "/" are input variables, while anything to the right are output variables. The equal signs "=" in a row delimit the end of the variable definition and the beginning of the body of the table that contains the values of these variables that will be examined. The final delimiter at the end of the row of equal signs is a period.

The main body of the table contains the values for each of the variables that will be examined. Each row is examined sequentially. The first row is read "if input-variable-A is equal to value-A-1 and input-variable-B is equal to value-B-1 and input-variable-C is equal to value-C-1, then set output-variable-X to value-X-1 and set output-variable-Y to value-Y-1." There may be as many rows and columns in the table as the user wishes to define. The first row that registers true simultaneously for all variables on the left hand side is the row that sets the values of the output variables on the right hand side. In this

Table 1

SAMPLE RAND-ABEL TABLE

```
[ COMMENTS:
  Anything between these brackets is comment and not executable code.
  Comments are used to document what is in the table and to provide an
  audit trail of the reasons or values in the following table. ]

Decision Table   [Unique name of table for purposes of identification.]

  input-       input-       input-       /  output-      output-
  variable-A   variable-B   variable-C   /  variable-X   variable-Y
  ==========   ==========   ==========   /  ==========   ==========.
  value-A-1    value-B-1    value-C-1       value-X-1    value-Y-2
  value-A-1    value-B-1    value-C-2       value-X-2    value-Y-3
  value-A-1    value-B-2    value-C-1       value-X-3    value-Y-4
  value-A-1    value-B-2    value-C-2       value-X-4    value-Y-6
  value-A-2    value-B-1    value-C-1       value-X-5    value-Y-7
  value-A-2    value-B-1    value-C-2       value-X-6    value-Y-8
  value-A-2    value-B-2    value-C-1       value-X-7    value-Y-4
  value-A-2    value-B-2    value-C-2       value-X-8    value-Y-5
  value-A-3    ++           --              value-X-9    value-Y-6
  --           ++           --              value-X-10   value-Y-7
[End Table].
```

kind of table, only one row will set the values of the output variables. Once this row is "triggered," the program exits from this table and proceeds to the next section of code.

The symbols "++" and "--" both mean "I don't care what value the variable in this column has, count it as returning a value of 'true,' thereby allowing that row to "trigger" regardless of the current value of this variable." For example, in the second to last row, as long as input-variable-A is equal to value-A-3, then regardless of the values of input variables "B" and "C," output-variable-X will be set to value-X-9, and output-variable-Y will be set to value-Y-6. The only difference between the two symbols "++" and "--" is that the former is used for variables that use numeric values such as "4.7" or "5," while the latter is used for enumerated variables that use nonnumeric values such as "High," "Blue," or "Bad." In our example, input-variable-B is assumed to be numeric, while the other two input variables are assumed to be nonnumeric.[1]

---

[1]A new version of RAND-ABEL distinguished "unspecified" (--) from "don't care" (**).

The last part of the table is the "End Table" statement, which determines the end of the values to be considered. Notice that the phrase "End Table" is a comment, while the actual end-of-table delimiter is the period. This format is used because it is easier to see an "End Table" comment than it is a trailing period.

The analyst may modify the existing tables by changing the values of the variables in the main body of the table. In addition, the analyst may prefer to add additional input or output variables to an existing table and define the appropriate values for these additional variables. Finally, the analyst may wish to add more tables to consider additional factors not yet accounted for in the existing tables. As mentioned above, the analyst may perform any of these changes even while the model is running.

Of course, some changes are easier to make than others. For example, if one is adding a variable to a table that is defined only for that function, then the change can be made using the RAND-ABEL interpreter while the model is still running. However, if the variable being added should affect, or be affected by, other functions, then the new variable must be added as a global variable. The latter case does require several more steps and requires the model to be recompiled. To help ease the problem, a number of dummy (or not currently used) global variables are defined. The analyst can use these global variables without recompiling, which aids in a faster response time and testing model development concepts.

There are also distinctions between the standalone version of the S-Land and the version incorporated in the full RSAS. In the standalone version, the analyst is free to define any variables, since all of the resolution of the model is contained in the standalone version. However, in the full RSAS version, what the analyst wishes to define may already exist somewhere else in the global database. In this case, a procedure to locate and access the desired values must be followed so that all parts of the model are using the same "ground truth" data. Although the full system version is more difficult, it does allow the analyst to access a global model rather than only a single theater as in the standalone case.

SAMPLE AIRBORNE LANDING OPERATION

The success of the operation will be a function of a variety of factors, including the degree of surprise achieved, the number of interceptors and escorts, the surviving landing force, the size and preparation of the defending force, and the missions of each side. The end result will be losses of ground and air forces on each side, damage to the target site, and possibly a change in the control of the target.

The first step is to calculate the local degree of surprise achieved by the operation. This is a function of the local air control and any strategic surprise that Red has achieved in the air war (see Table 2). This is actual RAND-ABEL code presented in the table. The first row of the table is read in the following manner: if the air control over the target belongs to the attacker AND the attacker's strategic air surprise is high, then the local degree of surprise for this operation is high. If the air control had instead belonged to the defender (fourth row), then the local degree of surprise would only be medium.

Table 2

AIR DROP DEGREE OF SURPRISE

```
Decision Table     [ Air drop degree of surprise ]
                   att-strategic-  /   local-degree-
  air-control      air-surprise    /   of-surprise
  ===========      =============       ============.
  att              High                High
  att              Med                 High
  att              Low                 Med
  def              High                Med
  def              Med                 Med
  def              Low                 Low
  --               High                High
  --               Med                 Med
  --               Low                 Low
  --               --                  Low
[End Table].
```

Any number of columns may exist on either side of the "/" symbol. *One may freely add or subtract columns on either side of the "/" symbol at any time, even when the model is running.*[2] In addition, *the values in the tables may be numbers, "soft" values* (like High, Medium, and Low), or equations, which allows the analyst to select different methodologies for different situations.

The output of the first table (degree of surprise) is then used as an input to the next table (see Table 3). The first row of this table is read "if the number of defensive counter air (DCA) sorties is less

Table 3

AIR DROP LIFT LOSSES

```
[ DATA NOTES:
  The airlift loss rate and the fraction lost on ingress are
  determined by the density of DCA aircraft, the ratio of
  interceptors to escorts, and the current air control over the
  target.  Numbers in the right columns are broadly based on informal
  discussions with analysts at SHAPE Technical Center and the Warrior
  Preparation Center. ]

Decision Table  [ Air drop lift losses ]
  DCA-     esc-                      local-degree- / lift-       frac-lost-
  sorties  sorties                   of-surprise   / loss-rate   on-ingress
  =======  ======================    ===========     =========   ==========.
  <50      >=(0.25 * DCA-sorties)    High            0.02        .30
  <50       <(0.25 * DCA-sorties)    High            0.03        .35
  ++       >=(0.25 * DCA-sorties)    High            0.07        .40
  ++        <(0.25 * DCA-sorties)    High            0.10        .45
  <50      >=(0.25 * DCA-sorties)    Med             0.05        .40
  <50       <(0.25 * DCA-sorties)    Med             0.09        .45
  ++       >=(0.25 * DCA-sorties)    Med             0.12        .50
  ++        <(0.25 * DCA-sorties)    Med             0.15        .60
  <50      >=(0.25 * DCA-sorties)    Low             0.10        .45
  <50       <(0.25 * DCA-sorties)    Low             0.15        .50
  ++       >=(0.25 * DCA-sorties)    Low             0.20        .60
  ++        <(0.25 * DCA-sorties)    Low             0.25        .70
  ++       >=(0.25 * DCA-sorties)    --              0.05        .50
  ++        <(0.25 * DCA-sorties)    --              0.10        .60
[End Table].
```

[2]See the caveats above regarding defining new local versus global variables.

than 50, and the number of escort sorties is greater than a fourth of the DCA sorties, and the degree of surprise is High, then the lift loss rate is 2 percent, and the fraction lost on ingress is a tenth of that. In other words, if there are few interceptors and sufficient escort when surprise is high, then there will be few losses to the lift aircraft and almost all of the landing force will arrive intact. Notice that the table is preceded by the DATA NOTES section of comment code that explains the logic represented by the table and the sources of the data.

After the landing force has been reduced by losses on ingress, the battle on the ground is then assessed. The next table determines the effects of terrain on limiting the opposing forces for this day's battle (see Table 4). In this table, only LOC chokepoints, or Landchoke, are distinguished because of their strong limitations on forces attempting to engage each other. These limitations are represented as the maximum force the attacker may bring to bear on the defender, the maximum force the defender may have deployed over this same frontage, and the minimum defenders required to hold this piece of ground for the better part of a day. For most types of targets, a minimum of a battalion is required to hold that target. However, in many mountain passes, a company may be sufficient to delay the attacker.

After the sizes of the engaged forces have been determined, the type of battle is determined (see Table 5). The first row is read "if there are not enough defenders to hold this piece of terrain, then the type of battle is a breakthrough," which means that the position will be overrun. Rows two and three declare that any fighting on NEUR-18 (the Finnish- Wedge) LOC chokepoint will be a special case depending upon the days of preparation available to the defender.

Notice that this table allows the analyst to focus on a particular target at a specific point in a given theater, without requiring every target at every point in every theater to be defined in the same amount of detail. This table allows the analyst to distinguish the type of battle fought on the LOC chokepoint at point NEUR-18 without requiring the analyst to uniquely define the type of combat at every other target in the theater. By contrast, many hex-based models require that all the terrain features for a given hex be defined for all hexes before the

Table 4

POINT TERRAIN EFFECTS TABLE

[DATA NOTES:
blue-arena - (Type-arena) the name of the blue arena of the blue/red pair. This column allows default lines for each arena.
blue-axis - (Type-overlay) the name of the blue axis of the blue/red pair
target - (Type-pt-axis-target) the name of the target at the blue-axis

max-att-EDs - (1.0) the maximum attackers allowed at the target to attack
max-def-EDs - (1.0) the maximum defenders allowed at the target to defend
min-def-EDs - (1.0) the maximum force necessary to maintain a credible defense--otherwise, the defending force is overrun, represented by the "breakthrough" type of battle.
EDs are defined to be Equivalent Divisions, where 1.0 equals one division.]

Decision Table

blue-arena	blue-axis	target	/	max-att-EDs	max-def-EDs	min-def-EDs
NEUR	NEUR-9	Landchoke		0.25	0.17	0.03
NEUR	NEUR-10	Landchoke		0.5	0.35	0.06
NEUR	NEUR-11	Landchoke		0.5	0.35	0.06
NEUR	NEUR-12	Landchoke		0.5	0.35	0.06
NEUR	NEUR-18	Landchoke		0.25	0.17	0.03
NEUR	NEUR-19	Landchoke		0.5	0.35	0.06
NEUR	--	--		0.75	0.52	0.1
NEUR	--	--		1.0	0.7	0.1

[End Table].

Table 5

POINT COMBAT TYPE BATTLE

[Determine type of battle]

Decision Table [Point axis type battle]

def-EDs	prep-days	blue-arena	blue-axis	target	/	battle
<min-def-EDs	++	--	--	--		Breakthru
++	>2	NEUR	NEUR-18	Landchoke		Prep-def
++	++	NEUR	NEUR-18	Landchoke		Delib-def
++	>3	NEUR	--	--		Delib-def
++	++	NEUR	--	--		Hasty-def
++	>3	--	--	--		Delib-def
++	++	--	--	--		Hasty-def

[End Table].

model can function. This requirement places a tremendous data input burden on the analyst.[3]

The next table determines the defender's loss rate and the exchange rate representing the number of attackers lost per defender killed (see Table 6). The first row is read "if the target is a landchoke and the type battle is a breakthrough, then the defender loss rate is 100 percent, while the exchange rate is half that number." Notice that for any other type target, the exchange rate is lower for a breakthrough

Table 6

POINT COMBAT LOSS RATES

[NOTE:
The defender's loss rate (DLR) and exchange rate (ER) equations are simple approximations of Lanchester equations as defined in CAMPAIGN-MT for CEUR corps-sized LOC battles. However, they have been modified in these tables by increasing the numerator in the DLR equations. The point battles tend to be more intense because smaller units are engaged. The exchange rate tends to be higher in urban terrain.]

Decision Table [Point loss rates]

target	battle	FR	/ DLR	ER
Landchoke	Breakthru	++	1.0	0.50
Landchoke	Hasty-def	++	(.25 * FR / (FR + 2.80))	(7 / (FR + 1.8))
Landchoke	Delib-def	++	(.21 * FR / (FR + 3.00))	(13 / (FR + 2.0))
Landchoke	Prep-def	++	(.18 * FR / (FR + 3.23))	(17 / (FR + 2.0))
Airfield	Breakthru	++	1.0	0.20
Airfield	Hasty-def	++	(.34 * FR / (FR + 2.80))	(6 / (FR + 1.8))
Airfield	Delib-def	++	(.28 * FR / (FR + 3.00))	(12 / (FR + 2.0))
Airfield	Prep-def	++	(.24 * FR / (FR + 3.23))	(16 / (FR + 2.0))
--	Breakthru	++	1.0	0.25
--	Hasty-def	++	(.25 * FR / (FR + 2.80))	(8 / (FR + 1.8))
--	Delib-def	++	(.21 * FR / (FR + 3.00))	(14 / (FR + 2.0))
--	Prep-def	++	(.18 * FR / (FR + 3.23))	(18 / (FR + 2.0))
--	--	++	0.1	1.0

[End Table].

[3]The problem is not limited only to hex-based models but to any model whose data structure requires every terrain element be defined to the same level of detail before the model can operate.

since it is easier to "root out" the last defenders. Airfields are comparatively easy to "mop up."

The next table allows the model to account for different climatic conditions to be represented. This is not "playing weather" but rather the effects of season in a general way. For example, when determining air sortie generation, the hours of daylight in Northern Norway vary widely between summer and winter. Similarly, the ability to perform ground combat and maneuver is also affected in a general way by seasonal factors (see Table 7). The default season is always the Fall (in the Northern Hemisphere) for consistency between theaters.

The last table represents the damage to the target resulting from a division-sized unit with the specified mission fighting over that type of target (see Table 8). Keypoints in this case are assumed to be soft targets like intelligence collection stations. One may also specify a different type of target for different points in different theaters.

Table 7

POINT GROUND COMBAT LOSS SEASONAL MULTIPLIERS

```
[ Determine climate factors ]

[ DATA NOTES:
  The numbers in this table are guesses. However, Fall is the
  default season. Winter reduces the intensity of the war but also
  reduces attacker's ER due to shorter line of sight. Spring has a
  thawing period in NEUR that makes it difficult to maneuver. Summer
  has a lot more small lakes in NEUR, making the effect similar to
  Spring. ]

Decision Table  [ Point axis ground loss seasonal mults ]
  blue-           /  season-   season-
  arena  Season   /  DLR-mult  ER-mult
  =====  ======   /  =======   =======.
  NEUR   Spring      0.8       1.1
  NEUR   Summer      0.7       1.1
  NEUR   Fall        1.0       1.0
  NEUR   Winter      0.6       0.9
  --     --          1.0       1.0
[End Table].
```

Table 8

POINT COMBAT DAMAGE RATES

Decision Table [Point combat damage rates]

target	att-mission	def-mission	/	%-damage-per-att-ED	%-damage-per-def-ED
Keypoint	Occupy	Occupy		0.25	0.00
Keypoint	Denial	Occupy		0.50	0.00
Keypoint	Occupy	Denial		0.10	0.80
Keypoint	Denial	Denial		1.00	1.00
--	Occupy	Occupy		0.15	0.00
--	Denial	Occupy		0.30	0.00
--	Occupy	Denial		0.15	0.40
--	Denial	Denial		0.40	0.50
--	--	--		0	0

[End Table].

V. CONCLUSIONS

This new approach has some distinct advantages over previous simulation methodologies. The methodological advantages include transparency and flexibility because of the table structure and the interpreter feature, allowing changes to be made while the model is running. This appears to be a significant advance the state of the art.

The advantages to this application (CAMPAIGN-ALT) is that it is modular by functional area, may be selectively modified by the analyst, is fast enough to be used in a quick-analysis global model, and follows the logical progression of a planner who is preparing a concept of operation or a campaign plan. S-Land allows the RSAS to represent a large number of theaters of operation in a manner allowing focused resolution on certain areas of interest, without requiring a large amount of memory or computation time. In particular, it allows the analyst to focus on key interactions of strategic or operational interest at any time during the running of the system, without the massive overhead of attempting to represent every possible event in detail.

S-Land has been designed with expandability in mind. The major variables, such as air, coastal, and ground control, will not be replaced or made obsolete. Instead, the definition of these variables and their represented effects on the rest of the model will be refined. Other variables may need to be added to aid in the refinement process. For example, the air approaches to a particular target area may have a major impact on the sortie rate and survivability in a sector. The variable "air approach status" may be defined in addition to "local air control" to either modify the influence of the "local air control" variable or to modify the variable directly. In either case, "air control" is a general enough concept that it will always be apart of the model even when the model expands.

Every model has its limitations and S-Land is no exception and certainly no panacea. While many significant changes are easy to incorporate with a minimum of programming expertise, others are not. For example, if one wants to show sensitivity to something for which there is no currently defined variable, then one may need a programmer's assistance to define the variable and specify how it can be evaluated with available information. In addition, as one increases complexity--as is the usual tendency, whether or not the complexity is objectively justified--then the number of rules may increase rapidly. Rule expansion will be particularly great in theaters with numerous nodes and links (e.g., an Iran rather than an Iceland). New rules and concepts should not be frequently included without an overall design goal in mind, but such expansion can be straightforward and clarity can be maintained if a strong-willed analyst maintains control. Finally, it should be noted that the modeling of command-control is inherently difficult, and the first-generation S-Land models are unabashedly simple in this regard and in other areas, such as logistics representation.

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