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TARGET MODELING AND WEAPON CAPABILITY ANALYSIS

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1. PURPOSE

The purposes of this document are:

(a) To record and explain those methods now being used by the Tactical War Studies Group for target modeling and analysis of weapon capability.

(b) To record those questions in this area which do not yet have satisfactory methodological treatment and may justify further development.

2. GENERAL APPROACH

Military operations are, in essence, a planned application of violence for the purpose of attaining some political goal. In the overall approach, military operations are subdivided into six functional fields: 1.) Fire, 2.) Maneuver, 3.)Intelligence, 4.) Command/Control/ Communications, 5.) Service Support, and 6.) Procurement. Fire includes any application of violence by some entity called a weapon to some entity called a target. Each functional field has such obvious and influential interconnections with the other five functional fields that it is seldom profitable to study it in isolation.

Thus the study of target-weapon interactions is initiated "from the top"; it includes the purpose of Fire and its interaction with other functional fields in addition to the interaction of specific weapons with specific targets.

Because of this generalized approach our top-level models employ approximate methods to process ranges of parametric value. This step results in identification of assumptions, input value, or computational algorithms which strongly influence the output values. The identified sensitive items can then be examined in greater detail by second-level models. In concept this process can be repeated to finer levels of detail and end at some bed-rock of actual experimental data; in practice it usually terminates with a wish that somebody, somewhere would develop some relevant experimental data.

3. DEFINITIONS

Target .... anything fired at....[1]. After numerous attempts at a more restrictive definition of the word Target, we have reverted at last to the above. This merely reflects the fact that Fire has been, and will continue to be, directed at a wide variety of objects in the execution of military plans.

It appears that three conditions must exist to convert an object into a target for some given weapon:

a.) The object must exist.

b.) The object must be "seen" (in the most general sense) by the weapon.

c.) The object must be susceptible to some form of damage by the weapon.

To convert the object into a *military* target a fourth condition is added, because military operations are a *planned* application of violence.

d.) There must be some purpose leading to attack of the object by the weapon.

This idea of purpose permits a somewhat more restrictive definition.

Potential Target......anything which, when influenced by fire, will lose capability for functional performance adverse to the interests of the firing force.

Not all potential targets by reasons of being are fired at. The process which converts a potential target is quite simply described:

a.) Some Potential Targets are "seen" and thus become Acquired Targets.

[1] The American Collegiate Dictionary.

b.) Some Acquired Targets, after a process of Fire Direction, become Designated Targets for specific weapons.

c.) After successful weapon launch, the Designated Target becomes a Target.

The Capability Model[2] is a computerized application of the above -described process, and has proved very useful for top-level analysis leading to identification of important variables and sensitivities. The model is a very rapid and flexible processor of input data, with capability for output presented in several different formats. Its merits in this regard have a reverse side:

a.) The GIGO[3] rule applies. Great malodorous mounds can be produced in seconds. Thus it is important that inputs be selected with care, recorded in detail, and explicitly discussed in presentation output.

b.) Labor on input is an extensive effort. Thus it is very desirable to minimize run-to-run changes, especially in the listing and description of potential targets.

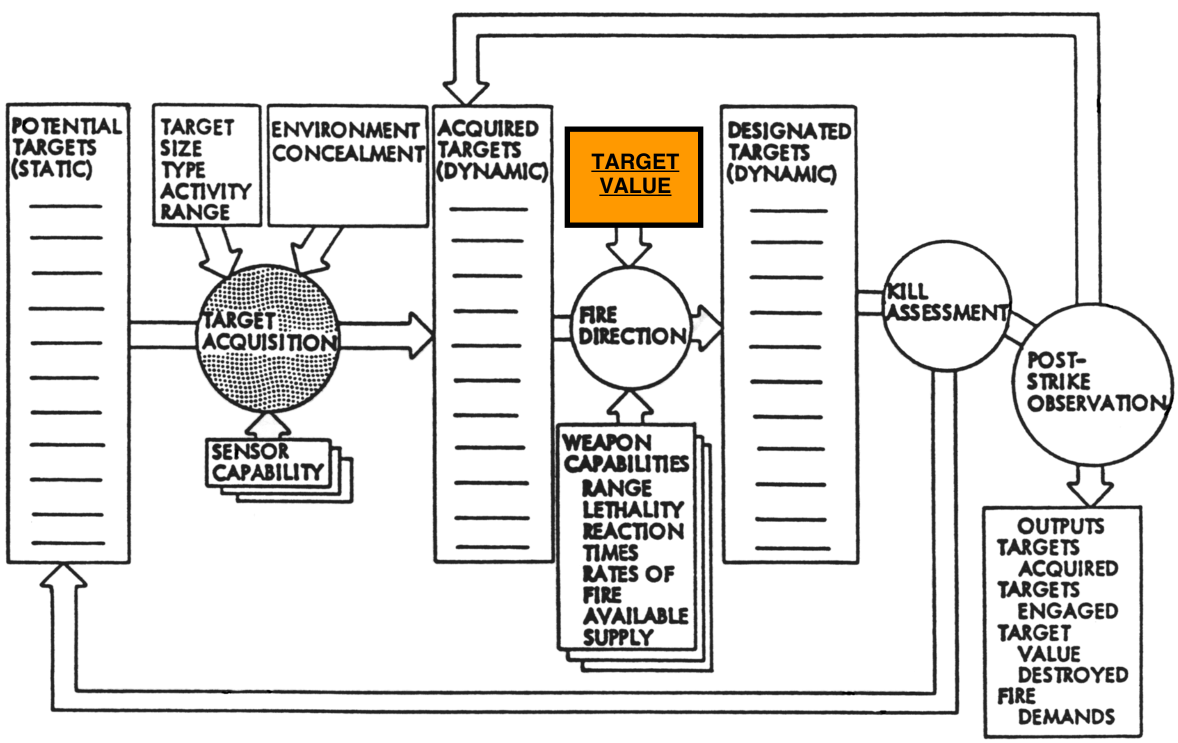


Figure 1 - Combat Capability Model

2 See Figure 1 for gross flow diagram
3 Garbage In Garbage Out.

4. LISTING AND DESCRIPTION OF POTENTIAL TARGETS

The above definition of Potential Target unfortunately places little restriction on the categories of objects which may be listed. For example, here are two entities which do not obviously include themselves in a listing of potential targets.

a.) The coral reef which must be gapped to permit passage of landing craft.

b.) The black-pajama peasant who moonlights as a Viet Cong.

An exhaustive listing of type potential targets might be arrived at by cataloguing all objects which have historically become military targets and supplementing the list with such things as satellites which have not yet been fired at. The feasibility of such a project is dubious,, but a master list of all potential targets developed by other methods can certainly be prepared.

The current method of listing potential targets is as follows:

a.) One or more scenarios describing plausible military campaigns are prepared. These scenarios include, among other things, a Natural Environment and a Hostile Environment.

b.) From the Natural Environment a selection is made of natural or man-made features which may have capability for functional performance adverse to the interests of the friendly force. This process has so far been completely judgmental , guided by interpretations of doctrine - a comparison of postulated opposing courses of action (including logistics operations) reveals those features which may become "key". A more formal, possibly computerized, terrain analysis might improve the process; this is another potential project.

c.) The Hostile Environment (Enemy Order of Battle plus paramilitary or subversive elements) is disposed on the terrain in accordance with some credible military plan. The picture may be made dynamic by appending movement and activity schedules; in this case, differing potential target lists are extracted from various "snapshots" - stop-action enemy dispositions at specified times.

The Enemy Order of Battle contains a number, usually very large, of military elements organized into military units and other aggregations of various sizes. A military element is defined as a transportable or mobile entity which performs or enable one or more of the above-listed military function, and which cannot be subdivided without qualitative denial of its primary function(s). Men are elements as long as they are, say, riflemen or clerks, but tank crewmen are included in the element tank and the driver is included with his truck.

Dependent on the phenomena (especially weapons) being considered, we may have interest in the elements considered as Elemental Targets or in aggregations of elements which are treated as Composite Targets. The minimum description of a Composite Target which suffices for weapon effectiveness evaluation must include size, configurations and content of the group and the vulnerability (often averaged) of the elements. All these numbers are very arbitrary and subject to suspicion, yet output based on these numbers may be very determinative of weapon design. A careful and thorough reconsideration of Composite Targets, from the view of existence, signature, and vulnerability, is much needed.

a) Composite Target ***b) Surface Area Target***

Figure 2

It is possible that the difficulties associated with Composite Targets can be partially or completely avoided by the concept of Surface Area Targets. In Figure 2, the difference between the two concepts is illustrated by a group of six Elemental Targets. For attack on this group as a Composite Target, the position of each element must be known accurately enough so that some figure can be drawn enclosing the six and an aim point established at the center thereof. The other viewpoint notes merely that the elements are within some terrain compartment with reasonably definite boundaries. It is not necessary that any single element be accurately located; it is sufficient to have observed entrance to the compartment and failure to exit. The differing concepts of Surface Area Target and Composite Target have significant effects in the fields of Target Acquisition and Fire Direction; these effects are discussed below.

d.) The concept of Surface Area Target is necessary for study of forms of fire other than Destruction Fire. These include:

1) Harassing Fire

2) Suppressive Fire

3) Interdiction Fire, in the artillery sense of preventing movement through an area by threat of destruction.

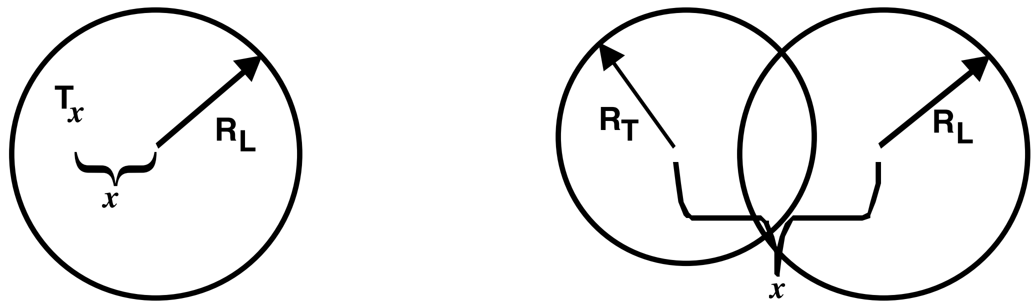
4) Fire intended to change the characteristics of some portion of the natural environment; e.g., smoke or mining.

The listing of Surface Area Targets in a scenario context is even more judgmental than the listing of terrain features as targets. Since the Surface Area Targets are primarily used to obstruct the enemy's maneuver or protect the friendly maneuver, they are not acquired by observation, at least not directly. Rather, they are directly designated in fire orders. The Capability Model accepts these targets by giving them a probability of acquisition of l.0 and a very high value at a certain time, thus ensuring that they are fired upon. If they do any damage to potential targets in the area that fact is recorded; However, there is no method for assessing their effectiveness in accomplishment of their true purpose (e.g., harassment).

The potential targets, once listed, must be described to provide input values for assessment runs. These descriptions are organized under the headings of vulnerability, signature, and value and discussed in succeeding paragraphs.

5. TARGET VULNERABILITY

Target vulnerability, weapon accuracy, and weapon lethality interact to determine the probability that the target is "killed" by the weapon. The results can be computed by two very simple formulas:



a) Point Target ***b) Area Target***

Figure 3.

<u>*Point Target*</u> $P_K = L\left(P_r\left[0 < x < R_L\right]\right) P_G$

<u>*Area Target*</u> $E_K = L \sum_{x_i\{0, R_T + R_L\}} C(x_i)\; P_r\left[\left(x_i - \frac{1}{2}\Delta x\right) < x < \left(x_i + \frac{1}{2}\Delta x\right)\right] P_G$

where:

$P_K =$ probability that target is killed.

$E_K =$ expected fraction of target killed.

$R_T =$ radius of target

$R_L =$ lethal radius of weapon

x = miss distance

L = lethality of weapon within lethal radius

C = coverage function

P_G = probability of good guidance

The sketches and formulae above imply circular approximations; the Capability Model is not restricted to these but can apply the same general methods in the forms listed in Figure 3. In many, if not most cases, the inaccuracies of circular approximation are trivial in comparison with the sensitivities discussed below.

The point target formulation is used in cases where $R_T \ll R_L$. P_K is used for targets which cannot be partially killed. These are typically elemental targets and often treated as point targets. However, some point targets may be subject to partial kill (E_K) considerations
(e.g., a stack of fuel drums). Conversely, some area targets may require P_K treatment (e.g., a man fired at by a rifle gets the area target treatment.).

Either P_K or E_K requires some definition of the word "kill". This has an inherent meaning only in the case of an animate being, and even in such a case disabling is as useful for military purposes as death. In the methodology under discussion "kill" is defined as impairment of military function and there are in general four possible levels of "kill":

Harassment without inflicting actual physical damage on the target, results, usually temporarily, in lowered efficiency in the performance of military functions.

Suppression again without actual physical damage, results in preventing performance of the target's military function - again normally for a limited period, often the period of fire delivery.

Damage to the whole target or some vital functional component results in prevention of function until repair is effected.

Destruction for military purposes, is damage making the target non-functional , and extensive enough to make replacement preferable to repair.

The first two categories of kill are most relevant to targets containing people, whose behavior is influenced by danger. Because human behavior is quite unpredictable, P_K or E_K under these kill categories cannot be well-quantified. Nevertheless, these are important types of fire, especially for land combat operations.

Damage short of destruction has been recognized as constituting a "kill" for some study purposes, notably SAM site "suppression". In this case, it is recognized that a radar inoperative for the period of an engagement is as beneficial to the friendly objective as a radar completely destroyed. The general utility of damage to targets cannot be appreciated, however, without some target valuing system which explicitly includes a dimension of time.

Destruction is in all cases as good as or better than damage. However, obliteration of the target is no more purposeful than the precise amount of damage which makes replacement preferable to repair.

In practice, a fairly arbitrary single criterion of kill is assigned for each target. The whole question of various types and levels of kill and their relevance in a varying combat situation needs further work.

In the case of a composite target E_K expresses the expected fraction of elemental targets killed, or the probability of kill of any arbitrary elemental target. The value of the composite target is considered as reduced by the fraction E_K.

This is appropriate for what is termed a simple composite target. A simple composite target is a collection of elements all of essentially the same kind, and without any functional interaction between those elements. An example would be a fuel dump consisting of a number of containers dispersed on the terrain.

A complex composite target, on the other hand, contains differing elements which depend on interaction to produce a value of the whole greater than the sum of the values of the elements. An example would be an infantry platoon. In this case, it is suspected that loss of value is not linear with fractional damage, but perhaps more as notionally illustrated in Figure 4.

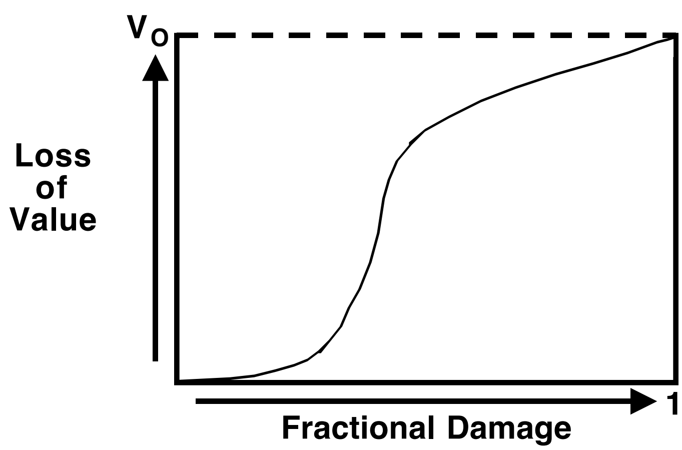


Figure 4 - Complex Target

The terms L and R_L express the lethality of a specific weapon against a specific target, or conversely the vulnerability of the target to the weapon. In the present condition of the methodology a different pair of values of these variables is used for each pairing of target and available weapon. In view of the inaccuracies of our basic data and the computational approximations, it would be both permissible and desirable to generalize the relationship in some fashion. One possible approach would be to describe the target in terms of vulnerable area, to describe the weapon in terms of total energy, and then use some "coupling factor" pairing a target "hardness" class with a weapon effect mechanism class. Work of this nature is a desirable future project.

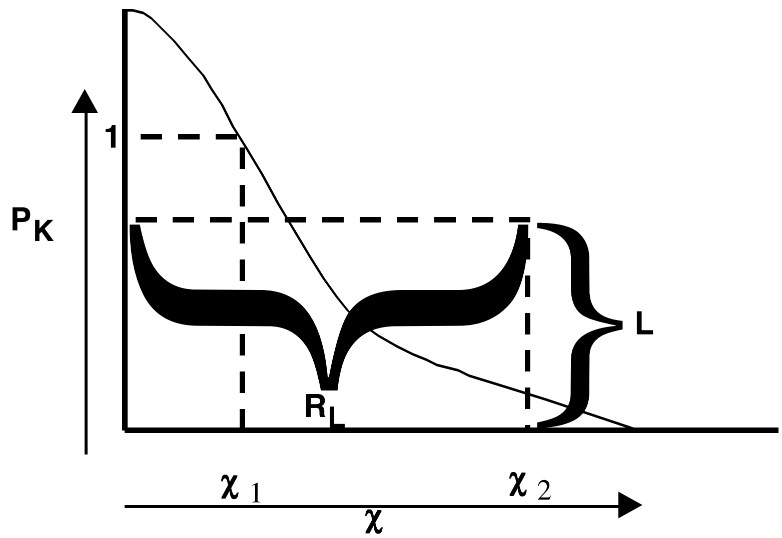


Figure 5 - Lethality

Figure 5 illustrates the general concept of R_L and L. Consider the ordinate first as an amount of energy delivered to the target; this obviously decreases due to solid-angle, and other considerations as the miss distance x increases. The level of energy which constitutes a (previously defined) kill is attained at some miss distance x_1 for $x<x_1$ this energy level is exceeded, but since $P_K \leq 1$ the additional energy does not count, At some point x_2 . usually rather indefinite in theory, the kill probability becomes negligible.

The paired terms R_L and L are derived by calculating a right cylinder equivalent in volume to the figure of rotation about the y-axis generated by the x-axis and the solid line of Figure 6. Many such pairs are possible; in practice that for $L= 1$ is usually taken

The cases in which hit _on_ the target is required (e.g., rifle-fire) are handled by setting R_L=0.

If the weapon is a distributing, rather than unitary, munition (i.e., consists of a number N of sub-munitions) the lethality computation is modified. An r_l and l is computed for the effectiveness of the sub-munition against the target (element). The sub-munitions are then considered as distributed within a circle (other shapes can be computed, but are not normally used) of radius R_C. The lethality is computed as

$$L = 1 - e^{\frac{-NrL^2}{R_C^2}}$$

This formula reflects a uniform random distribution of sub-munitions with R_C (edge effects neglected); this is the lower limit of lethality but cannot be materially improved unless the sub-munitions can be patterned very accurately.

The R_L and L of a weapon against a given target can of course be modified by natural cover or protective construction shielding the target. Each such situation is different and must be specifically calculated. Except for target elements which must be exposed to be functional, e.g. radars, it is normally possible to postulate cover which effectively defeats the weapon under consideration. In such cases one should assess the time, labor, and operational penalties of affording such protection to each target of that class exposed to the weapon, and weigh such investment against the possible lost value of targets unprotected or protected to a lesser degree.

For targets containing humans, and especially the mobile ones, R_L and L can be expected to decrease after the first round or volley, as protective reactions occur.

For rough sizing work, if W is warhead weight R_L varies as $W^{1/3}$ for unitary weapons, and as $W^{1/2}$ for distributing weapons, L being constant in both cases. Any conclusions from such scaling laws should be verified by warhead design calculations.

The coverage function C varies in form with the geometry being used in the models of target and weapon effect. For a weapon which must hit the target to achieve any effect $R_L = 0$ and $C = 1$.

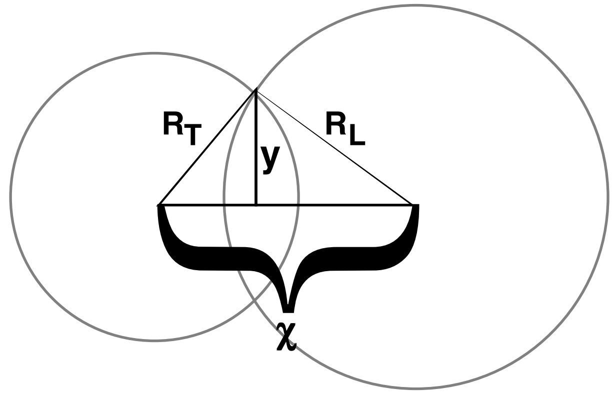


Figure 6 - Coverage Function

For circular models:

$$C = \frac{1}{\pi R_T^2}\left\{ R_T^2 \arcsin\frac{y}{R_T} + R_L^2 \arcsin\frac{y}{R_L} - \frac{1}{2}x\,y \right\}$$

where $$y = \frac{1}{4x}\sqrt{s\left(s - R_T\right)\left(s - R_{L)}\right)\left(s - x\right)}$$

and $$s = \frac{1}{2}\left(R_T + R_L + x\right)$$

6. WEAPON ACCURACY

The weapon accuracy is represented in the general P_K/E_K formulas by the $\Pr[\ ]$ factors. As stated they imply an assumption of circularity in error distributions; when applicable, formulae representing bi-variant distributions and "stick" or patterned volley phenomena are available.

Circularity is believed to be an adequate assumption for very generalized studies, such as for gross weapon sizing or gross comparisons of weapon effects. It should be supplemented by better representations for any more detailed studies, especially when one wishes to discuss the accuracy capabilities of some candidate guidance system.

Weapon accuracy calculations must be clarified by defining and relegating to other variables the following classes of error:

a.) Target location and aim point designation errors[4]. These can sometimes be adequately modeled as a circular normal error source, and for computational convenience be vectorially combined with weapon accuracy.

b.) Gross functional failures by any element of the guidance and control system, including human operator mistakes (as distinguished from sensing or correctional errors). These sources of gross system failure are represented by the factor P_G - probability of good guidance - in the weapon effectiveness equations. This factor could include such terms as the probability of firing on valueless decoys.

7. TARGET ACQUISITION AND AIM POINT DESIGNATION

The classification and description of Potential Targets by *Signature* is among the products expected to emerge eventually from a study of Intelligence. As a long-range goal it is intended that the Intelligence sub-model of the Capability Model be enabled to produce the following data:

a.) The probability that any given potential target is detected (a function of time and sensor capability).

b.) The probability that the target is identified sufficiently to establish its value.

c.) The probability that the target is described sufficiently to establish its vulnerability.

d.) The probability density function of distance between designated aim point and optimum aim point ("target location error").

Items a), b), and c) are not discussed herein, except for the observation that b) and c) are now assumed to have value 1.0 in the Capability Model, which makes the modeled Fire Direction not a particularly realistic model of true Tactical Fire Direction.

Several distinct classes of error are compounded into "Target location error" , these are Observation, Reference, Grid Transfer, Target Composition, Target Motion, and Aim Point Selection.

[4] See paragraph 7

For fixed targets located in some "map" - not necessarily topographic - all error sources other than aim point selection are replaced by a single map error. The magnitude of this error is determined by the accuracy with which the map can be constructed and/or the accuracy with which the fixed point can be represented on the map. Surface area targets are subject to this map error but are often large enough so that it is trivial in effect.

Mobile targets or fixed targets not located on a map must first be *observed* by some sensor; this introduces errors attributable to the resolution capability of the sensor and any environmentally-caused aberrations in transmission of the observed target emanation.

The observed target must then be located relative to some object in a "map' - either the sensor itself or some other *reference* point. This involves errors of distance and relative bearing of target from reference point and map location of reference point. In the case of a sensor collocated with a direct-fire weapon, the map location error is not applicable.

In case the map in which the target is located is not the same as that in which the weapon launcher is located a grid transfer error is introduced. With this is included a map location error of the launcher.

In case the potential target is a collection of elemental targets, errors of target composition are introduced. Target composition is the process by which composite targets are formed and consists in fixing and describing the perimeter and center of value of some geometric figure containing the elemental targets. Only errors in establishment of the center enter into target location error as here defined; those concerning the perimeter enter into determination of target vulnerability (see (c) above).

Any change in the target's state of motion after the last opportunity for weapon guidance correction introduces a bias, rather than a random component, in the target location error. However, the total effect of all possible changes of motion, perhaps weighted by some factor reflecting the likelihood of the change, is to introduce a target location uncertainty which can be reasonably well represented by a component of random error.

Errors in the Aim Point Selection are peculiar to the guidance system employed and applicable only in the case of some homing systems. Credit is given in the calculations for an optimum aim point, but some systems may be unable to differentiate one point from another or may home on the point of greatest contrast.

The above components of target location error appear to be all independent and can probably be well represented by composition of the independent errors into some normal probability density function. Confident quantification is dubious at best, but comparison of the potential errors for different classes of targets may give some insight into the applicability and utility of various guidance systems.

8. TARGET VALUE

That a policy of pure attrition of enemy resources is both ruinously expensive and militarily unproductive has been amply demonstrated by the U.S. Vietnam experience. If such theories were even employed in combat against an enemy even approaching the U.S. in military potential the war would at least be short.

It is high time that analysts seriously approach the subject of sound Tactical and Technical Fire Direction. Fire must be applied in concert with maneuver to achieve tactical objectives consistent with some appropriate military strategy.

Though Tactical Fire Direction in the field is not a mathematical process, there is nevertheless a logic in the process and the analyst can best assist by attempting to create a suitable mathematical model of this logic. The Capability Model applies the following logic:

a.) All acquired Targets are ordered by the product of target value and P_K/E_K of each available weapon.

b.) Targets are designated for available weapons in descending order of the value of these products, however,

c.) Weapons of least versatility are exhausted first, in order to reflect the usual field procedure of using unit weapons before calling for support fire.

The target value used in Capability Model can be derived by any process desired, including arbitrary assignment of priorities.

The tactical war study team is well advanced in development of a target valuing system, partially documented in Chapter 6 of *The Anatomy of Combat* third draft. This system includes two principle features (believed to be virtues):

a.) Target value is time-dependent.

b.) Target value is related to accomplishment of friendly objectives.