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An Investigation of the Role of System Effectiveness in the Acquisition and Sustainment of U.S. Defense Systems: 1958 to 2021

John M. Green—is a Senior Lecturer in the Systems Engineering Department, Naval Postgraduate School. His related experience includes employment as Manager of Advanced Systems at ITT Gilflan and as a Principal Member of the Engineering Staff at Lockheed Martin. He holds an MBA and MS in computer science from University of New Haven, an MA in international relations from Salve Regina College, and a BS in physics from Saginaw Valley State University. He is also a graduate of the Naval War College, College of Command and Staff. He is currently a candidate for the PhD in systems engineering at Southern Methodist University.

Green is a Senior Member of IEEE and AIAA. He is a member of the Military Operations Research Society (MORS), the American Society of Naval Engineers, the Institute for Operations Research and Management Science, the Association of Old Crows, and the International Council on System Engineering. [jmgreen@nps.edu]

Abstract

This paper addresses the system effectiveness methodology and its intended role in acquiring and sustaining U.S. military weapon systems from 1958 to 2021. Given the prolonged period covered by this study and the many changes to the acquisition process, it would be reasonable to expect the methodology to change and adapt, and the study supports this assumption. The study uses the innovative approach of applying three qualitative methods: a structured review of the literature related to system effectiveness, a grounded theory analysis of the structured literature review, and a historiography of the initial grounded theory results. The research identifies five epochs, each marked by changes in the acquisition guidance. The conclusions are fourfold. First, the role of system effectiveness today is vastly diminished from its original purpose because the original material was not widely accessible to the community of interest during the formative years. The grounded theory result was that the concept was never allowed to mature because of changes that marked the second epoch's advent. Second, analysis of source documents provides insight into how to correct past misconceptions and incorporate system effectiveness into modern engineering. Third, the models developed in epoch one may have relevance for today's problems.

Introduction

This paper presents the outcome of an investigation into the role of system effectiveness in the acquisition and sustainment of U.S. defense systems from 1958 to 2021 (Green, 2022). The paper describes the inception of system effectiveness, the attempts to apply the concept, and ultimately, using an approach that combines a structured literature review, grounded theory analysis methods, and historiography techniques, a theory as to why system effectiveness fell into disfavor.

Given the prolonged period covered by this study and the many changes to the acquisition process that occurred during the period of interest, it would be reasonable to expect a change in the role of system effectiveness. The literature supports several changes throughout the time frame (Coppola, 1984). Still, changes were not necessarily driven by the acquisition process itself but by the underlying methodologies for developing systems that were also changing. The analysis shows a dynamic tension between the diverse communities involved in developing system effectiveness, which eventually led to the demise of the development of the concept as a methodology. However, it still exists as a concept in systems engineering texts, such as Habayeb's (1987) *Systems Effectiveness* and Wasson's (2015) *System Engineering Analysis, Design, and Development*.



Background

World War II highlighted the need for a concept by which the military could assess the effectiveness of weapons systems. Complex problems faced the Department of Defense (DoD). State-of-the-art solutions were required, as were methods by which to evaluate them. In the 1950s and 1960s, military systems were pushing the state of the art. Postwar systems were even more complex, encompassing programs such as the B-52 bomber and the Polaris missile program.

Moreover, given the nature of their missions, they had to be reliable and effective. As a result, Secretary of Defense McNamara introduced Systems Analysis into the defense acquisition process to address the quantification of cost and the effectiveness of weapons systems (Aziz, 1967). The initial response to McNamara's challenge came from the Army, Navy, Air Force, and analysis organizations within the DoD. As a result, throughout the 1960s, there was a flurry of activity by all three military services as they tried to incorporate McNamara's ideas into their vision of the acquisition process (Blanchard, 1967a).

A review of the literature related to System Effectiveness showed inconsistency in the concept from its first uses in the early 1960s through today. Earlier work by the reliability community started in the late 1950s. It served as the basis for developing the concept in the 1960s. While the literature shows little academic interest in the topic, a substantial body of work is available produced by the DoD and defense contractors. There was a serious effort by the DoD to develop System Effectiveness as a discipline highlighted by the development of the Weapon System Effectiveness Industry Advisory Committee (WSEIAC) methodology (Air Force Systems Command [AFSC], 1965b) to predict and measure System Effectiveness. By the early 1980s, the concept had all but disappeared from the literature. As System Effectiveness faded to a definition in the *Defense Acquisition Guidebook*, substantial interest in the topic of measures of effectiveness began to dominate the defense-related literature and is the most common concept currently in use. Further, the approach combines a structured literature review and grounded theory analysis. The structured literature review serves a unique role as the database for the grounded theory analysis.

Defining System Effectiveness: What Is System Effectiveness, and Why Is It Important?

Cost-effectiveness, System Effectiveness, integrated logistics support, and maintainability comprise the acquisition and sustainment process (Blanchard, 1967b). Of these four components, System Effectiveness is the linchpin. System Effectiveness is the starting point for deriving the other three components. As Blanchard (1967a) noted, "The ultimate goal of any system or equipment is to fulfill a particular mission for which it was designed. The degree of fulfillment is often referred to as System Effectiveness."

The original intent of system effectiveness was to focus management attention on overall effectiveness throughout the system life cycle. Further, system effectiveness is a framework for analytic methods to predict and measure the overall results of the analysis while placing the contributing characteristics in their proper perspective relative to the desired outcome of the system performing the mission. Thus, the system effectiveness framework provides a basis for developing needs and requirements during project definition and evaluating accomplishments during the acquisition and operation phases.

As developed by the DoD, System Effectiveness combined elements of reliability theory and system analysis. It was an outgrowth of work started in the 1950s by the reliability community and the system analysis work done by the RAND Corporation. Dordick noted in 1965 that it could be an uncomfortable relationship because the two groups viewed the problem from different perspectives.



The official definition of System Effectiveness is “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” (Blanchard, 1967a). However, the official definition does not indicate the scope and scale of system effectiveness as initially envisioned. Instead, system effectiveness represents an engineering management process concerned with describing, controlling, and measuring system performance in practice and a measure. Specifically, the management process provides a framework for system development through the four phases (conceptual, definition, acquisition, and operational) described by the *Air Force Systems Engineering Management Procedures Manual* (Gelbwaks, 1967).

As a measure, system effectiveness is one of the two elements of cost-effectiveness. Together, system effectiveness and cost-effectiveness represent the key elements of a 15-step management approach formulated to deal with the cost and complexity of modern military systems (AFSC, 1965a).

Restating the definition of System Effectiveness per Blanchard (1967a, 1967b), the management goal is to establish the probability that a system can successfully meet the operational demand within a given time when operated under specified conditions. This goal is the probability of success for the system. Accordingly, the framework focuses on evaluating or predicting the degree of effectiveness for any system configuration (existing or proposed). This degree of effectiveness has a cost associated with it that is the value used in the cost-effectiveness (CE) equation (Blanchard, 1967b),

$$CE = \frac{SE}{IC + SC}$$

where:

SE = cost of system effectiveness

IC = initial cost of procurement

SC = sustainment cost (life cycle cost)

System Effectiveness has three elements that determine both cost and the probability of success. This paper refers to them as the pillars upon which the System Effectiveness concept rests. These pillars are:

1. **Availability:** Is the system ready to perform its function?
2. **Dependability:** How well will the system perform during a mission?
3. **Capability:** Will the system produce the desired effects?

The first pillar is commonly referred to as operational availability or readiness, and the second pillar is commonly called mission reliability. Finally, some sources equate the third pillar, capability, with design adequacy, that is, is the design adequate for its intended mission? The three pillars are probabilities; thus, system effectiveness, the measure, is the product of availability, dependability, and capability. The intent was to use the System Effectiveness concept as a vehicle to proceed from predicted values in the conceptual phase of acquisition to empirical values as the system design matured and became operational and sustainment costs become paramount.

Statement of the Problem

Current literature referencing the system effectiveness concept (and, by extension, effectiveness measures) describes it ad hoc, based more on tribal lore than primary sources



(Reed & Fenwick, 2010). This approach is understandable because the legacy literature describes four system effectiveness models, one for the Army, one for the Air Force, and two for the Navy. In addition, terminology issues further exacerbate the problem. For example, the Navy has system effectiveness and operational effectiveness models. Further, the operational effectiveness model uses the three pillars (with different names), whereas the system effectiveness model has an entirely different approach that does not directly use the three pillars. The latter model is what the Navy intended to use for system effectiveness studies, even though the model was inconsistent with the Army or the Air Force (which use the three pillars but different names for the pillars). Finally, the Navy used the operational effectiveness model to train its analysts and supervisory personnel.

A second problem is the complexity of the mathematics used to describe system effectiveness. The common depiction of system effectiveness (the measure) is a scalar model of the three pillars' mathematical product. In reality, system effectiveness is the product of the availability vector [A] times the dependability vector [D] times the capability vector [C] (AFSC, 1965a), or

$$SE = [A][D][C]$$

A third problem is the lack of current references. The literature search turned up only one document written in the last 10 years that discussed system effectiveness: the *Operational Availability Handbook* (NAVSO P-7001; Assistant Secretary of the Navy, 2018). The handbook provided definitions and a computational approach to availability but left the determination of system effectiveness to the reader. The document illustrates ad hoc behavior by use of an incorrect definition of system effectiveness as follows: "Systems Effectiveness: The measure of the extent to which a system may be expected to achieve a set of specific mission requirements. It is a function of availability, **reliability**, dependability, **personnel**, and capability."

First, in the original model, system effectiveness is a function of availability, dependability, and capability for a reason. Moreover, the system effectiveness model answers the following questions: Is the system available when required? Is the system reliable throughout the mission? Furthermore, is the system capable of satisfactorily completing the mission? Second, the use of reliability and personnel is out of context with the intent of the original model. Reliability has a specific mathematical definition and is usually applied at the part level, whereas availability and dependability are system level measures. Finally, personnel would be an input parameter that impacts availability. As a result, the provided handbook definition does not support the system effectiveness criterion of being quantifiable and probabilistic (AFSC, 1965a, 1965b).

The final problem relates to the issue of measures of effectiveness and system effectiveness. AMCP 706-191 defined measures of effectiveness as an input into the system effectiveness process (Department of the Army, 1971). Measures of effectiveness became the ultimate measure with the demise of system effectiveness. Avoiding confusion between the two concepts is simple. First, system effectiveness is a function of the three pillars. Second, a measure of effectiveness measures how a system functions within its environment (Green, 2014). The difference between the two is a matter of context.

Specific Contribution of the Research

This paper reports the results of a study that thoroughly explores system effectiveness (Green, 2022). Specifically, this paper reports on the methodology used in that study. The unique contribution of this research is that it extends knowledge in the domain of system



effectiveness related to acquisition and sustainment.¹ The research's value is its significant contribution to the system effectiveness body of knowledge. It presents a more current, thorough, and detailed analysis of a topic of interest to the acquisition and sustainment communities and supporting disciplines such as system engineering and reliability engineering. The research is novel because it uses several analysis techniques in a triangulated approach not generally applied to studies in this area. The research combines a structured literature review with grounded theory analysis and historiography techniques to develop a deeper and more detailed understanding of system effectiveness based on a comprehensive database of relevant papers from current and historical sources. This understanding provides a foundation for expanding the understanding and development of measures of effectiveness within the framework of system acquisition.

Related Work

Structured literature reviews and grounded theory have their roots in the social sciences. However, applications of grounded theory can extend beyond the social sciences. For example, Johnson recently published a doctoral dissertation titled *Complex Adaptive Systems of Systems: A Grounded Theory Approach* (Johnson, 2019; Johnson et al., 2018). In addition, structured literature reviews and grounded theory are being used in software engineering (Babar, 2019; Hoda, 2021; Stol et al., 2016).

Research Methodology

The research problem of investigating the role of system effectiveness in the acquisition process over 60 years does not fit into a traditional dissertation-like process. The answers to the research questions are qualitative, not quantitative. The data is the literature. Gathering and analyzing literature that went back before 1958 requires a different form of a literature review; hence, after some trial and error, the structured literature review concept was adopted for the subject research. Towards the end of the literature search, the need for a more detailed analysis process became apparent. The structured literature review was vital in determining the patterns in the literature. However, the structured literature review did not provide a methodology to aggregate the perceived patterns into a central concept or theory. Grounded theory methods were selected to meet this need because they focus on the topic at hand as limited by the researcher. Finally, assembly of the timeline–literature analysis concept led to the inclusion of historiography techniques to assist with developing the timeline.

There are four essential elements to developing a structured literature review and grounded theory analysis:

- **Step 1:** The research question
- **Step 2:** The structured literature review
- **Step 3:** The domain of inquiry
- **Step 4:** Critical elements in findings

The research into the combined or triangulated methods indicated five benefits (ResearchArticles.com, 2019):

- 1) Increased validity of the results
- 2) A more nuanced view of the problem
- 3) Increased confidence in the results
- 4) Unique answers or results

¹ *Sustainment* is the appropriate term. *Sustainability* and *sustainable* have taken on specific meanings within the environmental community.



5) A better understanding of the phenomenon involved

The techniques are sequential and recursive. Each pass through the data builds off the last pass, refining and distilling the observations into a central theme.

The Research Questions

The research question is the starting point, and the structured literature review represents the timeline and the data that support answering the research question. Finally, the domain of inquiry is the examination of the literature in the context of the timeline using grounded theory. The outcome is in the form of themes and patterns that emerge from the literature analysis with time.

The goal is an in-depth understanding of system effectiveness from its origins to 2021. The aim of the research is to assess how System Effectiveness evolved with changes in the U.S. DoD acquisition and sustainment processes. Table 1 presents the questions that served as drivers for the study.

Table 1. Research Questions

<i>Question</i>	<i>Topic</i>
<i>Q1:</i>	What factors led to the change in the role of System Effectiveness?
<i>Q2:</i>	What themes began to emerge with the changing role?
<i>Q3:</i>	What were noticeable patterns of change?

The Structured Literature Review

The structured literature review served two purposes in this study. First, the literature is the data, and using a search protocol identified material related to system effectiveness facilitating the development of an organized database. Second, the structured literature review served as the first filter in identifying potential patterns for the grounded theory analysis. Figure 1 describes the overall literature search process. The scoping study of Figure 1 identified possible sources to search. Table 2 presents the list of sources used. Also, the scoping study helped to limit the keywords used in the literature search. Table 3 lists prospective keywords developed from several sources, the primary source being the paper written by Tillman et al. (1978). Finally, Table 4 presents the final list used in the protocol.

Before undertaking the research, the Tillman et al. paper was a known entity. The paper surveyed the literature and identified 89 references specific to system effectiveness. The paper also described the main system effectiveness models developed to that point in time.

The focus of the search was on primary literature or original reports and secondary literature, which describes or summarizes the original writings. Also important is the category of the literature. What is its source? Table 5 presents the various literature categories used in the search. The order of search was (1) peer-reviewed material, (2) grey literature, and (3) books (texts and professional).

Grey literature is unpublished or not published commercially (see Table 5, items 2–7; Kamel, 2019). Because the development of system effectiveness was primarily a government effort, the majority of the literature retrieved fell into the grey category. The initial searches used different browsers and search engine combinations. For example, combining Firefox with DuckDuckGo or Google and Edge using Bing and Startpage was compared to Chrome using Google. The Google search engine was picked as the best option for this research because it



had an excellent search string feature, and Google Scholar is a bonus. Additionally, the Chrome browser has a better download feature.

The literature retrieval process used three steps:

- 1) The use of a focused search string on the sources of Table 3
- 2) The use of “snowball” searches
- 3) A general web search using the focused search string

The use of a focused search string simplified the building of the database. Storing of the results was in folders named for the keywords. All filtering was manual, and sources identified but not available were not included in the database. Figure 2 uses “records” as a general term to cover papers, books, and reports.

TITLE-ABS ((“System Effectiveness” AND (“keyword”)))

The issue of using “system” vice “systems” is essential. It turns out that the use of systems provides lots of results, most of which are not usable. On the other hand, the use of “system” provides more focused results that are usable.

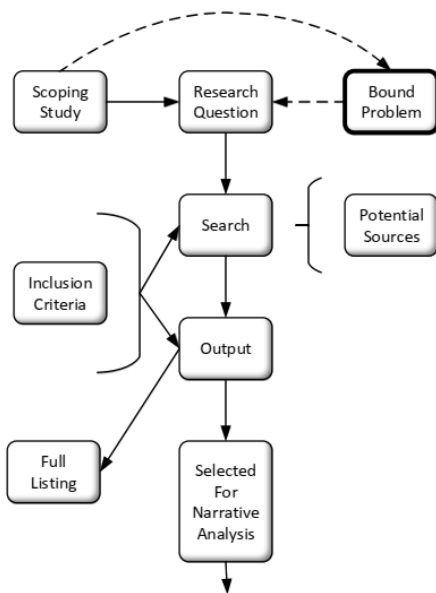


Figure 1. The High-Level Literature Search Process

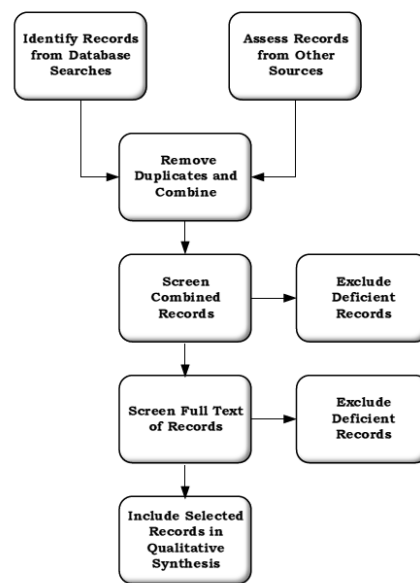


Figure 2. The Structured Literature Review

The desire to conduct as complete a search as possible drove the selection of sources to search (Table 2). Unfortunately, most 1950s and 1960s materials exist only in microfiche format, and COVID-19 restrictions limited access to archived materials. The search of Table 3 covered all sources listed. However, the primary focus was on the government column. The Defense Technical Information Center (DTIC) changed the public interface to use the Google search engine early in the research phase. This change had two undesired effects. First, the early searches were not repeatable, and the Google search engine provided few results. Fortunately, DTIC has a research portal that provides good results with the search string and the snowball search discussed below. Regretfully, the portal is not available to the public.



The second step was a “snowball” search (Wohlin, 2014) using the reference section of the selected papers. This search produced another 52 unique papers that were retrievable. Finally, the search string was also employed in a general web search, resulting in three conference proceedings found in Google Books unavailable from other sources. There were numerous references to conference proceedings as a significant source of information. However, few were available electronically, and those available were expensive.

Tables 3 and 4 present the list of keywords considered and selected, respectively. The keywords of Table 4 not used were tested but returned results not germane to system effectiveness. The primary focus of the search was thematic. What was the paper’s subject, and how did it relate to system effectiveness? The specific focus was on papers that addressed the theory, application, or programmatic issues.

The focus in examining search returns was title relevance, abstract relevance, and paper content, in that order. In addition, the search return had to demonstrate relevance to system effectiveness, the DoD, and the acquisition and sustainment process.

Table 2. Sources Used in the Literature Search

Academic	Government	Professional	Other
Scopus	Defense Technical Information Center - DTIC	Wiley	World Catalog
arXiv.org	Rand	IEEE Xplore	Proquest
ResearchGate	Naval Postgraduate School Calhoun Repository	Jstor	Internet Archive
Science Direct	National technical reports library - NTRL	SAE	SlideShare
Publons	Acquisition Research Journal	Operations Research	Google Scholar
Springer Science Plus Business	Web of Science	Library Genesis	Georgia Tech Research Library
Directory of Open Access Journals (DOAJ)	National Technical Information Service - NTIS	Naval Research Logistics Quarterly	
	MITRE	ARC(AIAA)	



Table 3. Prospective Key Words

Tillman, Hwang, and Kuo [11]	Other Sources
Reliability	Sustainment
Availability	Tactical availability
Operational readiness	Readiness
Repairability	Acquisition
Maintainability	Mission Reliability
Serviceability	Cost Effectiveness
Design adequacy	Operational Availability
Capability	Mission analysis
Dependability	Measures of effectiveness
Human performance	Measures of performance
Environmental effects	

Table 4. Selected Key Words

Reliability	Maintainability
Availability	Operational Availability
Operational readiness	Readiness
Dependability	Mission Reliability
Design adequacy	Cost Effectiveness
Capability	Mission analysis
Measures of effectiveness	Measures of performance

Grounded Theory and Coding the Data

McCall and Edwards (2021) identified three methodologies associated with grounded theory: the classic grounded theory of Glaser and Strauss (1967), the pragmatic grounded theory of Strauss and Corbin (1990, 1998), and constructivist grounded theory espoused by Charmez (2006, 2014). The discussion of the differences among these methodologies is beyond the scope of this paper. However, the study that this paper is reporting on used the pragmatic grounded theory approach. The following reasons are the basis for selecting this approach: First, it recognizes the literature as the phenomena to be studied. Second, it takes an interpretive approach that allows the development of a more profound understanding of the literature and the evolution of an abstract theory. Resultant theories are the researcher's interpretations of causal mechanisms. Third, the role of the researcher is that of an interpreter. However, this approach recognizes the researcher's personal experience and knowledge as a factor. The data sampling process is a back-and-forth effort that results in substantial memo writing and diagramming to identify and incorporate the data into manageable sets. The technique employs three distinct methods: open coding, axial coding, and selective coding. These sequential processes take the researcher through the steps to develop the data patterns (open coding) and examine the derived patterns for causality (axial coding). Axial coding confirms relationships between categories or bounds their applicability. Selective coding is about determining which category embodies the characteristics of the previously derived patterns. This category becomes the core category and represents the resulting theory. The overall procedure is recursive and proceeds until the sequence results in a candidate theory.



Table 5. Categories of Appropriate Literature

1. Peer-reviewed sources (journals and conferences)
2. Dissertations and theses
3. Professional journals
4. Conference proceedings (non-peer reviewed)
5. Government documents
6. Articles
7. Working papers and other unpublished material
8. Books

Analysis and Synthesis

The Data

Over 600 sources covering approximately 70 years (1950 to 2021) were the basis for developing the grounded theory. This research was unique in that the literature was the data. In addition, the resulting narrative was not linear. In the beginning, system effectiveness was the focus. However, in the end, the literature was more about analysis of alternatives (AoA), acquisition reform, and problems with reliability.

Step 1: The Analysis of the Data

Tables 6 and 7 are examples from the research report. Table 6 is the historiography, and Table 7 is the curated literature pertinent to the time frame. The aim was to present the main events during the period of interest with relevant documents published within the time frame. Comparing the event list with the publication list gives the reviewer an indication of what is of interest within the world of acquisition and sustainment during that period.

Table 6. Major Milestones, 1981–1990

Year	Milestone
1981	MIL-STD 721C published - Removed system effectiveness terminology
1981	Blanchard & Fabrycky, <i>Systems Engineering and Analysis</i> published
1983	DSMC publishes <i>System Engineering Management Guide</i> (SEMG) mentions system effectiveness
1984	TRADOC PAM 11-5 (COEA) revised with force focus
1985	MORS starts <i>Modular Command Evaluation Structure Study</i> (MCES)
1986	MCES report completed, First detailed study of Measures of Effectiveness
1986	DSMC (Arnold) publishes <i>Designing Defense Systems</i>
1987	Air Force R&M 2000 initiative
1987	Army reliability initiative coordinated with with Air Force R&M 2000
1987	Navy - Willoughby's "Best Practices Approach"



Table 7. System Effectiveness Publications, 1981–1990

Year	Title/Author
1980	System effectiveness models: an annotated bibliography (Tillman, Hwang, and Kuo)
1981	MIL-STD-721C, <i>Military Standard: Definitions of Terms for Reliability And Maintainability</i>
1981	MIL-HDBK 189 <i>Reliability Growth Management</i>
1982	DoDI 3235.1-H <i>Test and Evaluation of System Reliability, Availability, and Maintainability</i>
1983	The Measures of a System - Performance, Lifecycle-Cost, System Effectiveness, or What? (Blanchard)
1983	<i>System Engineering Management Guide</i>
1984	<i>The Human Operator and System Effectiveness</i> (Erickson)
1985	Design Adequacy: An Effectiveness Factor (Habayeb)
1985	Effectiveness Analysis of Evolving Systems (Karam)
1986	Command and Control Evaluation Workshop (Sweet, et al.)
1986	<i>Measures of Effectiveness in Systems Analysis and Human Factors</i> (Erickson)
1986	<i>Designing Defense Systems</i> (Arnold)
1987	Testing the Modular C2 Evaluation Structure and the Acquisition Process (Sweet/Lopez)
1987	<i>Systems Effectiveness</i> (Habayeb)
1990	<i>System Engineering Management Guide</i> (Kockler, et al.)

Table 8 presents the structured literature review’s initial or open coding analysis.

Table 8. Initial Coding

Patterns
Changes with time
Changes with policy
Changes with DoD structure
Changes with technology
Changes with knowledge
Disparate technical disciplines
Tension among technical disciplines
Inconsistent models of System Effectiveness
Following fads
Lack of outside participation
Lack of participation by academia
Misuse of the concept
Lack of a consistent language

Step 2: Results of the Initial Coding

Initial coding is the search for trends and patterns in the database. The recursive analysis process initially divided the timeline into arbitrary 10-year increments. Further examination led to an initial division of the timeline into three epochs, defined as



1. McNamara’s tenure as the secretary of defense
2. The introduction of the 5000 series of acquisition instructions in 1971
3. The advent of the Joint Capabilities Integration and Development System (JCIDS) process in 2002

Each pass through the data refined the timeline into sub-epochs that clarified the patterns and associated factors. The final result was five epochs. The adoption of commercial standards in 1993 and the current implementation of the Adaptive Acquisition Framework (AAF) complete the list. Table 9 lists the epochs with their causal event and interval of influence.

Table 9. EPOCHS

Year	EPOCH	Causal Event	Interval
1958	EPOCH I	Defense Reorganization Act	None
1971	EPOCH II	DoDD 5000.1	13 YRS
1993	EPOCH III	COTS	22 YRS
2002	EPOCH IV	JCIDS	9 YRS
2018	EPOCH V	Digital Engineering/AAF	16 YRS

The recursive process identified thirteen patterns. The grounded theory literature made it clear that behavior patterns were as crucial as a definable event. For example, a pattern of behavior might be the constant changing of personnel within a particular office in the DoD. A definable event might be the release of a new acquisition instruction. The two ideas merge when a new acquisition instruction is issued every time the leadership changes. This form of reasoning was the basic logic used for identifying the following patterns.

Initial Coding: Patterns and Concepts

1. **Changes with time:** The factors in this pattern address the history of system effectiveness as a function of time. It traces the development of the System Effectiveness models, their impact on military standards, and their subsequent input into the sustainment process. Example factors include the development of *reliability engineering*, *systems engineering* and *logistics engineering* alongside the attempts to develop system effectiveness.
2. **Changes with policy:** Identifies the significant policy changes that occurred to the acquisition structure with time from 1958 to the present. Sample factors include the *cycles of acquisition reform*, *the type of cycle*, and *the form of the changes*.
3. **Changes with DoD structure:** Factors in this pattern include *reorganization of research labs*, *changes in responsibility for system effectiveness within the DOD structure*, and *a lack of central authority*.
4. **Changes with technology:** The factors in this pattern refer to the emphasis of reliability over complexity. For example, the user community initially originally favored systems that demonstrated *mission reliability over capability*.
5. **Changes with knowledge and the knowledge base:** This could also read “changes with lack of knowledge or knowledge base.” Factors include *loss of experienced analysts*, *inexperienced analysts*, *lack of reference material*, and *lack of example reports*. The latter two are problem areas because early material exists primarily as microfiche. Retrieval rates for the study was four of eight documents requested, and the waiting period was over 30 days.
6. **Disparate technical disciplines:** This pattern is distinguished by *a lack of common background or education*.



7. **Tension among technical disciplines:** Factors in this pattern include a *failure by some disciplines to see the big picture*. This is better known as “*if your only tool is a hammer, you tend to see problems as a nail.*”
8. **Inconsistent models of system effectiveness:** The factors in this pattern center around *differences in what comprised effectiveness and similar terms that had different meanings among the various models of system effectiveness*.
9. **Following fads:** This pattern contains the factors that describe misguided attempts to redefine System Effectiveness to accommodate the management of the fad du jour. An example is *equating system effectiveness to quality at the expense of capability*.
10. **Lack of participation by industry:** This pattern is found throughout the literature. Factors include *proprietary methods that are time-tested and no financial incentives to change*.
11. **Lack of participation by academia:** Factors in this pattern address the *lack of research and publication* by the academic community.
12. **Misuse of the concept:** This is a common issue in the literature. Factors include *failure to understand the purpose of the system effectiveness concept and misrepresentation of the concept as solely a reliability model*.
13. **Lack of a consistent language:** Currently there is a lack of common and consistent terms for use when discussing system effectiveness. Factors include *no ontology and/or taxonomy* for system effectiveness and cost-effectiveness. The *lexicon* developed in the 1960s does not describe system effectiveness adequately. This has led to a confusion between what is system effectiveness and what is a measure of effectiveness.

Results of the Axial Coding

Axial coding is about causation. Again, this coding step is recursive, and the stopping point is when the grouping of patterns and their causal effects are complete. Table 10 presents the distillation of the 13 patterns into a list of candidates for the selective coding step. At this step, the outcome of the analysis was that five causal effects incorporated the 13 patterns.

Table 10. Axial Coding Results

Causal Effects
Tension among technical disciplines
Immaturity of the concept
Changes with time
Following fads
Changes with technology

Analyzing these five effects over the timeline leads to a sense of disarray. For example, Dordick (1965) identified the tension and lack of consistency between disciplines early on. The immaturity of the system effectiveness concept was a second contributor to the disarray. Too many people confused the concept with only reliability and maintainability (RAM) modeling because the various models shown in Blanchard’s (1967a, 1967b) papers did not fully develop, nor were the models integrated into one consolidated model. In addition, McNamara was in office for only 4 years after he officially instituted system effectiveness. DoD Directive 5000.1 came 2 years later. Thus, taking the five causal effects together leads to the conclusion that the concept of system effectiveness was not allowed to mature. Development stopped, and people moved on.



The analysis of these five effects over the timeline leads to a sense of disarray and a lack of leadership. For example, the tension between disciplines was identified by Dordick (1965) at the beginning. The sense of disarray is heightened by the continued immaturity of the system effectiveness concept. Too many people confuse the concept with RAM modeling because the various models shown in the Blanchard papers (1967a, 1967b) were not fully developed nor integrated into one consolidated model. Three points stand out in the literature. First, Aziz (1967) pointed out the confusion in terminology and the lack of organized progress, particularly in performance analysis. Second, Coppola (1984) considered system effectiveness to be a transient idea and noted that system effectiveness gave way to life cycle cost as the emphasis. Third, the advent of MIL-STD-721C (DoD, 1981) supported Coppola's point, removing all references to system effectiveness.

The Theory

It would be easy to say, given the evidence, that system effectiveness is a failed concept, that the theory is one of failure. However, Habayeb (1987) presented a solid case to the contrary. The book presented three applications: hardware system evaluation, organizational development and evaluation, and conflict analysis. In addition, Rudwick (1969) identified three positive characteristics of the WSEIAC definition of system effectiveness:

1. The definition allows for the determination of the effectiveness of any system type.
2. The definition supports the measurement of any system in a hierarchy of systems.
3. The definition forces the analysis to focus on the three pillars.

Further, a search on Habayeb (1987) led to new material in Asia, specifically China. The Chinese have adopted the WSEIAC concept, referring to it as the ADC (for availability, dependability, and capability) model.² These points further support the theory that the development of system effectiveness stopped before maturity.

The Theory of Immaturity

The outcome of the selective coding step is the Theory of Immaturity. How can a concept that is in its sixties be immature? Simple. What may be signs of failure can also be signs that the idea never reached its full potential. That is the contention here. The literature shows that system effectiveness may have been a victim of a short attention span within the DoD environment. The era of system effectiveness began and ended with McNamara. Additionally, there were four variants of the system effectiveness model in play: one model for the Army, one for the Air Force, and two for the Navy (Blanchard, 1967a, 1967b). Four models for the same purpose do not indicate maturity. Finally, the services lost control of the acquisition process by the secretary of defense implementing DoD Directive 5000.1 in 1971. The literature indicates a lack of support by the disappearance of system effectiveness from DoD Directive 500.1 A mature process would most likely have received support.

Threats to the Validity of the Study

Research validity is essential in a study of this type where the result is subjective. Two factors drive the conversation: the literature review and the coding.

The challenge of the literature review is building a comprehensive database. In addition, there were negatives, such as the impact of COVID-19 isolation restricting access to physical materials. Nevertheless, despite the limitations, this research is a comprehensive study of system effectiveness with over 600 records.

² The search used "Chinese and the WSEIAC model."



Verification of the coding work occurred at each level of analysis. A researcher from another university experienced in grounded theory performed a confirmation analysis of the coding.

Finally, an evaluation criteria checklist presented as Table 11 guided the grounded theory analysis. The checklist also serves as a guide for the reader to follow the analysis results.

Table 11. Evaluation Criteria

1	How was the original sample selected? On what grounds?
2	What major categories emerged?
3	What were some of the events, incidents, actions, and so on that indicated some of these major categories?
4	Based on what categories did theoretical sampling proceed? That is, how do theoretical formulations guide some of the data collection? After carrying out the theoretical sample, how representative did these categories prove to be?
5	What were some of the hypotheses about relations among categories? On what grounds were they formulated and tested?
6	Were there instances when the hypothesis did not hold up against the observed? How are the discrepancies resolved? How did they affect the theory?
7	How and why was the core category selected? Was the selection sudden or gradual, difficult or easy? On what grounds were the final analytic decisions made?

Answering the Research Questions

Table 12 restates the research questions that this paper set out to answer. The initial coding identified thirteen factors that provide an answer to Q1. Chief among these factors is the tension between disciplines. The people involved practiced different disciplines and brought different perspectives and experiences to system effectiveness. Coppola was a reliability person, and his comment about system effectiveness meshes with Dordick's perspective about the difficulty in having different disciplines set aside their differences. The answer to Q2 has three answers or themes. The first theme emphasized RAM at the expense of capability. The second theme was life-cycle cost (LCC), which incorporated the cost of RAM. Again, the capability pillar was not in the picture. The third theme focused on sustainment, which encapsulated the first two themes. It became more about a sustainable system than a capable system. The answer to Q3 is yes. First, there was a shift in focus to LCC and, second, how to accomplish or perform analyses. The Cost and Operational Effectiveness Analysis (COEA) followed LCC and differed from a systems effectiveness study focused on the three pillars. The COEA followed a rigid, prescribed approach only to be replaced by the AoA concept, an analytical comparison of alternative material solutions that satisfy an established capability.



Table 12. Research Questions

Question	Topic
Q1:	What factors led to the change in the role of System Effectiveness?
Q2:	What themes began to emerge with the changing role?
Q3:	What were noticeable patterns of change involved?

The concept of system effectiveness is always lurking in the background, as exemplified by the *Operational Availability Handbook* (NAVSO P-7001) of May 2018. However, there are weaknesses in the concept. There is an issue with both a lexicon and a taxonomy. Thus, there is a need for an ontology to provide structure and organization. Resolution of these issues and needs would remove system effectiveness from “tribal lore” to established fact. The ontology would also provide a framework for the quantification of system effectiveness.

Summary of Research Results

Conclusions

The selected research method(s) served to clarify how system effectiveness came about, the attempts to make it viable, and how it meandered from the original concept. The triangulated approach led to the Theory of Immaturity by identifying patterns, concepts, and causal relationships. The research methods also clarified future research directions and highlighted issues and ideas that can improve the understanding and usage. The system effectiveness concept has application to a wide variety of systems engineering problems, including a system of systems architecture and cost-effective modeling with tools such as the Constructive Product Line Investment Model (COPLIMO).

Future Work

There are four recommendations: First, build the ontology. Second, refine the four system effectiveness models into one model. Third, establish the limits of the mathematical model. Finally, explicitly define the difference between systems. Finally, explicitly define the difference between system effectiveness and measures of effectiveness. Future work will develop an ontology and taxonomy that will provide a defined foundation to inform the application of system effectiveness and its methods. A second focus will be on developing case studies to illustrate the application of system effectiveness, clarify the lexicon, and uncover shortcomings not discussed in the literature.

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