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On the Careful Use of Models

Presented to the 14th International Symposium on
Military Operations Research

The Royal Military College of Science
Shivenham, Swindon, Wiltshire, U.K.
Wednesday, 3 September 1997

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Abstract

The objective of this paper is to stimulate discussion of the current climate for development and application of models. Periodically the analytical community, particularly those involved in support of program decisions, show renewed interest in the use of modeling to support decision making. Over time the literature is replete with reported breakthroughs, successful application warnings about the difficulties of modeling and the risks inherent in simulation supported decision making.

This paper presents a view of some principles which should be observed in developing and using models to support system acquisition decisions. These views are based on several (some painful to recall) experiences, exposure to others efforts, and discussions with colleagues.

The role and risk of model support in the advocacy role; the trade-off of transparency and fidelity; the use of models to support decision risk assessments; and some thoughts on the question of "why model?" are among the topics to be discussed.

Modeling and Simulation

The objective of this paper is to stimulate discussion of the current climate for development and application of models by operations research analysts to support defense decision making. My remarks are directed toward modeling in support of materiel acquisition, force structure and design, and other traditional management and operational planning decisions. I am specifically avoiding the subject of modeling in support of training and other than traditional mathematical models.

Periodically the analytical community, particularly those involved in support of program decisions, show renewed interest in the use of modeling and simulation to support decision making. This is the case now.

I must admit that this paper is not the result of painstaking research on designing, building and application of mathematical models. It is instead, the synthesis of many years of experience in modeling and simulation and in working with others in the use of such to support defense decision making and readings.

While I acknowledge responsibility for this paper, as noted above, it is an assimilation of my own personal viewpoints and ideas I have picked up from discussions with and reading the works of other operations research analysts. I acknowledge borrowed

or adopted concepts in those cases for which I am able to separate them from the amalgamation of my own experiences (some painful), insights

I must admit up front that the tone of this paper is cautionary. This does not in any sense indicate a lack of appreciation of the value of modeling as an operations research tool, useful in support of management and operational decision making. –In a sense, all operations research activity involves to some degree, the building and application of models and I have made my 'fortune', if that's what you call it, as an operations research analyst.

As in almost everything human, modeling rides on a pendulum. Today the pendulum position is at a state of high interest in modeling. Just a few years ago, it was at the other extreme of little interest by decision makers. I have no doubt it will be back there in a few years again and it is our fault. – That is one reason a word of caution is in order.

Why model?

We model to compare alternative courses of action, decision alternatives. In military operations research we often are called on to conduct a study to 'show that a specific new weapon system; combat, or combat support system; communication, command and control system; or one of many other proposed acquisitions will provide added value to our defense capability." That usually translates into a 'cost-benefit' or, as we used to call it a 'cost and operational effectiveness analysis'. We now call it an 'analysis of alternatives'.

To use a cliché, at the bottom line, we compare two numbers for each alternative considered, the cost of the alternative and the value or benefit achieved by selecting that alternative. Both of these numbers are derived from historical insight, technical and operational knowledge and experience, and possibly the application of models. In the case of the cost estimate, cost estimating relationships are used. To estimate the value, we use a variety of models, ranging from so-called analytic models (closed form models) to simple or complex force-on-force combat models or general heuristic models. The closed form models include linear programming, queuing theory, network theory, dynamic programming or general mathematical optimization models and so called 'engineering models such as the equations of motion of a ballistic projectile or the 'fly-out' model of a guided missile. The force-on-force models may be completely computerized, interactive, or, with the exception of bookkeeping, manual.

Despite all the renewed interest in the use of models, there remains those who are skeptical of the answers provided by models. Why is this so? Steve Bankes of the RAND Corporation, in "**Exploratory Modeling For Policy Analysis**"[1], provides some answers. These include such factors as attempts to predict outcomes which cannot be

1 Journal of the Operations Research Society of America, Vol. 41, No.3, May-June 1993.

predicted, development of models to support a preconceived conclusion, and inability to perform verification, validation, and accreditation of models for the specific uses to which they are applied.

To this list could be added a fourth reason modeling fails to satisfies its promise, that is -- applying a model when it adds no information value to the decision, or there is no decision to be made.

Before addressing the three factors cited by Bankes, I will address the fourth factor, application of models in a non-value added role because that is often the basic underlying cause of the other three failure modes.

A 'formal' model is not always necessary or cost-effective in supporting a specific decision or set of decisions. In 1980, Nickerson and Boyd[1] proposed an approach to estimating the value of developing (if necessary) and applying a model to provide 'better information' about the worth of alternative courses of action available to a decision maker.

Their approach is based on considering the use of model from the standpoint of the "value of information" perspective. Their methodology is based on the economic benefit of modeling. In military operations research we are frequently not able to express the alternatives in economic terms. Perhaps this is an area deserving more research attention since there is a cost to the taxpayer associated with each alternative and the ultimate decision is 'what military capability are we willing to pay for, or settle for. The economic consequences of a defense procurement, materiel, force structure, or force design, is seldom if ever related to combat, that is use of the resultant decision in combat. However, there is a 'life-cycle' ownership cost, and associated opportunities foreclosed costs, as a consequence of those decisions. The relevant question posed by Nickerson and Boyd is whether the value of the decision can be enhanced by the use of a model and is the cost of doing so commensurate with the economic gain potentially realized if the model is used.

Without getting into specifics, let me give a recent example I encountered. A new radio frequency missile countermeasure system has been proposed. The reason or need for the system is based on the fact that this new system is able to react to, and, with some degree of assurance, counter, if necessary, a much broader array of known threat systems than the currently employed system. In the course of business, it was proposed that we need to apply a moderately complex force-on-force model to demonstrate that the new system will provide an 'x' percent reduction in attrition across the force as compared to the existing system. {This example is complicated by discussions regarding the degree of precision of the model in estimating the attrition to be expected with or without the new system}.

Application of the Nickerson and Boyd proposed approach in a very superficial

1 "The Use and Value of Models in Decision Analysis", Operations Research, Vol. 28, No. 1, January-February 1980.

manner yields the following:

Without modeling the decision maker has two alternative decisions,

a. Don't buy the proposed system, or
b. Buy the proposed system.

The decision maker knows:

a. That we may or may not ever encounter the threats the system is designed to counter, and hence has no way of knowing the potential cost avoidance associated with buying the new system,
b. That if the threats are encountered, there is much value in not sustaining personnel casualties as a result,
c. The new system promises to provide protection against a much wider array of threats than the current system.

The analyst can add the following:

a. An estimate of casualty reductions if the equipped forces *ever* encounter a specified threat. *{ by applying a model}*:
b. Insight into the precision with which the model can provide this information and an understanding of the sensitivity of this to variations in own force and threat composition and disposition, and
c. Advice (perhaps in this case) that relatively little, if any, increase in information value can be gained by application of the model, beyond the information already available to the decision maker.

My point here is that the decision maker has sufficient information to make a decision if it can be demonstrated that the proposed system performs as promised. -- Application of a complex model to estimate the cost-effectiveness of the alternative vis-à-vis the current system provides very little if any information value to the decision.

I suggest that in a situation such as this, better use can be made of the analysts time and other program resources. For example a well structured test program, integrated with some consolidative modeling to assess the likelihood the system will perform as proposed would be valued information to the decision maker and future users of the system.

This is a good place to point out why this fourth mentioned failure mode is often the cause of the other three.

If we do not have a well thought out concept of the information or insight we are attempting to add to the decision process when we undertake to model, then we cannot make intelligent decisions regarding creditability of the model (accreditation) or validity for that matter. Nearly everyone acknowledges that validation and accreditation are relevant to our purposes. Secondly, time spent modeling cannot be spent analyzing the information already available to the decision maker and supporting analysis team.

Information that cannot be provided by the model in any event is ignored in the analysis process, due in part to shortage of time, the model provides no useful information, a less than maximum value decision is made and the model (and modeler) are blamed.

To reiterate, Bankes attributes modeling failures to three factors:

1. Attempting to predict outcomes which cannot be predicted;
2. Inability to perform verification, validation, and accreditation of models for the specific uses to which they are applied;
3. Development *{application}* of models to support a preconceived conclusion.

I really don't think the first one needs much elaboration. In any model of combat between two forces of any reasonable size, particularly as a component of a larger force engagement, if the general outcome is not obvious without modeling, then a model is not likely to be a reliable predictor of the outcome. There are too many factors, including the ubiquitously encountered 'fog of war', leadership, dedication to a cause, in addition to the unpredictable performance and reliability of materiel in a dirty combat environment.

Even the representation of weapon systems, whose performance in many instances can be modeled by closed mathematical models of the engineering and physical principles involved, cannot be completely counted on since there are weapon to weapon variations, unknown interactions with adjacent friendly and opposing systems, and in many instances, unknown and hence unverifiable interactions with the environment.

My discussion has slipped over from 'attempting to predict things which cannot be predicted' to 'inability to verify, or more in our terminology, inability to validate the ability of the model to predict specific outcomes of interest.'

On the latter point, Oreskes, Shrader-Frechette, and Belitz[1] contend that "verification and validation of numerical models of natural systems is impossible." They globally challenge the veracity of claims to have verified numerical models based on the fact that verification, by definition, is constrained to closed systems and "only purely formal logic structures, such as proofs in symbolic logic and mathematics, can be shown to be closed systems."

If that is in fact true in application to a natural system, whose response to various input stimuli can be observed and measured, then it certainly must be a true statement applied to models of systems which include humans and whose responses to input stimuli most often cannot be measured with any reasonable degree of completeness.

They go on to state that "Models can only be evaluated in relative terms, and their predictive value is always open to question." "The primary value of models is heuristic", they state.

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1 "Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences", Science, Volume 263, 4 February 1994.

Advocacy

Advocacy is a common use of models. Bankes cites this as one of the reasons modeling efforts often fail. This view is somewhat surprisingly not universally held. There was a heated debate partially played out in publications of the Operations Research Society of America in the early 1970's concerning the role of operations research as a tool of advocacy. The debate grew out of analyses done to support both sides of the Ballistic Missile Defense Treaty debate. In one article, Ian I. Mitroff[1] of the University of Pittsburgh argues that advocacy is an unavoidable role for science in general, as well as specifically, operations research. He goes on to argue that advocacy is an appropriate role, and, in many cases an essential element of scientific inquiry.

Nevertheless, in order for advocacy to effectively contribute to decision making, it must be balanced by counter-advocacy. In addition scientific integrity and commitment to providing sound and defensible information to the decision maker is essential. Otherwise, a right decision may be undermined by bad or biased analysis.

If our attention is focused on the point we wish to support, or the decision alternative we want to come out on top, then our efforts at model (and process) validation and accreditation are apt to suffer. We become less skeptical of model solutions if they support our hoped for answer. This has not only an integrity implication but also, undermines our ability to advise the manager concerning alternative trade-off, thereby depriving him or her information which might lead to a change of mind regarding the preferred solution.

I have been using some standard terms which, in fact hold differing connotations to many of us and in the different contexts in which we use them. Since the specific meaning is helpful to the points remaining in this paper and to preclude, as much as possible, misunderstandings regarding my comments in this paper, it is wise to define some terms. These include model, simulation, heuristic, verification, validation, and accreditation. Obviously the definitions given here are limited to the context of this paper and are relevant to their use herein.

Model -- In his paper reflecting on the origins of management science, Salveson[2] makes the following statement: "Mathematics and statistics contain the principles and methods of representing complex relationships and resolving their interaction so as to optimize some function or aspect of those relationships." For purposes of this paper, that statement will serve as a definition of "*model*". A consistent and more general definition is provided by Geoffrion[3]. He answers the rhetorical question, "what is modeling?" by

1 "The Myth of Objectivity Or Why Science Needs A New Psychology of Science", Bulletin of the Operations Research Society of America, page B-613, 1971.
2 "The Institute of Management Sciences: A Prehistory and Commentary on the Occasion of TIMS' 40th Anniversary", Interfaces, Vol. 27, No. 3, May-June 1997.
3 "The Formal Aspects of Structured Modeling", Operations Research, Vol. 37, No. 1, January-February 1989.

responding, "A very general answer is that it is the process of giving sharp definition to "knowledge" about some part of reality."

Simulation as employed here refers to the process of using a model of the actual system to mimic, in some sense, the actual system. That is we execute a model with specific input values in order to simulate the operation of a system under the conditions represented by the model with the specified parameter values. Often the word 'simulation' is used as a noun interchangeably with 'model' and 'model' is used as a verb interchangeably with 'simulate'. Not here though!

The more encompassing term '***modeling***' refers to the total process of defining the system of interest, building a model of the relevant part of the system, collecting data, 'running' the model, analyzing the answers, and providing information to the system decision maker. The value of a model must be considered in this larger context than simply the 'model'.

Someone has said, the key resources of modeling are data, models, and solvers. The product of the modeling effort is information (of) value to the decision maker, not a surrogate decision maker.

"The primary value of models is heuristic".

Webster defines *heuristic* as follows:

Heuristic--a method or procedure which involves or serves as an aid to learning, discovery, or problem solving by experimental and especially trial-and-error methods.

Thus, using a model heuristically means that I am not using the model to produce a value for some quantitative characteristic of the system, but rather to get an idea of the general magnitude of its value, particularly for comparison of the magnitude of its value under a variety of conditions.

For example, a model of the time, precedence relationships, and resource requirements for the activities comprising a project may have implied precedence and resource competition that is not obvious to casual examination. I may then be able to use the model to experiment with various levels of resource provision or staff-activity assignments looking for ways to reduce the total project time. The level of detail of the model or the precision with which I can predict actual task times may render the absolute value of the project time estimate useless but yet the model may be useful in identifying actions which will --<u>tend</u> to reduce the overall time or enable the more efficient use of human or materiel resources.

In military operations research we probably most frequently use models heuristically. Often heard is the statement, 'we are using the model to get relative comparisons of the performance of the alternative systems'.

The use of a model in an heuristic sense has implications for the verification, validation and accreditation process and requirements. I'll come back to this topic later.

Verification, validation, and accreditation. Oreskes et al adopt narrow definitions of these terms which I think are somewhat at odds with our common use of the terms. They base their discussion of *verification* on the definition of *verify*, meaning true. *Verify means an assertion or establishment of truth.* Webster's dictionary defines it as "to establish the truth, accuracy or reality of." As a general rule, we use the term to mean that the computational rendering of the model is as was intended by the model builder. In the sense that we mean that the model is true to the model builder's intent, these two definitions converge.

The U.S. Department of Defense Instruction (which provides policy guidance on, among other issues, the development, management and use of models), defines verification as "the process of determining that a model implementation accurately represents the developers conceptual description and specifications."

Oreskes et al continue their discussion of verification by discussing means often used to 'verify' that numerical solutions of models coincide with the analytical solution at the boundary or at specified initial conditions. They express two cautions in this regard, 1 – "the congruence between a numerical and an analytical solution entails nothing about the correspondence of either one to material reality," and, "Furthermore, even if a numerical solution can be said to be verified in the realm of the analytical solution, in the extension of the numerical solution beyond the range and realm of the analytical solution (for example, time, space, and parameter distribution), the numerical code would no longer be verified." And yet, this is the very reason we build and apply 'numerical' models! That is to predict outcomes for conditions beyond the range of applicability of the analytical tools or outside the realm of conditions for which we have available observations of the actual system and possibly outside the realm of conditions for which we can observe the actual system. That fact of life may be due to safety, cost, or inability of our observation systems to capture the conditions or outcome for some large portion of the range of conditions of interest.

We often use a strategy called 'test-model-test' to 'validate' {Oreskes et al say verify} our model and to 'calibrate it'. Here again we are validating one model against another and using the 'test model' to calibrate the mathematical model. Since the test model has some entities which are actual system components, including human interface with these components in some cases, it is often useful to do such calibration. Nevertheless, we must keep in mind that we have not validated the model against reality, but against a simulation of reality.

General use of the term *validation* in the modeling community refers to the process of demonstrating that the model is an accurate representation of the system. Clearly this must be answered in the context of the intended use of the model and not as an absolute statement. This has enormous ramifications for '*federations of models*', and current

initiatives to develop a system to facilitate the distributed use of models or object components of models by third parties. Sikora and Williams[1] acknowledge the pitfall, "As we all know, a model may be perfectly valid for one application and at the same time perfectly invalid for a different application." That is, it is inappropriate to access a model or model object from another source without first conducting validation studies to determine whether the verity of the model holds, not only for the application considered but also in connection with the scale and system details represented in other components of the overall model and the interface logic among them. Model federations can be powerful tools, for good or bad analysis. Sikora and Williams provide some suggestions for ensuring that the proper care in VV&A precede the application of models and particularly federations of models.

Oreskes, et al contend that no model, *in and of itself*, can be valid unless it is a model of a closed system and "only purely formal logical structures, such as proofs in symbolic logic and mathematics, can be shown to represent closed systems."

We also use the term *accreditation*, a word defined by Webster as to mean "to give official authorization to or approval of, ..." In the modeling community we use the term in this sense to convey the fact that the model user has certified that the model is *valid* for the stated purpose of the user.

Thus, we use the two terms, valid and accredited to convey that the model has been determined to be an accurate representation of the system and that the "system" it is an accurate representation of, is acceptable for purposes of the study under question.

In the realm of military operations research, we often combine a calibration process with validation, perhaps in a sequential manner. That is we tune the model with a set of observations (test data or historical data) and then test the accuracy of outcomes compared to another set of observed outcomes of the system. However, the fact that we achieved a good fit with the actual or test data we have, does not, in itself, imply that the calibrated model is a good fit beyond the range of conditions contained in our calibration/validation sample.

If not careful, we can use the terms to cloak many model weaknesses with respect to any use. While the model may contain some representation of many system components and component interrelationships, usually the 'validation' focuses on those which are most relevant to the use envisioned by the model developer. A "validated" model may then be accepted by another user as accurate with respect to all system elements and interrelations contained in the model. If all elements needed for this new study are found to be represented in the model, then that user may be inclined to accredit it without sufficient examination of the validity of those representations.

1 "Verification, Validation and Accreditation - What is it Today?", PHALANX, The Bulletin of Military Operations Research, Vol. 30, No. 2, June 1997.

{Discuss an example}

{That's our dilemma, What, then, shall we do about it?}

Models and the application of those models to simulate system performance are tools available to the operations research analyst to support decision making. We often get off-track, and behave as if the models were ends in themselves. In fact, currently a great deal of time and money is being spent on modeling with only casual consideration of the use to which the models will be put – only superficial consideration to the types of decisions to be supported and the system/model context relevant to those decisions. Technology pull is a term that comes to mind. Seemingly limitless advances in computation power (speed of computation and memory capacity); standardization of processing code (numerical methods, statistical packages, and graphics); and distributed access to the code and processing power of other institutions) tempt us to build bigger, more complex and more comprehensive models which now include "representations" of systems components previously unaffordable or practically infeasible.

Some of us remember the frustration of past lives when we "knew" our models were crude representations of the system under study but were unable to do anything about it. Just not enough computational power to include command and control or logistics systems performance or adjacent or other service shooters in our model. Now we can so we do. Somehow we forget that another reason we did not include logistics was we did not know how to represent its influence on the battle because the system "entities" we had represented did not directly interface with the logistics system. ---- Now we can 'wrap' the logistics model, and, by transmutation, numerically or logically connect it to the higher level system model.

There are several inherent risks in this approach to development of ever more complex models, an example being scale incompatibility. While we can easily find ways to patch over this problem by computational schemes, these may impose implicit faulty model entity definitions. --- This is not to say that such devices render the model invalid for specific purposes, only that extreme care is required to ensure that it does not invalidate the model for the particular purposes at hand. There is also the danger that the general customer population perceives that this, now more capable model contains a 'valid definition' of the relevant logistical entities and other entities dependent on this definition.

Risk management in this activity includes the following principles:

a. Keep our focus on the decision we, the analysts are supporting;
b. Get to know the system in a broad context and in the specifics related to decision at hand;
c. {A decision is usually necessary because someone is dissatisfied with the

current operating process or the results thereof}, therefore, we should get to know how the system operates; in what manner we wish to alter that, {it consumes too much of some scarce resource, it takes too long, it is becoming technologically obsolete, ... whatever.); and how the decision maker thinks the alternatives will improve the system.

While Nickerson and Boyd provide a formal mathematical structure for estimating the value of information provided by a model in a specific decision context, even this step may not be warranted at times. Sometimes casual observation allows one to decide whether the model I can build and apply or select and apply is likely to yield information leading to a better valued decision than can be selected based on the information already available to the decision maker. Other times I can determine that the model complexity required to provide information value is not feasible, practical or affordable (time or money). – Or, sometimes the model required to provide information value is not verifiable or subject to validation. In all of these situations, the term model refers not only to mathematical relationships or logical relationships, but also to the data required to complete the model.

In summary, the question, should I apply a model to support the decision at hand is, itself a cost-benefit question. As Nickerson and Boyd assert, "Model results are information to the decision maker, not the optimal decision." Is the value of the information I gain from a model worth the cost of modeling?

Heuristic Uses of Models

The Operations Research Society of America published an article by Hodges[1] in which he discusses, in essence, heuristic uses of models. Hodges suggests six uses of "bad models". He contends that most military combat models are bad in that they are, if nothing else, "conjectural, that is, neither supported nor contradicted by data, either because data do not exist or because they are equivocal."

Three of his suggested uses of bad models are relevant to the theme of this paper, namely, "as a vehicle for *a fortiori* arguments[2]", "as an aid to thinking and hypothesizing", and "as a stimulus to intuition in applied research or in training".

The latter two uses imply that the essence of modeling and simulation is questioning. Questions must precede the design and development of any model or the

1 . Hodges, James S., "Six (or so) Things You Can Do With A Bad Model", Journal of the Operations Research Society of America, Vol. 39, No. 3, May-June 1991

2 *a fortiori arguments*: (a-for-she-'or-e) from the stronger argument; with greater reason or more convincing force – used in drawing a conclusion that is inferred to be even more certain than another.

selection of an available model. The application of the model to gain information or answers to questions. This is also the view implied by J. A. Stockfisch[1] of the RAND Corporation who states that "However else systems analysis is defined, question raising and finding some rational answers to at least some of them is what the subject is about."

It follows that models are of most use to those who build them. That is so because the greatest value of modeling is the process of analyzing the system to be modeled and rendering the understanding gained, as a set of mathematical and logical relationships which represent the component inputs (stimuli), processes, and outputs.

A model should only be used in connection with observation or within the context of an analysis which considers model answers in context with the experience of the decision maker or the analyst who is nearly as familiar with the system and decision alternatives within the context of the system as is the decision maker.

In most analyses, including model application, done to support materiel acquisition decisions, that can be done in connection with operational testing, for example, field trials, complemented by simulated trials with some combination of virtual and constructive simulation. Often system technical tests, hardware-in-the-loop tests or human participation war games provide a useful balance or 'sanity check' on computer based models.

Most important, we must remember that models are tools of analysis and ultimately of decision making. The first issue of volume 28 of the Journal of The Operations Research Society of America was devoted to a group of papers on decision analysis. The very first sentence of the first paper, written by Professor Ronald Howard[2], is: "Making decisions is what you do when you don't know what to do." That makes sense and it also helps us put the development and application of decision analysis tools in perspective.

We don't know what to do. We often are not sure what all the options are. And, in fact, we are often unsure of our overall objective, or more precisely, what the value trade-off is among competing objectives or goals. It is within this context that we design, develop, and apply decision analysis support tools such as models.

Fidelity versus transparency. This is a straightforward concept which we have all wrestled with from time to time. Several years ago I had occasion to be casually involved in a series of discussions regarding the models and methods being used to calculate war reserve stockpile requirements. The process was a very time consuming process requiring the development of scenarios, time-phased force deployment lists, threat strengths, and the conduct of wargames to obtain consumption rates for tens of munitions types. The resulting requirement estimates differed noticeably from one cycle to another, sometimes as a result of the current favorite weapons system on the horizon or alterations in

1 "The Intellectual foundations of System Analysis, RAND Corporation Paper p-7401, undated.
2 Howard, Ronald A., "An Assessment of Decision Analysis", Journal of the Operations Research Society of America, Vol. 28, No. 1, January-February 1980.

operational concepts for engaging hardened targets for instance. The then current senior officer in the decision chain was an analyst himself and he caught on to the process. He directed that a much simplified process be developed to 1) shorten the time required for the process, enable more 'sensitivity analysis', and make the process more transparent so he could better discern what system characteristics were driving the results. When he was briefed on the emerging results of studies based on these new 'transparent, simplified models he began asking questions. Does your model include the effects of terrain? Does your model account for battle damage repair and return to battle of weapon system 'A'? Do you account for munitions lost in damaged and abandoned weapons? Do you include the mix of munitions lost in damage to ammunition storage points and lost in attacks on logistic trains? Does your results account for environmental constraints on use of certain weapon types? And on and on – You get the picture. The decision maker wants a transparent model which accounts for all the complex sub-systems and interactions of the actual system being modeled.

I believe that as a general rule, more complexity (and apparent) fidelity in a model is driven by a desire to delegate decision making to the model. There is an aura of fidelity and objectivity associated with large complex models which account for as many as possible of the relevant factors in a system associated with the decision under consideration (and in fact, sometimes system components and interrelationships irrelevant to the current decision).

Model transparency, often as represented by a model of 'first principles', provides realistic transparency, not only into the system as it is represented in the model and not represented, but also into the 'subjectivity' of the modeling process supporting the decision analysis.

Berger and Berry[1] discuss the "illusion of objectivity" associated with 'standard' statistical analysis of experimental data. Their main point is "that reaching sensible conclusions from statistical analysis of these data may require subjective input." And hence the conclusions are themselves subjective.

They go on to argue that "this conclusion is in no way harmful or demeaning to statistical analysis. Far from it; to acknowledge the subjectivity inherent in the interpretation of data is to recognize the central role of statistical analysis as a formal mechanism by which new evidence can be integrated with existing knowledge. Such a view of statistics as a dynamic discipline is far from the common perception of a rather dry, automatic technology for processing data."

I believe that this argument applies to the use of models in general, not just to statistical models. This view is consistent with other views I have shared with you today, namely those of Hodges; Oreskes, Shrader-Frechette, and Belitz; and Nickerson and Boyd.

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1 "Statistical Analysis and the Illusion of Objectivity", American Scientist, Vol. 76, March-April 1988.

Some observations –

Generally speaking, models which are built and applied to answer specific questions or to support specific decisions are most likely to be successful. Such models should be built and applied if it is determined that they are likely to provide information value to the decision maker commiserate with the cost in time and money to build and apply them. Nickerson and Boyd[1] provide some valuable insight and suggest an approach to doing so.

Models should be used in an exploratory fashion, to gain insight, and where possible to support a fortiori arguments. Seldom if ever should models be used to provide the 'optimum' solution. This, along with focus on the question to be answered, provides the proper basis for model validation and accreditation. Bankes[2], Hodges[3] and Oreskes, Shrader-Frechette, and Belitz[4] all provide cautions, and suggestions regarding sound application of modeling in support of decision making.

Verification, validation and accreditation, and consequent proper application of models is strongly dependent on a well defined and tightly structured model architecture. Such system structure facilitates reuse of the model in other applications by easing the task of adding necessary additional model components, designing and executing interface with other models or new model components, and is absolutely necessary for any hope of reasonable validation of successor models. Current U.S. Department of Defense initiatives in developing a "High Level Architecture" has the intent of fostering a standard 'systems approach' to model development. Arthur M. Geoffrion, based on research he conducted at the University of California, Los Angeles, describes a structured approach to modeling[5] which complements the ideas contained in the High Level Architecture concept. Adherence to structural and standardization concepts such as these will pay dividends for the modeling and simulation analysts as well as the decision makers they serve. This, if for no other reason than that the modeling efforts will provide usable, understandable, and reliable information value to decisions and it will happen in a useable time frame.

1 "The Use and Value of Models in Decision Analysis", Operations Research, Vol. 28, No. 1, January-February 1980.
2 "Exploratory Modeling For Policy Analysis" Operations Research, Vol. 41, No.3, May-June 1993.
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