Establishing System Measures of Effectiveness

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Abstract

One of the most important tasks in the systems development process is that of performance analysis. It is needed to ensure that the system meets its requirements, is delivered on schedule, and developed within allocated costs. It consists of two phases: performance prediction and performance measurement. Proper selection of performance measurement attributes is essential to this process. These measurement attributes commonly called "measures of effectiveness" or "MOEs" provide quantifiable benchmarks against which the system concept and implementation can be compared. Early in the life of a system, prediction is required for feasibility and specification development. Towards the end of systems implementation and development, performance measurement techniques play a major role in system testing and verification. Choosing incorrect MOEs will result in a system that does not meet customer expectations. This paper introduces a comprehensive and systematic process by which viable MOEs that quantify and analyze system performance may be developed. The approach is based on research into Command and Control System evaluation performed at the Naval Postgraduate School during the late 1980's. This paper extends the research to open systems in general and develops several of the original theoretical concepts in more detail.

Introduction

The design of a system is an ill-posed problem that has no solution without a set of criteria to guide choices [Oliver et. al., 1997]. Morse and Kimball first addressed the issue of performance prediction and measurement in the summary of their World War II analytic work published as "Methods of Operations Research" [Morse and Kimball, 1970].[1] They cite an excellent example of how the role of effectiveness measures in systems thinking can be used to shape systems to operate in a particular environment. Antisubmarine warfare systems were a high priority because of the U-boat threat and the attrition of merchant shipping. The question to be answered was what was the difference between an aggressive and defensive use of antisubmarine formations and their component antisubmarine warfare systems? For the former use, the expected number of U-boats killed by an antisubmarine hunter-killer group was the effectiveness measure. For the latter, the effectiveness measure was the probability of preventing convoy formation penetration by the U-boat. Thus, while both formations had ships as basic component systems, hunter-killer groups were centered on an aircraft carrier and antisubmarine destroyers employing a methodical search and destroy process. The convoy was comprised of merchant ships and destroyer escorts using high-speed transit of the submarine areas as a defensive process. Thus, it can be seen from this example that effectiveness measures are critically important because they are the criteria that drive the system solution that is found.

Selection of Performance Measure Attributes

Oliver's approach to bringing definition to the ill-defined problem is to break the systems engineering process into two parts: what he describes as the Systems Engineering Management process and the Systems Engineering Technical process. Within the Systems Engineering core technical process he describes six steps as shown in Figure 1. This process recognizes that an open system interacts with the environment beyond its boundaries. Steps 2, 3, and 4 are crucial in that they bound the system, capture the systems behavior and define the effectiveness measures, the criteria that mean success or failure. His approach is based upon the concept that a system is a unified collection or set of objects that exhibit a unique set of behaviors when combined together in their operating environment. It is very similar to the approach shown in Figure 2. This approach was developed by the Military Operation Research Society's (MORS) work on Measures of Effectiveness for Command and Control. It also focuses on an early bounding of the system followed by selection of performance measures [Sweet, et. al., 1985].

[1] The work was originally known as Operations Evaluation Group Report (OEG) 58.

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Abstract

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The logic behind bounding the system early is driven by the performance measures development process. The system boundaries define the set of system parameters that drive system performance. A change in the boundaries changes the parameter set and the resulting system behavior and its performance. This is often overlooked in the system development process. There is an expectation that there is a magic list of canned effectiveness measures that the Systems Engineers can use like a lookup table in the early stages of development. Failure to understand this point can have a ripple effect throughout the system lifecycle.

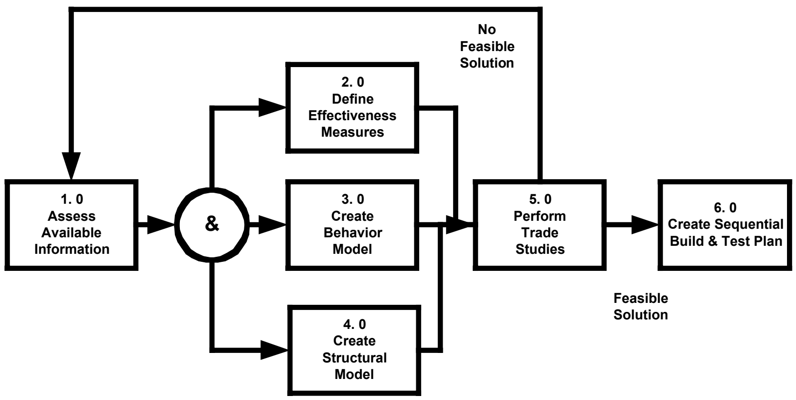

Figure 1. The Steps of the Core Technical Process

<u>**Definition of Effectiveness Measures**</u>

There are a number of terms used to describe system performance. While several of these terms are often used interchangeably to describe the same thing (e.g., Measures of Performance (MOPs) is interchanged with Measures of Effectiveness (MOEs), the MORS's work recognized that there is indeed a hierarchy of effective measures. MORS identified the following key concepts: parameters, Measure(s) of Performance, Measure(s) of Effectiveness, and Measure(s) of Force Effectiveness. While the later term is not appropriate for systems in general the idea is valid and will be addressed below.

This hierarchy follows the system of system concept first presented by Ackoff [Ackoff, 1971]. The following definitions clarify the hierarchy.

<u>**Parameters**</u>**:** the properties or characteristics inherent in the physical entities, whose values determine system behavior and the structure under question, even when not operating. Typical examples include signal-to-noise ratio, bandwidth, frequency, aperture dimensions, and bit error rates.

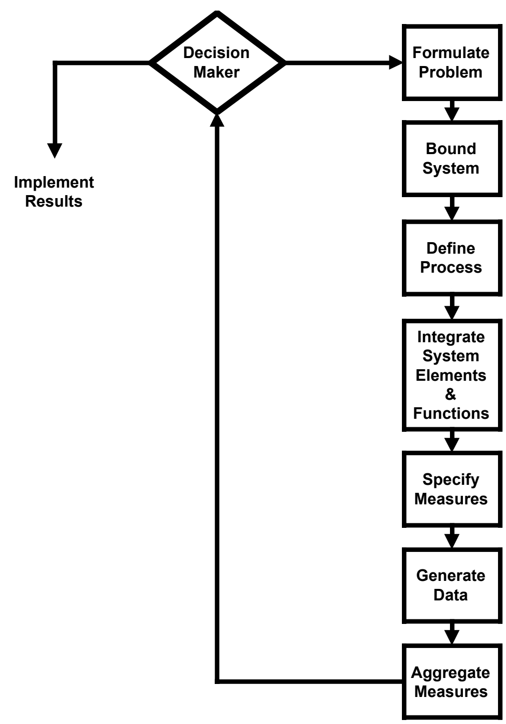

Figure 2. The MORS's Command and Control System Definition Process

Measures of Performance (MOP): measures derived from the dimensional parameters (both physical and structural) and measure attributes of system behavior. MOPs quantify the set of selected parameters. Examples include sensor detection probability, sensor probability of false alarm, and probability of correct identification.

Measures of Effectiveness (MOE): measure of how a system performs its functions within its environment. An MOE is generally an aggregation of MOPs. Examples include survivability, probability of raid annihilation, and weapon system effectiveness.

In the MORS work the term Measures of Force Effectiveness was defined as:
Measures of Force Effectiveness (MOFE): measure of how a system and the force (sensors, weapons, C3 system) of which it is a part perform military missions.

This last definition can be modified for the general systems case as follows:
Measures of Systems Effectiveness (MOSE): measure of how a system of systems performs its mission.

The relationship between the various elements of the hierarchy is shown in Figure 3.

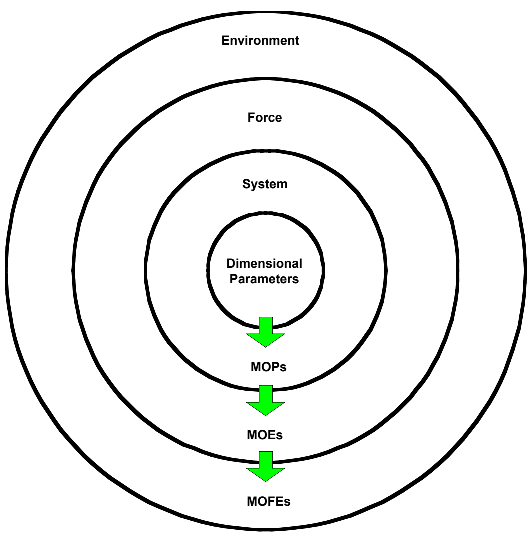

Figure 3. The Effectiveness Measures Hierarchy

Features of measures

With effectiveness measures defined and ordered it bears repeating that they are the standards against which the performance of a system is compared to determine to what extent user requirements are met. They are the criteria used to make the trade-off decisions of what to build. They are the criteria that drive the system solution that is found.

Effectiveness measures are derived from first principles. They are mission and scenario dependent and must discriminate between choices. System parameters are often mistakenly used as effectiveness measures. As an example, sensor search rate has been specified as an MOP, however, increasing the search rate of a sensor improves the probability of detection thus search rate is a parameter.

Effectiveness measures must be both measurable and testable. This means that they are quantitative in nature. Further, they have to realistically measure the systems purpose or objective. Failure to do so results in a system that fails to meet its purpose.

The issue of sensitivity is important. The effectiveness measure(s) not only needs to reflect a change in the parameter set, it must also have a reference from which the change can be evaluated. Doubling the value of a parameter does not necessarily correspond to a doubling of the effectiveness measure. Expressing MOPs, MOEs, and MOSEs as a probability allows us to determine if a parametric change is statistically significant.

Finally, effectiveness measures must be independent at the level of analysis under evaluation. In other words, MOPs should be independent but they can be aggregated into MOEs. The MOEs would be independent of each other and can be aggregated into an MOSE.

Table 1 summarizes the desired characteristics of measures.

Characteristics	Definition
Mission Oriented	Relates to force/system.
Discriminatory	Identifies real difference between alternatives.
Measurable	Can be computed or estimated.
Quantitative	Can be assigned numbers or ranked.
Realistic	Relates realistically to the system and associated

	uncertainties.
Objective	Defined or derived, independent of subjective opinion.
Appropriate	Relates to acceptable standards and analysis objectives.
Sensitive	Reflects changes in system variables.
Inclusive	Reflects those standards required by the analysis objectives.
Independent	Mutually exclusive with respect to other measures.
Simple	Easily understood by the user.

Table 1. Desired Characteristics of Effectiveness Measures

Application

Figure 4 captures the relationship of the parameters and effectiveness measures in the performance prediction process. The parameters are input into the modeling process along with the scenario requirements and environmental conditions. The effectiveness measures are the logical output.

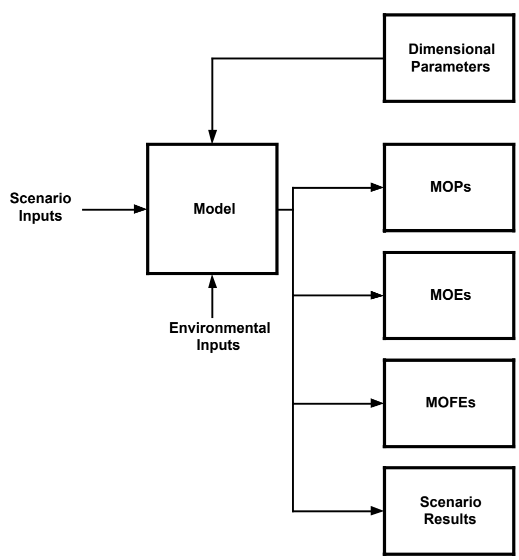

Figure 4. Modeling system Performance [Leite and Mensh, 1999]

Consider the following example: a football team is a system of systems. Its effectiveness measure is its probability of winning. It is composed of four major subsystems, coaching staff, offense, defense and special teams. An example MOE would be the probability of calling scoring plays (or a sequence of plays that lead to a score) by the coaching staff. A MOP would be the probability of completing a pass by the offense or the defense's probability of causing an incomplete pass. The mix of players on the field would determine the parameters (yards per carry, etc.) at any given time. Changing the quarterback would change the probability of completing a pass.

The Role of Time

Time is often used as an effectiveness measure. The concept of timeliness is attractive as an effectiveness measure. However, this paper argues that time is a parameter and thus should not be cast in this role. Time is the independent variable and outcomes of processes occur with respect to time. L'Etoile defines Critical Time (Tc) as the time within which the mission (task) must be completed to be successful [L'Etoile, 1985]. Using Tc as the independent variable, the effectiveness measure is the probability of completing the task within the allowed time.

Summary

The system bounding process is the starting point for determining effectiveness measures in that it defines the set of parameters and their hierarchical structure within the system of systems that drives system performance. Effectiveness measures are also hierarchical with MOPs determined by sets of parameters, MOEs building off the aggregation of MOPs, and MOSEs building from the MOEs. Care must be taken to ensure that effectiveness measures reflect the systems objective. Care must also be taken to not confuse parameters with measures. If it can't be expressed as a probability it probably is not an effectiveness measure.

Biography

Mr. Green is a Senior Principal Systems Engineer at Raytheon Naval and Marine Information Systems. He was the chair of the MORS MOE working group for several years and was involved in the original research upon which this paper is based.

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