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THE FUTURE OF ARMY ITEM-LEVEL MODELING

PAUL H. DEITZ

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FEBRUARY 1988

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Battlefield models can be classified according to a hierarchy of levels, each addressing a particular scale of battlefield integration. From top down, those levels are 1) Theater, 2) Corps, 3) Division, 4) Battalion, 5) Unit, and 6) Item (One-on-One). This paper deals with the problem of relating item-level measures of performance to actual battlefield effectiveness.

Level 6 modeling is particularly crucial now and will be more so in the future. It is the level at which individual weapons are examined in greatest detail; this includes the diverse aspects of vulnerability, mobility, structural integrity. signature, and lethality. This level plays a central role in developing system concepts, design optimization, evolving battlefield strategies, and logistics planning. Unfortunately, item-level modeling has not generally kept up with the technology advancements in weapons engineering. The design choices available to weapons designers include applique and special armors, new configurations of shaped-charge liners and materials for construction which have ramification

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→for system strength, mobility, vulnerability, and detection.

Item-level modeling must evolve in a number of crucial ways. First, high-resolution simulations are required to provide supporting data for design/optimization. Second, an <u>integrated</u> collection of multiple high-resolution simulations must exist so that design tradeoffs, robustness, and countermeasures can be assessed. Finally, battlefield measures of effectiveness, derived from support of models in Levels 1) through 5), must provide the metric for the design tradeoffs available in Level 6). Keywords: → to fld 18

In this paper we will discuss the steps currently used to define and analyze future Army systems; we will find the approach more subjective than need be. We will propose a technique by which quantitative system measures of effectiveness can be evaluated within the context of a Unit-Level wargame. Through this approach the various aspects of system performance can be analyzed for their contribution to overall mission effectiveness.

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I. INTRODUCTION

The objective of the Army materiel acquisition process can be stated quite simply: to supply the Army with equipment which will optimally assist in winning future wars. Given that goal, how best can we decide what equipment and systems to build and what their characteristics ought to be?

Before exploring possible answers to that question, let's list the major steps in the acquisition of an item-level system, which we take here to mean a tank, a missile system, a self-propelled howitzer or some similar item. They are:

A] Define the need for a given item (system)

B] Define the optimal characteristics of that system i.e. how to sort out the benefits and burdens of various options

C] Postulate specific system designs and analyze in detail the degree to which candidate designs meet the criteria of B]

D] Build, test, and modify the prototype to see whether C] (developed in theory) can be actualized

E] Build the inventory.

What kind of rational tools does the Army have that might be used to address steps A] through C]? Various war games are available, each addressing a particular level of battlefield integration. From top down, those levels are 1] Theater, 2] Corps, 3] Division, 4] Battalion, 5] Unit, and 6] Item (One-on-One). The focus of this paper is on the requirements for Item-Level Modeling, level 6].

It is this level at which individual weapons are examined in greatest detail; this includes the diverse aspects of vulnerability, mobility, structural integrity, signature, and lethality. This level should play a central role in developing system concepts, design optimization, evolving battlefield strategies, and logistics planning.

It can be seen that in level 6], Item-Level Modeling provides the rational techniques by which step C] of the item-level acquisition process can take place. It would appear, then, that steps A] and B], the definition of the general and specific characteristics of system itself should arise from the higher levels in an analytic hierarchy, 5] the Unit level and above (levels 1] through 4]).

In this paper we will discuss how system concepts are developed in the Army today, where we perceive shortcomings, and what might be done to address the shortfalls.

II. STATUS QUO

How does the Army currently sort through steps A] through E] in the acquisition process? We assert that currently the choice of a particular class of end item (step A]) is made by essentially a subjective process. It is decided that "The Army needs a new Infantry Fighting Vehicle (IFV)." This decision may be *subjectively* influenced by war games run at levels 5] or higher, but to the best of our knowledge, for example, there is no unit-level model which has been designed to sort through the myriad of options for *general* system definition.

When it comes to issue B], defining the optimal characteristics of the fuzzy system defined in step A], there do not appear to be more objective tools. For example, there is no unit-level model that has been configured to assess the battlefield effectiveness of IFVs as a function of the dozen or so most dominant measures of system performance. Rather, at an early concepts stage, system specifications are generated by a committee of experts for various aspects of item-level subsystems. If the issue is a IFV, a panel is formed of armor, mobility, and weapons experts. Invariably, each expert proposes specifications for his area of expertise based on his perception of the highest achievable goals, irrespective of the required benefits or implied burdens that such an process entails. Thus systems specifications arise based on what technology can provide on a discipline by discipline basis, not on what the actual benefits could be achieved based on an integrated system approach which reflects optimal design criteria.

This mode of operation has a number of unfortunate ramifications. One area that has gotten little attention until recently is logistics support. System acquisition has been approached as though unit purchase costs and subsystem by subsystem performance were the key drivers. In fact it is now recognized that the lifetime logistic costs and the accompanying issues of reliability, availability, and maintainability (RAM) are the key attributes. Today's committee-decision approach for setting system specifications (Issue B]) is incapable of dealing with the issue, "Should a modern battle tank have a crew of three instead of four?"; or "Should the next IFV trade three tons of armor protection to gain an increased top speed of 15 mph?" The former question raises questions about possible reduced effectiveness for a specific (tank) system, but the advantage of spreading the same number of troops over a 30% increase in the number of vehicles is never addressed. The latter question poses a typical Operations Research/Systems Analysis (ORSA) conundrum. We'd like to have *both* high protection and high mobility, but the reality of all our systems is that they are constrained. And the constraints are many; cost is one, weight is another, size (to fit on a C 141) is another. Weight (of armor) helps in protection, but hurts in mobility. The synergisms and conflicts are many, and probably the key aspect of this problem is the manner in which system integration takes place. It's unfortunate that the integration process must rely so heavily on a subjective approach.

What about step C] of the acquisition process? Here the Army tends to do a bit better. Although we have incomplete and predominantly subjective system specifications to work towards, many aspects of projected performance are examined. Design factors involving chassis strength, mobility, armor protection, fire control have tended to get high scrutiny over the years. Other factors such as system design practice so as to achieve minimal detectivity in the battlefield have received little or no attention until recently.

A significant factor in the ability to perform detailed system analyses in a timely fashion has been the emergence of new set of high-resolution engineering tools built around Computer-Aided Design (CAD) techniques.

The subject of an earlier AORS paper[1] the key theme is that the great majority of current system analyses require detailed three-dimensional geometry in order to be performed. Questions relating to system weight, protection, signature, etc. all are based in part on geometry (and accompanying material properties) and various aspects of performance.[2], [3] Although such analytic tools are not universally used, there is a rapidly growing awareness that they are increasingly required to give both the required precision in many investigations and the ability to perform system integration and tradeoffs.

The expected result of process C] is, at best a loose design of a system, so that the real aspects of integration are left to the prime contractor to sort out. Finally, a prototype is built and tested against the (incomplete) criteria which have evolved in phases B] and C].

III. AN EXAMPLE

To understand better how system definitions and requirements are formulated today, we discuss a set of systems now under consideration by the Army, The Armored Family of Vehicles (AFV).* The Army is now faced with a set of

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1. P. H. Deitz, "Solid Geometric Modeling - the Key to Improved Materiel Acquisition from Concept to Deployment", in the *Proceedings of the XXII Annual Meeting of the Army Operations Research Symposium*, 3-5 October 1983, Ft. Lee, VA, pp. 4-243 to 4-269.

2. P. H. Deitz, "Predictive Signature Modeling via Solid Geometry at the BRL," *Proceedings of the Sixth KRC Symposium on Ground Vehicle Signatures*, 21-22 August 1984, Houghton, MI.

3. P. H. Deitz, "Modern Computer-Aided Tools for High-Resolution Weapons System Engineering," *Proceedings of the CAD/CAM Mini-Symposium, MTAG 84*, 28-29 November 1984, Seattle, WA, pp. 23-42 (Published by US Army Industrial Base Engineering Activity, Rock Island, IL.)

* The study of the AFV requirements is being led by Systems and Technology Planning Office, TACOM. The author wishes to emphasize that the use of this particular program to illustrate perceived shortcomings in the procurement process is not meant to reflect negatively on the program. Through his personal involvement in the AFV study, he can attest that the the S&T Planning Office is well aware of these philosophic problems.

decisions about how it will design and constitute its future fleet of ground fighting vehicles. The philosophic departure for current future systems is taken from "Army 21, A Concept for the Future".[4] Army 21 is the US Army's war fighting concept for the early 21st Century. Following an overview of the future field of conflict, it gives a listing of the future force characteristics. Some of these are given in Figure 1. Each of these desired future force characteristics is attractive and desirable. As noted earlier, the reality of system design requires that difficult decisions must be made on competing attributes. Also as noted before, there is no rational, quantitative set of metrics based on a war game scenario which actually reflects optimized attributes in terms of a "modeled" Army 21.

Furthermore, Army 21 focuses on technology bases which provide support to achieve future system requirements. The identified capabilities/technologies are given in Figure 2. Army 21 states[5] that "there must be a thorough assessment of the overall benefits of the technology before specific materiel requirements can be developed." The document further states that "To make Army 21 achievable, the AMC/TRADOC partnership must create a disciplined process for incorporating the Army 21 philosophy throughout the materiel development cycle from this point on into the 21st century."[6]

To return to the AFV planning process, a (loose) set of design criteria have been inferred from the scenarios implied by Army 21. An O&O Plan[6] thus further distills Army 21 to provide technology guidance and threat/deficiency definitions. In yet another fundamentally subjective step, a Special Study

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[4] Draft version prepared by the USA Training and Doctrine Command, Ft. Monroe, VA.

[5] See reference 4, page 5.

[6] "Draft Umbrella: Operational and Organizational Plan for Armored Family of Vehicles", final draft prepared by the USA Training and Doctrine Command, Ft. Monroe, VA. (August, 1985)

a. Small, self-sufficient organizations
b. High mobility - countermobility
c. Firepower intensive
d. Less manpower reliant
e. Extremely agile - quick dispersion and massing capability
f. Capable of fluid, continuous operations
g. Rapid strategic deployability

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m. Less fuel consuming - energy efficient
n. Stealth equipment (reduced, multiple or stand-of signatures)

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t. Commonality of equipment

Figure 1. Examples of the General Force Characteristics as Given in "Army 21, A Concept for the Future."(See reference 5, pp. 5-1 to 5-2)

a. Firepower -
  - Lethality
  - Extended Range
  - Smart Sensors
  - Fire Control
  - Robotics

b. C3I -
  - Command, Control, and Communications
  - Intelligence

c. Mobility -
  - Light Weight
  - Miniaturization
  - Navigation
  - Robotics
  - Common Platforms
  - Propulsion
  - Countermine
  - Gap/Obstacle Crossing
  - Countermobility

d. Survivability -
  - Detection
  - Hit
  - Vulnerability
  - Repairability

e. Support -
  - Supply
  - Maintenance
  - Transportation
  - Field Services
  - Simulators and Training
  - Devices

Figure 2. Technology Bases Which Support the Future Requirements
(See reference 5, pp 7-3 to 7-4)

Group, Armor, developed the following design objectives for the AFV:

a] Maximum Component Commonality
b] Common Vetronics[7] Architecture
c] Maximum Chassis Commonality
d] Multiple System Capabilities
e] Modular Capabilities
f] Common Signatures.

Here again, although the AFV O&O provides some goals which offer payoffs, there is nothing in the way of quantitative system criteria that can used as concrete objectives in the system design process.

For example, objectives a] through d] seem to be reasonable goals, but just what, for example, is "Maximum Component Commonality" and for what criteria does it occur? Other questions arise. What are the benefits and burdens of using a common chassis(s) and turret-ring variants to address the 29 or so identified battlefield missions vice generating 29 separate, individually optimized designs? Ignoring for a moment cost factors (which are a major influence), we seek an analytic "scenario" into which we can place candidate "optimized" and "compromised" designs to test effectiveness. However currently, *we have no (quantitative) measure(s) of system effectiveness*. Other questions can be raised. Why should we have common signatures? Why not have minimal signatures where reasonably achievable *and* the payoff is there? Further, within each signature band, why not randomize the signals so as to make target classification more difficult? Again, there is no way to test this hypothesis, since we have no quantitative metric which reflects the scenario(s) for which we are presumably designing.

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[7] Vetronics (Vehicle Electronics) is an initiative to integrate advanced electronic systems using bus concepts for data and control.

IV. TOWARDS A MORE RATIONAL DECISION PROCESS

Clearly, the establishment of quantitative system design criteria is a difficult and challenging problem. This is due to a number of factors including the high dimensionality as well as the general interdependence. How can this situation be approached?

As an approach to analyzing complex systems Deaton has reviewed some methods which can be characterized as *subjective* in nature. She asserts that[8]

> "Decision making can be divided into four phases: (1) recognition of a decision problem and definition of its nature and dimensions, (2) probability measurement, (3) outcome evaluation, i.e., how good or bad the outcome is, and (4) choice - usually the alternative which has the highest expected value or which returns the most value per unit cost."

In addition, techniques such as task decomposition can assist in the analysis of complex processes.[9]

> "Decomposition . . . is described as specification of choice alternatives which are usually defined as a set of consequences following from the alternatives. At this level, utilities are assigned to the outcomes, and expected utilities are computed for course of actions."

This process of decomposition can continue to lower levels. As this process continues, complex tasks are are resolved into simpler subtasks. However, these processes often involve probabilities and effects which are unknown to the analyst. This is the case we are presented with here, without some analytic extensions to current war game capabilities.

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8. M. D. Deaton, "Utility: Recent Theory and Some Applications," U. of Wash Tech. Rpt. 76-4, Sept. 76.

9. See reference 8.

However, it has been asserted by Shepard[10]

> "Because there is serious doubt that man has the ability to process information involving large numbers of dimensions, procedures requiring overall judgments of worth for complex stimuli are unsuitable for many real world problems."

Thus we must seek techniques which at least substantially reduce the subjectivity involved in setting system definition and design criteria for weapons. We now propose an approach with just such a goal.

A. Probability of Mission Effectiveness as a Figure of Merit

Let us define a battlefield system, S, which is characterized by N quantitative Measures of Performance (MoP). Typical MoPs might be the magnitude (in mm equivalent RHA) of KE protection for horizontal attack*, the magnitude of system radar cross section (in sq mm, which relates to the probability of detection in the battlefield), the mobility of the system (top speed, agility), etc. Figure 3 lists some examples of MoP that might be relevant for an IFV. Next, a unit-level war game (ULWG, Level 5, Section I.) must be configured so as to reflect a particular scenario according to the systems, strategies, and deployments implied by Army 21. This is done with a specific mission in mind. A particular mission might require an IFV to traverse from point A to point B within some maximum time and, when reaching Point B, successfully employ its main armament to destroy a particular target. The ULWG must include the N dimensions by which system S is to be characterized. Next a set of values is chosen for each of the N MoPs, and the progress of system S to the goal (destruction of a target upon reaching Point B) is followed. If System S with the given set of MoPs accomplishes its

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[10] R. N. Shepard, "On Subjectively Optimum Selections Among Multi-Attribute Alternatives," in M. W. Shelley and G. L. Bryan, *Human Judgments and Optimality*, New York: Wiley, 1964, pp. 257-281.

* RHA stands for Rolled Homogeneous Armor; KE stands for Kinetic Energy round, one type of antitank warheads.

MoP_1 - Mobility/Improved-Road
MoP_2 - Mobility/Rough-Terrain
MoP_3 - Magnitude of CE Protection/Horizontal
MoP_4 - Magnitude of CE Protection/Vertical
MoP_5 - Magnitude of KE Protection/Horizontal
MoP_6 - Magnitude of KE Protection/Vertical
MoP_7 - Probability of Visual Detection
MoP_8 - Probability of Acoustic Detection
MoP_9 - Probability of IR Detection
MoP_{10} - Probability of MMW Detection
MoP_{11} - Magnitude of Neutron Shielding
MoP_{12} - Number of Crew Members
MoP_{13} - Lethality of Main Gun

$\vdots$

Figure 3. Examples of Measures of Performance (MoP) for a Particular System.

mission, the simulation so notes it, and repeats the mission with the same N MOP values but with a new set of stochastically drawn parameters for the ULWG. These would include hit probabilities of red systems, weapons effects, detection probabilities of red surveillance systems, etc. After many iterations, a probability function would be generated for System S in this specific scenario for the Probability of Mission Effectiveness (PME), where

$$PME' = F[MoP'_1, MoP'_2, MoP'_3, . . . MoP'_N],$$

and the primes (') indicate that PME has been calculated for one set of MoPs. A value of unity means that the mission is accomplished 100% of the time for the given set of MoPs. If two sets of MoPs both yield a PME of unity, the effectiveness between the two systems is indeterminate. The simulation is now repeated for many combinations of MoPs* so that a probability function based on N independent variables is defined

$$PME = F[MoP_1, MoP_2, MoP_3, . . . MoP_N].$$

PME is clearly a complicated function which will not be, for example, a linear combination of the MoPs. To the contrary, as noted above, many MoPs are likely to be dependent (eg. mobility, weight, size, etc.). With a PME thus defined, not only can the effect of changing a given MoP be ascertained while holding other MoPs constant, the importance to battle field mission of a given MoP can be inferred by examining the contribution of other MoPs to the success of that defined mission.

Having generated a PME, we can now proceed to the evaluation of specific systems. A system concept can be generated; as noted in Section II., the actual system should be modeled using solid geometry techniques. The N MoPs can be generated using tools of the type noted in references 1-3. The MoPs

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* We will ignore here the practicalities of this approach including the fact that, if poorly formulated, the required amount of calculation can become intractable.

can be plugged into the PME function so that the mission effectiveness of this particular system is derived.

As this process is repeated for a number of specific candidate designs, both the *relative* and the *absolute* values of competing designs can now be judged. In addition, by examing the statistics derived during the calculation of the PME function (including the shape of its probability surface in hyperspace) we can infer the direction that design philosophy ought to take in order to generate more effective systems.

It should be added that this ULWG must avoid the problems of an oversimplified scenario in which only one-on-one or one-on-few are played. Both red and blue weapons systems must be played in the proper mix and at a broad enough level of force involvement to avoid spurious results and false (apparent) dependencies. It would also appear that, given necessary augmentation, a number of extant war games might support the role of generating PMEs. Such candidates might be CASTFOREM,[11] JANUS,[12] TANKWARS[13] and CORBAN.[14]

B. An Example of Probability of Mission Effectiveness

We now give a trivial example of this approach in order to make this concept more understandable. A mission is defined for a supply vehicle to traverse from Point A to Point B. For this example, the vehicle will be characterized by two MoPs, 1] Ballistic Protection (MoP_1) and 2] Probability of Detection*

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[11] CASTFOREM (Combined Arms and Support Task Force Evaluation Model) was developed by the US Army TRADOC Systems Analysis Activity (TRASANA).

[12] JANUS was developed by the Lawrence Livermore National Laboratory.

[13] TANKWARS was developed by AMSAA and BRL.

[14] CORBAN was developed by BDM Corporation.

* This is the probability that a *red* threat will detect the blue system being played parametrically.

(MoP_2). As noted above the ULWG is configured so that the appropriate threats, terrains, and red/blue strategies are included. Next, a level for MoPs one and two are chosen and the simulation exercised stochastically. At that point the PME is defined for that pair of MoP values. This process is repeated for each pair of MoPs for all ranges of interest: a PME is thus generated as a function of two-space. The results of such a calculation *might* look as shown in Figure 4. The three dimensional curve illustrates that the probability of mission effectiveness (PME) increases as Ballistic Protection (MoP_1) is grows; PME also increases as the Probability of Detection (MoP_2) decreases. The horizontal[+] lines on the slope of the curve indicate levels of constant Mission Effectiveness. Mixes of the two MoPs on such lines imply equal effectiveness.

From such a function the actual tradeoffs between protection and detection can finally be understood in the context of an actual battlefield scenario. Through generation of a PME function, the benefits of arbitrary mixes of MoPs can be interpreted. It should be recognized that many mixes of specific MoPs that might be used to calculate a PME *may not be practically achievable*. That does not lessen the value of the exercise, because this tool would give the system designer guidance in the direction that his efforts should take. The constraints of actual technology come to bear when specific designs are created and analyzed. If the individual MoPs are calculated using rigorous analysis supported by solid geometry, then that particular design represents a valid point in the domain of the PME. The set of all such designs in which valid technology and analysis is performed will then represent the subset of the PME space for which we can *realistically* develop military systems. In addition, the development and analysis of such PMEs could point the way towards the development of high-payoff technologies. We note further that a number of PMEs can be generated for a given system, each representing specific mission roles that it should be capable of supporting.

[+] With respect to the MoP_1-MoP_2 plane.

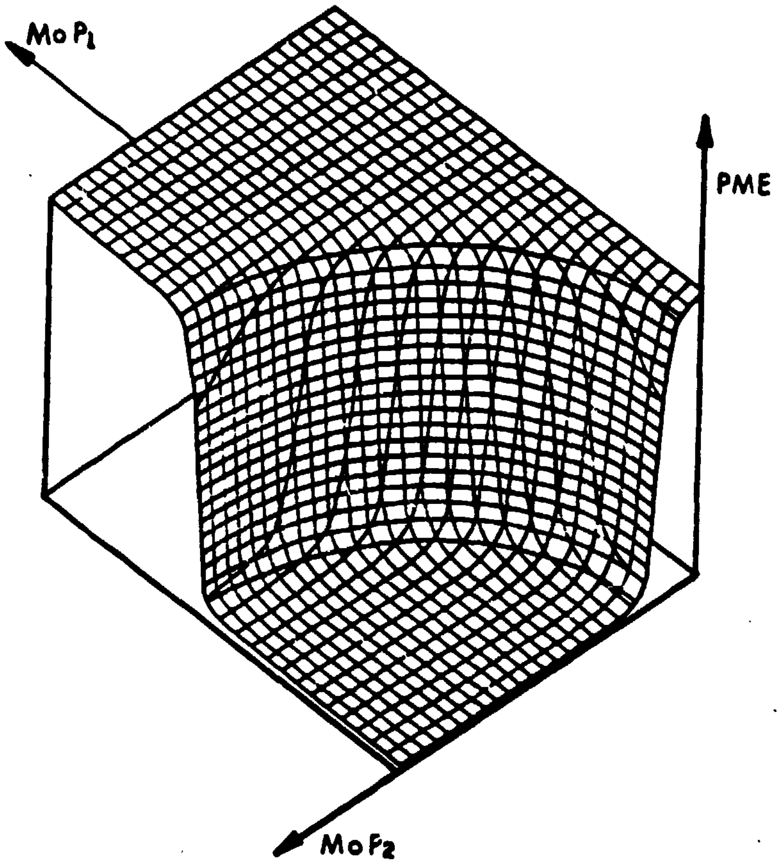

Figure 4. The Probability of Mission Effectiveness (PME) as a function of the Measures of Effectiveness (MOP) Ballistic Protection(MOP_1) and Probability of Detection (MOP_2). For this simple two-parameter system, mission effectiveness increases with ballistic protection; it decreases with increasing probability of detection. The horizontal lines on the slope of the curve indicate levels of constant Mission Effectiveness. Mixes of the two MoPs on such lines imply equal effectiveness.

V. SUMMARY AND CONCLUSIONS

We have briefly reviewed the way in which the Army specifies its needs for new systems as well as the specific requirements for those systems. It seems clear that current procedures are overly dependent on subjective input for:

- Definition of general item requirements.
- Effectiveness criteria by means of which to focus the technical mix of system performance characteristics.
- Appropriate quantitative analyses for some aspects of system performance.

Since the system design goals are invariably not well defined or quantitatively specified, it's often difficult to identify crucial design aspects which ought to be the focus of principal resources.

We believe these shortfalls can be addressed by developing *objective* techniques in which battlefield scenarios are combined with specific mission objectives in the context of a Unit-Level war game. It seems possible that such a capability can be achieved through augmentation of one of a number of extant models (e.g. CASTFOREM, JANUS). By this approach, one of which was sketched in the previous section, we believe that quantitative Measures of Performance can be related to Mission Effectiveness. We believe that such an approach would bring more credible scrutiny to competing Army system concepts. It would also identify high payoff supporting technologies while pointing the way towards optimal designs of the future.

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1. P. H. Deitz, "Solid Geometric Modeling - the Key to Improved Materiel Acquisition from Concept to Deployment," in the Proceedings of the XXII *Annual Meeting of the Army Operations Research Symposium*, 3-5 October 1983, Ft. Lee, VA, pp. 4-243 to 4-269.

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4. Draft version prepared by the USA Training and Doctrine Command, Ft. Monroe, VA.

5. See reference 4, page 5.

6. "Draft Umbrella: Operational and Organizational Plan for Armored Family of Vehicles," final draft prepared by the USA Training and Doctrine Command, Ft. Monroe, VA (August 1985)

7. Vetronics (presumably Vehicle Electronics) is an initiative to integrate advanced electronic systems using bus concepts for data and control.

8. M. D. Deaton, "Utility: Recent Theory and Some Applications," Univ of Wash Tech Rpt 76-4, September 1976.

9. See reference 8, page 9.

10. R. N. Shepard, "On Subjectively Optimum Selections Among Multi-Attribute Alternatives," in M. W. Shelley and G. L. Bryan, *Human Judgments and Optimality*, New York: Wiley, 1964, pp. 257-281.

11. CASTFOREM (Combined Arms and Support Task Force Evaluation Model) was developed by the US Army TRADOC Systems Analysis Activity (TRASANA).

12. JANUS was developed by the Lawrence Livermore National Laboratory.

13. TANKWARS was developed by AMSAA and BRL.

14. CORBAN was developed by BDM Corporation.

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