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APPLICATION OF FUTURE STATE DECISION MAKING IN THE EAGLE COMBAT MODEL

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Earlier reports, however, have asserted that systematic combat models which use the so-called present-state decisionmaking paradigm have a fundamentally flawed decisionmaking process. This report investigates the application in EAGLE of an alternative, future-state decisionmaking architecture, called the Generalized Value System (GVS), describes the general changes to EAGLE code and data structures necessary to implement this methodology, and presents an example of how we believe this methodology would execute within EAGLE.

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Abstract

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I. Introduction

Military force planners must continually postulate the scenarios, threats, available systems, political and economic environments, and national resolves which will exist at some future time. Moreover, these planners now face increasingly tough choices with respect to how best commit ever-scarcer resources to procure weapon systems and develop force structures that are sufficiently effective to deter any postulated future battles from occurring.

Combat simulation models play a major role in the development of doctrine, force structures and systems. Several widely varying general approaches to the modeling of combat have been studied - historical curve fitting (e.g. QJM, [3]); man-in-the-loop (MITL) models (e.g. JANUS, [18]); systemic (no man-in-the-loop) simulations (e.g. VIC, [19]); and analytic models (e.g. COMAN, [1]). Of these approaches, systemic and MITL models are by far the most commonly used for weapons system and force structure analyses. These two approaches, however, are not interchangable, and numerous tradeoffs are involved in the choice between a systemic or an MITL model.

MITL models are generally easier to set up and run. They usually require far less extensive data bases and can use far simpler programming logic, since real players are able to react and make decisions in unforseen circumstances. MITL models, however, are not well suited for many analytical studies because their results are generally difficult to replicate, and critical command and control decisions usually lack clearly defined audit trails. Thus, with MITL models, the contributions to the overall outcome of new weapons systems, force structures and doctrines becomes almost inseparable from the dynamic of the individual players, the "fog" of even simulated battle, or pure luck. (On the other hand, most current systemic models require frequent stops for code or data modifications and subsequent restarts when, according to the judgement of analysts, the model fails to take reasonable or realistic military actions. Continually having to implement such a stop/restart sequence effectively turns a systemic model into an MITL model, and usually a very inefficient one at that. Despite this, because of their ability to conduct controlled replications and produce reasonable audit trails, systemic models seem likely to remain favored for most analytical studies.)

In an earlier report [11], we developed the argument that a fundamental flaw in current systemic combat simulations is the so-called *present-state decisionmaking* paradigm. In this paradigm, as exemplified by the Tactical Decision Rules (TDR's) or decision tables of VIC, the model makes tactical decisions by examining the values of various attributes of modeled entities and comparing these to certain (generally multiple) test and threshhold values, in what is effectively little more than "IF ... THEN" constructs. Our position in [11] was that this paradigm is flawed in that, in reality, all combat decisions above the level of simple battle drill are made, implicitly, to produce some desired result, not at the present time, but somewhere in the future. The correct role then, of the present state, is really to "trigger" a *planning process* and act as of a set of *initial conditions* for some other model with which the future, and the impact of various alternative actions can be predicted. Therefore, in our view, the flaw with current decision tables is that the analyst who developed the table almost certainly had in mind some predicted future that should occur based on the present state as reflected in tables, but this model exists only in his or her mind and is therefore neither able to be validated nor subject to the establishment of audit trails. We have further proposed an alternate future-state architecture for decisionmaking in systemic models as part of the *Generalized Value System* [GVS] developed during the ALARM [4] project at the Naval Postgraduate School. Selected aspects of the GVS will be outlined later in this report.

EAGLE [17] is a systemic combat simulation which is currently under development by the TRADOC Analysis Command at Fort Leavenworth and which contains several novel and significant features. First, EAGLE is written using the object-oriented Artificial Intellegence (AI) language LISP [6]. Object-oriented programming is widely viewed as promising significant improvements in programming efficiency through class structure inheritence and code reuse. LISP processes primarily strings of characters as opposed to numbers, and is ideally suited for describing both combat missions and decisions in understandable, natural-language terms. In EAGLE, LISP's AI capability has allowed the development of an extremely sophiticated tactics knowledge base to support decisionmaking. Furthermore, EAGLE is the first model we are aware of which was designed from the outset to essentially mirror the doctrinal Command Estimate process [16] of military decisionmaking as taught in the Command and General Staff Officer Course.

The purpose of this report is to propose a GVS future-state prediction methodology that is generally compatible with the EAGLE architecture, to describe the general changes to EAGLE code and data structures necessary to implement this methodology. and to outline an example of how we believe this methodology would execute within EAGLE.

II. Future-State Decisionmaking and the Generalized Value System

As we indicated above, and as we investigated at length in [11], command and control decisionmaking in current systemic models follows what we have called the present-state decisionmaking paradigm. That is, the model compares the values of various modeled quantities to certain (generally multiple) threshhold values, and implements a decision based on what is effectively an "IF ... THEN" construct. We hold that this paradigm has the fundamental weakness that only the current values of the attributes are tested against the decision tables, yet these values should properly be viewed as only initial conditions from which some future state(s) will evolve, and the fundamental reason why the model is supposed to trigger a decision is that, in the judgement of the analyst who developed the table, this future will be undesirable unless some current change is made. But, with decision tables, the model and process which predicted this undesirable future are effectively hidden, and really exist only in the analyst or programmer's mind.

Given what we believe to be the fundamentally flawed nature of the present-state decisionmaking model, we proposed in [11] an alternative architecture for decisionmaking in systemic models. This proposed architecture blended what we believe are the basic elements of realistic decisionmaking - the current situation only initiates a planning process: this planning process includes an explicit projection of the anticipated future: and any actions are initiated solely to change this predicted future - with the basic limitations of current computer simulation - most algorithms must be reduced to quantitative computation. In our proposal, the essential elements of this future-state decisionmaking architecture, which we referred to as the Generalized Value System, were postulated to be:

1. For each model entity, an explicitly defined state vector, consisting of quantifiable elements which the model is capable of representing.
2. A plan or mission. This will be essentially a set of time, distance and force-oriented constraints which a given model decisionmaker will try to satisfy.
3. A set of explicit algorithms which can produce predicted future states of any given entity, given a present state.
4. A set of algorithms for deriving a quantitative measure (or measures) of the value of any entity, given the state of that entity. These algorithms must include the time discounting of value proposed in [10].
5. A set of algorithms for converting a plan or mission and a set of current and future values into decisions.

Before continuing, we would make one additional point regarding future-state prediction in combat models. This point is that there are really four fundamental, and to some degree independent, questions that any command and control process must address. (Interestingly enough, these bear some similarities to certain classic problems in mathematics, although at this time we see no clearly exploitable advantage in recognizing this relation.)

1. What procedure, algorithm or test determines whether a particular course of action will (or perhaps more appropriately *should*) accomplish the mission? This question is very much like the question of how does one mathematically verify that a proposed solution to a problem is valid.
2. Is there a feasible course of action which will still accomplish the mission? This question is akin to the mathematical question of existence of solutions (which can often be answered in the affirmative even when a solution cannot be produced).
3. If there are any feasible courses of action, is there one which is, under some measure, optimal? This issue is similar to the mathematical question of uniqueness of solutions (which, again interestingly, can often be answered even when no solution has been produced).
4. How can one construct feasible courses of action, given that they exist?

As we proceed in this report, we shall comment on the degree to which proposed structures and algorithms can answer each of these questions.

As we emphasized in [11], future-state decisionmaking and the GVS are really only an architecture - a philosophy of how to more accurately model combat decisions - not any one particular set of algorithms. As we pointed there, several of elements of the GVS architecture were independent of each other, and could be implemented with more than one particular algorithm. The primary purpose of this report is to demonstrate the application of this architecture to the development of specific algorithms for a model now under development - EAGLE.

III. The EAGLE Model

As we alluded to in the introduction, EAGLE [17] is a new developmental model with several unique and intriguing features. A complete description of all these features is far beyond the scope of this report. (Full details are available to appropriate agencies from TRADOC Analysis Command, Fort Leavenworth.) Nevertheless, there are a few of these features that are especailly noteworthy because of their relationship to command and control modeling. The first is that EAGLE is written in LISP [6], a language originally developed for Artificial Intelligence research. LISP is an especially attractive language for command and control simulations, since it was designed from the outset to be used for simulating decisions. Virtually all other languages available today, including ADA, lack this feature, and generally model command and control only with varying degrees of awkwardness. LISP is also fairly unique in that it operates primarily not on numbers, but on lists. Numbers may be included in these lists, but more commonly the lists are made up of strings of characters. Thus, a LISP model can make tactical decisions based on model-stated criteria such as "receiving-heavy-incoming-fire." This feature provides both almost immediately self-documenting code, and a degree of visibility and comprehensibility not offered by TDR's or other current model constructs. Furthermore, LISP also encompasses very highly structured knowledge bases (KB's) in which not only can command and control decision logic be deposited, but from which such logic can also be easily recovered and easily modified. Lastly, current versions of LISP are object-oriented. Object-oriented programming generally allows for much more robust data structures, since objects can be ogranized into hierarchies with lower-ranked objects automatically inheriting elements from objects higher in the structure. Thus a change to the data structure for a "parent" can be automatically passed on to all of the "children," without the need to modify any code other than on the parent. (By contrast, changing a single calling arguments string in a FORTRAN subroutine can require changes to massive numbers of other, related programs.) This object-oriented structure again seems especially well suited for simulating combat, since most military entities belong to very well-structured hierarchies.

The EAGLE model has another very appealing feature, apart from its LISP-based structure. It is the first combat model, to our knowledge, designed from the outset to incorporate fundamental elements of the doctrinal Command Estimate decisionmaking process [16] as taught to and used by Army officers during Fort Leavenworth's Command and General Staff Officer Course. Major elements of this process are found in the extensive and sophisticated preprocessor being developed as part of the EAGLE project. This preprocessor is menu-driven and integrated with a terrain KB. Using the preprocessor, an analyst can rapidly develop a tactical scenario in the same sequence as the Command Estimate process. The menus allow formulation of complete sets of plans and orders for each subordinate unit, and, if necessary, a set of tailored tactical decision rules appropriate for each plan. Furthermore, each plan is broken into clearly identified phases, with potential critical events also identified within each phase. Lastly, each phase of a subordinate unit's plan also is clearly linked to a phase of that subordinate's command headquarters' plan. (Normally, of course, each phase of a command headquarters plan will encompass several phases or tasks for a subordinate.)

Actually, EAGLE recognizes two basic types of "units" in the above context. The first type is called a *resolution unit.* A resolution unit is both the smallest level tactical unit played in the model, and the *only ground* maneuver entity in the model which engages in combat activity. A command, or headquarters unit, by contrast, is purely a planning activity, and may have as subordinates either other command units, or resolution units. (An actual command headquarters, e.g. a brigade HHC, has dual representation - a command unit object which represents the planning functions, and a resolution unit which models the physical functions, such as movement of the command post.) These two object types are also treated differently in terms EAGLE's mission planning structure (albeit these differences often seem subtle and to involve more definitions than substance).

The overall structure of the model decisionmaking architecture in EAGLE starts with a defined plan (generally prepared using the preprocessor). A plan consists of a sequence (list) of phases, each associated with a unique order. Each order is then another sequence or list, each element of which contains, as a minimum, a task, an objective, and information on when or under what conditions that task would start and end. (Curiously, there is no slot in the task list for the enemy force, if any, to be defeated, or of any degree of destruction to be inflicted on the enemy. This is certainly less than fully realistic, and does have implications for any future-state prediction processes.) Resolution units then carry out these orders through a sequence of operational activities. Figure 1 displays some of the common phases and tasks that may comprise a plan, and the operational activities allowable for a ground maneuver unit. Although the conceptual structure of EAGLE allows phases to start and end at specific times, the current model in fact changes phases under only one of two criteria - on-order (i.e. when directed by higher) or on-own-initiative. Thus a critical aspect of each phase is the *transition rules*, which are contained in the KB, that signal the need to start the next phase. For resolution units, these rules determine whether a change in phase is warranted by examining various attributes which the model documentation refers to under the general heading of the unit's self objective status or self decision factors. (Like almost all LISP constructs, these attributes will be string values and the associated rules string-based. In other words, the rule for breaking contact may consist of the unit's objective status being determined to be 'breaking-contact-receiving-hvy-losses.') While on order rules are clearly required in order to effect synchronization of the various phases of the plan, the uncertainity of when they will "fire" does significantly complicate the future-state prediction problem. Furthermore, including time-dictated transitions in any given plan will virtually force some kind of future-state prediction, since the amount of combat power sufficient to accomplish a mission with no time constraints may be insufficient when time constraits are added. Lastly, in any event, the current on-order transition rules should be enriched to address such essentially future-state issues as whether requiring one subordinate resolution unit to assume a hasty defense prior to starting the next phase of its plan, while another completes its part of the current phase, will result in sufficient additional losses that the first unit then becomes ineffective to perform its next task? (We refer to this last question as the *slack time* issue, and shall wherever possible, address it and the other issues raised above in this report, although full consideration of the scope of some of them is far beyond what we will be able to cover.)

IV. The GVS/EAGLE Test Bed Scenario

In order to demonstrate the algorithms and data structure necessary to incorporate the GVS future-state decisionmaking architecture into EAGLE, we shall use a single, very representative scenario. (This approach is similar to that we used to demonstrate the proof

Selected Blue Phases

Main-atk-conduct-passage-of-lines (bde/div)
Conduct-spt-atk-through-feba-bn (bde/div)
Conduct-spt-atk-through-feba-reg (bde/div)
Main-atk-penetrate-feba-bns (bde/div)
Main-atk-attack-2nd-ech-feba-reg (bde/div)
Hasty-Defend-in-place
Main-atk-attack-2ech-feba-div (bde/div)
Main-atk-attack-2ech-reg-feba-div (bde/div)
Main-atk-attack-rear-feba-reg (bde/div)
Follow (bde)
Conduct-spt-atk-feba-reg (div)
Main-atk-penetrate-feba-reg (div)
Main-atk-penetrate-2ech-feba-div (div)

Blue Tasks

- Attack
- Defend
- Deploy
- Delay
- Marshal
- Follow

Blue Operational Activities

- Traveling-Overwatch
- Bounding-Overwatch
- Break-Contact
- Defeat
- Defend-Assembly-Area
- Defend-Battle-Psn
- Defend-Hasty-Battle-Psn
- Delay
- Occupy-Assembly-Area
- Occupy-Battle-Position

Figure 1 · EAGLE Phases, Tasks and Operational Activities

of the basic GVS concept in VIC [12].) The basic elements of this scenario are graphically portrayed in Figure 2.

In this scenario, a Blue brigade, consisting of two mechanized task forces, one armor

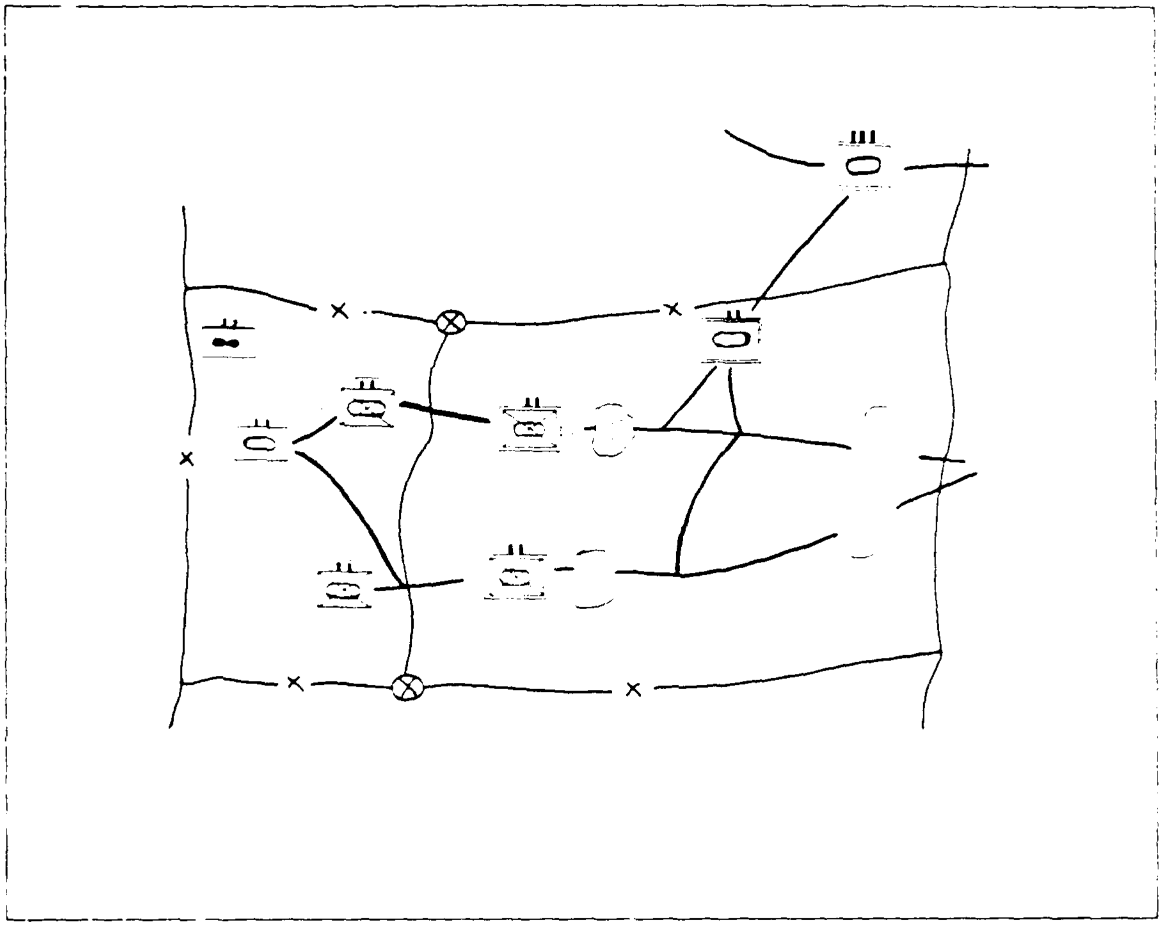

Figure 2 - The Basic Scenario

task force and an attack helicopter battalion has been tasked to penetrate an attrited defending Red motorized rifle regiment with which the brigade is already in contact. The Red regiment is in a hasty defense with its two remaining motorized rifle battalions on line in its first echelon, and its tank battalion situated in an assembly area for use as a counterattack force. In addition, but clearly important for the Blue commander's planning, a Red tank regiment (probably from the same division as the defending motorized rifle regiment and probably with the mission of division-level counterattack) is situated outside the brigade's area of operations. We assume the blue commander's general plan will be to attack with the two mechanized task forces abreast, to sieze objectives A and B respectively, then pass the armor task force through to sieze objective C while the two mechanized task forces consolidate their objectives. Upon securing objective C, the armor task force will consolidate that objective while some unspecified (for this example) following brigade passes through to exploit the attack. The attack helicopter battalion is in reserve. Mobility corridors are indicated by the solid lines connecting units and objectives.

In terms of the EAGLE structure, we postulate the brigade is part of a division

Division Tasks	- Blue-Main-atk-penetrate-feba-reg
	- Blue-Main-atk-penetrate-2ech-feba-div
	- Blue-Hasty-Defend-in-place

Figure 3 - Phases of the Division Plan

Division Phase - Blue-Main-atk-penetrate-feba-reg		
	Brigade Phases	- Main-atk-penetrate-feba-bns
		- Main-atk-attack-2nd-ech-feba-reg
		- Hasty-Defend-in-place
Division Phase - Blue-Main-atk-penetrate-2ech-feba-div		
	Brigade Phases	- Hasty-Defend-in-place
Division Phase - Blue-Hasty-Defend-in-place		
	Brigade Phases	- Prepare-for-attack

Figure 4 - Phases of the Brigade Plan

plan/order that consists of the tasks shown in Figure 3. As we discussed above, this division plan then will create a brigade plan/order consisting of one or more phases for each phase of the division plan, as, for example, shown in Figure 4. Lastly, the brigade will then convert each phase order it has received from the division into one or more tasks for each subordinate unit, as, for example, is shown in Figure 5.

In an actual operation each level of command is assigned an area of operations (AO). The AO includes an actual physical "box" on the ground, as is shown for the brigade in Figure 2. By doctrine, each commander is responsible for everything that happens in his AO, and, subject to whatever rules of engagement apply, has the authority to attack all enemy assets in his AO with whatever means may be appropriate. Thus, as Figure 2 indicates, a unit's AO must encompass not only territory on the enemy side of the FLOT, but on the friendly side back to that unit's rear boundary. When command headquarters plan, they commonly assign subareas of their assigned AO to their subordinates. Thus, for example, Figure 6 shows the brigade subdividing a portion of its AO into two battalion-sized AO's and then assigning each of these to one of the lead attacking battalions.

Also by doctrine, each level of command has an area of interest (AOI). In contrast to the AO however, the AOI is not necessarily a physical area on the ground and is not

Division Phase - Blue-Main-atk-penetrate-feba-reg
Brigade Phase - Main-atk-penetrate-feba-bns
TF 1/92 Tasks - attack
- defend
TF 3/80 Tasks - attack
- defend
TF 3/5 Tasks - follow
Atk Hel Tasks - marshal

Brigade Phase - Main-atk-attack-2nd-ech-feba-reg
TF 1/92 Tasks - defend
TF 3/80 Tasks - defend
TF 3/5 Tasks - deploy
- attack
- defend
Atk Hel Tasks - marshal

Brigade Phase - Hasty-Defend-in-place
TF 1/92 Tasks - defend
TF 3/80 Tasks - defend
TF 3/5 Tasks - defend
Atk Hel Tasks - marshal

Division Phase - Blue-Main-atk-penetrate-2ech-feba-div
Brigade Phase - Hasty-Defend-in-place
TF 1/92 Tasks - defend
TF 3/80 Tasks - defend
TF 3/5 Tasks - defend
Atk Hel Tasks - marshal

Division Phase - Blue-Hasty-Defend-in-place
Brigade Phase - Prepare-for-attack
TF 1/92 Tasks - marshal
TF 3/80 Tasks - marshal
TF 3/5 Tasks - marshal
Atk Hel Tasks - marshal

Figure 5 - Resolution Unit Tasks in the Brigade Plan

assigned by higher headquarters. Rather, the AOI really represents that *time horizon* out to which a commander must be looking in order to effectively react to unforseen events

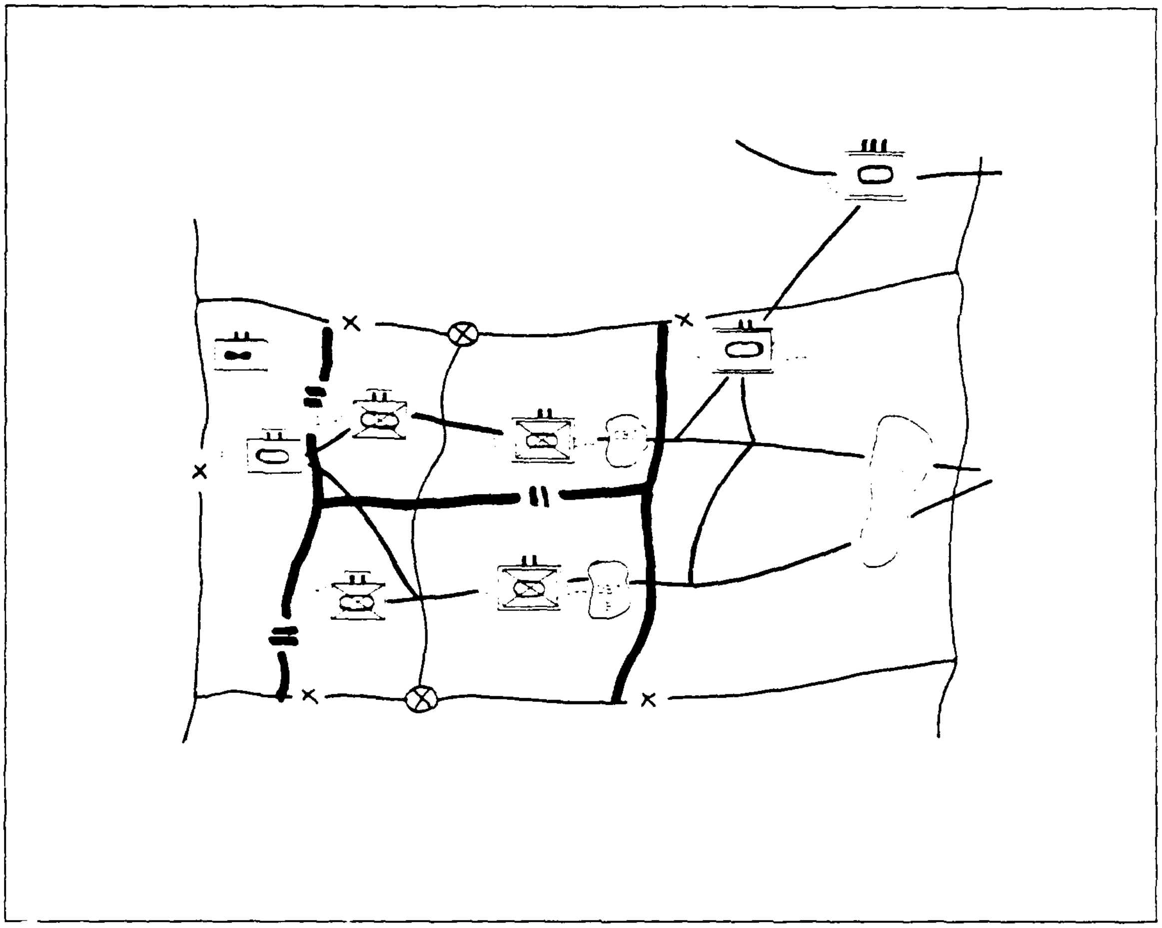

Figure 6 - Areas of Operation for the Basic Scenario

or counter unexpected threats. While there are suggested doctrinal times associated with the AOI at each level of command, determination of each unit's AOI is up to that unit's commander and depends primarily on the length of that headquarters' decision cycle. The AOI will normally contain not only the unit's AO, but also appropriate portions of higher and adjacent units' AO's. The AOI plays a pivotal role in the GVS architecture. In GVS, the combat power of assets which are not available for employment at the present time are exponentially discounted depending on the time interval until they will become available [10], and the "time constant" used to normalize this discounting is determined by requiring that any asset at the outer boundary of the AOI have only a nominal fraction (5%) of its full power. Figure 7 displays both the brigade's and one battalion's AOI's superimposed over the respective AO's, assuming the appropriate time horizons are three hours for the brigade and one hour for the battalion. (Note that the AOI used in this context should not be confused with what doctrinally referred to as a named area of interest (NAI). An NAI is some specific limited area on the ground where a commander may focus intelligence collection assets, e.g. to discern enemy movements.)

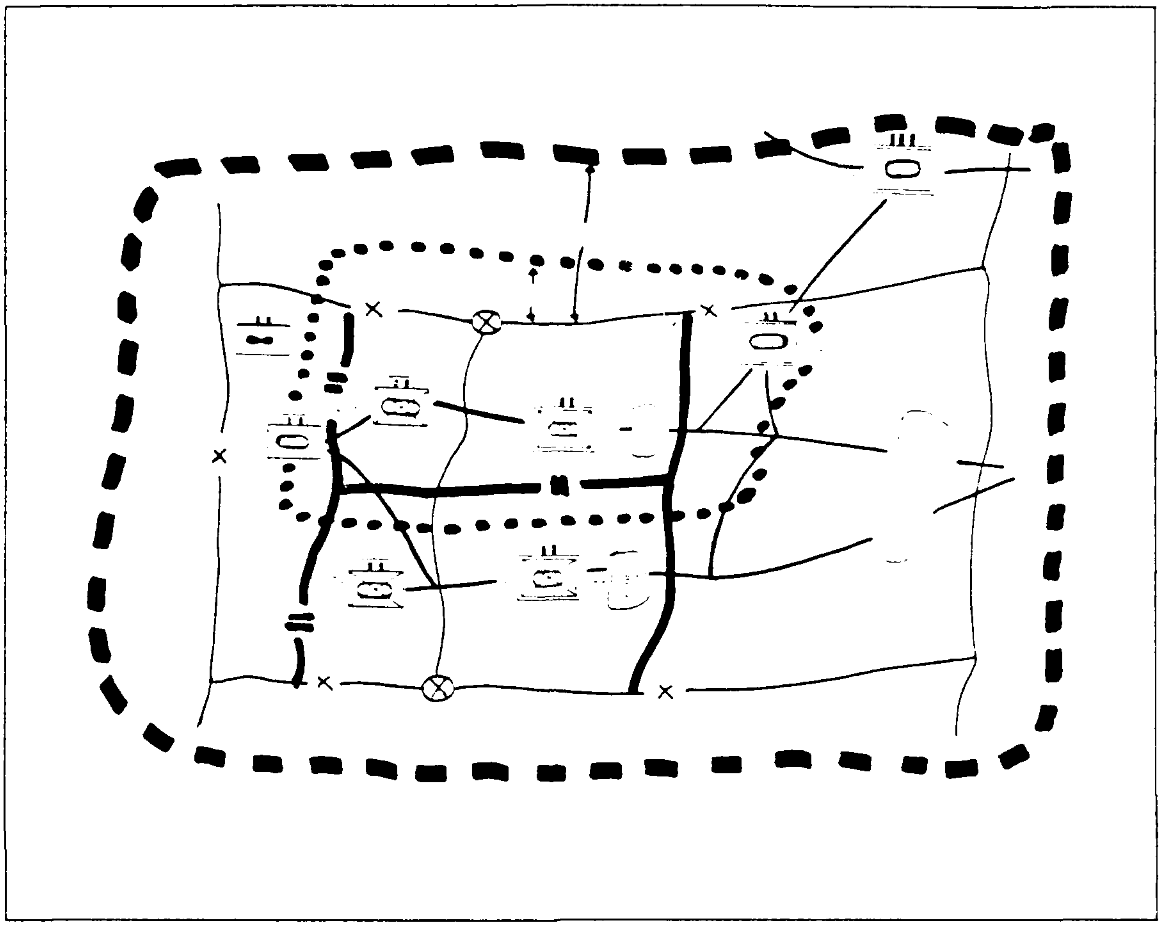

Figure 7 - Areas of Interest for the Basic Scenario

Although we shall not be able to develop this theme fully in this report, another key concept from ALARM which we believe may be exploitable in developing a future-state prediction capability for EAGLE is that of the time domain networks (TDN). A TDN is effectively simply a PERT or CPM network representation of a plan. The nodes of a TDN represent critical events in the plan and the arcs represent the phases or operational activities necessary to progress through the plan. Such networks are integral parts of Soviet planning [8], where they are used to automate the process of predicting combat outcomes. (The analogous process, when done by a U. S. G3 is called "war gaming a course or action.") Conceptually, creation of such a TDN for each plan in EAGLE should be relatively simple, given the already existing plans and orders structure. Figure 8 displays such a TDN for our sample scenario. Actually, the network in Figure 8 is slightly ambiguous in that, without reference to the phase transition rules for this order in the EAGLE Tactics KB, it is not clear whether both mechanized task forces, or only one, would have to reach their objectives before the armor task force can deploy. (For our scenario, we shall assume that both mechanized task forces must reach their objectives prior to deployment of the armor task force.) In general, we expect that all on-order TDN transitions could be reduced to simple "and" or "or" combinations of completions of the preceeding arcs, or such combinations plus a specified time in the network having passed.

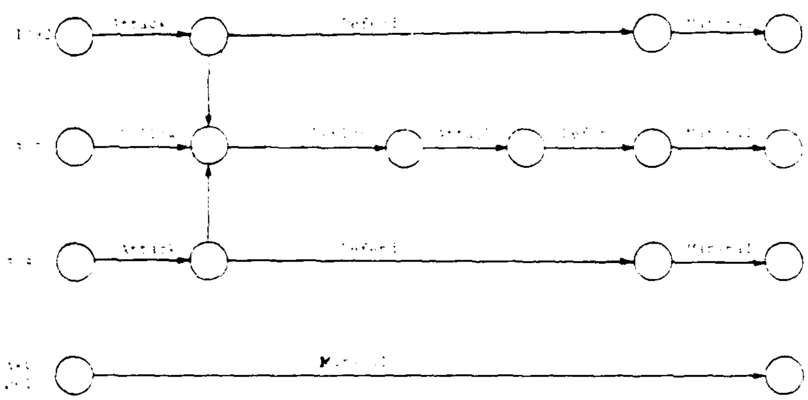

Figure 8 - The Time Domain Network for the Basic Scenario

V. The GVS Process for EAGLE

In this section, we provide a step-by-step outline of our proposed implementation of the GVS into EAGLE. Where known, specific EAGLE/LISP/KEE notation is used. In order to demonstrate the steps, the scenario presented in the previous section will be assumed. While our focus for this example is a brigade and its associated battalion resolution units, adding echelons above the brigade level should follow similar logic. The primary differences when higher echelons (e.g. divisions or corps) are added will be longer planning horizons and a broader spectrum of assets to be considered in the alternatives.

The GVS process described below should be performed at a every change of phase within a plan, irrespective of the unit level, and thereafter at a regular time interval, depending on the unit. We initially recommend that the resolution units be reforecasted every 30 minutes, brigades every 60 minutes, divisions every 120 minutes, and corps every 240 minutes. (Similar times should be utilized when GVS prediction is implemented for the RED Units). Our initial proposal will address the Blue forecast only. The principal steps in this process are described below.

Step 1 - As each plan is prepared for each unit in the preprocessor, an Area of Interest associated with that plan must be generated.

The AOI may be a geometric area (assumed to have piecewise linear boundaries) or a time horizon. A slot, e.g. **a-gvs-area-interest-(unit designation)**, which points to the AOI, must be created as part of the plan. The two characteristics required of the AOI are:

a. It must be large enough (in both the time and space domain) to forecast to the end of the objective of the Plan.
b. It must relate to each "terrain analysis" area currently done in the preprocessor.

(As discussed earlier, it might prove quite useful for the preprocessor to also generate a time domain network for each plan. This TDN could be stored as a linked list structure equivalent to Figure 8. Developing the necessary code to generate this TDN from an EAGLE plan may be a non-trivial endeavor, especially as regards the conversion of EAGLE transition rules to network activity start/stop conditions. Nevertheless, as we shall point out later, having such a network available, along with the necessary references to associated ground coordinate, e.g. objectives, offers an alternative mechanism for future state prediction, and is a potentially fruitful area for further research.)

For our subsequent discussion, we assume that we can access the AOI for the each plan. We also assume that a routine will be available which can test whether or not a given location is in some specified unit's AOI, although calls to this routine will occur later in the process.

Step 2 - Each unit should have two slots, one corresponding to a list of the "tail numbers" of each friendly unit in the AOI and the other corresponding to a list of the perceived tail numbers of all enemy units known to the unit.

The friendly units would include all organic assets plus any Artillery, ADA, Fixed-Wing, Engineer, Logistics, etc. units attached or OPCON to the unit being considered. With slight modifications, the current **a-local-sitmap-friendly** slot of the **perceptions** object in the Characteristics-KB could be used for this. In our example, only ground maneuver units (defined as including helicopter assets) will be considered. The list of enemy units could be stored in either the (modified) **a-local-sitmap-enemy** slot of the same object, or in the (modified) **a-prioritized-opponents** slot of the **res-decision-factors** object of the same KB. Enemy units would be added to this list from two sources:

a. Those within the visible detection (currently 4K) circle of each resolution unit. Some code modification would be required to ensure these are passed "up the line" to the resolution unit's command headquarters.
b. Those that are detected through the INTEL/FUSION process which currently produces target to Headquarters Units and to the Artillery FSE. Again, some code changes would be required here, e.g. to include passing appropriate information up and down the line.

The modifications to the detection list data structure should ensure that each detected enemy unit in the AOI has not only a tail number, but a location, a direction and speed of movement, and a last time detected (and perhaps the identity of the detector). In the full model, some filtering of this list based on size would also be appropriate. For example, brigades might keep track of only battalion-size enemy units, while divisions might track only regimental-size enemy units.) In any instance, we shall assume that such a list of friendly and enemy units is available for consideration during any forecast.

Steps 1-2 are not properly part of the actual GVS forecast calculations, but must nevertheless be implemented before the calculations can be done. The remaining steps will then be cycled through for each unit which is being forecast. For our example, this means the brigade and its associated resolution units.

> *Step 3* - Compute, at the current time step, the total "discounted" power for each resolution unit and the brigade headquarters, using the AOI as previously determined.

The actual mechanics of the computation of discounted power are documented in previous GVS papers [11]. This is basically a distance (time and space) discounting, relative to the blue force, which produces a current point estimate of the power of both the red and blue forces. We propose, at least initially, to base the measure of power for the GVS curves on the EAGLE **a-unit-eff** attribute, which is computed on a scale of $0 - 100$, and which represents the percentage of unit effectiveness relative to what if would be at full (TOE) strength. The unit's full strength firepower score would then be multiplied by this percentage to give the adjusted power (before time discounting). We would propose that, at a later time, more sophisticated measures be investigated, e.g. through use of a Required Manning Level, related to Radiation, MOPP, and Crews available, etc. (The categorical judgment methodology proposed by Crawford [2] has several attractive features with respect to this issue.)

This power calculation is, of course only a single point estimate, not a projection. However, we believe the power calculated for the Red resolution units provides a potentially useful *quantitative* basis for determining the order of precedence in the **a-prioritized-opponents** slot in the **res-decision-factors** object in the Characteristics-KB. Furthermore, although we have not yet fully developed the argument for this assertion, there is also a possibility that the ratio of the overall Red and Blue GVS powers derivable from this point estimate might also provide a simple, yet powerful basis for inferring the existence of a feasible plan to accomplish a given tactical goal - *provided the time horizon within which the goal must be accomplished is within the AOI and provided the size of the AOI has been correctly chosen* - without having to completely war-game the plan through. (This claim, were it to prove out, would be analogous to our earlier observation that in many mathematical instances it can be proven that a problem has a solution, even though one cannot produce that solution. However, as we noted, we have not pursued this particular line of investigation sufficiently to be certain of its utility.)

However, even if a sufficiently favorable current GVS ratio were to ensure the existence of a feasible plan, that does not necessarily guarantee *any particular* plan is feasible, only that *some* plan should be. Neither will a favorable GVS ratio, in and of itself, indicate how feasible plans might be arrived at. Verifying the feasibility of any particular plan requires an explicit future-state prediction, i.e., to use the mathematical analogy, substitution of the candidate solution into the problem. The "brute force," and clearly unacceptable way to do this projection would be to run the actual model, within itself, and observe the results. We believe that acceptable surrogates for this procedure are computationally feasible, and shall now describe one such alternative.

Step 4 - Begin the GVS projecting process using Δt minute time increments.

(We propose using a Δt of 5 minutes for resolution units, and possibly longer for higher level command units.) We currently believe that the most efficient vehicle for this projection will be the creation of temporary or "shadow" objects, which have virtually identical structure to the "real" resolution units. Correctly done, this will allow the use of the inheritance structure of EAGLE to efficiently pass any necessary attributes. These shadow units could then be moved, attrited, etc., without the need to make any changes to the real units. This approach would, however, require careful purging at the end of the forecast of any reference to these shadow objects from portions of the model such as the Terrain Manager.

Step 5 - Check next task for unit to determine whether a transition from the current task is required.

This will require reference to the plan as stored in the Tactics-KB to determine, based on the positions and powers, whether a change of phase/tasks is required. Here again, having a shadow unit with pointers to all of the attributes, including the phase transition rules for that unit's specific plan, would greatly simplify this process.

As alluded to earlier, whether a new task is implemented on-order as opposed to at a particular point in time can be a crucial issue. In actual operations, local commanders will probably prefer that all transitions be on-own-initiative (such as being able to order 3/5 to attack down the appropriate corridor depending on how the "fight is going"), since this retains maximum flexibility. However, from higher's point of view the attainment of Objective C by 1800 may be essential, subject to certain constraints on losses by subordinates. The EAGLE structure (and certainly GVS planning) must be responsive to both. As noted above, we propose to initially use the default rules, modified as necessary, to determine whether an on-order phase change will fire. At the same time, we will also impose a time constraint on attainment of the final objective, i.e. it must be forecast to occur before the end of the planning horizon, thus perhaps "forcing" (or determining as infeasible) some tasks which may exist for the unit. It has been suggested that the EAGLE construct of the Abstract Higher Level may be used as the "referee" between time and event driven tactics. Correct resolution of forecasted phase changes is a critical area. Also a consideration here is the slack time issue which we have previously commented on.

Step 6 - For resolution units in contact, project the attrition during the upcoming time step.

Note that determining whether a phase change occurs at the start of this interval must precede this step, since the attrition will relate directly to the task to be performed during the upcoming interval. Determining which units are in contact can be done very straightforwardly, e.g. by a simple geometric distance calculation between centers of mass. Once this is determined, we propose to project the attrition using the simple, range-dependent, homogeneous, square law difference equation counterpart of:

$$\frac{dx}{dt} = -ay\left(1 - \frac{R}{R_{max}}\right)^{\mu_y}$$
$$\frac{dy}{dt} = -bx\left(1 - \frac{R}{R_{max}}\right)^{\mu_x}$$

where

a = casualties/y-firer-time

b = casualties/x-firer-time

R = range between firer centroids

R_{max} = closest range at which no attrition is possible

μ_x = shaping parameter for attacker (x)

μ_y = shaping parameter for defender (y)

(The shaping parameter relates to the types of weapons in the firing force and is well documented by Bonder and Farrell.) This surrogate for the detailed attrition process in EAGLE is very representative of how a planner would war-game alternatives in an aggregate sense. At the completion of this step, an estimate of the attrition, based on location at the *start* of the time interval has been made. This calculation is necessary not only to be able to compute powers at the next step, but also to be able to use existing EAGLE logic for movement. If the shadow unit object implementation is used, this newly computed value of **a-unit-eff** can be stored in the same named slot as used by the real unit.

Step 7 - Forecast a new route if the unit has not reached its final objective, has no additional routes stored, and the end of the planning horizon has not yet been reached.

This step, in addition to the move step described below, raises the issue of how much of the existing EAGLE code to use. If a new route is determined in the forecast using C2-processes (which sets indices for the movement rules) then extreme care must be taken to restore the data before exiting from the shadow objects. Our current inclination is to use the EAGLE move rules algorithms for the movement forecast, whereas we do not propose using the EAGLE code for the attrition forecast.

Step 8 - Move the units for one time step along, the network of routes, toward their next objective.

The rate of movement will be based on the matrix of speeds for each operational activity for GO, SLOW GO, NO GO terrain which is available in the KB. The *raw* speed inputs, modified by the attrition speed degradation factors as used in the resolve-attrition-event in EAGLE, will be used. This is essential in order not to inflate movement rates in the forecast.

Step 9 - Return to Step 5 unless the planning horizon time has been reached.

Step 10 - When the planning horizon has been reached, invoke the rules of feasibility.

These rules will be based on mathematical relationships between the RED and BLUE curves generated. (In the VIC test we used the very simple criterion of did the attacker/defender power ratio exceed 3:1 or not. The determination of the exact rules to use here is really another research issue in itself.) The fundamental question which this step answers is "will my current plan remain feasible out to the planning horizon?" If the answer to this question is yes, then the GVS routine would return control to the EAGLE execution model to proceed. Otherwise, alternative courses of action would need to be developed and evaluated (again using future-state prediction). Developing alternative courses of action is not trivial, and involves issues well beyond the scope of this report (some of which were addressed, at least generally, in [11] and [12]). However, we would expect that if any contingency missions exist in the Scenario-KB, then the first step here would be to conduct explicit future-state predictions for them. Then, if none of the contingency missions could restore feasibility, then, a noted above, we would either have to generate a feasible course of action "on the fly" - a much more difficult problem than proving feasibility of an already developed course - or stop the model for human intervention. A abbreviated set of sample calculations, using the steps described above and keyed to our scenario, is contained in Appendix 1.

We would observe that this proposal, because it would utilize much of the existing EAGLE code, would probably be fairly straightforward to implement. On the other hand, because it utilizes EAGLE code for essentially all but the attrition forecast, it might turn out to be closer to the earlier discussed (and not particularly attractive) recursive calling of the model by itself. An alternative would be the TDN forecasting investigated by Manzo and Hughes [8]. This would allow for the use of very simple heuristics (e.g. those found in manuals such as [14]) along each of the arcs, and probably greatly reduce the computation required - at the cost of a more complicated data structure and longer development time.

VI. Summary and Conclusions

In this report, we have outlined a proposed future-state decisionmaking architecture for the EAGLE combat model. We have not actually implemented this proposed architecture, however its implementation should be fairly straightforward because the design utilizes a significant amount of existing code. Implementing this architecture would enable the model to determine, ahead of time, when given tactical plans were no longer feasible.

so that appropriate alternative plans could be either developed or implemented. The proposal may be computationally intensive, and therefore an alternative architecture is also proposed, although implementing this alternative architecture would require significantly greater programming effort.

In any event, if the EAGLE model is to avoid what we believe to be the fundamental pitfall of all current systemic combat models - present-state decisionmaking - our proposal, or some variant of it, will need to be incorporated into EAGLE.

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Appendix 1 - Sample GVS Calculations

This appendix presents sample calculations of the Generalized Value System forecast of the power of the brigade-level task force shown in Figure A-1. (This is the same scenario described in the body of the report, with coordinate locations added. The coordinates are in kilometers relative to an origin in the lower-left corner of the map.) The example is presented as a series of tables for each of three options described below. Each series of tables describes the status (power) of Blue and Red, starting at the current time and forecasting to the end of the plan represented by that option (or to infeasibility).

As described in the report, an exponential discounting factor is applied to each unit, based on the expected time until that unit is in position to exert its power by (in this case) direct fire. This discounting is reflected in column 6 of the tables. The power of each unit in contact is also reduced based on attrition losses. Column 4 in the tables reflects these losses. Finally, we use as the measure of feasibility for the Blue plan that the ratio of Blue to Red power must exceed two.

As noted above, there is one series of tables for each of three options:

Option 1 assumes that neither Red unit (4th Tank Battalion or 51st Tank Regiment) moves to counter Blue. In this case, the power ratio always exceeds the threshold and therefore Blue should be able to reach Objective C by time 100.

Option 2 assumes that the 4th Tank Battalion moves to counterattack Blue TF 3/5 at the road junction located at (16,6). In this case, the power ratio falls below the threshold at time 90, which indicates that, unless Blue were to take further action, he may not be able to accomplish the mission of taking Objective C.

Option 3 assumes that the 4th Tank Battalion moves to counterattack Blue TF 3/5 at the road junction located at (16,6), but that Blue counters by committing the Attack Helicopters, at time 80, so that they can attack by time 90, i.e. before the counterattack hits TF 3/5. This restores the feasibility ratio, and indicates that Blue has sufficient power to handle this contingence. More importantly, and this is a very important aspect of future-state prediction, not only does this calculation show that this alternative will restore feasibility, but it also indicates WHEN to alternative needs to be implemented. In this instance, the calculations indicate there is no need to act at the current time, since the power ratios are still feasible 60 minutes from now, and the alternative plan does not need to be implemented until after that time.

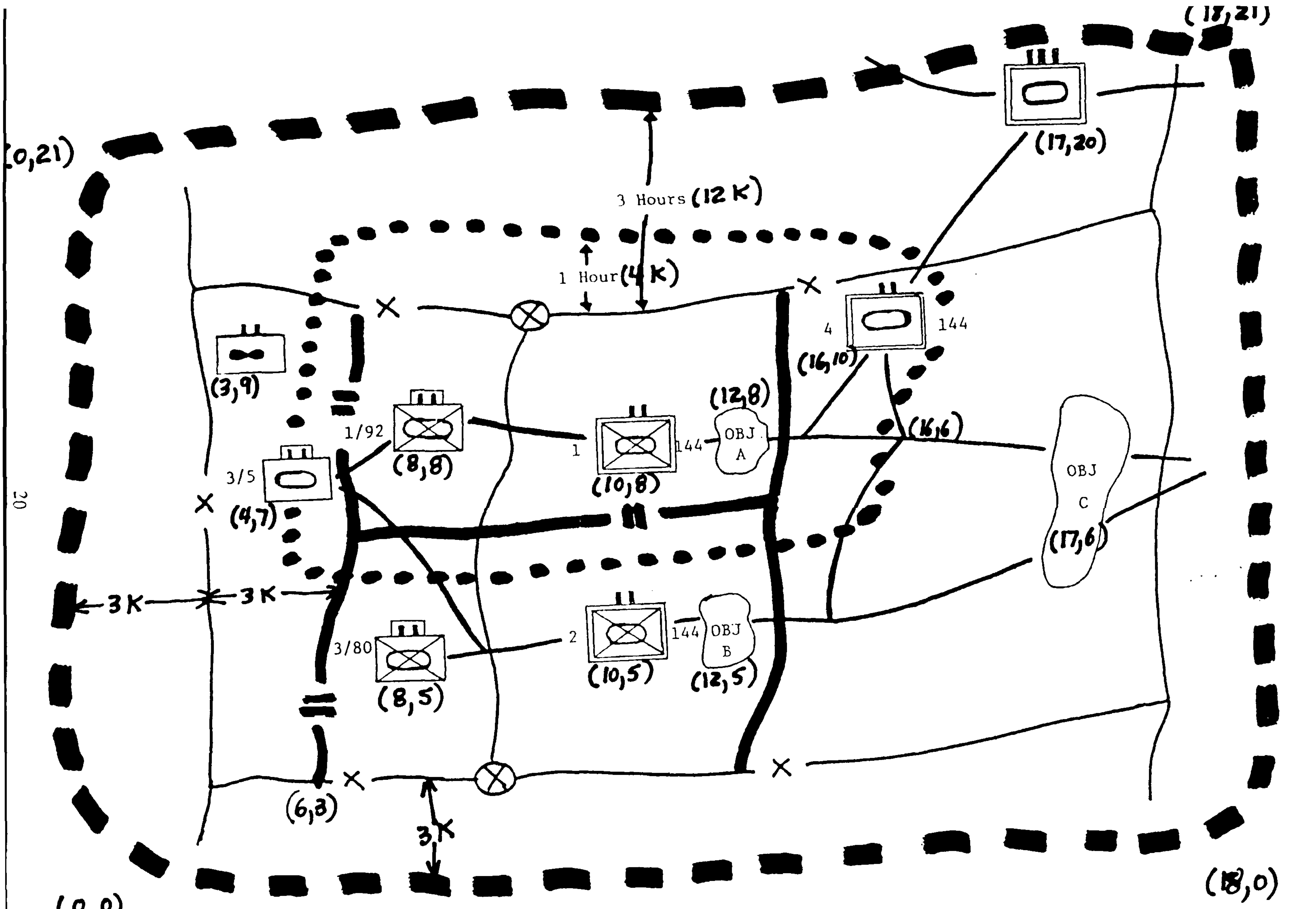
(0,21)
(18,21)
3 Hours (12 K)
1 Hour (4 K)
(17,20)
4
144
(16,10)
(3,9)
(12,8)
1/92
OBJ
A
144
1
(8,8)
(10,8)
(16,6)
3/5
(4,7)
OBJ
C
(17,6)
3 K
3 K
3/80
2
144
OBJ
B
(8,5)
(10,5)
(12,5)
(6,3)
3 K
(0,0)
(18,0)

Figure A-1

TIME—0 (Start forecast) OPTION 1

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"ir post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(8,8)	0	50	350	0	350	
TF 3/80	400	(8,5)	0	80	320	0	320	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1410	
MR Btn⁻ #1	200	(10,8)	0	40	160	0	160	
MR Btn⁻ #2	200	(10,5)	0	60	140	0	140	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							605	1410/605=2.33 Blue OK now

TIME— 30

OPTION 1

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(10,8)	0	90	310	0	310	
TF 3/80	400	(10.5)	0	130	270	0	270	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1320	
MR Btn⁻ #1	200	(11,8)	0	80	120	0	120	
MR Btn⁻ #2	200	(11,5)	0	110	90	0	90	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							515	1320/515=2.56 Blue OK

TIME—60 OPTION 1

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF1/92	400	(12,8)	0	160	240	0	240	On objective A
TF3/80	400	(12,5)	0	200	200	0	200	On objective B
TF3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1180	
MR Btn⁻ #1	200	Defeated, no longer a factor					0	
MR Btn⁻ #2	200	*Defeated, no longer a factor*					0	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							305	1180/305=3.87 Blue OK

TIME—90 **OPTION 1**

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(16,6)	5 min.	0	450	25	425	At road junction
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1335	
MR Btn⁻ #1								
MR Btn⁻ #2								
TK Btn #4	250	(16,10)	15 min.	0	250	80	170	Units are closer, but neither has moved
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	Units are closer, but neither has moved
Total Red							585	1335/585=2.28 Blue OK

TIME— 100

OPTION 1

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(17,6)	0	0	450	0	425	On objective C (unopposed)
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1360	
MR Btn⁻ #1								
MR Btn⁻ #2								
TK Btn #4	250	(16,10)	15 min.	0	250	80	170	
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	Units are closer, but neither has moved
Total Red							585	1360/585=2.32 Blue OK & objectives attained

TIME— 0 (Start forecast) OPTION 2

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(8,8)	0	50	350	0	350	
TF 3/80	400	(8,5)	0	80	320	0	320	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1410	
MR Btn⁻ #1	200	(10,8)	0	40	160	0	160	
MR Btn⁻ #2	200	(10,5)	0	60	140	0	140	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							605	1410/605=2.33 Blue OK now

TIME— 30 OPTION 2

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until ""in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(10,8)	0	90	310	0	310	
TF 3/80	400	(10.5)	0	130	270	0	270	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1320	
MR Btn¯ #1	200	(11,8)	0	80	120	0	120	
MR Btn¯ #2	200	(11,5)	0	110	90	0	90	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							515	1320/515=2.56 Blue OK

TIME— 60 OPTION 2

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	On objective A
TF 3/80	400	(12,5)	0	200	200	0	200	On objective B
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1180	
MR Btn¯ #1	200	Defeated, no longer a factor					0	
MR Btn¯ #2	200	Defeated, no longer a factor					0	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							305	1180/305=3.87 Blue OK

TIME—75

OPTION 2

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(10,6)	15 min.	0	450	100	350	
Helos	550	(3,9)	10 min.	0	550	80	470	Not committed
Total Blue							1260	
MR Btn¯ #1								
MR Btn¯ #2								
TK Btn #4	250	(16,10)	15 min.	0	250	80	170	Initiates move to CA at Rd junction
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	
Total Red							585	1260/585=2.15 Blue OK

TIME—90 OPTION 2

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(16,6)	15 min.	200	250	0	250	
Helos	550	(3,9)	10 min.	0	550	80	470	Not committed
Total Blue							1160	
MR Btn⁻ #1								
MR Btn⁻ #2								
TK Btn #4	250	(16,7)	0	50	200	0	200	CA on TF 3/5
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	
Total Red							615	1160/615=1.88 Blue *not* OK

TIME— 0 (Start forecast) OPTION 3

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(8,8)	0	50	350	0	350	
TF 3/80	400	(8,5)	0	80	320	0	320	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1410	
MR Btn¯ #1	200	(10,8)	0	40	160	0	160	
MR Btn¯ #2	200	(10,5)	0	60	140	0	140	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							605	1410/605=2.33 Blue OK now

TIME— 30 OPTION 3

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until ""in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(10,8)	0	90	310	0	310	
TF 3/80	400	(10.5)	0	130	270	0	270	
TF 3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1320	
MR Btn¯ #1	200	(11,8)	0	80	120	0	120	
MR Btn¯ #2	200	(11,5)	0	110	90	0	90	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							515	1320/515=2.56 Blue OK

TIME—60 OPTION 3

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until ""in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	On objective A
TF 3/80	400	(12,5)	0	200	200	0	200	On objective B
TF3/5	450	(4,7)	30 min.	0	450	180	270	
Helos	550	(3,9)	10 min.	0	550	80	470	
Total Blue							1180	
MR Btn⁻ #1	200	Defeated, no longer a factor					0	
MR Btn⁻ #2	200	Defeated, no longer a factor					0	
TK Btn #4	250	(16,10)	30 min.	0	250	100	150	
MR Reg. #51	700	(17,20)	90 min.	0	700	545	155	
Total Red							305	1180/305=3.87 Blue OK

TIME—75 OPTION 3

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power *lost due to* attrition	5 Current power if unit *is "in pos."* (1 minus 4)	6 Amount of power discounted *for "not in* pos."	7 Current *power* (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(10,6)	15 min.	0	450	100	350	
Helos	550	(3,9)	10 min.	0	550	80	470	Not committed
Total Blue							1260	
MR Btn¯ #1								
MR Btn¯ #2								
TK Btn #4	250	(16,10)	15 min.	0	250	80	170	Initiates move to CA at Rd junction
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	
Total Red							585	1260/585=2.15 Blue OK

TIME—110 OPTION 3

Unit	1 Full Strength Power (in pos."	2 Location	3 Estimated time until '"in post."	4 Total power lost due to attrition	5 Current power if unit is "in pos." (1 minus 4)	6 Amount of power discounted for "not in pos."	7 Current power (5 minus 6)	Notes
TF 1/92	400	(12,8)	0	160	240	0	240	
TF 3/80	400	(12,5)	0	200	200	0	200	
TF 3/5	450	(17,6)	0	180	270	0	300	On objective C
Helos	550	(16,7)	0	80	470	0	470	Some losses from Red 4
Total Blue							1180	
MR Btn‾ #1								
MR Btn‾ #2								
TK Btn #4	250	(16,7)	0	150	100	0	100	
MR Reg. #51	700	(17,20)	45 min.	0	700	285	415	
Total Red							515	1180/515=2.29 Blue OK—All objectives attained

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