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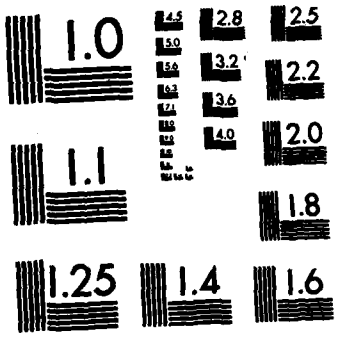

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IMPROVING THE MILITARY CONTENT OF STRATEGY ANALYSIS USING AUTOMATED WAR GAMES: A TECHNICAL APPROACH AND AN AGENDA FOR RESEARCH

Pa . K. Davis, Cindy Williams

J e 1982

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Prepared for

Defense Nuclear Agency

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The Rand Strategy Assessment Center (RSAC) seeks to improve U.S. strategy analysis by combining the best features of political-military war gaming and analytic modeling. Earlier Rand work demonstrated the feasibility of automating the war game by replacing some or all teams by computer models based on artificial intelligence techniques. This Note describes new concepts for building a high degree of military content into the automated war games. The concepts involve rule-based logic structures that we call "analytic war plans," and higher-resolution versions that we refer to as "branched scripts." These logic structures define the range of strategies and grand tactics from which the computer models ("Red Agent" and "Blue Agent") can choose. The Note also describes our intended approach to combat modeling and explains how we intend to achieve realism and to reflect effects of numerous special phenomena usually ignored by modelers (e.g., attacks on C^3I systems and disruptions of rear areas). The concepts in this Note will play a major role in RSAC development over the next several years. They are intended to provide ample opportunity for ambitious evolution.

A RAND NOTE

IMPROVING THE MILITARY CONTENT OF STRATEGY ANALYSIS USING AUTOMATED WAR GAMES: A TECHNICAL APPROACH AND AN AGENDA FOR RESEARCH

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PREFACE

This Note, largely completed in the spring of 1982, describes new and tentative concepts for use in the Rand Strategy Assessment Center (RSAC), a large, ambitious, and high-risk program supported by the Director of Net Assessment in the Office of the Secretary of Defense, and facilitated by the Defense Nuclear Agency, under Contract No. DNA001-80-C-0298. Because many of the ideas expressed here are new and imprecise, and because they are intended to help guide a substantial research effort, comments and suggestions are especially welcome. Please contact Dr. Paul K. Davis, Director of the Rand Strategy Assessment Center.

SUMMARY

BACKGROUND

The Rand Strategy Assessment Center (RSAC) seeks to improve U.S. strategy analysis by combining the best features of political-military war gaming and analytic modeling. War gaming provides a rich context for analysis by imbedding events such as a given strategic nuclear exchange in the framework of a larger war. War gaming also brings out clearly: asymmetries between antagonists, the role of nonsuperpower countries, the shadow that nuclear forces cast over events below the nuclear threshold, and a wealth of phenomena and operational constraints often ignored by modelers. Past war games have had human teams, and have most often been used for training. Although valuable, the games have usually been slow, narrow (treating only one scenario), undisciplined, and unreproducible.

The RSAC's objective is to find ways to make war gaming more efficient, rigorous, and analytical. Our approach involves artificial intelligence techniques producing computer models able to act in place of some or all of the human teams. This speeds game play, allows us to examine many scenarios, and--very importantly--imposes a rigorous discipline requiring statements of assumptions and rationale. Human teams can still play, all or part of the time, but the intention is to capture most of the human-expert contribution in background research providing decision rules, heuristic combat models, and a menu of plausible strategies.[1] The human analyst can then control the variables as he examines a range of different situations.

[1] See Davis and Winnefeld (forthcoming) for a comprehensive overview of the RSAC and its application as seen in September 1982.

Although an early RSAC breadboard system demonstrated the general feasibility of automated war gaming in January of 1981, it remained to be seen whether the automated war games could be provided enough military content to make them truly valuable. This Note describes new concepts for providing that content. In our view, they are logical and compelling--if not yet refined or tightly defined. However, they also constitute an approach greatly at variance with more traditional ones.

ANALYTIC WAR PLANS

A unifying principle for RSAC work is the concept of "analytic war plans": logic structures that attempt to describe with some rigor the many high-level decisions the United States and Soviet Union would need to make during conflict. These analytic constructs differ markedly from formal U.S. war plans, but the issues they capture are important to real-world planners--whether or not those planners write down the issues. The decisions involve military objectives, strategy, theater-level tactics, escalation, and termination. The logic structures allow antagonists to look ahead and to change plans in the course of conflict to reflect changes in: the current or projected military situation, political alignments, observed antagonist behavior, and prospects for unintended escalation. The rules determining the decisions made in the logic structure have become a major focus for RSAC research.

Given sets of analytic war plans, RSAC computer automatons[2] representing the United States and Soviet Union will be able to "play

[2] Mechanisms that are relatively self-operating and take the place of human observation and decisionmaking.

chess" against each other in a representative domain of actions intended to be operationally realistic.

The analytic war plans permitting this are abstract rule-based generalizations of decision-theory "trees." We do not (and often could not) draw out the trees in detail. Also, the uncertainties that plague the game's superpower automatons differ from those in normal decision theory. For example, the Red player is unsure of the behavior pattern of his opponent, as well as unsure about the outcomes of possible battles.

Analytic war plans deal with events and decisions at the level of strategy and grand tactics. To each analytic war plan, however, we associate a "branched script," which represents a higher-resolution view. "Scripts"--consistent with normal use of the term--give a time-sequenced overview of "the story." Here, the story is the military campaign, with the script's branches occurring where there are decision points, uncertain battle outcomes, or special phenomena, which may or may not occur. Some of the branches correspond directly to those in analytic war plans, but others deal with higher-resolution tactical-level issues. Current RSAC work bases the scripts rather rigidly on background research describing plausible military operations in some detail. A script may specify that a battle's outcome be calculated with a particular combat model, or it may itself prescribe results of battle (and related uncertainties)--on the basis of expert judgment, historical data, or background modeling. As RSAC work proceeds, our scripts will become increasingly flexible, with more of the game events determined by on-line combat models and decision rules, and with detailed force

operations being "tuned" to the particular game context (see Steeb, Gillogly, and Allen, forthcoming).

The set of branched scripts used in RSAC war games determines the diversity of scenarios (the "scenario space") that can emerge in the course of the games. A particular scenario corresponds to a particular path through the branched-script structure. What path a game follows depends on the numerous assumptions on which RSAC analysis must focus. Thus, RSAC war games generate scenarios rather than begin with them.

TREATMENT OF THE COMPLEX PHENOMENA OF WAR

One unusual tenet of our approach is that we prefer to prescribe game events by using "scripted models" (i.e., by writing the game events into the branched scripts in some detail) when the alternative is either to use combat models with little credibility or to ignore certain phenomena altogether. Thus, our approach is in some ways closer to that of military war games with experienced officers dictating events (and a Control Team postulating troublesome but plausible "special events") than to simulation models. However, because we record the logic structures and decision rules, our war games can be analytic as well as largely automatic.

Among the many phenomena whose effects on strategy-level developments we wish to study with RSAC analysis are: disruption of strategic command, control, and communications (C^3); initial Soviet breakthroughs in Europe; rear-area disruption; and the shock use of chemical or tactical nuclear weapons. Typically, we will model the aggregated-level response to such phenomena rather than describe precisely how the phenomena occur. So, for example, it is important to model our ability to contain a postulated surprise breakthrough even if

the breakthrough "should not" occur; similarly, we will measure the significance of certain disruptions to strategic-nuclear C^3 without simulating the cause.

COMBAT MODELS

The last section of this Note describes our current thinking about the combat models needed for a mature RSAC. We intend the basic model, Campaign, to have at least three distinguishable functions:

- Supporting the war game's flow by dynamically updating data bases on forces worldwide and capturing real-world constraints on force operations.
- Describing force movements, results of battles, logistics operations, and so forth; also, making calculations to reflect some of the many uncertainties attending all projections of battle outcome.
- Displaying relevant military information in ways useful to those involved with the analysis or the resulting discussions and demonstrations.

Because the RSAC's charter is to focus on strategy-level issues, and because issues at that level are already highly complex when due account is paid to interrelationships among theaters and other factors, we believe that RSAC on-line force models should be highly aggregated and parametric. Furthermore, the variables under the control of the analyst should be those of interest at high levels rather than those of interest to model builders working upward from the microscopic end of the problem.

As discussed in the text, there is (and has long been) a need for hierarchies of force models, hierarchies that would allow the analyst to work at several levels of detail and to "calibrate" parameters of the aggregated models to results of the more detailed treatments. It is

possible to make substantial progress in this realm with proper coordination of efforts among different research groups in Rand, the government, and elsewhere. We note, however, that developing a hierarchy of simulation models is highly desirable, but not sufficient. The reason is that many aspects of war cannot be simulated in mathematical models and even if experts could agree on the appropriate variables (which would include leadership, morale, weather, and acts of God), there exists no data base from which reliably to measure the effects of the variables. It is also difficult to evaluate many of these variables in advance. These problems cannot be solved by additional historical research or by measurements on the test ranges, valuable though both efforts can be.

The lesson from this is not to ignore the "soft" variables--they are too important to ignore further--but rather to recognize that mathematical models can do little more than remind us that the soft variables exist. We believe, as a result, that it is appropriate, even as a matter of principle, for RSAC analyses to focus largely on the variables and distinguishable cases of aggregated (parametric) models, and to consider uncertainties at that level directly rather than to attempt uncertainty analysis by constructing an ultimate simulation model treating the tractable variables with Monte Carlo techniques. The purpose of more detailed models, including those with a high level of human participation, should be: (1) to identify the key variables and uncertainties to highlight in aggregated models and RSAC war games; (2) to improve the quality of expert judgment calibrating aggregated models; and (3) to provide recipients of analysis an occasional zoom-lens view of <u>illustrative</u> events at lower levels. We do not believe that <u>detailed</u>

models (e.g., TACWAR or the Advanced Penetration Model) should usually be conceived as plug-in modules for use in the basic on-line RSAC war games.

The technical design of the Campaign model will include some innovations. One concept in particular, generalized event scheduling, appears to be important for giving Campaign the flexibility and growth potential it needs. The basic requirement motivating the approach is that users must be able conveniently to vary operations, strategies, and preferences (in addition to varying force levels and the like, which is standard). Examples include alternative time-phased deployment lists and alternative time-phased employments of strategic nuclear weapons. This will require the builders of Campaign to anticipate as many alternative "event schedules" as possible, and to include the associated analytics in the baseline model. Furthermore, Campaign's interface with the user must explain the alternatives available. Although providing the user with different options or cases is part of almost all force models, we expect Campaign to go much further in this direction than is usual. Moreover, to improve computing efficiency and minimize glitches caused by on-line program changes having unanticipated ripple effects, we plan to include the options as "generalized <u>data</u> streams" rather than as part of the hardwired program.

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I. INTRODUCTION

> Strategy: the art and science of employing the armed forces of a nation to secure the objectives of national policy by the application of force, or the threat of force.

Research in the Rand Strategy Assessment Center (RSAC) is attempting to strike a balance between the virtues of analytic models for assessing combat outcomes and the richness of political-military war games. Research in the RSAC has demonstrated the feasibility of adopting the basic structure of the traditional war game while largely replacing the players with programmed automatons--automatons adequate for many types of analysis. These automatons are referred to as the Red Agent (representing Soviet behavior), the Blue Agent (representing U.S. behavior), and the Scenario Agent (representing the behavior of other countries). This RSAC system also includes a Force Agent responsible for keeping track of all the forces and targets and describing the results of conflict. The Force Agent must also support the decisionmaking processes of Red, Blue, and Scenario by estimating potential military outcomes under a variety of options. The basic structure of the RSAC system has been described elsewhere, and several publications on the Red and Scenario Agents have been completed or are in progress.[1] This Note (completed in Spring 1982) deals largely with

[1] See Davis and Winnefeld (forthcoming) for an overview as of September 1982. The original Rand concept for automated war gaming is described in Graubard and Builder (1980) and in unpublished work by James Dewar. Scenario Agent is described in Dewar, Schwabe, and McNaugher (1982) and in Schwabe and Jamison (forthcoming). Pioneering work underlying the Red Agent is described in Jones (1974 and 1979). Recent work is reported in Jones, LaCasse, and LaCasse (forthcoming). An advanced Red Agent is under development by Steeb, Gillogly, and Allen (forthcoming).

the Force Agent and the force models needed to support RSAC analysis. However, the ideas described here are having a major effect on all aspects of the RSAC system.

Multiple challenges face designers of the Force Agent. First, it is technically complicated to develop an interactive game-supporting computer program to keep book and supply information to Red, Blue, and Scenario Agents. (Michael Mihalka and Arthur Bullock of Rand developed an early program of this type, Foment, in connection with several studies supported by the Air Force and OSD.) The second-generation Force Agent program, Campaign, is being designed from scratch but will incorporate many of the game-related technical features of Foment. These topics are the subject of Sec. III.

The second challenge is to acquire a set of models suitable for the many military assessments needed in the course of a game: models describing the effect on targets of an attack by a specified set of nuclear weapons, the rate of movement in conventional warfare, and so on. Foment provided primitive models for the first-generation RSAC system, but substantial improvements will be necessary for Campaign.

There is a third challenge (for the RSAC as a whole, not just designers of Force Agent), which goes beyond what was attempted in the first-generation system and the Foment model: describing possible "real wars" in such a way as to bring out key issues of strategy, grand tactics,[2] and battlefield tactics (especially for theater war). The

[2] We sometimes use the term "grand tactics" in referring to the realm between mere battlefield tactics and strategy. The decision to make an amphibious landing at Inchon was an example. Grand tactics are decided by military leaders.

problem here is not so much the inadequacy of Foment in particular as it is the general paucity of models suitable for coping with the full range of phenomena of interest. As noted early-on to the authors, by Andrew Marshall, models have become highly sophisticated and detailed with respect to certain aspects of warfare (such as target damage, attrition, and logistics) but have ignored or treated only crudely a wide range of other aspects (such as maneuver warfare, shock effects, and unconventional operations--to say nothing of leadership and morale). Furthermore, the usual tendency is to force criteria and objectives into quantitative terms (for example, using force ratios as criteria and advancing to a certain line as an objective). This may be adequate for some purposes but suppresses many features of war that are difficult to capture in a few quantitative algorithms.

In developing a second-generation RSAC system, we are making fundamental departures from past patterns in modeling by focusing on such matters as:

- military and political objectives;
- options for strategy and grand tactics;
- descriptions of the likely and possible courses of the war (that is, the timelines for strategically significant events);
- the constraints imposed by ever-changing political factors;
- real-world inefficiencies in decisionmaking, especially when deception is at play; and
- the many uncertainties that exist regarding the behavior of an adversary and other countries' behavior, the technical performance of systems and armies, the nature of modern war, and the ability to achieve surprise or to be surprised.

The net effect of this emphasis is to move away from the simpler forms of modeling and closer to the techniques used by war planners.[3] However, what we seek is a synthesis rather than a choice. War planning is, to some extent, an art subject to the idiosyncrasies of the general officers and political leaders of the time. For analytic purposes in evaluating alternative force structures or broad national strategies, we need to extract illustrative features of the art and to reflect them in what amounts to a different type of model. The technique the RSAC is using is described in Sec. II.

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[3] It is interesting to note that the direction of RSAC work is consistent with the recently expressed suggestions for strategic analysis made by John Battilega after extensive study of Soviet planning style (see Battilega, 1981). See the recent trenchant comments by Michael Howard (1979).

II. ANALYTIC WAR PLANS AND BRANCHED SCRIPTS

A fundamental hypothesis in our work is that the number of options for strategy and grand tactics in a real war can usually be bounded so long as one suppresses matters of detail (for example, the precise timelines for a plan or the precise allocation of forces). This is true because of certain objective factors (such as the limited number of key cities, ports, and military installations), the difficulty of continuously fine tuning a major operations plan involving multiple commands, and limitations imposed by doctrine and equipment. For the purposes of analysis, it should not be necessary to consider all possible strategies and grand tactics. For example, if we test alternative future force structures in a well-chosen but finite range of war games, in each of which the adversary's options are again well-chosen[1] but limited in number, the tests should be valid measures of the robustness of our capability. Even though what might arise in a real war could be significantly different in its details, it would have enough in common with the test cases to imply capability for the "real" cases. It is essential, therefore, to include in test cases controversial strategies and grand tactics.

Unfortunately, an extreme version of this view has usually been applied, a version in which very few scenarios, virtually devoid of tactics, are examined. The feeble rationale put forth is that decisions on force structure must not consider tactics, because tactics for future

[1] Choosing such options is not an easy task. It is essential, for example, that they include significant departures from conventional wisdom about adversary actions. However, they must obviously pass some test of plausibility or the number of options will explode. Open mindedness is important here, as is the existence of serious research on other than best-estimate cases.

conflict are impossible to predict with confidence. Among the many penalties for such an approach has been the much-decried American "mind-set" focused on firepower and attrition and insensitive to operational issues. In effect, analyses that may have been useful for defense programming also provided the language and paradigms that subsequently permeated U.S. strategic discussion, even much of the thinking of military officers, whom the programmers assumed to be more concerned with tactics. This phenomenon has been discussed at length by Steven Canby and Edward Luttwak in a number of publications over the last decade.[2] Recently, it led to a decision by the Army's Chief of Staff, General Edward Meyer, to change substantially certain aspects of Army doctrine, increasing its emphasis on maneuver. Meyer has also strongly supported a shift toward unit integrity, away from the long-standing individual replacement system. This will probably have little effect on the standard measures emphasized in system analysis, but is expected to have a major effect on unit cohesiveness and thus on battle outcomes.

Another effect of the excessively simple programming scenarios has been to further discourage what is difficult in any case: development of models treating such operationally rich phenomena as surprise breakthroughs and strategic use of airborne forces--even though the Soviets have high respect for the quick, daring, and decisive operation (Despres et al., 1976) and even though they are becoming increasingly capable of carrying out such operations. As a result, the menu of models available for RSAC use is limited, although there do exist some complex computer-assisted war-gaming systems/models capable of treating some of these phenomena with human players.[3]

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[2] See Luttwak (1979), Canby and Luttwak (1979), and Gray (1981). For balance, see also Mearsheimer (1982).

[3] We have in mind BDM's ICOR, INWARS, and BAM models, and the Army's McClintic (see U.S. Army War College, 1981).

So far, our examples have involved conventional warfare. However, the same problems outlined above plague us in the realm of strategic nuclear forces (Ermarth, 1978), especially for treating wars lasting days or weeks, or for wars involving surprises such as special operations against U.S. command, control, and communications. It is notable that most unclassified discussions of advanced systems such as ballistic missile defenses ignore the dependence of such systems on early warning systems that might be destroyed long before the classic massive exchange.

ILLUSTRATIVE PHENOMENA TO BE REFLECTED IN WAR GAMES

Table 1 lists some specific effects that currently are not treated well in force models, particularly those simple enough to be suitable in an automated war game.[4]

These phenomena are troublesome in different ways. In some cases, modeling is conceptually complicated. Consider, for example, the effects of terrain. For mature theaters such as Korea or the NATO/Warsaw Pact region, it is possible to develop detailed analogue or digital representations of terrain, and to model firepower-related phenomena in the preferred killing zones. However, when the nature of combat is only uneasily related to firepower, the conceptual problems are formidable for would-be modelers. An example here is the problem of defense in rugged mountains with only a few main roads. History

[4] Wise analysts have, of course, worried about the troublesome phenomena for years. Moreover, there exist some studies in which simple models have been modified creatively to gain insights about phenomena such as breakthroughs or the feasibility of alternative strategies. It is precisely this approach that we hope to expand upon and systematize. An example of this approach is the MASTER model under development by Weiner and Wagner at Rand.

ways. Table 2 provides three examples. Let us consider the second one in some detail.

The Soviet Union undoubtedly has agents in the United States with a wartime mission of destroying key command and control installations such as the ground stations for the early warning satellite system. Although the agents are present, opinions surely differ about their likely effectiveness. However, if they were successful, they would have a very large effect. It follows that we should incorporate such agent attacks in some of our RSAC war games. Moreover, we should account for the

Table 2

ILLUSTRATIVE MAPPINGS OF PHENOMENA TO MODELS

Phenomenon	Significance	Implementation in Models
Special-operations units destroy specialized cranes in Persian Gulf port.	Some ships cannot unload. Others must use "Over the Shore" logistics.	Increase unload time for some ship classes, and allow time for others to transfer cargo to amphibious ships in Saudi Arabia (i.e., add standard delay times dependent on ship class).
Covert in-place agents in United States and allied countries destroy ground stations of early warning satellite systems (DSP).	Reduces warning time for bombers, ICBMs, and NCA. Degrades BMD systems. Affects Blue Agent attitudes.	Decrease bomber prelaunch survivability, especially against SLBM attacks; initiate airborne alert and associated degradation-with-time models if appropriate; decrease likelihood of successful launch under attack except for first days after loss of ground stations.
Surprise early Pact penetration on Central Front (faster-than-anticipated massing of forces).	May allow devastating Pact breakthrough.	Allocate Soviet forces among axes of advance consistent with a surprise breakthrough attempt. Start land-warfare models and test NATO ability to contain the Soviet penetration.

probable effects of such attacks. Note that it is not necessary to include a simulation model that would describe precisely how the attacks would take place, how many people would be involved, and so on. What is needed, however, is a mapping from the event's occurrence in a particular war game to procedures in using the Force Agent. In this example, one mapping would be to the bomber prelaunch survivability model, which relates bomber survivability to such variables as the number of Soviet submarines off the coast of the United States, the state of bomber alert, the technical characteristics of Soviet SLBMs and U.S. bombers, and warning time for launch of Soviet SLBMs. If, in the game, covert agents destroyed key ground stations, that fact should affect bomber warning time appropriately and perhaps should affect the feasibility of launch under attack for U.S. ICBMs.

The last example in Table 2 shows a somewhat different type of mapping. That "event" is successful Soviet surprise and deception allowing them to mass forces without being detected. This type of event occurs frequently at the tactical level in war, but the RSAC does not seek to follow events at that level (e.g., battalion maneuvers). In the defense of Europe, however, a sufficiently large massing of forces could have strategic significance--primarily because NATO's forces have little depth. If the Soviets successfully penetrated before NATO's operational reserves could envelop the Soviet forces, there would be a classic "breakthrough operation" that might well devastate NATO's overall defensive strategy. The RSAC cannot hope to simulate details of such operations, or to reflect the full range of possible breakthroughs. However, there is ample research available to construct the conditions

for "representative" operations of the sort we fear. What Table 2 suggests is that in RSAC war games in which the Soviets are credited with successful surprise and deception leading to an early penetration on the Central Front, the Force Agent calculations would be performed using the representative situation. This would mean using a data base in which unsuspecting NATO forces are allocated normally along the Central Front, but Soviet forces are massed for a breakthrough at one or more points. The basic theater-warfare model would then be used to determine the consequences. If NATO's operational reserves were ample, alerted, and fast-moving, the penetration might be contained. If not, the penetration might expand into a "breakthrough," which in turn would mean a massive defeat of NATO forces in that region.[8]

There is nothing new in using simple preexisting models to address relatively complicated questions for which the models were not specifically developed. Good analysts do this all the time in answering quick-response questions. However, for RSAC purposes we will need to expand upon and systematize this procedure with explicit mappings thought out in advance. Otherwise, we will not be able to incorporate in RSAC war games many of the phenomena such as those in Table 1.

The Need for Multiscenario Analysis

As mentioned above, not all of the items in Table 1 are difficult to model. Some are troublesome only because they are controversial. The scenarios chosen for many government analyses (often chosen by committee) focus on one or two basic situations and seldom contain controversial tactics or strategies--not out of ignorance but because

[8] The authors thank Richard Kugler of the Office of the Secretary of Defense for suggestions on how to model the envelopment of a penetration easily.

the difficulty of handling more than one or two scenarios forces an emphasis on the alleged best estimate.

To make matters worse in this regard, such analysis often revolves around the special demands of programming force structure in-the-large. In such programming analysis, it would be inappropriate to have the war game stop at an early point because of a fluke of a horseshoe nail or clever adversary tactics. Consequently, the planning scenarios tend to disregard such distracting problems. But then, the programming scenarios tend to be used far more generally--to become the currency of debate and discussion.

One of the problems facing the RSAC, therefore, is not simply finding suitable models, but including as well a broad range of challenging scenarios that permit exploration of the varying aspects of conflict. One possible approach to this problem would be to develop a large set of crafted and detailed scenarios, and to analyze each in the traditional manner. Examples of such stressing scenarios can be found, for instance, in studies on possible Soviet views of nuclear war (Russell Shaver and colleagues at Rand), in detailed scenarios of conventional crisis leading to nuclear conflict (Eugene Durbin and others at Rand), and in scenarios describing NATO's reaction in crisis (Earl Boyd and Rand colleagues). Also, Joseph Russell at Boeing Aerospace Company and C. Makins and others at Science Applications, Inc., have studied how stressing scenarios can be used to test U.S. capabilities for protracted war.

The difficulty with detailed traditional analysis of many such scenarios is that, except in the case of pure strategic nuclear warfare, it has been manpower-intensive and, often, not very "analytic." In

practice, people do not perform multiscenario analyses except when models are efficient and the definition of "scenario" reduces to something simple (e.g., "bolt out of the blue" vs. "generated alert").

With this background, the ability to analyze large numbers of scenarios rich in military detail has been a major objective of the RSAC from its inception. It is for this purpose that the technique of automated war gaming should be most powerful, and it was with this requirement in mind that we are developing an analytic technique involving "analytic war plans" and "branched scripts." A motivating force has been the need to be able to treat a broad range of scenarios and phenomena such as those in Table 1. Some of the basic principles in our approach are as follows:

- The RSAC agents should be able to treat a representative set of wars at a level sometimes called "campaign analysis."
- At the level of strategy and grand tactics, we will draw on the campaign analysis and use logic structures called "analytic war plans" to describe the many decision points and other branch points (e.g., effects of unpredictable third-country decisions) that would be faced by the United States and Soviet Union in conflict.[9]
- As a mechanism for implementing the analytic war plans in games, and for introducing into the games a higher level of tactical detail, we will use "branched scripts," a generalization of the scenario approach long used for military emphasis,[10] but one emphasizing analytic

[9] The problem of choosing adequately complete sets of war plans for analysis applies to scenarios, alternative characters for the Red Agent and the other countries reflected in Scenario Agent, and alternative strategies and grand tactics for the Blue Agent. Unfortunately, there is no rigorous linear algebra of scenarios describing how one proves "completeness." Also, a robust set of branched scripts will not a complete analysis make unless the agent rules are balanced enough to assure that games will indeed spin out a broad range of scenarios using the branch structure available.

[10] One motivation for the term "script" is that we are developing an advanced Red Agent using a variation of an artificial intelligence technique known as the script approach (see Steeb, Gillogly, and Allen, forthcoming). Another motivation is that war plans with multiple variations based on developments in the campaign "look" like branched

rigor.[11] There is a one-to-one correspondence between top-level analytic war plans and the more detailed branched scripts.

- The set of war plans and branched scripts used in an RSAC analysis will define the "scenario space"--i.e., the set of all possible scenarios that can unfold in the RSAC games.

- As necessary, to insert interesting phenomena of military operations, some script details will be prescribed on the basis of off-line research (such as mobilization times, degree and implications of surprise); other aspects will be dealt with during the game by on-line calculations using various combat models (such as movement of forces by strategic lift, movement of the FEBA during attrition warfare), and on-line decisions by the various other agents.

- For analytic convenience and consistency with the gaming concept, the war plans and scripts available to the Red, Blue, Scenario, and Force Agents will be compatible: Red and Blue will recognize the range of each other's possible war plans. However, neither can be sure which war plan or branch the other will follow.

- We will try to identify and describe an adequately complete set of strategically distinct and interesting branches ahead of time, and build those into the analytic war plans and branched scripts that define the scope of the games. Obviously, this prevents the automatons from generating the full range of possible scenarios, but this penalty is more apparent than substantive, since the automatons are not now and will not soon be sufficiently smart to justify giving them complete freedom. The tradeoff is between dumb "generality" and sophisticated constrained play.

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scripts when written down--that is, timelines are outlined but there are multiple decision points and corresponding branches.

[11] The adjective "analytic" is important here because, at least in U.S. practice, formal war plans tend to emphasize the first steps and not go far with "what-ifs." U.S. style appears to be to encourage ad hoc responses once the war begins to develop. Obviously, however, U.S. military and political leaders are very concerned with the "what ifs." Thus, our approach is realistic at one level and unrealistic at another. We are less clear about the Soviet style, but we do know that they emphasize plans and preparations. Moreover, they plan to be on the offensive, and it is easier for the offense to plan several steps ahead. Soviet-style planning is the subject of ongoing research by John Battilega and Associates for Science Applications, Inc. We hope to incorporate the results in RSAC work.

- Given a particular war plan/branched script pair, parts of the script will be prescribed by off-line research and parts left relatively hazy with details to be provided by on-line calculations or decisions. As a rule, the tactics-rich portions of the war plans will be treated by prescription; by contrast, the portions characterized by attrition warfare, logistics flow, mobility of reinforcements, and the like, should be treated by Force Agent models sensitive to the variables of interest in the overall game. Similarly, national decisions will usually be prescribed only for the initial situation--an exception being when a particular branch (e.g., an Inchon landing) that might arise late in a game is known to be interesting from off-line research but requires some decisions or actions for which the various RSAC agents cannot easily be programmed.

- In principle, the future Force Agent model should be able to treat increasingly large portions of the overall script. For example, rule-based programming could be used to increase the tactical repertoire of the automated "commander" of forces, and to use maneuver tactics when appropriate.[12] Some of this has already been accomplished in a few models, but not in a way suitable for RSAC analysis.

Finally, let us review the basic elements of a war plan/branched script approach: (1) decision points (whether "hardwired" or generated); (2) available options; (3) option-selection rules; (4) actions emanating from options; and (5) information, as required, about the current world situation and the possible implications of actions.[13] The war plan/branched script concept is currently being tested with an interim version of Rand's automated gaming facility (see Winnefeld, forthcoming).

To better understand how the approach is used in an RSAC war game, suppose that an initiating scenario for a particular game has been

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[12] Such an approach is suggested in Dondero (1976).

[13] Other authors have proposed in general terms systematically developing campaign descriptions for war-game-based analysis, but we are not aware of any previous suggestions along the lines discussed here, especially with respect to formal "decision trees" or rule-based generalizations thereof.

specified and that the Red Agent has decided on a course of action. In the RSAC war games, the Red Agent must choose among a predetermined set of war plans. He will choose the one that most closely matches his objectives and perceptions about the likely course of events. So, for example, in a particular game, the Red Agent might decide to invade a neighboring country but try to minimize the likelihood of Western intervention. If so, his war plan (that is, the branched script he would choose) would include military and political actions consistent with discouraging intervention. By contrast, if the Red Agent believed intervention was likely and that limited war with Western powers was inevitable upon Soviet invasion, he would choose a war plan with military actions anticipating the conflict with the West.

A major reason for the branched script approach is that we believe it is important to ascribe to the Red Agent a modicum of intelligence--major nations do not embark upon military actions of consequence without recognizing uncertainties and planning for a range of contingencies (including the possibility of having to settle for a half a loaf).

Purely to illustrate terminology, let us first consider a highly simplified world consisting of three countries: Red, Blue, and X. Suppose that we have conducted a campaign analysis and concluded:

1. Red <u>may</u> invade X, by either of two strategic plans ("Fast" and "Slow").
2. Blue <u>may</u> intervene conventionally.
3. Red or Blue <u>will</u> win a decisive conventional victory.
4. The loser <u>may</u> escalate to nuclear war, in which case the other <u>will</u> retaliate.

This set of assumptions and rules is equivalent to defining the "scenario space" of Fig. 1. Figure 2 shows how the scenario space breaks into analytic war plans. Again, to each analytic war plan there corresponds a branched script providing a higher-resolution view of the problem.

RED AGENT DECISIONMAKING

Figure 3 describes the decisionmaking flow we anticipate for an advanced Red Agent like the one now being developed at Rand (Steeb, Gillogly, and Allen, forthcoming). The process begins with analysts deciding on the range of war plans needed for the game to satisfy the requirements of their particular study. In effect, they will reach into a box of war plans developed by off-line research and choose the ones they need. (Remember, however, that the branched script war plans are only incompletely defined in the off-line research.)

The second step is for the analysts to identify the independent variables they wish to explore in a series of games, a series that might take weeks to complete. They then choose one set of values for the independent variables (a particular Soviet character (IVAN), a particular U.S. character (SAM), a particular set of rules for NATO behavior in crisis, a particular future force structure, initial conditions for the state of the world, and so on).

The game then begins. When it is Red's turn, the Red NCL (National Command Level) must choose from among a finite set of war plans[14] using criteria involving objectives, risk, the current state of the

[14] An obvious question here is why the Red Agent cannot choose peace. The answer is that if the study at hand is one of crisis behavior rather than one of force effectiveness in war, such plans would indeed be included. As in all games, there must be an initiating scenario controlled by the game director or analyst team; here, we assume that the scenario leads to conflict.

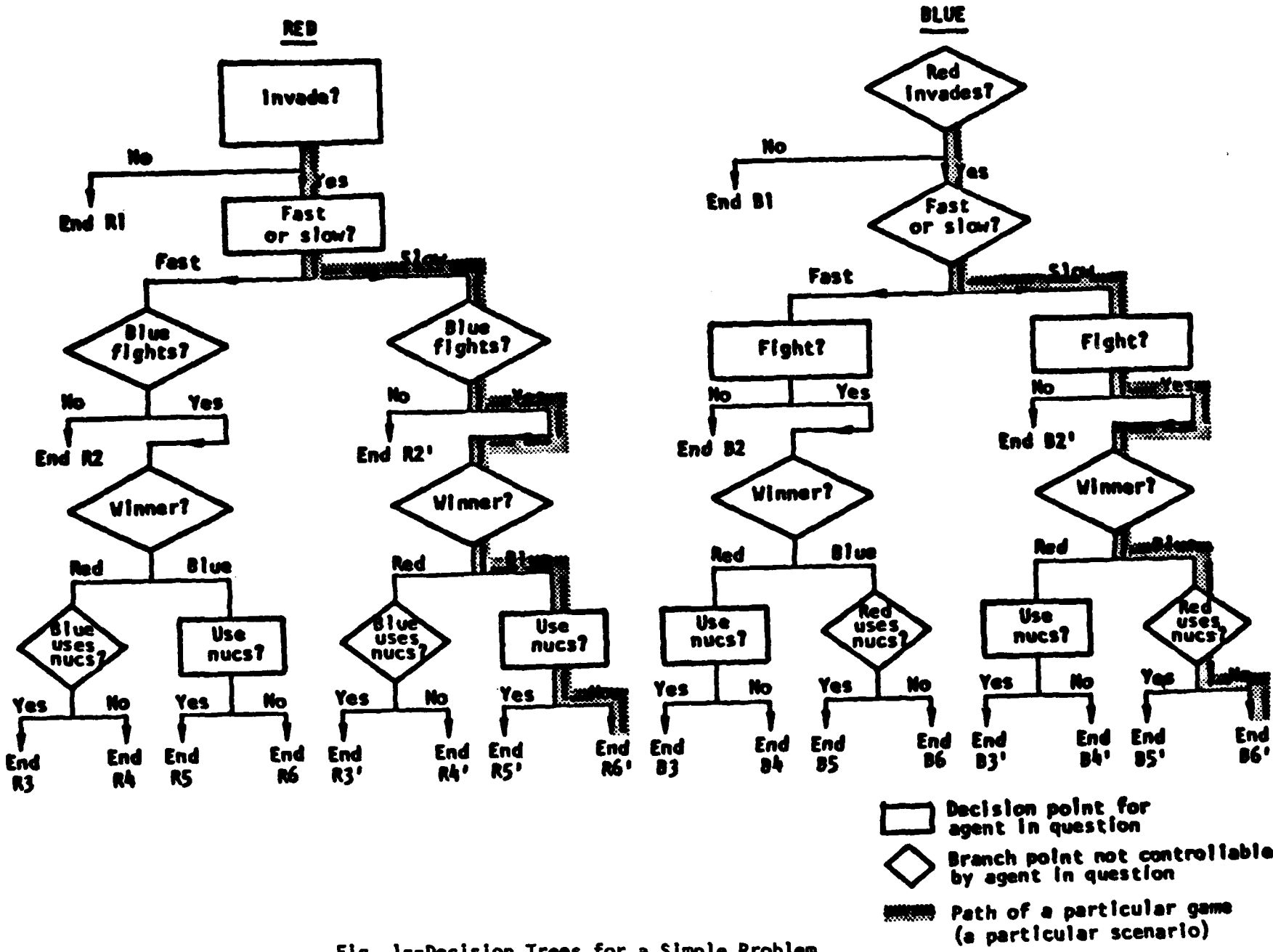


Fig. 1--Decision Trees for a Simple Problem

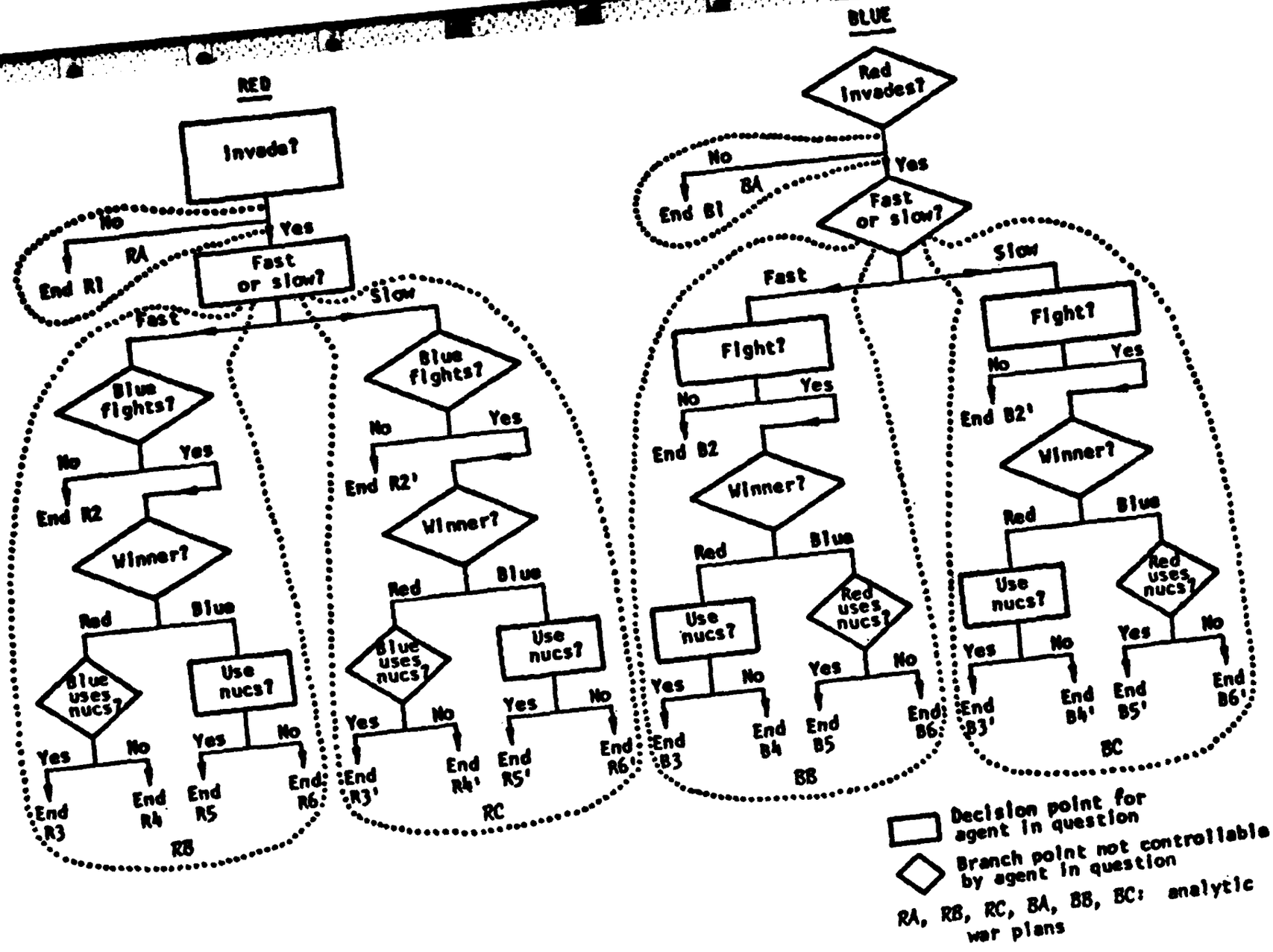
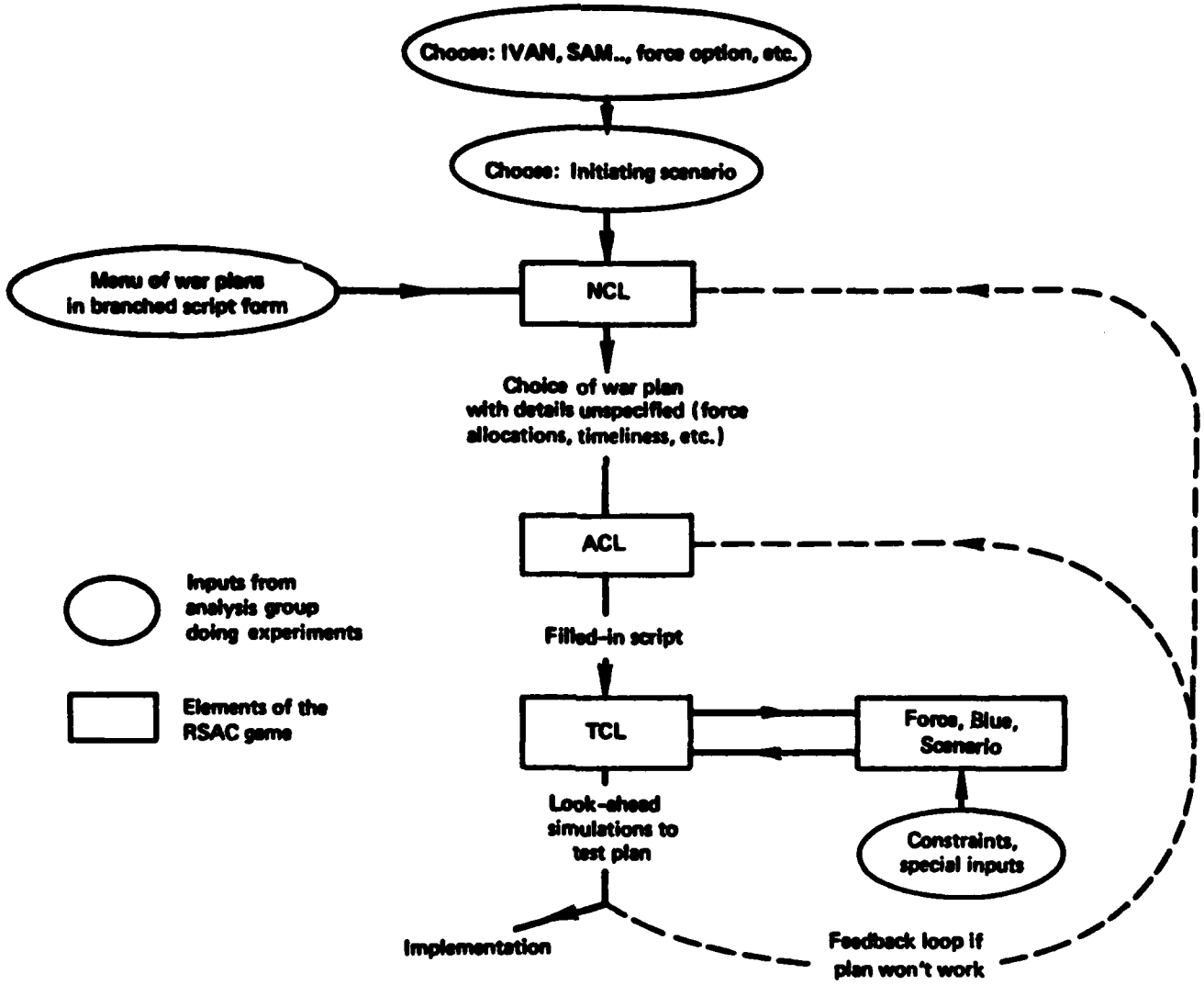


Fig. 2--Analytic War Plans as Portions of a Scenario Space



Note: ACL must use force and scenario.

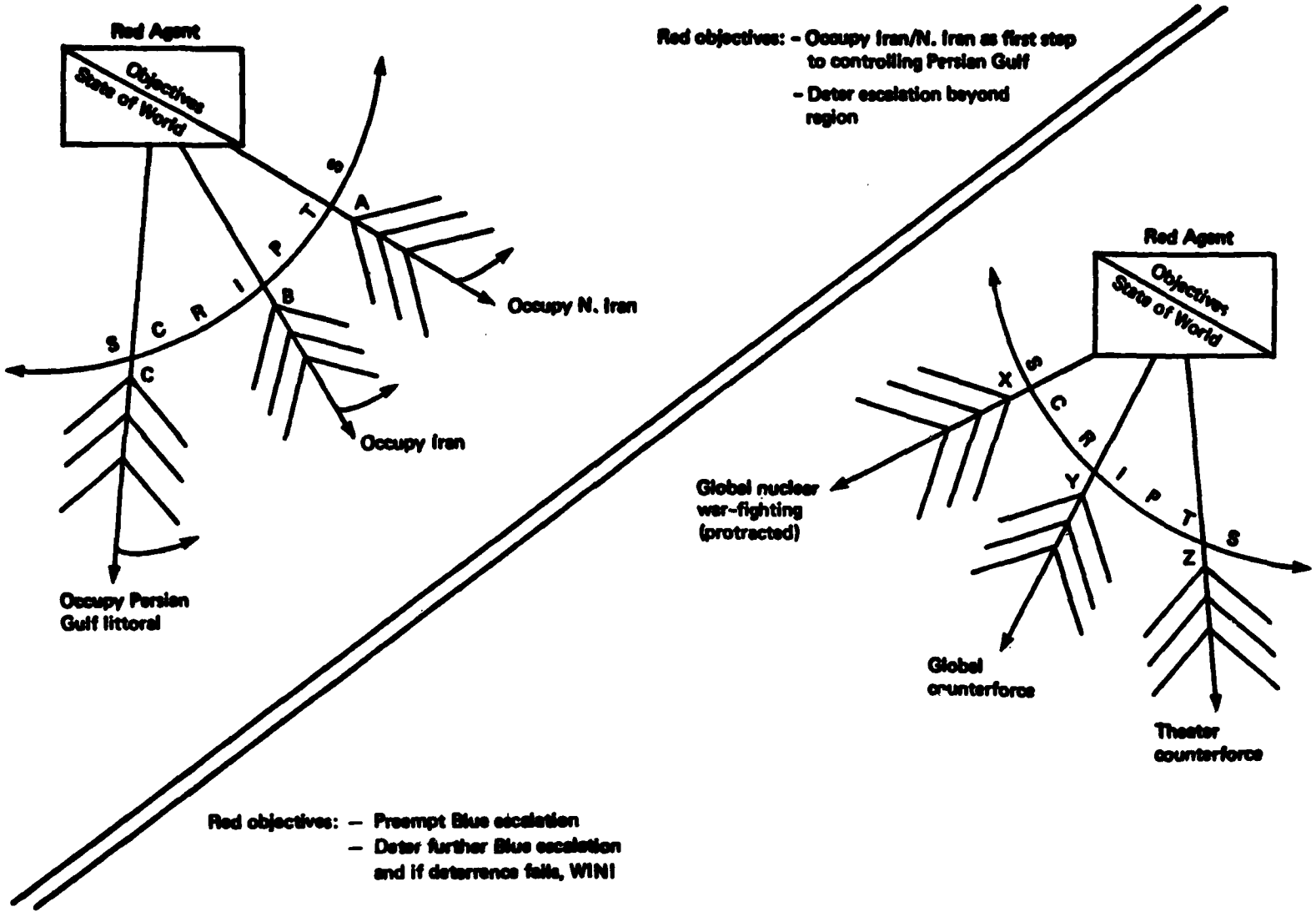
Fig. 3--An Advanced Red Agent Choosing a War Plan

world, and the like. The ACL (Area or Functional Command Level) of the Red Agent then refines the war plan, allocating forces and setting timelines in accordance with calculations made internally or constraints levied by the analysts. The TCL (Tactical Control Level) of the Red Agent then does a "look-ahead," using the tentative war plan and the look-ahead capability of Force and Scenario Agents and of Red's model of Blue behavior. As noted, this look-ahead will recognize Blue options. If the ACL concludes that the tentative war plan cannot be implemented, it reports that fact and after iteration, a final plan is chosen. The Red Agent then makes his move and the game proceeds.

When next it is the Red Agent's turn, he may proceed along the path of his chosen plan, or he may reach a decision point requiring him to evaluate the state of the world and perform a new look-ahead. This will determine which branch of his plan he follows next.

Figure 4 describes some illustrative war plans in skeletal form for conflicts in Southwest Asia and at the nuclear threshold. In most cases the branches are not shown explicitly, but their existence is indicated. The particular choices shown here might be suitable, for example, in a study of total force structure alternatives for 1990. For discussions of the issues in Fig. 3, see Davis (1982), Ross (1981), and Epstein (1981).

Figure 5 illustrates schematically, as did Fig. 1, that the scenario unfolding in a given RSAC war game corresponds to a particular path through the branch structure of a war plan. That is, we can use building-block scripts rather than having each script be complete (and largely redundant with others). The same principle applies, however: a



Red selects a script on the basis of his objectives and state of the world

Fig. 4--Illustrative War Plans in Branched Script Form

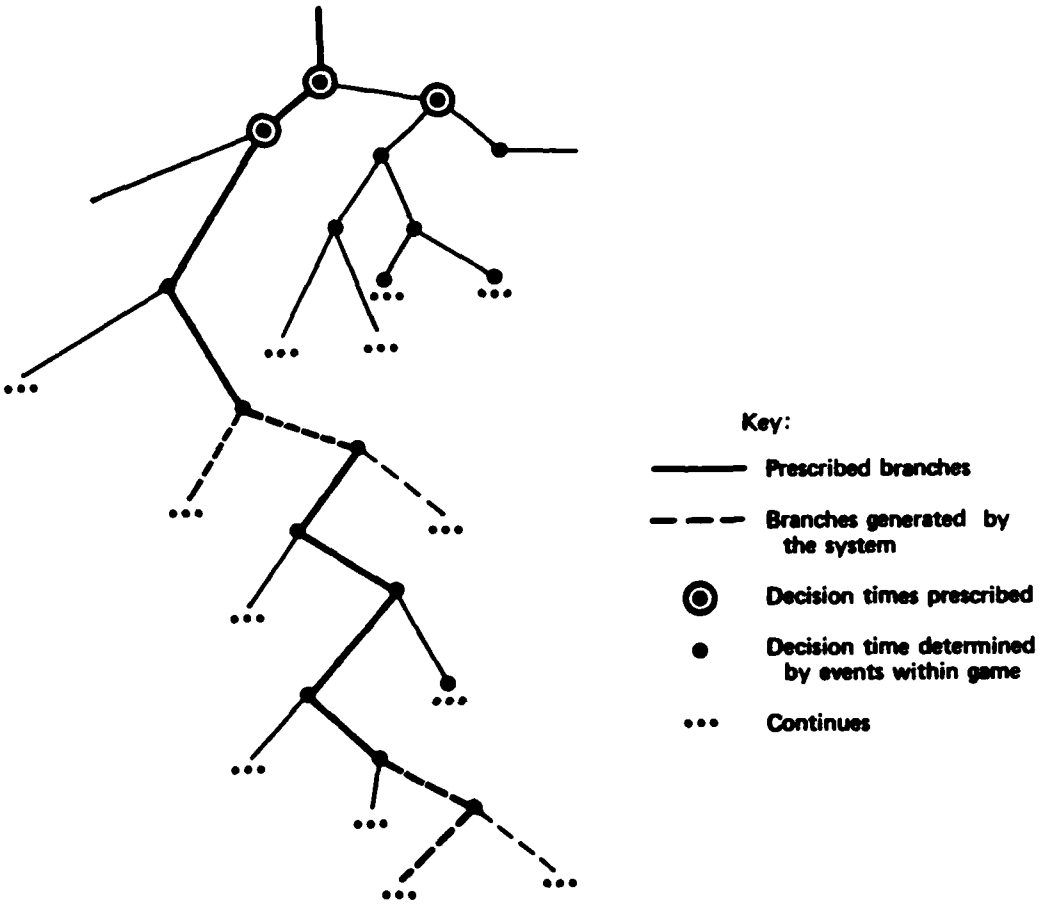


Fig. 5--The Path of an Illustrative Game Scenario

game scenario corresponds to a particular track through the branch structure. As indicated also in Fig. 5, parts of the branched scripts are specified in some detail by off-line research, whereas other parts are developed by the automatons and the Force Agent in the course of the game. The RSAC approach is not a pure "script approach" in the sense of the artificial intelligence literature: such an approach would require that an excessive percentage of the work be done off-line with the computers merely reading and displaying the fruits of that research (and filling in some blanks with simple calculations).

Figure 6 describes War Plan R of Fig. 4 in more detail and provides insight about the degree to which the war games are modeled off-line. As a general rule, consistent with the principles mentioned earlier, the tactics-rich portions of RSAC scripts are developed off-line, using the results of detailed research when available, and reflecting suggestions made by a number of military experts. This off-line work must provide the same level of detail as that provided by on-line modeling elsewhere in the script. So, for example, it must specify not only the nature of the military operations, but also the results (casualties, movement of the FEBA if applicable, consequences for the navies, and so on).[15]

QUESTIONS AND SOME PRELIMINARY ANSWERS

It is natural for the reader to be skeptical and have questions at this point. What follows is an attempt to address the most obvious of these.

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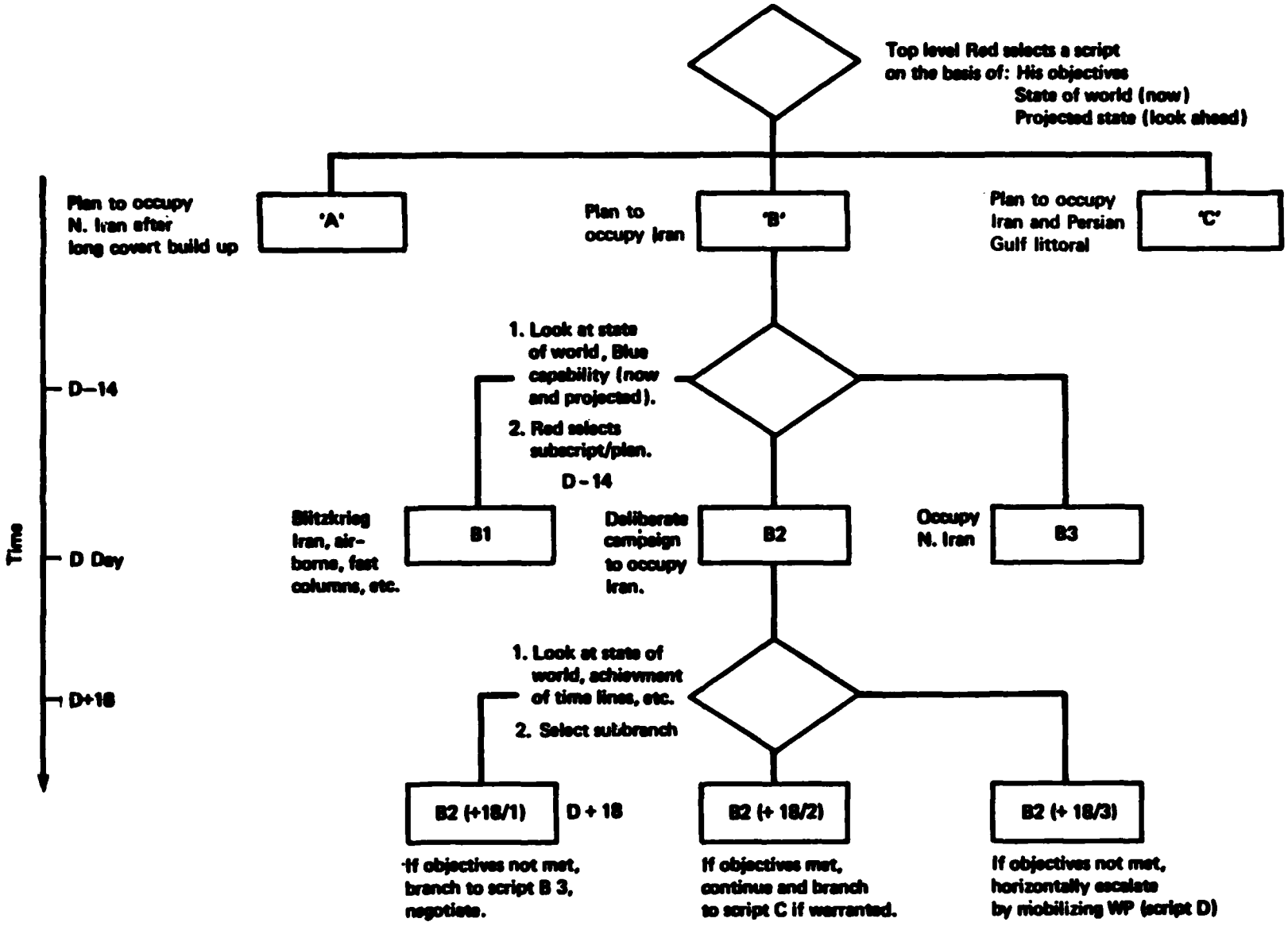
[15] Since this Note was written (in Spring 1982), we have used the Note's approach in war games. For sample first-generation scripts, see Jones, LaCasse, and LaCasse (forthcoming) and Winnefeld (forthcoming).



Red plan selection--SW Asia

Fig. 6--Increased Detail for Red Choosing War plans in Southwest Asia

Question: Are all game scenarios constrained to follow one or more routes through the predetermined branching structure?

Answer: Yes, except that: (1) experience with excursions relaxing constraints may cause us to add branches to cover cases we missed initially; (2) the scripts are not complete, and the system will have to generate its own branches beyond a certain point in the game. By the way, a major objective of the RSAC was to create reproducible war game analysis. Reproducibility implies the existence of some type of wiring, whether explicit in scripts or implicit in rules.

Question: Are the decision points and the associated times of decision "hardwired?"

Answer: As mentioned above, we want to diagram at least the early stages of conflict in advance--with all the branches identified. Initially, we will probably also "hardwire" most of the decision point times. This will greatly simplify the programming and analysis. However, as soon as possible we should begin to model the decision point times by building in rules such as: Decide (on a particular issue) whenever any of the following occurs: (1) the FEBA reaches X; (2) the adversary issues a nuclear ultimatum; (3) the adversary's alliance takes military actions inconsistent with the main branch of the plan. Many of the absolute times appearing in off-line analyses will be translated into time differences; that is, the time differences will be inputs rather than the absolute times. This will be important, for example, if we determine that the timeline of externally developed scripts is inconsistent with plausible decision or reaction times of individual states. In that case we can preserve the sound part of the external analysis (such as intelligence estimates of Soviet mobilization time and expert judgments about the time required for certain parts of military operations difficult to model) without adhering rigorously to a timeline with which we disagree.

Question: What happens if, in a game, a major political event occurs in between prescribed decision points (such as a nuclear ultimatum)?

Answer: If that happens at this stage, we can probably assume that the Agent rules generating the event have less basis in fact than the off-line research used to generate the branch structure. Hence, we should probably change the Agent rules so that the events will occur at the "right" time. If we discover a case in which the Agents look smarter than the off-line analysts, however, we should modify the script or add a branch. Later, the problem should resolve itself as we require the system to determine for itself when the decision points are reached (i.e., we can specify a decision point whenever certain events take place or certain objectives are reached). When we reach that stage, we will not be able physically to draw out the branch structure in advance--we will have prescribed it only in an abstract sense. Indeed, that is

the case even now for events occurring late in the game--the script is well defined only in the initial phases.

Question: Aren't we losing generality?

Answer: Yes and no. We cannot now build a system capable of both generality and military sophistication--we cannot build a continuum model of all crises, conflicts, and strategies. However, for analytic purposes, we need only examine an adequately complete set of situations. The space of permitted RSAC scenarios will be discrete but very large and robust. Remember that every branched script contains the potential for many scenarios. In the future (probably in the distant future except for some off-line research for intellectual purposes), we can go deeper and explore the consequences of many effects not treated by the baseline war plan/branched script approach described here. One such effect that may need earlier attention is the degree to which giving all the players full knowledge of the other players' war plan options limits the validity of our results.

Question: Are we ruling anything out?

Answer: The branched script approach has great evolutionary potential and will allow such features as "chess-playing," stochastic effects, and increasingly autonomous modeling of military operations (if the rule-based models alluded to earlier are developed). Again, however, the tradeoff in the first generations will be discrete-state analysis of militarily sophisticated war plans against continuum analysis with primitive models of conflict.

Question: It seems likely that once the branched scripts are developed, the next step will be to assign probabilities to the branches and work a minimax problem. That might be useful, but wouldn't it eliminate or reduce the role of the automatons and shift emphasis to the script development?

Answer: We anticipate that the third-generation automatons will indeed be capable of designing probabilities and calculating their "best" options. However, the result will not be a simple minimax problem because the style and values embraced and the models used by different versions of the automatons will vary. Moreover, the automatons will not, in general, have the same information or perceptions.

SUMMARY ON THE WAR PLAN/BRANCHED SCRIPT APPROACH

The significance and rationale of the war plan approach should now be evident. In summary, it appears that the most compelling reasons for the approach are as follows:

- It permits us to insert a higher degree of military sophistication into early versions of the system so long as there exists a body of research on which to call for insight. The research may or may not have produced a mathematical model--that is, we do not have to wait for the ultimate combat model.
- It enormously reduces the computing requirements for an advanced Red Agent, permitting such features as chess-playing.
- It has almost unlimited growth potential.
- The language and structure of the approach should be far more comfortable for experts in military operations and history than would computer approaches based on black-box force models, a continuum of possibilities, and the like.

III. REQUIREMENTS FOR NEW FORCE AGENT MODELS: SOME INITIAL OBSERVATIONS AND PLANS

FORCE MODELING ISSUES

Strategic analysis in the RSAC and in the intended government-controlled operational follow-on will require a wide range of force models. Some of the required models are already available or can be adapted from existing models. Others must be designed from the ground up according to RSAC specifications. This section describes the RSAC force modeling requirements and an approach for meeting them. A more detailed and systematic study is in preparation (Bennett, Williams, and Bullock, forthcoming).

It is useful to distinguish here between simulation models and aggregate (or parametric) models. Although no distinction holds in general, we consider simulations to be models in which the mechanisms causing the outcomes are explicit. By contrast, aggregated or parametric models are formulas that give the "bottom-line" dependence on key variables of the sort visible at a top level. For example, a bomber penetration simulation model would have equations with terms recognizably related to bomber-SAM encounter rates, kill probabilities, and so forth. A more aggregated strategic model might simply reflect Soviet air defense with a penetration probability, or might describe penetration as an exponential function of average bomber time in country, average bomber speed, total number of SAMs, and so forth. The exponential form might be derivable from first principles (given certain assumptions) or might be a purely empirical representation of simulation results.

A second distinction is also useful. In some cases (for example, models of mobility and prelaunch survivability), the parameters in our aggregated models will be calibrated against results of simulation models using best-estimate assumptions and appropriate excursions. In other cases, however (notably air, sea, and ground warfare), the more detailed models are a poor basis for calibration because they depend on assumed relationships among, for example, attrition, FEBA movements, and force ratios--relationships with only a tenuous basis in history or theory. In these cases, the RSAC models should not be based on more complex models alone. Rather, they should be designed to reproduce the predictions and uncertainties of military experts who have been provided analytic tools sufficient to help them develop their views as well as possible. This will require making use, at Rand or elsewhere, of such war games as the Army's McClintic, BDM's BAM, and IDA's TACWAR and IDAHEX.[1] It will also require a review of historical results and consideration of the many factors discussed in Trevor Dupuy's work (e.g., Dupuy, 1979), factors such as surprise, generalship, and quality.

The first-generation RSAC relied on a combination of automated calculations and expert judgment for carrying out force assessments. This combination is essential to the future RSAC, but both the calculations and the method of introducing expert judgment into the games need to be restructured. This dual requirement will become clearer in the discussion that follows.

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[1] See Comptroller (1980) and SRI (1977) for comparisons of several such models. See also U.S. Army War College (1981) and Institute for Defense Analyses (1977).

Automated calculations in the first-generation Force Agent were handled by Foment, a time-stepped computer program that treats conventional and strategic operations, and the interaction among them, at a highly aggregated level.[2] Not surprisingly for a model that was the first of its kind and that was begun without the RSAC application in mind, Foment suffers from a number of limitations that preclude its use in the future RSAC. Several of these arise from the program's structural inflexibility. Event scheduling, level of aggregation, and data treatment are rigidly fixed in the program. Because of the inflexibility, our analytic team must make frequent changes to the program itself and must resort to cumbersome manual data entry procedures to override hardwired program features in the course of a game. Another category of limitations consists of inadequate or nonexistent treatment of important force operations. For example, naval warfare in the model is confined to antisubmarine warfare against SSBNs and SSBN targeting against ground assets; chemical warfare is not treated at all; conventional warfare in mountainous terrain can be handled only crudely; strategic and tactical mobility are not modeled at all. Finally, Foment handles only some of the important interactions among operations, particularly across lines of theater, naval, and intercontinental nuclear warfare.

The method of inserting expert judgment into RSAC games must also be improved. In the first-generation RSAC, judgment calls were made "on the fly" as required during games. There were few calculational or display aids to support the experts, and there was no structure for

[2] The Foment model was developed primarily by Michael Mihalka and Arthur Bullock.

keeping track of judgments or of the assumptions underlying them. The future RSAC must better accommodate the formulation and tracking of expert judgments.

The following time-phased program of model development will produce a new Force Agent far better able to support the RSAC of the future:

- Incorporate the analytic war plans technique into RSAC games.
- Build the Campaign computer model to keep track of forces worldwide, perform force calculations at an aggregated level, and incorporate analytic war plans into game analysis. Rely initially on parametric models and "scripted models."
- Build a library of more detailed models to calibrate Campaign and to support experts writing analytic war plans.

This program is discussed in more detail in the following three subsections.

INCORPORATING ANALYTIC WAR PLANS INTO RSAC GAMES

Analytic war plans and their usefulness for studying a broad range of scenarios rich in military detail were discussed in Sec. II. With the war plans/branched script approach, the RSAC can hope to treat a broad range of ordinarily troublesome phenomena in a realistic and focused way, and can begin treating such phenomena early in their development.

In terms of the first-generation Force Agent limitations discussed in the last subsection, the approach promises a tremendous breakthrough: since the war plans and scripts required in an RSAC game will be prepared before the game based on off-line models and thoughtful research, they will provide a vehicle for introducing expert judgment into RSAC analyses in a transparent, easily traceable, and game-time efficient manner.

Initially, RSAC scripts will rely heavily on external sources in prescribing events. Foment calculations will be used when credible or adequate, but not otherwise.[3] Increasingly, however, the scripts will be able to call for calculations performed by the new Campaign model.

CAMPAIGN

Campaign, like its predecessor Foment, will be an aggregated, dynamic model that keeps track of military forces and operations worldwide. The model will incorporate some design concepts and calculational techniques from Foment, but will be more sophisticated, flexible, broad, and transparent. It will also be documented to the maximum degree feasible, although documentation of working models must, in practice, be constantly updated.

The design of Campaign is to be carried out at Rand. Documents are currently being prepared to define Campaign requirements within a suitable analytic framework. Force operations modeling concepts are also being determined and documented. Here, we present merely an early, informal discussion of Campaign requirements and design.

Taken individually, the following descriptions of Campaign's requirements may sound obvious or trite. But taken together, they define loosely a set of requirements that will be very demanding to satisfy, even over a period of several years:

1. Track and display forces worldwide.

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[3] Another way to say this is that we shall initially depend heavily on "scripted models" that may make no pretense of simulation, or even of being calibrated to simulations.

2. Handle mobilization and mobility.

3. Determine theater combat outcomes.

4. Describe outcomes of naval engagements.

5. Determine results of central nuclear conflict.

6. Provide uncertainty analysis.

7. Read and respond to analytic war plans.

8. Permit incremental implementation.

9. Handle suitable levels of aggregation.

A major challenge, of course, is to reflect the interrelationships: for example, the very nature of theater and naval wars must change if nuclear conflict occurs.

Display Requirement

Campaign must keep track of worldwide force status. As a minimum, the model should include the following displays.[4]

- A telescoping "global playing surface" showing locations and movement of forces down to the division/wing/battle-group level;
- Maps of potential theaters of conflict showing action at locations defined by the user;
- Maps showing important U.S. and Soviet targets and target damage; and
- Mission-oriented force-status displays indicating options available, degrading, or foreclosed.

[4] The techniques for such displays are relatively well developed at Rand and elsewhere. For example, BDM's BAM model provides a "zoom-lens" view of theater warfare. Rand has a similar feature in its rule-based model of Soviet strategic air defense.

The displays of mission status might be structured as a collection of "stop-light" matrices, with green, yellow, and red entries to indicate that certain operations can still be carried out, that they can be carried out only at a degraded level or with considerable uncertainty, or that they have become impossible. For example, one display might show how antisatellite activity affects the U.S. capability to detect Soviet SLBMs in time to launch bombers. Capability to launch under attack, to manage bombers, and to supply reinforcements can also be displayed in this format.

It is important to note here that displays are not just bells and whistles to be tacked onto Campaign at the end of its development but are an essential and integral feature of the model's design. They must be included in the original design and should be implemented early.

Informative displays will be important to the model developers themselves, as well as to analysts and recipients of analysis. If displays are implemented early, model developers can use them to "see" results as they build the rest of the system. The transparency they provide will facilitate system test and evaluation.

Displays will be especially useful in the RSAC's government-operated follow-on, where it is anticipated that high-level demonstrations will be carried out in support of strategic planning. In this setting, visual aids will help to focus attention on key events, interrelationships, and constraints.

Mobility Models

Campaign will include models for mobilization, strategic mobility, and tactical mobility. These models will be sensitive to assumptions of force and lift availability; base, overflight, and access rights; and force commitment locations. They will be explicit and flexible in their treatment of the time phasing of combat and support units.

The mobility model will calculate rates at which forces and equipment arrive at conflict locations. It will account for both inter- and intratheater movements. It will use Scenario Agent input concerning base, overflight, and access rights, and will interact with models of attrition along sea and air lines of communication and with port and air-base damage models.

The level of detail in the models should be at least comparable to OSD's BBOE.[5] For example, it will account approximately for resupply requirements and will distinguish among bulk, oversize, outsize, and human cargoes, but will not distinguish among different units of a given type.[6]

Theater Combat Outcomes

Most of the calculations in Campaign will be used to determine outcomes and interactions of force operations and to provide "look-aheads" for Red, Blue, and Scenario Agents. The system will model theater, naval, and strategic nuclear operations and their interactions.

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[5] See Johnson (1982). The BBOE model was developed in OSD's Office of Program Analysis and Evaluation.

[6] Many of the relevant issues, including intratheater movement, are discussed in unpublished material by Paul Davis and Barry Landson.

In some cases, Campaign will approximate results of simulations. In others, it will merely represent mathematically best estimates based on expert judgments.

In the theater, Campaign will include conventional ground and air combat effects on attrition and force movement (FEBA movement if the concept of FEBA is appropriate) in a variety of terrain types. It must include logistics effects, and these will interact with the strategic and tactical mobility models. It must also include effects of chemical and nuclear warfare and of the other "troublesome phenomena" discussed in Sec. II. Some of these phenomena will be explicit in the analytic war plans/branched scripts. However, Campaign must provide the framework for tracking their interactions. Moreover, if the scripts postulate the phenomena (e.g., a surprise breakthrough on Day 1 of a NATO/Pact war, with many NATO forces not yet at the positions assumed for D Day in most planning), the Campaign model should be able to describe NATO's capability to respond to the new initial condition--it should describe movements of forces from rear areas and reflect, in one way or another, attempts to envelop the breakthrough. Clearly, doing this with an aggregated model will require substantial work at a more detailed level. The result should be an aggregated model reflecting the key variables, but not necessarily simulating the underlying processes.

Outcomes of Naval Engagements

Since results of naval operations interact strongly with theater and central nuclear operations, Campaign must track movements of major naval entities and describe the outcomes of naval engagements.

Particularly important are effects of naval operations on lift capability, on air power and amphibious capability in the theater, and on SSBN availability. As a minimum, Campaign will model attrition in sea and air lines of communication (to include entry and exit ports), antisubmarine warfare (ASW), air barrier attacks, and naval air attacks on theater targets.[7] Effects on Red, Blue, and other parties will be included.

Campaign may use a rule-based model for naval movements and operations. Such a model could incorporate the artificial intelligence techniques developed at Rand by Philip Klahr and others.

Results of Strategic Nuclear Conflict

The following illustrates the types of strategic nuclear (intermediate and long-range) issues the Campaign model must treat as a function of time. This is not an all-inclusive requirements list; more detailed requirements will be discussed in Bennett, Williams, and Bullock (forthcoming).

- o Force Availability (see also Operations in Prolonged War, below)
  - generation
  - sustainability in prolonged alert
  - postattack endurability
- o Support Systems
  - tanker availability
  - C^3I (and counter C^3I) performance
  - logistics support for strategic operations
- o Strategic Defense
  - ballistic missile defense
  - air defense
  - civil defense

[7] See Schulcis and Robinson (1981).

- o Damage to Strategic Systems (including damage from special operations)
  - bomber prelaunch survival
  - prelaunch and postattack damage to SLCMs, theater-nuclear systems, etc.
  - antisubmarine warfare
  - damage to ICBMs
  - degradation in communication and warning systems
  - unexpected technical failures
- o Damage to Other Targets
  - industrial damage
  - damage to conventional installations and forces (which may be mobile)
  - population damage
  - damage to the logistics base
  - emergence of new targets (e.g., field armies at choke points)
- o Operations in Protracted Nuclear War
  - bomber recovery and reconstitution
  - strategic reserves and reloads
  - target acquisition
  - retargeting

Some of the features listed havě already been modeled at a level suitable to Campaign. For example, the Foment model includes calculations for bomber prelaunch survival, antisubmarine warfare against SSBNs, ICBM damage, and air defense penetration. The analytic foundations and assumptions behind these calculations will be checked as part of Campaign development.

Some features in the above list will be based on recent and ongoing research at Rand and elsewhere, much of it intended to translate target-damage results into <u>functional terms</u>--i.e., implications for time-dependent operational capabilities such as resupply and reinforcement of theater forces, postexchange tracking of Soviet nuclear forces, and others. For example, a current Rand study (led by Kenneth Horn and Elwyn Harris) is investigating the feasibility of deploying

survivable and enduring surveillance satellites. Campaign developers will use this study's results on warning system degradation due to antisatellite warfare, ground system losses, and high-altitude nuclear effects. Results from other Rand studies will be useful in modeling force availability, civil defense, and operations in protracted nuclear war. Researchers at Boeing and SAI are defining concepts and contexts for viewing protracted nuclear warfare, and at DCA, a study of strategic force management provides information on the potential value of retargeting strategic forces. A recent study at Strategic Air Command defines missions, requirements, and plans for carrying out operations in protracted nuclear war.

Many of the problems listed above are not well understood. Logistics support for strategic forces and interaction with conventional forces, especially in a long global war, are particularly difficult. These areas require considerable new research.

Uncertainty Analysis

The RSAC must treat uncertainties of several types:

- Strategic uncertainty, that is, uncertainty about future force structures and about major superpower or third party decisions--(Will the United States launch under attack? Will the United States have access to Spanish airfields?).
- Statistical uncertainty caused by random variation in effects that are reasonably well understood (U.S. weapon system performance, target damage, radio wave propagation).
- Uncertainty caused by inadequate intelligence information or a poor understanding of effects and relationships (e.g., Soviet weapon-system performance; FEBA movement and attrition in conventional warfare; and effect of tanker drawdowns on bomber recovery).

The RSAC structure is well suited to handling strategic uncertainty. In current experiments, analysts vary data bases and rules to study the effects of alternative force structures, scenarios, and adversary behavior patterns.[8] Postgame analysis of RSAC event streams will allow users to see interactive effects of a wide range of strategic uncertainties.

The Campaign model must also handle uncertainties of the other two types. Because of the emphasis on dynamic interrelationships, this will be one of the most difficult tasks in Campaign design. Unfortunately, uncertainties propagate uncertainly. Combining measures of uncertainty from different operations can be a tricky business. This is an area that will require extensive thoughtful analysis before a final design is formulated.

In some cases, standard statistical techniques will apply. Statistical distributions (to the extent that they are known) for various measures can be combined to provide measures of uncertainty for outcomes.[9] In other cases, Campaign will have to track and distinguish among discrete cases that are very different from each other. Data for these cases will probably come from expert judgment rather than from experimental evidence.

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[8] See Levine and Winnefeld (forthcoming) and Winnefeld (forthcoming).

[9] Distribution function techniques can be used when information is lacking or experts disagree; they are not limited to cases of random events with a physical basis. However, there are dangers involved because experts usually claim greater certainty than is justified, especially in discussing events they regard as unlikely.

Analytic War Plans

Campaign must be able to read and respond to analytic war plans implemented as branched scripts. Analytic war plans will be used to provide a rich context of scenarios for RSAC analysis. Through the war plans, effects of unmodeled or otherwise troublesome phenomena can be included early in RSAC analysis and without making special changes to Campaign. Therefore, it is important to design Campaign so that it can read and use them.

In the analytic war plan setting, the branches of a branched script will determine which Campaign calculations are carried out and which parameter values are used. Campaign must be designed so that parameters in its data bases can be adjusted as different branches are played out. Since one motivation for using branched scripts is that they will allow movement from one branch to another, Campaign must keep track of multiple parameter values for multiple branches. Thus the branched script technique creates a Campaign requirement for multiple, time-dependent data bases.

For example, current RSAC experiments directed by James Winnefeld use branched scripts for conventional conflict in Iran and in Europe. The scripts dictate mobilization of forces for both theaters. In a future RSAC, Campaign will provide arrival rates for the forces. The rates will depend upon which branch of a script is chosen at any time. Depending on the branch, the forces may be able to count on more or less lift capability, on more or fewer ports and bases available, on longer or shorter routes, and so on. Campaign must be capable of making the arrival rate calculations under any of these conditions, and of jumping

from one set of conditions to another. Campaign must describe not only the scenario played out, but also the potential scenario examined by the superpower automatons in look-ahead calculations. Therefore, Campaign must incorporate data bases and, in some cases, algorithms, for a variety of capability and route assumptions.

Incremental Implementation

Campaign will be an evolving system. The model will start with an overall design concept and will be implemented step by step, with thorough validation at each step. The model will also be expandable--users can study new operations and interactions without making major structural changes.

A number of concrete design elements will facilitate incremental implementation and expandability. Especially important are the following:

- Early display development.
- Interaction with analytic war plans.
- Generalized event scheduling.

The next few paragraphs discuss these design elements and their impact on implementation and ease of use.

The requirement for good displays was discussed early in this section. Displays will obviously be useful to analysts working in a fully developed RSAC. But displays will also be important to model builders themselves: If good displays are available early during implementation, developers will be able to see effects and interactions as they incorporate them. If the FEBA moves in the wrong direction, or

if a central nuclear strike has no effect on strategic targets, modelers can see at a glance that the calculations are not working.

Analytic war plans/branched scripts will allow developers to zoom in on modeled operations while treating others with fixed war plans until they are also modeled. Thus modeled operations can be considered in a rich context before all the interrelated operations have been modeled.

The concept of generalized event scheduling is quite different from those behind most force models and is intended to insure Campaign's flexibility and expandability. By allowing users to alter or add force interactions by means of changes in the input data rather than in the program itself, generalized event scheduling will reduce the frequency of program changes and operator overrides that are a nuisance in Foment.

With Foment, if a force interaction was not built into the original model, it can be incorporated into an RSAC game in one of two ways: by programming a change to the model itself (often involving unexpected ripple effects throughout the program) or by a sequence of override commands introduced by the operator during the game. Some commands should not be built into the model itself, even though they may be anticipated and repeated frequently, because they depend upon actions of other RSAC agents. Others cannot be anticipated in advance of a game. For such commands, the Foment operator has to use manual overrides during a game play.

For example, in Foment, NATO force structure is determined by a single data base. But depending on instructions from the Scenario Agent and on the pace of conventional war in Europe, NATO forces might be augmented by French forces at some point. To accommodate the addition

of French troops, the Foment operator advances the Foment clock to the time at which Red forces are about to break through into France, and then adds French forces to the Blue side. This addition must be repeated whenever the European war scenario is run. In Campaign, the addition of French forces would be specified as a sequence of commands in the input data. The sequence would be easily traced and repeated.

Of course, Foment could be modified to fix this one example. But strings of modifications for individual game moves will not solve the general problem--namely, that entering information produced externally to Foment (and other force models) is a cumbersome process.

The event scheduling concept, suggested for Campaign by Arthur Bullock of Rand, is a generalization of event scheduling as used in discrete event simulation models, where sequences of events start and stop at certain times or under certain conditions. The generalized concept was used in the Aerospace Corporation's Trajectory Reduction Program and earlier in their modularized Vehicle Simulation System.[10] Clearly, the concept itself is neither new nor risky to implement. It has been used for over a decade in diverse applications, including several detailed force models. We therefore are confident that it can be adapted to the needs of Campaign.

Level of Aggregation

The level of aggregation at which Campaign tracks forces and makes calculations is an important Force Agent design consideration. Level of detail must reflect Campaign's role as the RSAC's major on-line force model.

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[10] Aerospace Corporation (1971). See Fishman (1973) for a discussion of discrete event simulation.

Campaign's purpose is to provide an integrated, strategic-level view of the way events and capabilities unfold over time. The model must track multiple theaters and multiple operations simultaneously, and must focus on their dynamic interrelationships. Therefore it is important that Campaign avoid the detailed calculations for individual operations, although these must be made accurately and with care. Rather, the aggregate-level calculations for individual operations should be based on detailed studies using off-line models. But they will be incorporated into Campaign in such a way as to emphasize their strategic-level effects.

For example, in the central nuclear calculations, U.S. bomber prelaunch survivability (PLS), penetration capability, and damage to Soviet targets are interrelated. Since bombers at deep inland bases have a higher PLS than those at coastal bases because of longer SLBM flight times, such bombers may be assigned more important missions in targeting schemes. Therefore it is important for Campaign to distinguish at least among bombers from East Coast, central, and West Coast bases.

In general, Campaign calculations will be carried out at the highest level of force aggregation possible under the requirement to reflect the strategic-level effects being studied. In the theater, this means dealing with theater- or front-level effects, with calculations at the corps or possibly division level. When effects below this level are to be studied, they will be assessed beforehand using more detailed models or expert judgment and incorporated into games through analytic war plans.

For naval warfare, it will be important to distinguish among major ocean areas to account for different capabilities and vulnerabilities (especially to ASW and land-based air). Conventional naval forces will be treated at the battle group level. To account for the differential ASW threat to SSBNs as they move from one ocean area to another and for different SLBM arrival times based on SSBN positions, the model may have to track SSBNs individually.

Bombers will be tracked by type and by gross location (East Coast, West Coast, and inland). ICBMs will be tracked by type and in some cases by gross location.

It is possible to design Campaign to handle variable levels of aggregation. Such a capability would make the model more flexible and potentially more useful in a variety of contexts. Benefits and costs of this flexibility are still being weighed.

OFF-LINE MODELS

In addition to Campaign, the Force Agent will need a library of more detailed force models. These models will be used to guide the development of aggregated models, to provide more precise calculations when Campaign's level of detail is inadequate for an application, and to support experts as they write analytic war plans and branched scripts.

Some candidate models already exist. TACWAR, a division-level conventional warfare model developed at the Institute for Defense Analyses,[11] has been imported by Rand and may be used to "calibrate" a more aggregated model.[12] STAB, Rand's medium-aggregation-level bomber

[11] IDA (1977).

[12] Unfortunately, the quality of the "calibration" is limited fundamentally by uncertainties about real-world dependence of combat results on such variables as force ratio. The greater detail in TACWAR does not solve this problem.

Penetration model already calibrated against the Advanced Penetration Model (APM), was used to calibrate the bomber penetration calculations used in Foment.

Other models will have to be developed, some in conjunction with full studies at Rand or elsewhere. In particular, models of the effects of the troublesome phenomena described in Sec. II must be developed after extensive research in areas largely untouched by the modeling community. These studies and the resulting models are essential if the RSAC is eventually to deal with interesting phenomena in a rich context.

FUTURE RESEARCH

The Force Agent requires a diversity of new models and modeling concepts. Some of the concepts are already well understood. For example, the notion of generalized event scheduling that will form the backbone of Campaign is based on ideas that have already been proved in many applications of discrete event simulation. Aggregated models for nuclear target damage, bomber prelaunch survival, and bomber penetration are already used in Foment, and their incorporation into Campaign is expected to be straightforward.

On the other hand, some of the concepts will require major research efforts:

- Interaction between strategic nuclear war and theater war.
  - What is the nuclear damage to theater targets, and how does the damage affect force operations and theater outcomes?
  - How do conventional operations affect strategic forces? (ASW against SSBNs, damage to nuclear storage sites in the theater, damage to strategic C^2 assets in the the theater.)

- Time-dependent target data bases for strategic nuclear forces.
  - How do target values change as armies leave their barracks and ships leave port?
  - How do we account for probable new targets such as armies bogged down and clustered at a bottleneck? How do we model reconnaissance and attack of such new targets (by bombers and missiles)?
- Measures of effectiveness in theater warfare.
  - How should theater outcomes be described when there is no FEBA (mountain warfare, warfare in urban terrain)?
  - How can we measure effects of strategic surprise and deception?
- Interactions among naval and theater operations.
  - How do naval operations (ASW, attacks on sea lines of communication, air barrier attacks) interact among themselves?
  - How do naval operations affect strategic mobility?
  - How do naval operations affect air power in the theater?
  - How do theater outcomes affect naval operations?

It remains to be seen where the various research projects will be conducted. Obviously, tradeoffs exist between centralizing the work and exploiting existing expertise (which, regrettably, is highly decentralized). Although we have not conducted an exhaustive review of the modeling work going on nationwide, we do wish to note that several Ketron studies provide current descriptions of individual naval operations (Ketron, 1982), and that IDA has already begun a study of high-level interactions among naval operations (Anderson and Schwartz, forthcoming). We have also found useful a recent IDA study prepared for the OJCS in support of the Total Force Capabilities Analysis (Schultis and Robinson, 1981).

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