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NOTES ON THE ANALYSIS OF TERRAIN FOR FIRE AND MANEUVER MODELING

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1. Success in ground combat between Fire and Maneuver elements or units is largely influenced by skill in the use of terrain. Maneuver is a process of occupation of positions and of movement from there to other positions in accordance with some specific predetermined (and from time to time changed) course of action.

2. We have, in The Anatomy of Combat, expressed an intent to model terrain in terms of Features (suitable for occupation as positions, Routes (connecting features), and Obstacles. The problem now is to determine how this is to be done.

The utility of Features and Routes, and the difficulty posed by Obstacles, obviously differs according to the type of element which will use them. A rifleman occupies a smaller position than a tank, can use less cover and concealment, and can move on routes impossible for tanks. A terrain analysis made for riflemen will show more positions and routes and less obstacles, than a similar analysis made for tanks. Normally the tactical commander must make an analysis of terrain for the operation of some composite unit which includes elements of several types.

The relative utility of Features and Routes will also vary with the objective function of the unit making the estimate. Unless the area under consideration contains a final objective, of which the value lies in more than its purely military benefits; then the area will be in use for some limited time. The force must pass through or attack by or before certain time. This time dimension establishes the number of successive positions required for each element -- it must spend on features all required time not used up in traveling on Routes, which under fire is done at maximum speed. The relation between the Q value of time spent in the area (to be distributed among selected features) and the residual value of Blue and Red elements also affects the relative importance of offensive and defensive characteristics (see Paragraph 3) of selected Features.

The nature of the opposition will also affect the terrain analysis; primarily through the potential of its sensors and weapons, secondarily through its objective function. The first can be determined by Intelligence; the second can only be hypothesized by an exercise of generalship.

The following discussion is developed primarily from the viewpoint of a Blue commander having an offensive mission to pass through a given terrain area within a certain time and in the face of opposition. We consider first a single Blue element, type unspecified, and later extend to multiple elements and Fire and Maneuver units.

3. The identification of Features should be first and primarily from the viewpoint of Fire and Maneuver elements and sensors, with a capability to generalize to Fire and Maneuver units (those which contain Fire and Maneuver elements). These features are those which may become <u>objectives</u>, with a time-dependent value, integrated into some scheme of maneuver. one does not fight for suitable positions for artillery batteries or supply dumps; these conform their positioning to that of the Fire and Maneuver elements.

Fire and Maneuver elements characteristically enter into what may be called "duel" situations (either one-against-one or few-against-few). Therefore, desirable features for their positioning are those which give some advantage in a duel situation. The most desirable feature in any locality is that which gives the weapon of the Fire and Maneuver element maximum advantage for any duels <u>within its range</u>. When it does not yet have suitable targets within its range, positions are chosen solely for their protective qualities rather than any offensive advantage, although normally provision is made for rapid movement to an offensive position. The qualities which give true defensive[1] advantage to a feature are Field of View (observation) and Field of Fire; those which afford simply protection are concealment and cover.

4. COVER. In regard to each of the characteristics of a feature which influences its tactical advantages, we should first describe a thorough and detailed model and late search for useful approximations in actual computations.

[1] "Defensive" is relative. Even on offense, the features are occupied for short intervals, and must be defensible against enemy counter-moves.

Cover is natural or artificial protection against the effects of fire. Cover exists in the terrain, or is added to the terrain by exercise of Construction function; cover is to be distinguished from target hardening which adds protection to the elemental target itself.

We may need suitable descriptions of cover against each of the possible lethal effects of fire-heat, fragments, over-pressure, etc.; for the time being we will confine ourselves to protection against projectiles, including fragments. It is quite possible that our description of protection against projectiles may suffice, with different algorithms, to provide a description of protection against other lethal effects.

To define the cover afforded to a target in a specified location, one would use a set of target body axes (T-axes [2]). For all δ and γ referred to the T-axes, it would then be possible to describe the materials found along a ray from 0_T. This would be a complete description of cover and would permit calculation of penetration, resultant damage and target "kill" in all detail desired. Such a description would also serve to define the size of element which might use the cover, since the dimensions of air space surrounding 0_T would be included.

Now when we search for useful approximations to this detailed model, we are concerned with two different sorts of approximation -- those as to resistance of the cover to penetration, and those as to the shape of the cover.

The most useful approximation regarding resistance would be kinetic energy of projectile removed during penetration to free air space surrounding the target. This may be adequately accurate for all projectiles for certain types of calculation. For more precise calculations, the value of kinetic energy removed would be specified by classes of projectile -- the classes being identified by ranges of size, shape, weigh, kinetic energy, and orientation.

At this point, the description of cover around any point in space resolves itself into a specification, for arbitrary δ and γ referred to some "map-oriented" axes, of length of free air space and value of kinetic energy removed in penetrating thereto. It would then be possible to modify the $L(\upsilon_D)$ [3] for any direct impact or fragmentation weapon, and thereby its P_K, in view of the cover afforded by the position.

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[2] See TACWAR 31. Notes on the Accuracy of Projectiles.

[3] Ibid.

Approximations regarding the orientation of cover with respect to the target element must be made with great care. This because intelligent decisions can be made on behalf of both the target and the attacking weapon. The target can select positions to maximize protection against expected types of attack; while attacking elements can utilize, within their flexibility of movement and of trajectory, the line of attack having least cover. Statements of "average" cover or of protection against random attack are probabilistic notions and cannot be utilized for detailed analyses which allow for decision processes. At this point it is necessary to extend the discussion of Field of Fire.

One general observation may be made in regard to orientation of cover. This is that ground forms tend to give better protection for small γ than for large. this explains the advantage of high ground and "plunging" fire, especially for direct fire weapons.

5. FIELD OF FIRE. Since Fire and Maneuver elements normally employ direct-fire weapons, their Field of Fire is often limited by Field of View. Field of Fire is discussed first, however, with Field of View as a later "overlay", because Cover always implies concealment, but the converse is not true.

In the first place, the Field of Fire for any weapon is obviously limited to its maximum range. We draw a circle, with a radius equal to maximum range, around any proposed position, and examine the terrain within the circle. For an element operating without covering fire the entire circle is of concern. It is fairly easy to picture an application of the trajectory of the elemental weapon along rays of arbitrary δ in order to map those areas within the circle which cannot be reached with fire. These obviously reduce the effective field of fire.

An important question, though, is whether these areas can be reached from the perimeter of the circle without exposure to fire by the element occupying the position.

It is tentatively suggested that the worth of a given elemental position from the combined viewpoints of cover and field of fire may be calculated[4] in detail as follows:

a) The calculation is made (and the results will differ) for each type opposing element having a weapon of equal or lesser range than the element occupying the position. It is non-

[4] Such calculations are not contemplated, but the method is made quite detailed to facilitate later derivation of reasonable approximations.

pertinent to make calculations for a weapon of greater range; in such case the occupying element will have to do the closing.

b) Select the best approach route (from the point of view of objective function expectation in a duel -- see c) below) for the opposing element from the edge of the range circle to the chosen position. This will appear as a series of intermediate positions connected by routes.

c) Assign to the opposing element an objective function $\left(P_R V_R - P_B V_B\right)$. Then theoretically, by considering speeds of movement, degrees of cover, and capability of opposing weapons (and assuming the occupying element to remain in place) one can deduce the best course of action for the opposing element -- that which gives largest objective function value. presumably this value is negative -- otherwise the position would have less value than some alternate within range, and the element in occupation would be maneuvering to get to that better position. The deficit gives a measure of value of the position which must be assigned by the opposing element before an attempt to take it pays off. This can be considered a measure of its defensive strength.

6. CONCEALMENT is protection, by terrain or vegetation, or by camouflage placed in the environment, against detection by sensors. Concealment affects two of the functions of any opponent -- Intelligence and Fire -- it makes it possible the element will go undetected, that it may not be properly identified, and that it will not be accurately located for aiming purposes. However, the effect is always on a sensor -- either one that is in a pure intelligence role, or one that is operating in conjunction with a weapon in observed indirect or direct fire. Sensors of course vary in the target characteristics they are capable of observing. The concealment we are modeling here is an obstruction to the passage of electro-magnetic waves of various frequencies -- a "line-of-sight" phenomenon.

Exactly as with the Cover model, one can imagine specifying for each δ and γ a ray emanating from 0_T and a loss of energy (a function of frequency) along that ray due to reflection, scattering, or absorption. In many cases, such as optical wave-lengths, the loss of energy will be total even for very thin opaque materials such as foliage.

We, of course, would like to relate the specification of concealment to some reduction in probabilities of detection and identification and increase in target location error. All three are important: detection permits incorporating into postulated courses of action, identification reveals value and capability and thus enable proper estimation of objective function, target location error affects hostile P_K. Unfortunately, we are unable at this time to describe the algorithms converting a description of Concealment and Sensor capability into the relevant probabilities and errors. This must await study of the intelligence function. For now we merely postulate that these probabilities and errors are some function of available Concealment.

Weather does not affect Cover; it does affect Concealment in two ways. Visual observation is dependent on illumination of the target by sunlight -- direct, reflected, or scattered, by starlight, or by artificial light sources. The time of day obviously affects the illumination available. in addition, atmospheric humidity or dust content attenuates the energy of incident, reflected, or emanated electro magnetic energy (again as a function of frequency). The description of Concealment is not complete until Weather affects are included.

7. FIELD OF VIEW is the offensive complement of Concealment; the same relation as between Cover and Field of Fire.

For Concealment, as for Cover, one can imagine a mapping, within maximum range of the sensor occupying a position , of those areas not covered by direct line-of-sight (taking into account the height of the hostile element). This map overlaid on the Cover map defines those areas immune from any observation or fire, those subject to observation only, those subject to unobserved fire, and those subject to observed fire.

Thereafter, one can evaluate the feature, from the point of view of combined Cover, Concealment, Field of Fire and Field of View, as was outlined in Para. 5. However, in this case sensors are involved, at least to the extent of the rifleman's eyeball. Thus we must modify our estimates based on Fire and Maneuver only to reflect the impact of the Intelligence function -- probabilities of detection and identification and target location error.

8. ROUTES. Any element will be somewhat safer against hostile fire while in motion than while at rest in a position having no cover at all. This is, of course, due to the requirement imposed on the hostile weapon for a prediction of future position -- a "lead" in aiming, which produces a degradation of weapon accuracy. The error thus introduced will increase with increasing speed of the target element. Thus in analyzing a route we must appraise the characteristics which will affect the speed of an element which uses the route. The effect of the terrain is probably quite complex, and different for each type of element; it is desirable to search for some simple approximation to the

relative effects of terrain on mobility. Such an approximation will enable selection of the best route, even though its absolute worth may not be accurately calculable.

The motive power output delivered to wheels, tracks, or feet goes to provide acceleration, to overcome rolling friction, or to (or from) potential energy of elevation. The terrain has three corresponding qualities. Traction sets an upper limit (sometimes 0) on acceleration. Trafficability, which should be regarded as coefficient of rolling friction, demands a portion of the motive power. Slope creates a requirement for conversion to or from potential energy. Thus in evaluating routes we are interested in the values of these three variables.

The other requirement on a route, of course, is continuity. It must connect features and not dead-end at some obstacle to motion. (Obstacles to fire and observation are already taken care of under Field of Fire and Field of View.)

9. TERRAIN APPRECIATION BY A COMMANDER. Good use of terrain is probably an art rather than a science, as is the case with many military concerns. An art is very little amenable to mathematical analysis, and therefore our model of terrain appreciation by a commander may not represent very closely what is actual military practice.

The intelligence officer is pictured as analyzing the terrain prior to the formulation by the commander of courses of action for comparative evaluation. Thus he is interested in identifying <u>all</u> features and routes, rather than just enough to establish one course of action. This requirement for completeness is reinforced by the necessity to postulate hostile courses of action, and the realization that the enemy will not necessarily think in the same terms.

The process of terrain appreciation starts with receipt of a mission-type order (of course, it may constitute merely up-dating of some evaluation made for a prior order). The order normally delimits the area of operations, thus establishing geographic limits on the analysis. If the area is not delineated in orders, as sometimes happens for an isolated unit, the time period $t_2 - t_1$ establishes a maximum possible range of assigned elements and thus limits the area of considerations.

The order also establishes Q-values for certain terrain features which have been identified by higher echelons and incorporated into current strategy. This establishes a mandate to acquire (on offense) or retain (on defense) these features, given a positive objective function value for some possible course of action. As the orders come down, the features may not be individually distinguished; the order may be for occupation of an area. in such case the intelligence officer must select the best features or sub-areas within the objective area as a part of his terrain appraisal.

At the time of receipt of the order the commander's intelligence files and status files have a certain more-or-less credible content. His terrain appreciation is made in light of the enemy and friendly disposition as he knows it or decides to postulate it. The true value of terrain features varies with the enemy's assets and current course of actin; the commander cannot know the "true" value, but the analyst can. In the following description we are talking about "true" value, rather than that which can be estimated by an actual commander in the field.

Procedure:

a) Sub-divide the area of interest into smaller areas, locating the center of each area. For the purposes of this discussion it is assumed that the sub-division is by means of a square grid. Other forms, however, for instance a hexagonal grid or a division into irregular areas fairly uniform with respect to one characteristic, may have advantages in processing.

The fineness of the sub-division will affect the precision of the resulting analysis, as will be apparent from the subsequent discussion. It is possible that at a later point some connection can be derived between the time available for terrain analysis and the quality of planning and subsequent decision.

b) At the center point of each sub-division, establish the following values:

(1) Ground surface elevation.

(2) Trafficability, in the form of a "coefficient of rolling friction" for each type of friendly or enemy element involved in the problem.

(3) Traction, in the form of an upper limit of acceleration for each type of element.

Note: The values of trafficability will have to be derived from measurable characteristics of the soil, such as bearing ratio and cohesiveness. It is assumed that the discipline of soil mechanics can provide either theoretical or empirical values. Also, the coefficients of trafficability and traction may not be a constant but may vary with speed or acceleration. One can imagine applying the necessary formulae in as great detail as is profitable and then emerging with approximations in the form of the postulated constants, applicable over certain ranges.

(4) Average energy loss of electro-magnetic radiation passing through the grid square as a function of frequency and height above terrain.

c) Using the above values it is now possible to calculate for each grid square its Cover, Concealment, and Speed of Transit. Cover is mapped as precisely as desired by originating rays at regular intervals of δ and δ and determining distance to first cover and thickness of cover (number of consecutive squares in which ground surface intercepts the ray). Concealment is mapped as a function of range, by a similar process in which energy losses to squares in a given line are summed.

Speed of Transit (by type element) is calculated across the grid square in the eight directions determined by straight lines connecting to the center of adjacent squares. Available power is distributed between a rate of gain (or loss) of potential energy due to slope, a rate of work against rolling friction, and a lateral acceleration at turns.

Any grid square for which Speed of Transit in all direction is 0 for a given type element is an obstacle for that element, and cannot be considered as either a Route Segment or a Feature (since it cannot be reached).

Any grid square in which Speed of Transit is great enough to make it preferable to move rather than stop and seek cover is a Route Segment.

All other grid squares are Features. Note that a feature can be used as a Route Segment.

d) With this identification and description of Obstacles, Features and Route Segments, it is now possible to perform two key operations:

(1) Analyze defensive strength of features by previously-described evaluation of Field of Fire and Field of View.

(2) Identify all possible routes connecting any two Features and establish which route is safest.

One could imagine developing and storing in the Terrain File all such information. However, it seems better to model the process of planning as incorporating the two listed operations in a search for courses of action which is guided by the content of the Situation Map and the Mission-type order. This will be discussed in a later paper on Maneuver.

This terrain picture does not yet include the information necessary for planning construction, which includes among its tasks the improvement of Cover, Concealment and Trafficability. This subject is also deferred to a late paper.

10. CLASSIFICATION OF TERRAIN. The preceding has outlined a theoretical system for terrain appreciation by either commander or system analyst. Neither is capable of carrying out such an appreciation in the manner described, due to lack of time and to lack of access for the detailed measurements described. The analyst normally works from maps, which are too large-scale for any real detail as to cover, concealment, and trafficability. The commander can supplement these maps by more detailed photographs or sketches or by personal reconnaissance. However, unless an area is occupied for considerable time, even a squad leader who has only a small area of operations, cannot gain detailed knowledge by a personal reconnaissance made under time pressure and often under enemy fire.

For the detailed knowledge of a specific piece of terrain must be substituted a familiarity with the characteristics of various terrain types, so that the characteristics of a given piece of terrain can be approximately established by analogy with a similar piece of terrain which has been examined under more favorable circumstances.

This implies a classification of terrain into some number of distinct categories. Such classifications exist, ranging from the simple designators -- "swamp", "forest", etc., to such efforts as the U.S. Corps of Engineers Trafficability maps. None of these systems, so far as is known, are directly applicable to the classification of terrain for Fire and Maneuver operations.

We need such a system for further development of maneuver theory, and will be attempting to develop one. One possibility may be to establish a "profile" (by type element) of the density of route-connected features above a certain level of defensive strength (see Paragraph 5c).