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FUNDAMENTAL DIFFICULTIES OF THE HIERARCHICAL MODELING CONCEPT¹

HCBrown

The referenced paper identifies four fundamental difficulties. They are: 1) Complexity, 2) Level of Aggregation/Detail, 3) Lack of Physical Theory, and 4) Non-Linearity. This paper states the issue and comments on each.

1) COMPLEXITY:

"--- There are so many possibilities and choices of action in military activities that it is patently impossible to enumerate all the interactions that could be important."

COMMENT: We must differentiate between "choices of action" and "interactions" in the foregoing statement.

Regarding "interactions", if n is the number of different types of elements, the number of different types of interaction approaches $n(n-1)/2$, since we must consider support interactions as well as adversary interactions. Our recommended approach is to calculate, for an element or unit its total potential for the performance of defined functions and thus limit the number of different types of interactions. (Interactions are between functional potentials.) We have identified nine Combat and Combat Support functions (Fire, Maneuver, Intelligence, Command, Supply, Transport, Maintenance, Construction, and Signal) as the most fundamental to the outcome of combat; others might possibly be added later.

¹ Reference: DEVELOPMENTS IN THEATER LEVEL WAR GAMES. Cordesman, A. H., July 1975. (Materials for the C-5 Working Group - "Gaming & Simulation", of the 35th MORS.)

In a typical simulation, one might model the events in a logistic flow producing a certain ammunition supply status at an engaged unit and then simulate the expenditure, in detail, of this ammunition flow against enemy targets. We search instead for the algorithm connecting a Supply Potential ($\pi_{S,B}$) of the back-up logistic chain with the Firepower Potential ($\pi_{F,B}$) of the engaged Blue Unit, and then another algorithm connecting $\pi_{F,B}$ with the functional potentials of Red.

Regarding "choices of action", if this can be interpreted as "courses of action", there is an even greater proliferation. For example, for a given Supply Potential (throughput in tons/day), there can be continuous variation within wide limits as to the proportion devoted to various classes of supply and the proportion furnished to each of several users. In a simulation, one is forced to the representation of events following a small number of pre-established "doctrines" of supply distribution. Given the "potential" representation, one can distribute the throughput by "priority" factors which represent the whole spectrum of possible courses of action.

With this concept hierarchical models would not necessarily dynamically interact. Lower-level models should be used to derive the algorithms for functional potentials and their interactions; these algorithms should then be incorporated in the higher-level models.

2) LEVEL OF AGGREGATION/DETAIL:

"For the chosen aggregate, average actions, interactions, and results are assumed to represent the set of individual possibilities."

COMMENT: When Command (decision) is introduced into the model it will be inappropriate to use average results. If Blue/Red commands are equally skillful and timely, the result should approximate average, with a dispersion caused by other intangible factors such as Morale. Superior command decision will achieve results above average; inferior command decisions will achieve results lower than average. Intrinsic to our efforts must be to establish the deviation from average results which may be caused by varying decisions.

"---extrapolation from troops (which are physically killed) to companies (which are abstractions) requires specific physical relationships to pertain among the individual troops which comprise the company. ----- It is also necessary to assume a spatial distribution of the troops in the company."

COMMENT: It is necessary to keep track of the area occupied by the company or other unit (or alternatively, the average density of troops). This area is affected by the compartmentalization of the terrain, the necessity for massing to achieve superiority at selected points, and enemy pressure which denies movement or expansion of the area.

Within any such area there is an optimum distribution of troops which minimized the lethality of delivered fire, while maintaining capability for the assigned task. Whether this optimum is achieved is dependent on the decisions made at all echelons within the company. The quality of these decisions is affected by Intelligence, Command Skill, and Timing in formulation and transmission of decisions.

It is suggested that Fire results can be modeled not by assumptions as to the configuration of the units but by representation of the Firepower Potential modified by terrain characteristics (cover), density of the target unit, availability of threat intelligence (surprise), and the command skill (at all levels).

Of course, this merely a working hypotheses, which should be pursued by both theoretical² and "experimental" (statistical analysis of history) efforts.

"----- the key problem is ----- 'What is the necessary level of detail to include?' "

COMMENT: In a simulation the level of detail would be determined by the number of types of elements (with paired interactions) included and the number of type events in the description of the functioning of each of these elements.

In the "functional" approach, which we recommend, the level of detail would be determined by the number of variables included in the functional capability and interaction algorithms. We would still have to make decisions as to inclusion of detail (or the validity of approximations obviating detail), but they would be of a different type. It is expected that with the limited number of functions defined, we can either reduce complexity by less use of detail, or extend the same level of detail to embrace considerations not normally incorporated in models .

² See Para. 3)

3) LACK OF PHYSICAL THEORY:

"Unlike physics, there are no laws that enable direct computation of future histories when initial conditions are known. Consider for instance some questions relating to the term combat capability. What does it mean? In what terms is it defined? What contributes to it and how? ----- "Another fundamental problem is relating sizes, and firepower of opposing forces to resultant movement over the ground."

COMMENT: We do have a "physical theory" of combat, which, like all other theories, should be subjected to detailed theoretical development, empirical test and critique.

For the term "combat capability" we use Combat Potential (π), because of our distinction among functional Capability, Potential, and Performance.

What does it mean? Combat Potential is the ability to take (or hold) ground and to inflict casualties in execution of some course of action prescribed by directive information from the next higher echelon in the chain of command.

In what terms is it define? In terms of man-days of enemy effort negated (within a certain defined time period).

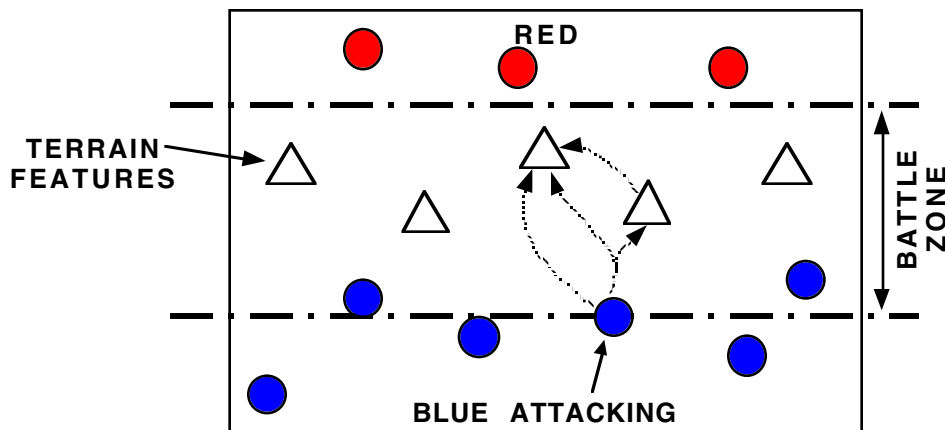
What contributes to it, and how? All nine of our selected military functions -- Fire, Maneuver, Intelligence, Command, Supply, Transportation, Maintenance, Construction, and Signal -- contribute to Combat Potential. The contribution of each can be described; for simplicity of this exposition, we shall discuss principally Fire and Maneuver.

We postulate that in combat rates of movement and rates of attrition are functions of each other and of the ratio of Combat Potentials of the adversary forces. Combat Potential is determined by:

- (1) The inventory of the force
- (2) The functional capabilities of the elements of the force
- (3) The situational efficiencies (η 's)
- (4) The directive information furnished by higher command

Directive information flows down (orders) and up (requests) the chain of command. It consists of values placed on occupation of terrain features (Q 's), on removal of enemy assets (V_{R_j} 's), on preservation of own assets (V_{B_i} 's), and on conservation (controlled expenditures) of supplies (V_S 's)

The chain of command is pictured as extending from the theater commander (or Chief of State, if Level I is considered) down to and including enemy individuals in the force. It is necessary to include the individuals if such factors as Motivation, Morale, and Leadership are considered.³



Sketch 1

Now consider the situation in which some unit is ordered to advance. The rate of advance of the unit will depend, according to some definition, on the advances of the elements composing the unit. Each of these is to advance, with more or less choice as to the route and objective, according to the directive information furnished to the element. The key pieces of directive information considered in its decisions are Q_ℓ - the value, usually time-dependent, of arriving at assigned objective and V_{B_i} - the value of self preservation. In addition, it must possess as Intelligence, or estimate, the "risk function" (Φ) produced by possible enemy fire during the movement. If

$$Q_\ell \geq \left(1 - \exp \left[\int_{\Delta M} \Phi dt \right] \right) V_{B_i}$$

the move will be made. Otherwise the element waits until a sufficiently favorable situation exists; i.e., until Φ has been reduced by removal of enemy elements or suppression of enemy fire. The element alternates between periods of movement and periods of waiting (probably with delivery of

³ These are discussed later.

fire). The length of these periods of waiting depend on the fire available, and particularly on the efficiency of coordination and control of this fire.

If the assigned Q_t 's are made higher, movement will be made faster, but Blue casualties will also increase, since more chances will be taken.

To this point, the theory has presented elements as standard automatons, making and executing rational decisions in accordance with received orders. The military history or military judgment from which we must derive our experimental evidence pertaining to this theory will undoubtedly display the influence of "human factors". Thus we must have some format for interpretation of this influence.

At present we feel that the "human factors" of an element can be classified as: 1) Skill, 2) Motivation, and 3) Physical-Mental Condition.

SKILL produces a variation in the functional capability of elements - e.g., a skilled rifleman achieves a higher p_{R_i} (single-shot probability of Red element kill), than does an unskilled one. Skill depends on Aptitude, Training (a function of command), and Experience (length of previous combat - which may also have an effect by weeding out the unskilled members of a unit).

MOTIVATION we define as the degree to which the individual accepts without change the directive variable values coming down the chain of command. Perhaps the most frequent variation would be to inflate the value put on self-preservation (V_{B_i}), but we might also experience inflation of V_{R_i} ("killer instinct") or other phenomena.

MORALE and LEADERSHIP are both allied to Motivation. Morale is collective motivation; unit esprit may cause elements to better accept directive information because of confidence in the ability and judgment of the leader.

PHYSICAL-MENTAL CONDITION is believed to affect both Skill and Motivation.

This is perhaps a very simplified model of the complex subject of human behavior under stress conditions. It does have the merit, however, of direct connection to our "physical theory" of combat; it should be used until modeling has progressed to the point where more complex theories (if appropriate) can be incorporated.

Specifically, in assessment of historical examples we should search for the influence of:

- a) Training/Battle Experience (Skill)
- b) Morale/Leadership⁴ (Motivation)
- c) Fatigue (Lowered Physical-Mental Condition)

The purely statistical assessment must be accompanied (due to the scarcity of truly parallel cases isolating one phenomenon) by theoretical explanations of probable effect. As an example, low motivation may produce a "floor" under V_{B_i} such that most individuals will not accept a low (V_{B_i}/Q_i) ratio handed down as directive information from a higher echelon - literally, the individual will not take the directed risk. It is no doubt possible to quantitatively predict the theoretical effect of this lack of motivation on movement in a given situation.

Even if we disregard the human factors, the physical theory of combat is considerable more complex than the simple example given above. One factor complicating the problem is the directive value placed on attrition of the enemy (V_{R_j}) . If this is high compared to the directive value placed on Q_i , the element will tend to prefer actions which lead to enemy kill over those which gain ground, and progress will be correspondingly slower. If Q 's are high in relation to V_{R_j} 's we will get tactics of maneuver and encirclement like the Panzer operations. If the opposite is true we are talking about deliberate battles of attrition like Verdun.

Another complicating factor is the state of intelligence. The rational element makes movement decisions according to directive information and the risk (Φ) as known to him. If he overestimates Φ , he will make slower progress; if he underestimates Φ , he will make faster progress, but at a higher casualty rate than was contemplated.⁵

⁴ Note that Leadership is an attribute of Command distinct from Decision Skill, Generalship, Management, etc. Most good commanders are at least adequate in each of these attributes - but not necessarily so.

⁵ Note that with perfect intelligence and decision the fraction of casualties incurred is limited by $\left[\left(V_{B_i}/Q \right) + \left(V_{B_i}/V_{R_j} \right) \right]$. With imperfect intelligence and decision there is no such limit.

Terrain, of course, also influences rates of movement. We picture the movement of elements as being along "routes" from "feature" to "feature". What distinguishes a "route" is that at any point on it, it is less hazardous for the element to keep moving than to stop. A "feature", on the other hand, provides some cover and field of fire; it is safer to remain on a feature than to move on a route. Routes are characterized by varying "trafficability" - which we define as the ratio of speed attainable on the route to some standard speed for the element being considered. (Obviously, definition of features and routes is element-dependent - what is a feature for a rifleman probably affords little cover for a tank.)

If trafficability is low, movement will be slow. The actual time taken between features will increase, that is obvious. But also the waiting time between moves will tend to increase. This is because risk is dependent on Φ integrated over the period of movement Δt_M - which has increased. Thus Φ must be reduced more, prior to movement, than for the better trafficability conditions, and this makes the wait time longer. (There is also the fact that a slower-moving target is easier to hit.)

If features are close together, movement will be faster. Φ is affected by the reaction time of the enemy weapons. Even though the same total distance is covered, risk is less if the movement can be in several short legs. Thus wait times between moves are less frequent and shorter.

As evidenced by the examples given above, the "physical theory" of combat interaction can provide hypotheses for explanation of all factors recognized as bearing on combat outcome. What is needed now is some comparison of theoretical prediction with observed results, which in this case must be statistics of past wars. The really fundamental difficulty here is that available statistics are very high-level (division or regiment at best) and the theoretical construct becomes very complex and difficult at levels even as high as platoon.

4) NON-LINEARITY:

" The upper models (toward the theater level) are primarily resource allocation models. ---To perform these resource allocation calculations, the upper level models use interaction factors --- that are developed in the lower level models and passed up the hierarchy. But the interaction factors depend on the numbers of military elements involved in specific engagements, encounters and battles. Consequently there is a non-linear process --- where the output of the higher levels depends on the lower levels which depend in turn on the output of the upper models."

COMMENT: The higher levels do not simply allocate resources - they furnish directive information (which includes resource allocation). Information-handling (directive information, status information, and Intelligence) is the only role of any superior headquarters (as distinguished from the commander himself) - all other functions are actually performed by elements at the bottom of the chain of command. (When a platoon leader fires a rifle, he is actually temporarily leaving his decision-maker Command role, though probably scoring a plus in the Leadership aspect. He probably ensures that his radio operator, functioning as "headquarters", stays on the net.)

The term "theater-level models" probably connotes consideration of types of forces not normally included in lower-level models - e.g., the functioning of Air Force elements in support of ground operations. It could well be, however, that such questions could be better studied in lower-level models. "Close Air Support" in many theater-level models has no apparent connection with the progress of the ground action.

To the extent that higher-level models are intended for analysis of the functioning and influence of the appropriate headquarters, rather than of the combined functioning of various components of the force, they all present the same problem for analysis.

The headquarters receives certain information - Intelligence, Status Reports, and occasionally Requests (directive information). It outputs Orders (directive information) which are intended to utilize resources available to it for the accomplishment of certain objectives. In order to select an appropriate course of action (which will determine the directive information to be passed to each of its directly subordinate headquarters) it must have a capability to Estimate the outcome of each potential course of action against each possible enemy courses of action.

To model each course of action and its outcome in terms of the specific events connected with the functioning of many types of elements controlled by a typical higher headquarters leads to ever-

increasing complexity of the model, accompanied by gross simplification because of machine limitations. To replace this detail by some such concept as Combat Potential may lead to better coverage of the problems.

