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THE NEED FOR A MILITARY SYSTEM EFFECTIVENESS FRAMEWORK: THE SYSTEM OF SYSTEMS APPROACH

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Abstract

The need for a comprehensive framework for the analysis of military system effectiveness is presented. Changes in the world's economy and its effect on decision making is discussed, as well as the three primary ways decision makers use information: resource allocation, requirements definition, and trade studies between system components. "System" and "system effectiveness" are clearly defined. The idea of a system of systems formulation for military system effectiveness analysis is presented, discussing the need to expand the consideration of the system from the vehicle (engineering) level to the theater or campaign level. The use of probability theory as part of the methodology is defended. Finally, an intuitive overview of the proposed methodology is presented, in a step by step manner. The methodology is called POSSEM (PrObabilistic System of Systems Effectiveness Methodology).

Introduction

Assessing the success and effectiveness of today's complex systems becomes an increasingly challenging problem. Demands for increased performance, lower system life cycle costs, longer operating capacities and improved productivity and efficiency must be balanced against limited resources, scant and sometimes unknown data, the identification and resolution of conflicts and problems, and resource allocation[1]. Consideration of these tradeoffs dictates the need for an integrated and systematic methodology that can identify potential problem areas and assess system effectiveness during all phases of the system's life cycle. This analytical framework must also support decision-making between alternatives and options while assessing the consequences of such decisions.

In the current world military environment, system effectiveness takes on a new meaning. In the past, military aircraft design has been characterized by an emphasis to design for optimum performance. Aircraft success was defined in terms of the aircraft's ability to perform at least as well as the requirements to which it was designed, effectively ignoring adaptability to rapidly changing threat environments. Performance was characterized by such attributes as speed, payload capacity, etc. Recent imperatives, however, have shifted the emphasis from performance to overall system effectiveness as a key measure of merit for the aircraft. Today, system effectiveness must not focus only on the aircraft's performance, but instead on its ability to satisfactorily complete its mission, against a wide variety of threats and situations, at an affordable life cycle cost.

Need for a Military System Effectiveness Framework

The Changing Economy and its Effect on Decisions Making

In recent years, the world has been changing at a remarkable pace. A revolutionary new economy has risen. This economy is based on knowledge rather than conventional raw materials and physical labor[2]. With this new economy comes new emphasis on technology and its impact, especially in the warfighting environment. Almost all of the world's countries spend a significant amount of their budget on the research, development and procurement of increasingly sophisticated weapons and warfare technologies[3]. This is necessary because countries need to maintain or enhance their military capabilities in order to maintain their supremacy over their adversaries. In

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addition, strong and capable military capabilities serve as a deterrent to other countries who might otherwise turn aggressive. However, the high cost of maintaining these capabilities must be balanced against limited resources. Former U.S. Secretary of State Dick Cheney is credited with the statement “budget drives strategy, strategy doesn’t drive budget”[2]. Military decision makers need to understand and assess the benefits and consequences of their decisions in order to make cost efficient, timely, and successful choices.

Along with changes in the world’s economy come changes in the way war is fought. Substantial progress has been made in both weapon lethality and military technology. In addition, the battlefield of today has become increasingly complex, with interactions and their consequences becoming more and more difficult to isolate and understand. Because of the rapid advance of these developments, the decision makers are often left with ambiguous information and relatively short time spans to conduct analysis. Often, these changes occur so rapidly that previous analysis is rendered obsolete. For example, an aircraft that is designed to incorporate a certain avionics suite will often find that those avionics are obsolete by the time the aircraft comes into production. The inherent uncertainty in this information makes definitive analysis difficult and implies that the use of probabilistic methods to understand and interpret this information is most appropriate.

Overall, military decision makers need to be able to rapidly and efficiently answer questions such as those raised by Jaiswal[3]:

> *What is the effectiveness of a weapon system or tactical plan in a plausible combat scenario?*
>
> *If the various factors influencing the performance of a system can be expressed qualitatively, can the performance be quantified?*
>
> *What force mix should be deployed for a specified mission?*
>
> *How many types of weapons should be deployed on various sites to provide cost-effective defense?*
>
> *How should weapons be assigned to targets to achieve a specified objective?*
>
> *Who is likely to win?*

These questions all point to the need for a military analysis capability that takes places at the theater level. Decision makers must be able to take rapidly changing information and technologies and combine them with projected situations in order to make decisions and understand their consequences.

The Link to System Effectiveness

What these decision makers are looking for is a quantification of system effectiveness. In this case, the system of interest is the warfighting theater or campaign. The primary tool of today’s military decision makers is the campaign analysis environment. These environments are modeling tools in the form of computer codes that model force-on-force engagements. They are often quite complex and vary in their abilities to capture different aspects of the warfighting environment. It is common for campaign analysis tools to have a detailed primary force models with only rudimentary modeling of secondary forces. For example, an Army code may have complex and sophisticated models for ground troops and support vehicles, but have a relatively simplistic air campaign model, or even no air campaign model at all. True joint force models (models that capture all aspects of the warfighting environment with an equal level of analysis) are relatively few.

Measures of Effectiveness

The output of these tools are system effectiveness quantifiers, or Measures of Effectiveness (MOEs). A measure of effectiveness (MOE) is a metric used to indicate the quality of a system[1]. It may be a measurable quantity or calculated from other output parameters, or it can also take the form of a weighted combination of several other metrics. These metrics often consist of final calculations of damage done or resources used. The following are some typical examples of campaign level MOEs:

> *Number of Red aircraft shot down by Blue aircraft*
>
> *Number of damaged runways*
>
> *Distance in kilometers to halt Red advance*
>
> *Number of returning aircraft from a specific mission*

Each theater or campaign tool provides either its own set of hardwired MOEs or enough output data for the user to create his own system effectiveness metrics (or both). It is through the shrewd choice of these metrics that the decision maker links the MOEs to the answers to questions such as those posed above.

Use of System Effectiveness Metrics

There are three primary ways that decision makers utilize system effectiveness information: resource allocation, requirements definition, and system component trade studies.

Resource Allocation -Most countries, when considering their military wants and needs, must deal with limited and often strict budgets. Different government agencies, often with competing agendas, must all vie for a finite set of resources. In addition, these agencies will often make decisions in isolation, negating the chance for potentially mutually beneficial, and cost effective, decisions. Deciding how to allocate precious funds and resources, therefore, becomes a key issue. System effectiveness concepts, when applied to the theater level, give the decision makers a way to link dollars to campaign level metrics. Comparisons may be made between dissimilar components of the system. For example, there may be a need to assess whether additional resources should be supplied to a missile program or an aircraft program. Straight one-on-one comparison of these two types of vehicles may be difficult because of their inherently different capabilities and performance. But when placed in the context of the overall system (the warfighting environment), their individual (or even combined!) effect on the overall system effectiveness metrics can be assessed and appropriate decisions made.

Requirements Definition -Another way system effectiveness metrics aid the decision maker is in the development of requirements for system components. Given the performance and capabilities of a system component, a campaign analysis tool can use that information to assess the effect of that component. But this assessment capability may be turned around. By varying the capabilities and performance characteristics of a notional system component, the optimal settings of these characteristics can be obtained that maximize system effectiveness. An aircraft may be used as an example. The question to be considered may be: what is the optimal aircraft strike speed needed to obtain a specific campaign objective? A notional aircraft is modeled and the strike speed allowed to vary in the campaign analysis until the selected MOEs reach their optimal value(s). Now the ideal strike speed is known for that class of vehicle. This information can be used to define a design goal for future aircraft, or it may be used to assess the potential of modifying existing aircraft to achieve the new strike speed. In this way, complete requirements for new system components and new technologies may be developed. Finally, sensitivities of the values of specific requirements may be assessed. This can be tremendously useful information: can a difficult requirement be relaxed, allowing cost savings or trade-offs between other characteristics, at a insignificant or acceptable reduction of overall system effectiveness?

Trade Studies Between System Components -Finally, system effectiveness metrics can be used to assess the differing values and effects of system and sub-system components. As mentioned earlier, it is often difficult to compare and contrast dissimilar sub-systems. By placing those sub-systems in a larger framework (or system), the changes they affect in the top-level metrics may be observed and quantified. For example, say it was of interest to consider which of two avionics packages would be better to use on an existing aircraft. Analyzing changes in individual aircraft performance with each of the avionics packages could be difficult or indistinguishable. But if the aircraft, with the avionics packages, were placed as system components in the theater, the effect of the avionics packages could be assessed. In this case the avionics packages were allowed to fulfill their intended function within the larger system, and thus their effects more easily quantified.

Lack of Overall System Effectiveness Methodology

Given the power of a system effectiveness consideration of the modern warfighting environment, coupled with its usefulness in decision making, it is surprising to find a lack of cohesive and accepted methodologies used to address campaign level system effectiveness in the open literature. To be true, there are a multitude of campaign level modeling tools, and the creation, use, and improvement of these tools is a flourishing endeavor[4]. In addition, many decision makers and analysts use these tools in their own individual way. But finding information specifically detailing overall *methodologies* is difficult. There are several possible reasons for this lack of obvious resources. These reasons are detailed below.

Semantics and Surplus of Synonyms

In order to formulate a systems effectiveness framework, it is important to understand and clearly define the concepts of both "system" and "system effectiveness". There is general agreement across fields and disciplines as to what constitutes a system. The following definition is representative of this agreement, and is an acceptable definition for the developing framework:

> *A **system** may be considered as constituting a nucleus of elements combined in such a manner as to accomplish a function in response to an identified need…A system must have a **functional** purpose, may include a mix of products and processes, and may be contained within some form of hierarchy…*[5]

However, the definitions of system effectiveness vary widely and are often application dependent. Some examples that illustrate the diversity of these definitions include:

> *"The overall capability of a system to accomplish its intended mission"*[9]

> *"The probability that the system can successfully meet an operational demand within a given time when operated under specified conditions"*[6]

> *"A measure of the degree to which an item can be expected to achieve a set of specific mission requirements, and which may be expressed as a function of availability, dependability and capability"* [7]

The authors of an annotated bibliography on system effectiveness models in 1980 concluded "A wide range of definitions, and measures of system effectiveness are used without strong guiding logic"[9].

The words "system effectiveness" and the concept they represent first reared its head in the 1950s and 1960s[8],[9]. However, these early formulations of system effectiveness were defined primarily as functions of the "-ilities": reliability, availability, repairability, and maintainability. As such, the system effectiveness concept was applied to a single component or tool that itself was defined as the system. For example, a missile would be defined as the system, and its system effectiveness assessed based on its availability, reliability, etc. While this was a revolutionary concept at the time, these definitions are not as useful if the theater itself is considered the system. Each component of the system may be assessed by its "-ilities" but these "-ilities" are inadequate to serve solely as the theater level measures of effectiveness. These pioneering definitions are somewhat still in use today[8,1], making research specifically on campaign analysis system effectiveness difficult to isolate.

Finally, "system effectiveness" holds different meanings for different communities and applications. Some organizations tailor their definitions and methods to apply to very specific problems[9]. A representative of the Potomac Institute for Policy Studies offers that the difficulty in finding information on system effectiveness lies in the broad connotations of the term:

> *"System Effectiveness has many different "branches", primarily based upon the application area, e.g., military system effectiveness, policy analysis, information system effectiveness, reliability analysis, etc. Within each application area there are multiple areas for consideration, e.g., in policy analysis there is the study of health care reform and its affect on society; the effect of transportation policies on a metropolitan area, etc."*[10]

In addition, "system effectiveness" is often synonymous with other concepts, such as "operations research" and "systems analysis". However, even these other concepts umbrella a huge array of specific analysis approaches and definitions, and locating the unique niche of military system effectiveness is difficult. For example, Reference 3 is a very recent (1997) state-of-the-art book on Military Operations Research. This book uses the words "system effectiveness" only once in a brief, passing note. Similarly, Kececioglu[8] in his 1995 book devotes only one small section to system effectiveness and defines it again in terms of mission reliability, operational readiness, and design adequacy, which is again difficult to apply to the theater.

A new, consistent definition for system effectiveness, therefore, is necessary and must be justified by identifying key elements crucial to a useful and informative definition. First, the term "effectiveness" implies that some sort of quantification needs to occur. This quantification must necessarily be the result of some sort of systematic analysis of variables and metrics that represent the system performing its function. In addition, in order to perform the quantification, an intended or expected effect needs to be identified in order to properly model the results of the system performance. Combined, these concepts result in the following definition put forth by the author for use in formulating the framework for the probabilistic assessment of system effectiveness:

> *System effectiveness is a quantification, represented by system level metrics, of the intended or expected effect of a system achieved through functional analysis.*

Another confusion arises when there is a lack of distinction between the modeling tools and the methodologies that use the tools. Research that asks the question "What is the current state of the art in system effectiveness methodologies?" often turn up only the codes that can be used in such methods. A true methodology should be a freestanding framework that is relatively independent of the tools it utilizes. As the tools improve in fidelity, they should be able to be substituted into the methodology with little or no interruption. Because the answer to this question usually results in a listing of modeling codes rather than methods or frameworks, an inherent lack of such methodologies is indicated.

Difficulty Accessing Government and Classified Material

Originally, system effectiveness studies were confined to military and space systems. Agencies of the US Government, such as the Department of Defense and NASA, were the ultimate customers. Because of this, the available literature on system effectiveness and the accompanying models were published primarily as technical reports, but rarely appear in widely published journals[9]. Today's analysts appear to have new interest in system effectiveness studies using campaign modeling, especially in the area of technology infusions. However, much of this work is classified or proprietary, limiting accessible publications and information. Finally, those non-government agencies that do make advances in theater modeling and system effectiveness may find it necessary to keep their in-house methods proprietary in order to retain their competitive edge.

System of Systems Approach

In order to successfully formulate a system effectiveness methodology, it is imperative to clearly define the system and its components. The preceding sections discussed the benefits to the decision maker of considering system effectiveness at the theater or campaign level. This endpoint represents an expanding progression of what is considered the system. The resulting "system of systems" formulation is a key concept in the development of the proposed methodology.

A Shifting Paradigm

In traditional design, most design decisions are made relatively early in the process, when the designer (or design team) has the least available knowledge about the proposed new system. Design decisions lock in financial commitments, so the bulk of the cost is committed early in the design process. As these decisions are made, design freedom falls off rapidly (Figure 1). A paradigm shift, founded on the notion of Integrated Product and Process Design (IPPD), is now widely accepted. IPPD seeks to bring more knowledge about the system life cycle to an earlier stage of the design process, in an attempt to delay cost commitments and also keep design freedom open[11]. In other words, the designer needs to understand and quantify the implications of her/his decisions earlier in the design process in order to effectively reduce cost.

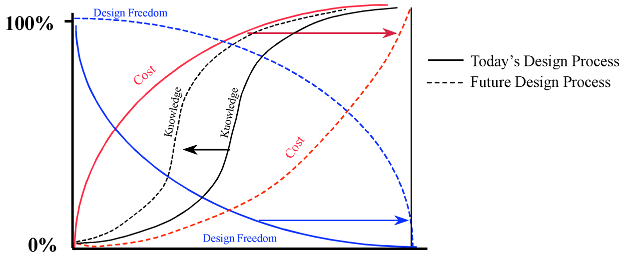

Figure 1 – Paradigm Shift: Bringing Knowledge Forward in Design Process

In addition, there is a parallel paradigm shift that considers what the measure of "goodness" is for a system. Traditionally, differing designs would be compared based on their performance. For example, the questions that would mark the "goodness" of an aircraft would be of the sort:

How fast does it fly?
How far can it fly?
How much payload can it support?

All comparisons between competing designs would be based on performance. The new paradigm shifts this emphasis not to individual system performance but to system effectiveness (Figure 2). For an aircraft, this effectiveness would be illustrated by the answers to such questions as:

What is the exchange ratio?
What is the damage per sortie?
What is the maintenance hours per flight hours cost?

Together, these two paradigm shifts represent a broadening view of the design process, expanding the ideas and concepts from detailed particulars to a "big picture" representation. This momentum will be carried forward, further expanding these basic concepts, to result in a system of systems depiction.

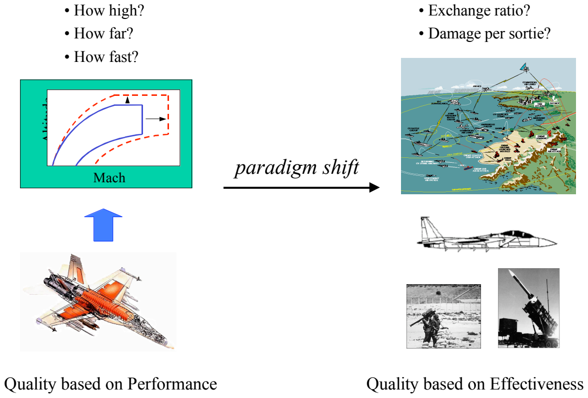

Figure 2 - Paradigm Shift: Performance Based Quality to Effectiveness

The Theater as the System

Using the traditional definitions, one can categorize an aerospace concept, such as an aircraft, as the system. Design and analysis conducted on the aircraft will result in system level Measures of Effectiveness (MoEs). System effectiveness, therefore, becomes a function only of that aircraft's design variables and parameters. The relationship between the aircraft's input design parameters and its outputs (called responses, or MoEs) is illustrated in Figure 3.

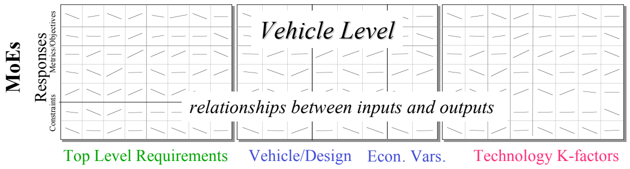

Figure 3 - The Aircraft as the System

While this method of analysis can result in the design of a vehicle that is optimized to its own mission and performance requirements, the vehicle remains independent of its role for which it was created. In other words, the aircraft is never placed in its correct context and evaluated as a system fulfilling its intended function. In order to place the aircraft in its correct context, the system must be expanded and redefined. No longer is the aircraft the sole system; rather let the aircraft's intended environment become the system. For a military aircraft, this new, larger system is the warfighting environment: the theater. Thus, the theater (system) becomes a function of its components (systems in their own right, yet sub-systems here) and the overall formulation becomes a "system of systems".

There is, however, a missing level in this formulation. The outputs of the vehicle level (performance parameters) do not usually map directly as inputs to theater level modeling codes. Rather, the inputs at the theater level usually consist of probability of kill values, or effectiveness values that are the result of component vs. component encounters. There must be an intermediary mapping that takes the output of the vehicle level as its inputs, and in turn generates outputs that serve as inputs to the theater level. This concept is illustrated in Figure 4. With this formulation comes a necessary redefinition of output parameters, solely for clarity. The output responses of all sublevel analysis will be called Measures of Performance (MoPs) and the output of the top level system (in this case, the theater) will be called Measures of Effectiveness (MoEs). Thus, referring to Figure 4, theater level MoEs are functions of vectors of subsystem MoPs (at the engagement level) which are in turn functions of the requirements, design and economic variables, and technology factors associated with the vehicle level inputs.

When the methodology is complete, there will exist a continuous mapping between vehicle level design parameters and theater level Measures of Effectiveness. Changes at the vehicle level can thus be propagated all the way to the theater level. Instead of optimizing an aircraft, for example, to its own pre-defined performance and mission constraints, the aircraft can now be optimized to fulfill theater level goals and objectives. In addition, as more system level components are treated as input variables, tradeoffs can be established not only at the individual component level, but across the components. In other words, the methodology will allow tradeoffs between, say, the effectiveness of a surface-launched cruise missile compared to an aircraft carrying a specified weapons load. Tradeoffs could also be made between the number of system components needed: two of aircraft "A" could produce the same effectiveness of five of aircraft "B", but at less cost. Thus, the methodology becomes a key device for design decisions as well as resource allocation.

Finally, the completed methodology can be used to actually determine the mission and design requirements for the vehicles themselves that comprise the system. By using the Measures of Effectiveness at the theater level as a measure of goodness, tradeoffs can be made between vehicle design and mission requirements. These requirements, when optimized to maximize the overall effectiveness of the system, become the requirements to which the vehicles are then designed.

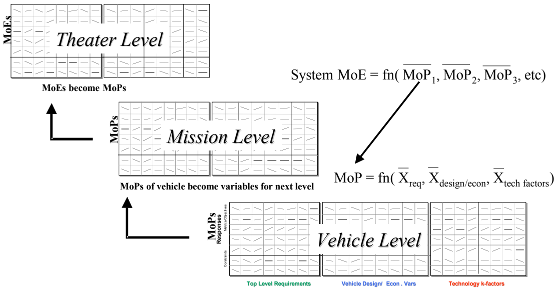

Figure 4 - System of Systems Formulation

A note must be made at this point concerning system decomposition. The first system to be put forth was the aircraft itself. It becomes obvious, in the light of the previous discussion, that the aircraft itself is a system of systems. The aircraft is made up of a variety of major components, which can be seen as sub-systems. In turn, each of these subsystems can be seen to be functions of their components, so they, too, are each a system of systems. Going in the other direction, the engagement level can be seen as a function of not just one aircraft vs. aircraft scenario, but must be comprised of many differing engagements in order to generate a complete set of information for the next system in the hierarchy: the theater. System decomposition, therefore, can be understood to have a pyramid shape, with each level in the decomposition being subdivided into its components, which are in turn subdivided. The question becomes, then, where does one stop? How much subdividing is necessary, and how many levels are needed? The answer to this depends on the definition of the problem that is being studied and the tools that are available. This leads to the idea of the "conceptual model", the development of which is an important step in the proposed methodology. It is up to the skill and experience of the designer or decision maker to accurately and adequately bound the problem and define the system and its components effectively.

Mathematical Modeling

Once the system and its components have been clearly identified, an analysis environment must be created. The key word in the definition of system effectiveness is "quantification". In order for the decision maker or designer to analyze the system effectively, the results of the analysis must be presented as quantifiable metrics. This involves restating a research goal or design decision into a question that can be answered quantitatively. Dixon[12] states this explicitly: "An engineering analyst must begin by defining quantitatively answerable questions". Mathematical methods, thus, become primary tools in system analysis because of their ability to rapidly provide these calculable (quantifiable) metrics.

In addition, mathematical modeling allows the user to understand and make informed decisions at various levels within the system hierarchy. With the "system of systems" concept comes an appreciation of the potential complexities and interactions involved. Mathematical modeling offers significant benefits: "There are many interrelated elements that must be integrated as a system and not treated on an individual basis. The mathematical model makes it possible to deal with the problem as an entity and allows consideration of all major variables of the problems on a simultaneous basis[11]."

Use of Probability Theory

The paradigm shift of Figure 1 makes the argument that bringing knowledge forward in time results in better decision making. However, it must be recognized that this knowledge has an associated uncertainty with it. This lack of certain knowledge could be based on missing, unavailable, or incomplete information, the incorporation of a new technology as a function of its readiness level, or even an uncertainty in the modeling tools used in the analysis. The question becomes how to accommodate this uncertainty into the mathematical modeling and subsequent analysis. The answer to this is to incorporate basic probabilistic elements into both the modeling and the analysis, and, by extrapolation, the overall system effectiveness methodology.

Understanding the sources of the uncertainty helps determine why a probabilistic approach is useful. Referring back to the "system of systems" hierarchy, it is clear that each subsystem level will have its own inputs. Perfect knowledge about these inputs is rare, and it is often that the designer or decision maker must make assumptions based on available data and personal experience. Using probabilistic inputs would allow the user to account for variation in his assumptions. Analysis based on these probabilistic inputs could provide useful information about the sensitivities of the inputs, which in turn could be translated into requirements definitions. By allowing the inputs to vary, the designer or decision maker could play "what if" games, using the models as a computationally and economically inexpensive way to explore the boundaries of the problem. And finally, variable inputs would allow an investigation of the robustness of a solution (i.e. that solution whose performance parameters are invariant or relatively invariant to changes in its environment).

Another major source of uncertainty can be found when considering the incorporation of a new technology. Modeling current technologies is straightforward, with the performance parameters of that technology generally known. However, current technologies may not be capable of meeting customer needs or design goals. In addition, current technology may be obsolete by the time the system is implemented. This necessitates a prediction capability concerning the impact of new technologies. Performance of a new technology is a function of its readiness level, but that function may or may not be completely defined. By modeling a new technology in a probabilistic fashion, one can explore various assumptions pertaining to the performance and the corresponding effects of that technology.

Overall, the presence of uncertainty in most complex systems points to the use of probabilistic elements. Coupled with a mathematical modeling capability, an analysis environment can be created for incorporation into a system of systems effectiveness methodology.

Proposed Methodology: POSSEM

All of the preceding concepts and ideas are now combined into one cohesive methodology. This section will discuss, in a general and intuitive fashion, the proposed methodology. Called the Probabilistic System of Systems Effectiveness Methodology, or POSSEM, the framework outlines a step by step process to assess the effectiveness of a complex military system. The entire framework is shown in Figure 5, and each component of the process will be discussed in detail.

Difference Between Analyst and Analysis Tool

At this point an important distinction needs to be made between the role of the analyst and the role of the analysis tool. The POSSEM framework is an analysis tool. It does not conduct analysis. Rather, it provides a clear, concise path to follow to aid the analyst in their assessments. Too often today modeling tools are confused with the actual analysis process. Just because a tool has been created and validated does not mean that anyone who can operate the tool is automatically going to generate useful, correct, and pertinent analysis. The tool can only be successfully operated by someone who is thoroughly familiar with the problem and has some understanding of both the inputs and the outputs used by the tool. The important, implicit assumption in the POSSEM framework is that it is to be used by an appropriate analyst.

Create the Conceptual Model

The first step in the POSSEM process is the most crucial: the creation of the conceptual model. As defined in Chapter III, the conceptual model is the "plan of attack" used towards solving a particular problem. It is the necessary up front work that the analyst needs to do before even considering running a single computer code. The conceptual model is a careful consideration of the problem at hand, and results in the identification of key elements that are subsequently used in POSSEM. As part of POSSEM, the conceptual model is created by answering three key questions:

What problem are we trying to solve?

What level of detail do we need?

What tools are needed and available?

The first question, *what problem are we trying to solve?,* serves to aid the analyst in identifying the basic goals of the analysis. Answers to this question provide information that aids in identifying what Measures of Effectiveness are needed, what input variables are appropriate, and, to some extent, what modeling tools may be necessary. A clear understanding of what the analysis goals are is crucial to a successful analysis.

The next question, *what level of detail is needed?,* is an often overlooked element. Too many times the analyst will let the capability of the tools drive the analysis, rather than the other way around. The analyst needs to decide, before conducting any code executions, how good is good enough. What level of fidelity on the answer is needed? What basic assumptions can be made that simplify the problem without placing the analysis at risk? Which components need to be modeled in great detail and which can be modeled more coarsely? The answers to this question will determine which types of codes and at what detail level are needed.

The final question, *what tools are needed and available?,* serves to recognize that as much as we would like to stay philosophically pure, analysts do sometimes have limitations on their available resources. A survey of appropriate modeling tools needs to be conducted, and the appropriate tools, at the appropriate level of detail, need to be selected. If an appropriate tool does not exist that meets the pure requirements of the analyst, a less suitable tool may be substituted. But this pre-analysis will allow the analyst to understand the limitations of their tool, and adjust their analysis accordingly.

Once these three questions have been answered, the analyst will then have the resources and information to conduct the initial problem setup. This involves establishing the baseline vehicles and technologies, determining the specific inputs and outputs of the problem, and defining the scenario most suitable for the investigation of the problem. But, as shown in Figure 5, the answers to the questions and the establishment of the problem setup is an iterative process. Tradeoffs must be conducted between the three questions and the resulting three areas of setup. For example, knowing what problem is trying to be solved keys directly into what level of detail is needed to solve that problem. The level of detail needed may or may not be driven by what tools are available. The scenario that is defined must include in its inputs and outputs those entities that are to be studied.

A solid conceptual model creates a solid foundation for subsequent analysis. It allows the analyst to more thoroughly understand the problem at hand, and provides crucial insight and information useful to the remainder of the analysis.

Identify Key Decision Nodes

The next step to POSSEM is to identify the key decision nodes. This step works with the scenario defined during the creation of the conceptual model, and is used to help combat the human in the loop problem. The goal is to retain the flexibility and uncertainty of having a human involved in the decision and assumption making process, yet create an environment in which the computer codes may be run quickly and efficiently. To do this, the analyst conducts a pre-processing of the scenario/campaign. Tree diagrams are constructed and used to identify the key decision nodes. For a very complex scenario, probabilistic screening techniques, such as those discussed in Reference 13, may be employed to help identify which of the decision nodes contribute most to the variability of the response, and which can be set to their most likely value.

Once the decision nodes have been identified, the analyst uses their skill and experience to assign probabilities to each path. This completed environment will then be used as part of the full probabilistic environment.

Create Linked Analysis Environment

The creation of the modeling environment in which to conduct the analysis is the next step. Using information generated in the conceptual model, modeling codes are selected that, together, will create an environment to which the answers to the problems posed in the conceptual model may be answered. During this step, the concepts of both model abstraction and model integration must be applied. Starting first with model integration, models are selected that form a continuous modeling path through the continuum, from the engineering level to the campaign level. Care must be taken to select the appropriate codes at the appropriate level of detail. Software zooming may be necessary to isolate and highlight a particular effect. Once the codes have been selected, the concept of model abstraction is applied. Those codes and areas that may be replaced by metamodels, similar to techniques used in Reference 13, will be chosen in order to increase efficiency and runtime, with an acceptable loss of fidelity.

The final step in the creation of the linked analysis environment is to link the various codes together in a computing environment. This could take the form of scripts that take the outputs of one code and feed it into the other, or the creation of a graphical interface or shell that conducts all the necessary data transfer. This step is not to be considered trivial by any means, and the successful creation of a linked analysis environment is a major achievement in the process.

Create Full Probabilistic Methods

Once the linked analysis environment has been created, it can be used to implement a full probabilistic environment. This involves applying the probabilistic methods described in Reference 13 to the linked analysis environment. To this end, ranges are placed on the selected input variables, and a Design of Experiments is conducted. Metamodels are created for those parts of the linked analysis environment identified in previous steps. Intermediate prediction profiles may be created at each juncture point for analysis purposes. Distributions are also placed around key threat variables, to model a changing threat environment. These distributions are carried throughout the entire analysis. Finally, code runs are conducted around the decision points in the scenario.

The results of the code runs conducted in this step will be a series of linked metamodels. These metamodels are then imported into a spreadsheet environment for final analysis.

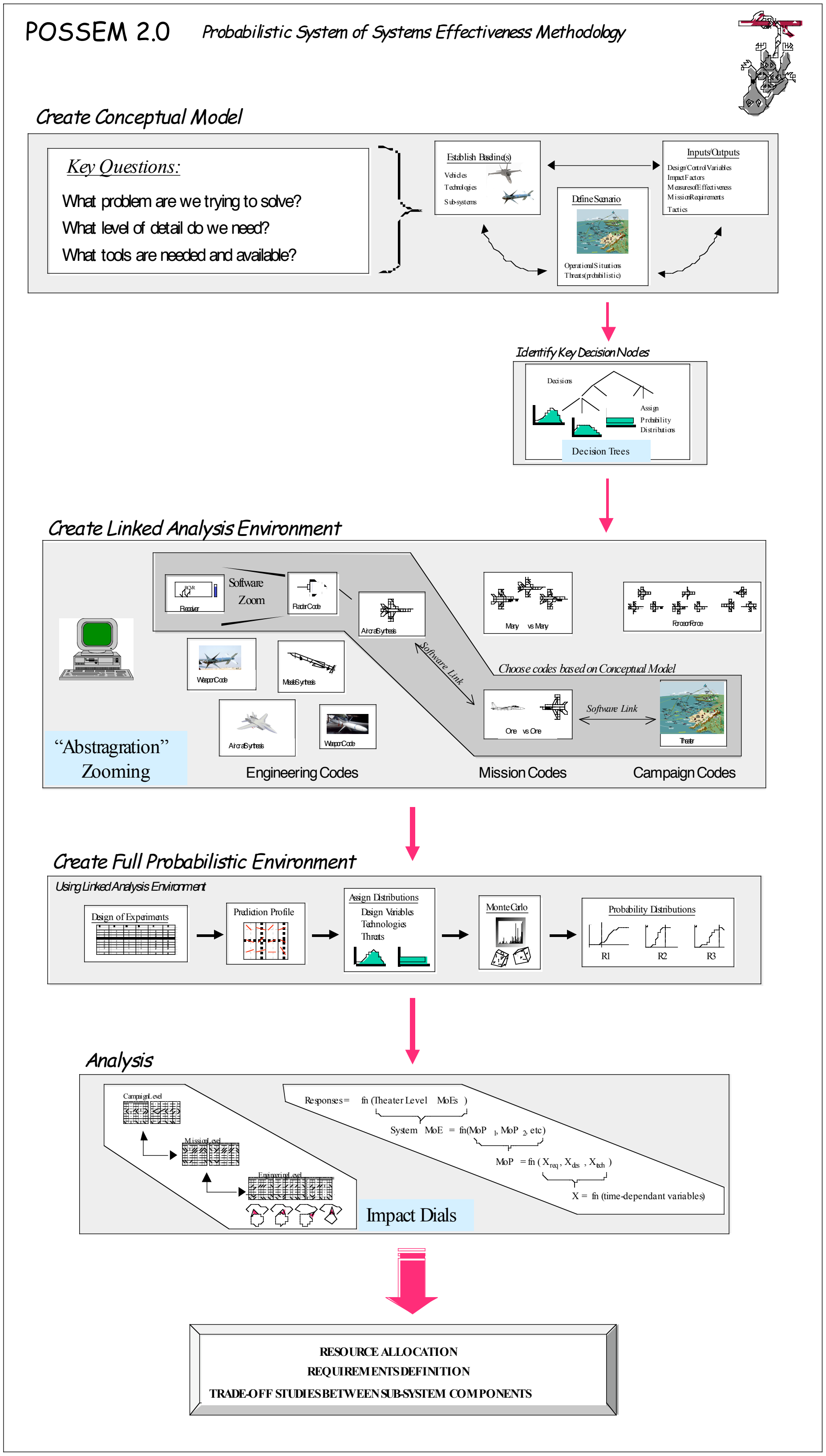

Figure 5 – The POSSEM Flowchart

Analysis

The final step of POSSEM is to use the generated metamodels and data to conduct the analysis. This is done by creating a spreadsheet environment that uses the metamodels to create analysis paths that link the outputs of one level of the continuum to the inputs of the next level. In this way, there is a traceable computational path that links the final Measures of Effectiveness down through the engineering level inputs. At each point along the analysis path, wherever there were probabilistic inputs, the spreadsheet will allow those inputs to be changed (within their ranges of applicability) and the results updated in real time through the use of the metamodels. This is the “Impact Dial” environment, and is a valuable tool for the analyst. With this tool the analyst can explore the impacts of various assumptions rapidly and efficiently. The final goal of the method is for the analyst to use this information to answer the questions posed in the conceptual model, aiding in resource allocation, trade studies between system components, and requirements definitions.

Summary and Future Work

This paper was meant as an overview, discussing the need for a military system effectiveness framework. In addition, a proposed methodology, POSSEM, was presented and discussed. The development of POSSEM has been an ongoing project, and the interested reader is referred to the following papers. The probabilistic methods used in POSSEM, as well as an overview of military modeling, is presented in Reference 14. A theater level test case applying the probabilistic methods to only the theater level was completed in Reference 15. This was done in order to identify any issues that might arise from such a probabilistic application. Finally, Reference 16 illustrates a theater level test case involving adding survivability concepts to aircraft and assessing their impacts on theater level measures of effectiveness. The first iteration of the POSSEM framework is presented. These references are currently available for download at

http://www.asdl.gatech.edu/publications/index.html

The next step in the research is to implement POSSEM completely, using a survivability test case. Survivability concepts will be applied to an aircraft at the engineering level, and the effects of these changes will be propagated through to the theater level. A complete linked analysis environment will be created and used for the study.

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