Analytical and Conceptual Frameworks for Automated Scenario Generation: Application to Tactical Theater Air Warfare

Joseph George Caldwell

July 21, 1989

Contents

I. Conceptual Framework

A. Definitions

This appendix describes conceptual and analytical frameworks for developing an automated methodology for generation of scenarios. The term "conceptual framework" refers to a description of the general concepts underlying our approach. The term "analytical framework" refers to a quantification of the conceptual framework, in terms of specific variables, functions, and procedures.

In this report, the term "scenario" is used to refer to a description of the initial compositions of the opposing forces, the targets, and the battle plan. In order to develop a battle plan, the opposing forces develop strategies and tactics. The term "strategy" refers to a probability distribution defined over a set of high-echelon (theater-level) actions or decisions (employment of task forces or force units at division or higher level). The term "tactic" refers to a probability distribution defined over a set of low-echelon actions or decisions (employment of units or weapons at the division level or below). (In air warfare, the term "tactical" refers to air attack in close support of friendly ground forces.) A "plan" is a particular sample from a strategy or tactic, i.e., a specified military action or decision, selected according to the probabilities that define the strategy or tactic.

The preceding definitions of "strategy" and "tactic" are military usages of these terms. In the terminology of statistical decision theory, there is no consideration of echelon, and both concepts would be referred to using the term "strategy" (i.e., a probability distribution defined over a set of actions or decisions).

In order to generate a scenario, it is necessary to specify the force levels and targets prior to battle, to determine a strategy (or tactic) for the employment of the forces, and to select a specific plan from that strategy (or tactic). At the strategic (theater) level, a scenario could involve simply the specification of an initial state of the forces and a strategic plan. At a tactical level, a scenario would include specification of the initial state of the forces, a strategic plan for the high-echelon forces, and tactical plans for the lower-echelon forces.

In addition to the military concepts of strategy and tactic, there is a third level of military planning, viz., "operational art." "Strategy" refers to the theater echelon level; "tactic" refers to division or lower-echelon; "operational art" refers to the army/front echelon levels. The concept of operational art is relevant to AirLand Battle doctrine, which is concerned with the rapid, synchronized movement, concentration and application of large military units.

The generation of a scenario involves the specification of the initial compositions of the forces, the targets, the combat goals of the two sides, the generation of strategies and tactics to achieve those goals, and the sampling of battle plans from those strategies and tactics. Hence, although the term "scenario" refers simply to a specification of the initial state of the forces and the battle plan, the task of developing an automated scenario generation system includes the tasks of developing automated strategy, tactic, and plan generation systems. The term "scenario generation," as used in this report, could reasonably be described by the terms "war plan generator" or "battle plan generator."

B. Motivation for an Automated Scenario Generation System

The conceptual framework for the proposed approach is derived from a consideration of why an automated scenario generation capability is needed. Such a capability is needed to generate probability samples of scenarios for use in test and evaluation of military concepts and systems. Because of the high cost of developing scenarios by manual means, many military systems evaluations are based on just one or a very limited number of scenarios. Moreover, the scenario generation process often takes place without reference to a well-defined probability space (i.e, a well-defined population of scenarios and a probability distribution for selecting members from that population).

Typically, the scenario generation process is "nonparametric." By the term "nonparametric" is meant that a scenario is specified in detail without reference to parametrically specified probability distributions. While the use of nonparametric procedures for specifying scenarios may be cumbersome, it is not the most serious problem, from a methodological point of view. A more serious problem associated with many scenario generation procedures is that they make no reference to a sample space or probability sampling. In statistical terminology, the developed scenarios constitute a "judgment" sample. The problem with judgment sampling is that, while everyone may agree that it is reasonable, the methods of statistical inference cannot be used to make inferences from the sample about a larger population of scenarios, based on the sample results.

In summary, there are two major problems associated with the use of manual methods for scenario generation. The first problem is the fact that the high cost of manually generating scenarios means that few of them can be used in an evaluation, thereby restricting both the reliability (precision) and the scope of inference of performance evaluations based on those scenarios. The second problem -- a methodological one -- is that the procedures used to manually generate scenarios typically preclude the legitimate application of statistical analysis procedures to make broad-scope inferences from analyses based on the scenarios, since the probability space underlying the scenario selection is not well-defined. To reiterate, the difficulty with "judgment" or "consensus" scenarios, then, is that, because no well-defined population of scenarios is identified, and because no well-defined probability sampling method is used to select the scenario from an identified population, the methods of statistics cannot legitimately be used to infer the performance estimates associated with the scenario to a well-defined large population extending beyond the scenarios actually used in the evaluation.

C. Goal of the Project

The goal in the proposed study is to develop a means for parametrically defining a population of scenarios, and a rapid means for selecting probability samples from that population. Such a capability could be used to provide samples of scenarios for evaluation studies, and those studies could then infer the results from the sampled scenarios to the larger scenario population. The basis of inference would be firm, and the scope of inference would be broad. The availability of a rapid means of scenario generation would enable statistical experimental design and sample survey procedures to be applied to the scenario selection process. The inference methods of statistics could then legitimately be applied to the analysis of the data obtained from the sampled scenarios.

The conceptual basis proposed for a scenario generation system is to specify a mathematical representation, or model, of combat; to use that model as a basis for specifying a population of scenarios; and to specify a method for selecting probability samples from that population.

D. Concept of Battle

The preceding paragraphs have described the general concept of a scenario. Prior to defining an analytical framework for scenario generation, we shall define some additional warfare concepts. The analytical framework that follows quantifies these concepts (i.e., both the scenario generation concepts and the additional warfare concepts).

First, we describe the major elements of tactical air combat (either actual or modelled). The major steps of the process are the following:

1. Define Force Elements and Targets

o Define offensive weapon types (in tactical theater air warfare, aircraft or aircraft force mixes)
o Define defensive weapon types (interceptors, either aircraft, artillery or missiles)

o Define targets (specification of value and vulnerability; vulnerability is specified by a damage function that specifies expected damage (probability that target is destroyed, or expected proportion of value destroyed, as a function of the weapons and interceptors allocated to the target))
o Define force units, task forces

In tactical theater air warfare, the term "weapon" would typically refer to an aircraft type, rather than a specific store (bomb, missile) carried by an aircraft. The term "target" may refer to a force element (weapon, interceptor) or item of intrinsic value (targets of intrinsic value include civilian population, agricultural territory, infrastructure elements, and industry).

2. Specify Constraints

o Resource Constraints
- o Numbers of weapons of each type
- o Numbers of interceptors of each type
- o Numbers of targets and characteristics (value and damage function parameters)

o Other Constraints
- o Physical constraints (rates, ranges, flyout radii, mission durations)
- o Organizational constraints
- o Environmental constraints (e.g., corridors, terrain, weather, day/night)
- o Logistic constraints (e.g., POL, ammunition)
- o Political constraints
- o Conditions under which certain targets will or will not be attacked
- o Military doctrine

3. Specify Combat Goals

- o Specify combat goals in terms of observable, quantifiable measures of the degree of success in achieving combat objectives, such as the following:
  - o Enemy targets destroyed
  - o Friendly targets saved
- o The combat goals may be specified in terms of the maximization or minimization of an objective function, or the occurrence of a specified set of conditions

4. Determine Strategies/Tactics

- o Determine strategies (probabilistic specification of the use of task forces or major units), in accordance with stated combat goals and doctrine
- o Determine tactics (probabilistic specification of the use of units or weapons), in accordance with stated goals and doctrine

5. Generate Battle Plan

- o Select a sample from the strategy and tactic distributions. (The strategy or tactic is a probability distribution over a set of military actions or decisions, such as the allocation of a number of weapons and interceptors to a set of targets. The battle plan is a specific set of decisions or actions sampled in accordance with this probability distribution.)

6. Execute Plan and Assess Results

- o Conduct (or simulate) the battle, using the plan
- o Evaluate objective function or note occurrence of conditions corresponding to goal achievement

7. Describe Scenario

- o The scenario is defined by the initial state of the forces and targets, and the battle plan, i.e., by items 1, 2, and 5 of this list. It is described by:
    - o Positioning of units (offensive, defensive)
    - o Engagements of units
    - o Assignment of aircraft to missions
    - o Assignment of aircraft to targets
    - o Allocation of interceptors to targets

Note that the scenario description corresponds to the end result of steps 1-5. It is the description of the initial state of the forces and the battle plan, but does not include the battle outcome. The scenario description need not (but may) include explicit description of the battle goals, strategy, and tactics, which are reflected in the battle plan. That is, although the generation of a scenario involves the generation of strategies, tactics, and plans, a description of a generated scenario need not include a description of the strategies and tactics developed and used to generate it.

E. Strategy Specification.

A critical aspect of the conceptual framework is the means for determining the strategies and tactics (step 4, above). We propose that the conceptual framework include the use of ”optimal strategies and tactics”, i.e., the strategies/tactics that achieve a stated combat goal. It is noted that not all military analysts agree that the use of optimal strategies is important, or even desirable. For example, some major wargame models (e.g., VECTOR II, VIC) utilize tactical decision rules derived from the judgment and experience of military experts, rather than optimal strategies.

We do not dismiss the importance of judgment strategies in certain applications, such as training and scenario evaluation. In fact, actual wars are fought using judgment strategies. We believe, however, that it is preferable to employ optimal strategies rather than judgment strategies as the basis for automated scenario generation, for several reasons. First, this approach acknowledges, accepts, and uses the science and methodology of statistical decision theory as the basis for evaluation. This approach is easy to defend. In evaluating a system, it seems reasonable to examine the system performance in a context in which both the offense and defense are operating in the best possible (optimal) fashion consistent with stated combat goals (even though it may be also of interest to examine system performance under suboptimal conditions). Second, corresponding to the class of optimal strategies is a well-defined population of scenarios; viz., the population of scenarios corresponding to optimal strategies. The population of scenarios corresponding to judgment strategies is not well defined. Third, the use of optimal strategies lends itself to speed, which is essential for an automated scenario generation system. While the use of judgment strategies may have a role in training and detailed wargaming, and in scenario assessment, it is not considered a good candidate for fast, automatic generation of many scenarios, or of scenarios having specified properties.

II. Analytical Framework

The following paragraphs present an analytical framework for combat, including air, land, and sea forces. The analytical framework that follows quantifies the concepts presented in the preceding paragraphs. The presentation that follows is in general terms, i.e., it applies to any type of warfare (land, air, or sea). In a particular application, not all of the structure that is defined below may apply, or be utilized (e.g., an aircraft mission analyst may choose not to become involved with the definition of task forces, but prefer to conduct an analysis simply in terms of total numbers of weapons and interceptors).

In quantitative terms, the analytical framework for the model is as follows. First, we define a number of ”task forces” (comprised of military units). A task force (Xi) = (x1,x2,...,xn), is comprised of various ”units” (e.g., in tactical theater air warfare, force mixes of aircraft), xj = (xj1,xj2,...,xjm), which are in turn comprised of various ”force elements” (e.g., in tactical theater air warfare, aircraft), xjk, which may be separately targeted, and the failure, neutralization, or destruction of which can affect the performance of the unit. These force elements include weapons (both destructive, such as artillery, and disruptive, such as EW or misinformation), command and control centers, communications equipment, intelligence sensors, supplies, and personnel.

One or more task forces may be assigned to a ”task-force mission”, which is defined in terms of the assignment of the task forces against another task force. A ”unit mission” is the assignment of units against other units, or against targets. One or more weapons of a task force may be assigned a ”weapon mission”, which is defined in terms of the assignment of the weapons against a target (force element, either weapon or nonweapon, or target of intrinsic value).

A ”battle strategy” is a set of probabilities, ”pi, that specify the likelihood that a task force will be assigned to a particular mission. A ”tactic” is a set of probabilities, pijk, that specify the likelihood that a weapon will be assigned against a force element.

A ”plan” (or battle plan) is a particular sample assignment, selected according to the probabilities specified by a strategy or tactic. In particular, a ”strategic plan” is a sample from a strategy, and a ”tactical plan” is a sample from a tactic.

A ”scenario” is a description of the force initial state (prior to battle) and a battle plan. This description does not include a description of the results (outcome) of executing that plan. The battle outcome is a random variable; because of stochastic variability, the same battle plan could realize many different outcomes. The battle outcome is determined by executing the plan in a real battle, or by inputting the scenario to a war-game (combat) simulation model.

A ”battle”, then, is the implementation of a battle plan -- the execution by task forces and units of their assigned missions, and the execution by weapons of their assigned missions. The term "battle" refers to all of the events that occur during the course of executing the battle plan.

The ”battle outcome” is a quantitative description of the result of the battle. The term "battle outcome" may be used to refer to a description of the battle at a series of points in time, or at a single point in time (the "end" of the battle), at which hostilities cease. It may be expressed in terms of the expected damage, or in terms of functions related to expected damage.

The expected damage is determined using damage functions, which specify the probability of destruction or neutralization of each target, or the expected proportion of the target value destroyed, given the interaction of the forces of the two sides:

$$dPxPy = D(X,Y,Px,Py)$$

where X symbolically denotes all of the task forces, units, and force elements of the friendly side (side 1, side A, the Blue side), Y symbolically denotes all of the task forces, units, and force elements of the enemy side (side 2, side B, the Red side), Px denotes a side 1 strategy (i.e., the probabilities of assignment of the friendly side task forces, units, and force elements to missions), and Py denotes a side 2 strategy (i.e., the probabilities of assignment of the enemy side task forces, units, and force elements to missions).

During the course of determining a specific strategy or tactic (i.e., Px and Py), the force levels X and Y are considered fixed.

As mentioned, the battle outcome may be expressed in terms of the losses of each type of force element, unit, or target of intrinsic value. Alternatively, discrete loss or victory indicator variables may be defined in terms of a set of logical statements about the magnitudes of losses of each force element, unit, or other target (just as goals are defined). For each side, a set of payoff functions, Hx and Hy, are defined -- one for each goal statement. The payoff is a function of the damage.

A ”war” is a sequence of battles. After each battle, the remaining forces are reconstituted to the extent that remaining force elements permit (recall that supplies, ammunition, payloads are force elements). A ”war strategy” is a scheme for determining a sequence of battle strategies.

”Goal Specification”. The goals are specified by the user, in terms of quantitative criteria associated with battle outcome. A goal may be specified in terms of expected damage to various types of force elements, territorial losses, personnel losses, target damage, or other measurable quantities functionally related to expected damage.

”Constraint Specification”. Constraints include:

- o Resource constraints (weapon, interceptor stockpiles)
- o Physical constraints
- o Organizational constraints
- o Environmental constraints
- o Logistic constraints
- o Movement constraints
- o Strategic and tactical constraints
- o Political constraints
- o Military doctrine constraints

FndID(18)
FndTitle(Analytical and Conceptual Frameworks for Automated Scenario Generation: Application to Tactical Theater Air Warfare)
FndDescription(This appendix describes conceptual and analytical frameworks for developing an automated methodology for generation of scenarios. The term "conceptual framework" refers to a description of the general concepts underlying our approach. The term "analytical framework" refers to a quantification of the conceptual framework, in terms of specific variables, functions, and procedures.)
FndKeywords(scenario; military scenario; senario generation; automated scenario generation; strategy; tactic; plan; tactical theater air warfare; test and evaluation; communications-electronics; modeling and simulation; Vista Research Corporation; Joseph George Caldwell)