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Youngren, Mark A.

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THE FUTURE THEATER-LEVEL MODEL: A RESEARCH PROJECT UPDATE

Mark A. Youngren
Samuel H. Parry
Donald P. Gaver
Patricia A. Jacobs

Naval Postgraduate School
Department of Operations Research
Monterey, CA 93943

ABSTRACT

Research has been conducted at the Naval Postgraduate School into new methodologies for joint theater-level combat simulation modeling, emphasizing C3I, operational intelligence, decisionmaking under uncertainty, and aggregated stochastic process modeling. Research outcomes to date as well as a prototype software tool are described in this paper.

1 INTRODUCTION

The Naval Postgraduate School has conducted research into new methodology for theater-level modeling under the name of "Future Theater-Level Model (FTLM)." This research has been sponsored by the Joint Staff, Directorate for Force Structure, Resources, and Assessment (J-8), with some additional sponsorship by the Defense Modeling and Simulation Office and the United States Army. In addition, much of the software development and detailed development of network adjudication has been accomplished by the George Mason University under contract to the Argonne National Laboratory (sponsored also by J-8). The Air Force Institute of Technology (AFIT) has also participated in the development of the model under J-8 sponsorship.

This paper will provide a brief overview of the modeling research by describing the capabilities incorporated into the model design and prototype software. **This effort is still in the research phase; the design is incomplete and has not been accepted by the sponsors as final. As a result, this paper represents the opinions of the authors and not necessarily the research sponsors.** However, significant progress has been accomplished to date in developing preliminary model designs and prototypes.

The focus of the research has not been on inventing new methodologies for the combat processes. We acknowledge that combat is still a poorly understood phenomena and more work is needed in the basics of military combat simulation. However, we think that there are enough people working in these areas; what is needed is inclusion of other areas that have not been well represented to date. Our research has focused on the areas that have not been included to date (at least not completely) in theater-level models: areas such as decisionmaking under uncertainty, operational intelligence, nonlinear maneuver, stochastic representations, etc.

We will start with the definition of the terrain (ground/air/sea) and the units within the model, and continue with a discussion of the current capability in each of four functional areas: maneuver; attrition; command, control, communications, and intelligence (C3I); and logistics.

2 TERRAIN AND UNIT REPRESENTATION

Ground Network

We have implemented a network-based model of ground maneuver. Each arc on the network represents the type of terrain found on the arc, the type of road, the "trafficability," and the effective width of the movement corridor for formations. A similar network is used to define amphibious landings and naval operating areas.

Air Network

FTLM has demonstrated a significant improvement in the modeling of air combat by including a multidirectional air network upon which air maneuver can occur. Until now, air movement in campaign-level models has been fairly simple, using techniques such as a straight-line distance from the FLOT to target (THUNDER) or using a few broadly defined regions within or across sectors (TACWAR).

Network for Naval Support and Amphibious Operations

FTLM can represent naval support to air/land campaigns and amphibious operations. A cooperative thesis effort involving both Army and Navy officers has explored the issues involved in the commitment of heavy and amphibious forces from the sea in a Korean MRC (Brouillette and Fulkerson 1994). The initial prototype (completed) represents Carrier Task Force Operating Areas. Units within the nodes (representing ship types such as carriers, cruisers, destroyers, frigates, LHA, LHD, LSD, LST, and marine prepositioning ships) have sensors, and can generate air missions and naval gunfire support. Further development of littoral warfare is programmed for FY95.

Ground Units

Ground units are defined in a manner similar to theater-level model ground representations such as the joint community's TACWAR model and the Army's CEM and FORCEM models. The nominal ground maneuver unit is a brigade, although the actual unit size is data defined.

Air Units

Air units are defined in the same manner as units represented in the Air Force's THUNDER model. The basic air maneuver unit is a flight group, consisting of one or more flights of one or more aircraft types. The composition of the flight group is dictated by its missions (attack, self-defense, SEAD, etc.), and is determined through a mission allocation methodology discussed under air maneuver and C3I.

3 GROUND MANEUVER AND ATTRITION

Movement

Units can assume the following formations within the network: administrative march, tactical march, movement to contact, attack, defend, delay, and remain stationary in a tactical assembly area (TAA). Formations are associated with movement and orders to specific units, as discussed later. In addition, the geometry of the unit, i.e. unit width and length, are defined in terms of these standard formations.

Unopposed unit movement rates are defined for each terrain class, each formation, and each unit category. These rates are used for movement over arcs and through nodes when units are not in contact. Opposed movement rates are formed from an algorithm based on attrition, similar to that used in the US Army's Concepts Evaluation Model (CEM). For each terrain type and posture, a curve is provided that determines the movement of a given battle using a function of relative attrition. In both cases, the capability exists for the movement times to be drawn stochastically from a distribution.

Command and Control for Maneuver (Unit Orders)

The model may be run either in a closed form systemic mode or in an open, man-in-the-loop gaming mode. In either case, the following orders may be issued to units: Initialize (simulates unit arrival in theater); Administrative march; Tactical march; Move to contact; Attack; Defend; Delay; and Establish a tactical assembly area (TAA). In the closed form simulation, all orders are contained in an operational course of action execution file, which gives the order set for each unit, to include the initiation time and duration of each order. In the gaming mode, an initial set of orders may be established as well, but the analyst can interrupt the model at any time to amend or replace orders.

Command and Control for Maneuver (Movement Path Selection).

Non-engaged units (those units not currently in a battle) that are executing any order except TAA have a path associated with their order. The path determines the route a unit will march, if it has a March (Tactical or Admin), Move To Contact, or Attack order. The path determines the route of retreat for a unit that is executing a Defend or Delay order. The path can be defined in two ways, through the default automatic path generator, or by manual input of the desired intermediate nodes. The default behavior is to automatically generate a path. The auto-generation logic uses a modified Dykstra's algorithm to determine the least cost path to the desired destination node. A user input, or manual, path can be specified as a list of nodes that will be traversed sequentially. The auto-path generator is used to fill in the gaps between manually entered nodes.

At the heart of the path logic is the Dykstra's algorithm. By modifying the cost function used on a case by case basis different path generation requirements can be fulfilled using the same code module. In general, the cost associated with an arc is equal to the time necessary to traverse the arc. The time is a function of the arc terrain, the unit formation and the unit category and size. The time to traverse an arc can be modified depending on the order being planned for.

The path selection algorithm permits a broad spectrum of possible decision structures, all based upon the perception of the route, the terrain, the enemy, etc. This permits an examination of the impact of poor intelligence, bad weather, countermobility measures, reconnaissance, etc. upon the movement of forces (with eventual outcomes relating to warfighting effectiveness). The order structure, however, has not yet been implemented (planned for FY95) and the ground truth adjudication has only been implemented for combat engagements to date.

Ground Close Combat Attrition

FTLM has developed an adaptation to network maneuver of the close combat attrition model used by the US Army Concepts Analysis Agency - the Attrition Calibrator (ATCAL), based on combat scoreboards from CAA's COSAGE model. This combines an Army attrition methodology with the increased capability for maneuver and C3I provided by a ground network. It is also consistent with the basic framework of the Army's proposed replacement to CEM (the CTLS model, currently under development).

In combining ATCAL with a maneuver network, FTLM has developed and implemented the logic for fighting on nodes and arcs, fighting in multiple directions and engagements, attack, defense and withdrawal over networks, etc. The current software implements the deterministic version of

ATCAL, similar to that incorporated in the THUNDER model. However, modifying the software to use the stochastic inputs (such as those available from US Army CAA's STOCEM model) is very simple if desired.

Indirect Fire Attrition

Artillery used in direct support or as reinforcing to a brigade is included in the close combat through ATCAL. Artillery used in GS/GSR roles, to include surface-to-surface missiles, is evaluated using the same "Superquickie" algorithm used in CEM/FORCEM. Missiles are also represented in FTLM; if they have internal guidance and air defense avoidance capabilities, they compute paths through the air network; otherwise, they fly straight paths to the target.

3 AIR MANEUVER AND ATTRITION

The following capabilities have been implemented to date in the air model.

- Explicit consideration of the location of Air Defense sites, with the interaction of SEAD, flight packages, and approach corridors.
- Modeling attacks over ground targets from the "rear" or in multiple directions, as demonstrated in DESERT STORM.
- Explicit vectoring of aerial air defenses
- Examination of the payoffs for reconnaissance, airborne early warning and detection systems, BDA, and other measures designed to improve the perception of enemy threats on the ground or in the air.

Air Maneuver

Aircraft in FTLM maneuver over the air network using the same least-cost-path algorithm used in ground maneuver (although the air costs tend to be different). This permits flights to avoid perceived enemy air defenses (ground and air) where possible, with a ground-truth adjudication penalty if they are proved to be wrong.

Strike Package Formation (Mission Allocation)

One of the requirements for a theater-level model to represent an air campaign is to have a process that breaks down the air apportionment (as determined by the CINC or JTF commander) into specific mission assignments for specific aircraft. Many models require much of this work to be scripted (for example, the aircraft must be assigned to 19 very specific mission types in THUNDER). Although scripting can be employed in FTLM if desired, much of the power of FTLM's air representation is the incorporation of algorithms that tradeoff target values, possible flight paths, and SEAD/escort aircraft availability to put together packages of aircraft (flight groups) that will provide the highest payoff within the air apportionment. A thesis from the Air Force Institute of Technology (Griggs 1994) has provided the methodology and the GAMS code to develop packages off-line. This methodology has not incorporated into simulation software at present (we plan to do so in FY95), but the capability was successfully demonstrated in the thesis.

The present FTLM software provides the capability to define a target value by air grid, selects targets by priority within six mission types: DCA, Fighter sweep (FSWP), CAS, AI/BAI, Strategic target attack (STI), and Reserve. DCA, FSWP, and CAS assignments work in a manner similar to the low-resolution THUNDER model. AI and STI missions choose a least-cost path through the network based on perceived air defenses. Strategic targets are randomly generated at nodes (the parameters of the randomness and nodes are user input), as they strategic targets to not presently affect the simulated campaign. This may be replaced by specific target lists if desired.

Ground-based Air Defenses

The air network capability provided by FTLM permits an explicit consideration of air defense sites on the ground. A recent NPS graduate thesis (Wang 1994) provided the mathematics for implementation of circular air defense detection and engagement zones on an air grid network, as well as algorithms for efficiently choosing the least cost optimal paths through the air defenses. This thesis work has been coded into software. The jamming and surface-to-air attrition algorithms implemented with this software are taken from the documentation of version 5.8 of THUNDER.

Air Attrition

At present, two different models of air attrition have been implemented in code, both based on THUNDER. The first is a fairly detailed representation of air-to-ground, ground-to-air, and air-to-air engagements that are adjudicated node-by-node during ingress, operations at the target area or engagement area, and egress. This representation uses the algorithms documented in version 5.8 of THUNDER. The second method uses a low resolution version of the current THUNDER code, which relies on a user-input attrition rate for ingress, egress, and terminal defenses.

Command and Control for Air Maneuver and Attrition

As with the ground model, the air model may be run either in a systemic or interruptible mode. The command and control options in the interruptible mode establish the higher-level objectives and constraints for the air execution. At the beginning of each air planning cycle (the times and intervals of the planning cycle are user-selectable), the analyst can alter the air apportionment, some of the air rules of engagement (such as the planning cycle, the ratio between interceptors scrambled and threat detected, and the fighter sweep priorities between missions), the air-to-ground target priority (by individual air grid), and also can view on-line reports of the air activities over the previous cycle.

Command and Control (Flight Path Selection)

The flight paths are automatically chosen by the model based on the dynamic perception and the cost function the analyst inputs into the model. Different paths may be chosen between ingress and egress.

4 COMMAND, CONTROL, COMMUNICATIONS AND INTELLIGENCE (C3I)

The greatest contribution from FTLM will be in the area of C3I. FTLM is not designed for traditional C3I analysis *per se*; such analysis typically examines the *performance* of C3I systems, networks, communications, etc. Instead, FTLM can be used to examine the *impact* that such systems have on the joint warfight at the aggregated level of analysis. This area has generally been neglected in the past because all of the theater-level analysis tools (e.g., CEM, TACWAR, etc.) are deterministic. Deterministic models by their very nature are not well suited for an examination of uncertainty - yet uncertainty, the effort to reduce it (intelligence), and the effort to manage it (command and control) dominate the impact of C3I on joint warfighting.

The next generation of models (e.g., CTLS, RAND's TLC/NLC, next generation THUNDER) are stochastic in nature and seek to represent the variability inherent in combat. However, not much research has been conducted to date on uncertainty; the FTLM research, which is not tied to any specific architecture, can provide benefit to the combat modeling community as a whole.

Sensor Models

The FTLM model presently has simple sensor models implemented to test the fusion and inference methodologies. Work is planned by J-8 for FY95 to obtain specific sensor models and data to support real system representations in the FTLM format. Even though the detailed models of real-world sensors are not yet available, if an analyst has information about what particular sensors can detect and the expected deviation from ground truth associated with each sensor, their effects can be modeled at an aggregate level. This representation is at least as good as, if not better than, that provided by alternative models.

At present, an analyst can define sensor systems that can provide observations of one or more types of assets (e.g., tanks, APCs, artillery) with error (a property of the sensor). Three types of sensors can be set up:

- Area sensors: Area sensors provide coverage over any defined rectangular area of the theater. (e.g., JSTARS).
- Scheduled sensors: Sensors can be set up on any type of schedule, to include continuous coverage and one time missions, that will observe one or more arcs and/or nodes (e.g., an overhead sensor or reconnaissance mission).
- Combat (unit) sensors: Sensors that are associated with combat units (provide local information and reconnaissance).

The following output is produced by the sensors: Date/time of sensor report, node/arc location of detection, and, for each type of asset observed, a count of assets detected.

Data Fusion

The FTLM data fusion methodology uses the sensor reports and order of battle (OB) information (also referred to as "TOE" information) to infer the presence of enemy units on the arcs and nodes that define the theater. Friendly units provide SITREPs in accordance with their communications capability to provide the information equivalent to sensor reports.

The output from the data fusion at the node is a distribution for each random variable representing the number of assets of a given type at the node, and a probability vector that contains the current perceived probability of all possible combinations of units (nominally brigades) that could be at the arc/node.

Most models, if they develop a perception at all, simply generate a single perception (randomly selected) and treat that as if it were certain. FTLM provides a major advance in theater-level simulation modeling by explicitly tracking the uncertainty associated with any nodal perception. As a result, it is sensitive to the accuracy as well as quantity of intelligence reports (sensor reports) available, and can show some impacts of reduced intelligence capabilities. In addition, the explicit treatment of uncertainty permits a much more realistic decision process to be represented.

Inference about Enemy Concepts of Operation

Another innovation in FTLM is the attempt to infer the "big picture" from the fused information at each arc / node. Although nodal information may be used as target acquisition to direct strikes, FTLM goes further and uses the information to infer what course of action (COA) the enemy is pursuing at the operational level, which is used to make friendly decisions at the operational level.

Basically, we define an operational COA as a set of maneuver forces with missions, boundaries, times; an apportionment of air forces; missions for naval forces; a schedule which synchronizes the application of the forces; and options that can be pursued given inferences about enemy COAs.

The analyst is expected to define the possible friendly and enemy courses of action to the model. Because we are trying to represent the possible actions on both sides under conditions of uncertainty, rather than executing a scripted scenario, the analyst may need to game some of the concepts prior to doing full scale runs. To do this, the model can provide an interactive gaming mode that allows a user to see only the perception of one side or another, and make decisions accordingly. The results of these games, if they pass the sensibility test using military judgement, can be used as possible courses of action. Note that each side will start with executing only one COA (although that could change to another based upon perceived enemy actions and outcomes), but will maintain a perceptual model of the relative likelihood of all possible enemy COAs.

Decisionmaking Under Uncertainty

FTLM allows a much richer set of decisions than current theater-level models, simply because of the amount of information and quantitative measures of uncertainty maintained by the model. For example, a typical model might have a reserve force committed to the sector where the (actual or perceived) force ratio falls below some threshold. In FTLM, a reserve decision might be based on requiring that the likelihood of all COAs other than the dominant one fall below some threshold, thus using the reserve as a hedge against uncertainty in enemy COA (e.g., I don't want to commit my reserve to the west if the possibility that he will attack in strength to the east is still too high). This is merely an example; the rule sets presently implemented are quite simple and the complex rule sets will not be developed until FY95.

5 LOGISTICS

The FTLM concept calls for logistics to have two major effects on the outcome of a campaign:

- Logistics can act as a *physical constraint* that degrades capability. For example, an airbase that runs out of munitions can't generate armed sorties. This is a traditional application of logistics.
- Logistics can also act as a *planning constraint or enabler* that permits or denies the use of some possible operational concept in planning or execution.

Logistics as a Physical Constraint

Implementation of combat logistics flows and the degradation of capability resulting from interrupted flows has not yet been implemented in the FTLM software. The future implementation of the existing constraints (with data) used in other theater-level models should be straight-forward.

Logistics as a Planning Constraint or Enabler

The more interesting and challenging task for FTLM to demonstrate is the use of operational logistics as an operational constraint or enabler. An initial demonstration of this capability has been developed as part of student theses in support of the US Army Early Entry Lethality and Survivability Lab (Brouillette and Fulkerson 1994). These theses has been developed jointly by Army and Navy students to show how the operational perception can affect the decision to commit major reinforcing forces from the sea. In the theses, a major indicator used to estimate the time of a North Korean attack is the size and rate of buildup of logistics stockpiles to support North Korean army operations. There is much more than that in real life, of course, but this does demonstrate the ability of FTLM to use logistics perception to influence inference about enemy COAs and the execution of friendly COAs.

6 FUTURE DEVELOPMENT OF FTLM

FTLM is an ongoing research project. The major research projected for FY95 includes the development of decision algorithms under uncertainty, littoral warfare representations and logistics.

In order to support the evaluation of the concepts and algorithms developed under this research, a prototype evaluation tool has been developed. An early version of the tool was developed on a PC platform operating under Windows, but the operating environment quickly proved to be too limiting to fully explore the concepts enumerated in this paper. As a result, NPS will be adding the C3I functionality developed under this research to a Unix-based SIMSCRIPT model (the "Arc-Node C3I Model") developed by the George mason University / Argonne National Lab for J-8. This SIMSCRIPT model will form the basis for further prototype development under this project.

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AUTHOR BIOGRAPHIES

MARK A. YOUNGREN is a Lieutenant Colonel in the US Army, serving as an Assistant Professor of Operations Research at the Naval Postgraduate School. His research interests are in the area of stochastic modeling, particularly applied to large aggregated systems such as theater-level combat. He is a Director of the Military Operations Research Society (MORS), editor of the *Military OR Analyst's Handbook*, and an associate editor of *Military Operations Research.*

SAMUEL H. PARRY is a Professor of Operations Research at the Naval Postgraduate School. His primary focus for the past twenty years has been on the modeling and simulation of combat in both high resolution and aggregated levels. He has conducted research primarily for the Army during that time, but more recently, his efforts have focused on joint operations in the new world order.

DONALD P. GAVER is a Distinguished Professor of Operations Research at the Naval Postgraduate School. He has worked on a variety of problems in mathematical modeling and data analysis, using statistics, probability, and simulation extensively. He was a co-winner of the Koopman Prize of the Operations Research Society of America in 1992.

PATRICIA A. JACOBS is a Professor of Operations Research at the Naval Postgraduate School. Her research interests are in the areas of stochastic modelling and statistics. She is an associate editor of *Management Science*.