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A METHODOLOGY TO ASSESS THE VALUE OF COMMUNICATION SYSTEMS

by

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A major shortcoming in current defense communications architecture acquisition is the lack of credible methods to assess the operational value of the various architecture alternatives. Modern communication systems are procured on the basis of how well they meet system performance criteria, but little is understood about how the individual systems increase the operational value of the entire defense communications architecture. This paper applies the Decision Analysis technique of Value-Focused Thinking (VFT) to develop a methodology to assess the operational value of communications architectures. The research employs VFT to develop a value model linking the tasks and attributes of communications systems with operational value, then demonstrates the ability of the model to compare competing communication acquisition alternatives by exercising the model in a hypothetical architecture decision example. The Communications Value model is useful for assessing operational value of the current defense architecture baseline and its competing acquisition alternatives, and also to generate additional alternatives that enhance or increase overall communications architecture operational value.

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Preface

I adopted this project to continue graduate research I performed while at the Air Force Institute of Technology (AFIT), where I quantified the operational contribution of the Global Positioning System (GPS) to combat outcome. My intent was for this project to adapt my GPS approach to a space operations force enhancement mission area other than navigation. I selected the mission area of communications because I could not find any research that successfully defined and quantified how modern communications, especially satellite communications, really assisted the warfighter in combat. Many analysts felt that satellite communications were essential to military victory, but no one had documented why they were essential, or what risk a warfighter incurred if he fought without adequate communications capability and capacity. I fully expected to spend just a few weeks researching the problem, a few more weeks creating a solution, and then a quick packaging of the results into a concise report. The communications value problem proved much more difficult than I had expected.

I genuinely appreciate the help of my lifetime confidante, partner, and wife, Geri, who continually encouraged me when it seemed that this research problem was just too difficult to solve. My most valuable research contact was Dr Greg Parnell, a retired Air Force Colonel and now a professor at Virginia Commonwealth University; Dr Parnell was my thesis advisor at AFIT and dedicated a significant amount of time to seeing this project through to completion. I also appreciate the help of Dave Taylor from CSC

Corporation for his Value-Focused Thinking assistance on this project. This was a true team project, and I could not have accomplished it alone. Finally, the valuable counsel of Lt Col Terry Clark kept me focused and on track even in the midst of the foggiest intersections during the project. I truly appreciate the time she dedicated to making this product a success, and especially for promoting it within the AF community. And nothing I ever envision or accomplish is possible without the unfailing strength of my Savior and Counselor, Jesus Christ. Wise men still seek Him.

Abstract

A major shortcoming in current defense communications architecture acquisition is the lack of credible methods to assess the operational value of the various architecture alternatives. Modern communication systems are procured on the basis of how well they meet system performance criteria, but little is understood about how the individual systems increase the operational value of the entire defense communications architecture. This paper applies the Decision Analysis technique of Value-Focused Thinking (VFT) to develop a methodology to assess the operational value of communications architectures. The research employs VFT to develop a value model linking the tasks and attributes of communications systems with operational value, then demonstrates the ability of the model to compare competing communication acquisition alternatives by exercising the model in a hypothetical architecture decision example. The Communications Value model is useful for assessing operational value of the current defense architecture baseline and its competing acquisition alternatives, and also to generate additional alternatives that enhance or increase overall communications architecture operational value.

Chapter 1

Communications System Value

Modern communication systems, specifically satellite communications, are often described as both a force enhancement tool facilitating more efficient command and control (C^2) of military forces and as a very powerful force multiplier.[1] Statements by our military leaders tout these systems as the key to victory in the Persian Gulf War, also known as the world's first space war, the first knowledge war, and the first information war.[2] Indeed, our current joint doctrine is to avoid engaging an enemy without adequate communications and information system support.[3] But despite their ever-increasing reliance on communications systems, Department of Defense decision-makers currently have *no defensible means* to define the operational value of modern communications systems, much less to compare the value of one system or architecture to another.[4] This paper responds to that analytical need, and develops a methodology to assess the operational value of communication systems architectures, providing acquisition decision-makers with a quantitative tool to compare competing communication system alternatives.

Requirement to Measure the Operational Value of Communications

The need for a communications value analysis tool has not escaped the attention of government observers. The General Accounting Office (GAO) cited the dire need for a method to measure the operational effectiveness of defense communications systems. After reviewing the Defense Information Systems Network (DISN) planners' attempts to meet DOD communications requirements, the GAO reiterated the need to measure operational effectiveness:

> …even basic objectives, such as DISN's ability to provide its users with the needed quality and volume of communications services, have not been validated by users and lack evaluation criteria upon which to measure success. Without this type of information, Defense has no way of knowing whether it will be spending billions of dollars acquiring, operating, and maintaining DISN facilities and services that efficiently and effectively meet its needs.[5]

Our entire military communication systems architecture is coordinated by the Defense Information Systems Agency (DISA), the DOD combat support agency tasked with anticipating warfighting needs and providing seamless, end-to-end information services to the National Command Authorities under all peace and wartime conditions. DISA also coordinates all new systems for integration into a master DISN communications system architecture.

> The DISN architecture prescribes a global network integrating Defense Communications Systems assets, [military satellite communications] MILSATCOM, Commercial [satellite communications] SATCOM initiatives, leased telecommunications services, dedicated DOD Service and Defense Agency networks, and mobile/deployable networks…. The purpose of DISN is rapid information access to conduct effective military operations; and in particular, to allow any warrior to perform any mission, anytime, any place in the world, based on information needs.[6]

In accordance with its charter to select and develop a single communications architecture, DISA's master architecture document compared three master architecture alternatives using six parameters, assessing the ability of each alternative to meet the criteria as High, Medium or Low. Alternative 3, scoring the most "High" ratings, was selected as their investment strategy for the next century.

Table 1. DISA Assessment of Master Communications Architecture Alternatives[7]

Evaluation Criteria	Alternative 1	Alternative 2	Alternative 3
Flexibility/Scalability	Medium	Medium	High
Security	Medium	Low	High
Ease of Transition	Medium	Low	Medium
Interoperability	High	Low	High
Technological Feasibility	High	Medium	Low
Affordability	Low	Medium	High

While the DISA analysis was better than simply flipping a coin, it did not consider the operational needs of the warfighter. All parameters were assumed to be of equal importance; for example, the ease of transition to the new system was weighted the same as the security of the system. But operators are not usually concerned with how difficult the system was to develop - they just want it to work when required.[8] DISA's analysis typifies the lack of analysis depth which, following a brief survey of available studies and literature, seems to be a common thread among communication system evaluations to date. This lack of depth hinders decision-makers, who require meaningful insight into how their decisions affect the architecture performance attributes most valued by warfighters.[9]

Attempts to Determine Communications Value

Reviews of literature, technical publications, databases and interviews with DOD operational, modeling, and acquisition agencies indicate that no one has successfully captured communications operational value. Anecdotal information and accounts stating the need for more communication capacity and some of the expected benefits for commanders abound, but they include no quantitative comparison of communication systems demonstrating their relative value and tradeoffs.[10]

Several agencies are attempting to quantify the operational effects or value of communication systems. The AF military satellite communications (MILSATCOM) program office at the Space and Missile Systems Center is contracting for the development of a space communications analysis tool called the System Effectiveness Analysis Simulation (SEAS). This model is designed to be a quick reaction analysis tool that assesses the impact of satellites and related ground facilities on military capabilities and combat outcomes.[11] SEAS appears to be the first model of its kind, but it only addresses satellite communication, thus representing only a portion of our national communication architecture. While this tool may meet the needs of a satellite communications program office, it does provide insight into the value of an entire communications architecture.

Another operational analysis tool is Air Force Studies and Analysis Agency's THUNDER campaign model. While THUNDER is currently the mainstay of our force-on-force air campaign models, it only recently gained limited satellite modeling capability (capturing only intelligence, surveillance, and reconnaissance support). Communications are addressed in a theater missile defense module, but modeling is limited to delays in moving warning and assessment data from sensor to shooter. Further space enhancements are planned in future revisions to the model.[12]

Probably the best potential source for communications value or effectiveness methodology is a large modeling effort underway in the Office of the Secretary of Defense. The Joint Warfare System (JWARS) is a joint effort to model the behavior and effects of command, control, communications and intelligence, surveillance, and reconnaissance (C4ISR) systems and infrastructure.[13] Unfortunately, the JWARS effort is just entering the prototype development phase, and a working model will not be available for several years.[14]

The demand and unmet requirement for a communications architecture operational value analysis tool provides the impetus for this research project.

Research Objectives

The purpose of this study is to develop and demonstrate a methodology to assess the operational value of communications systems to support acquisition decisions. Specifically, this paper will:

- Construct a straightforward value framework robust enough to thoroughly evaluate architecture value, while remaining simple enough for both senior decision-makers and lower-echelon operators to use.
- Demonstrate that any modern communications system, or architecture of systems, can be analyzed to identify the operational value of its performance attributes.
- Walk the decision-maker or analyst through the steps necessary to adapt this Communications Value model to their particular tradeoff decision.

Overview

This paper is organized as a tutorial describing the development of a value model for communications architecture acquisition decisions. The tool used to address the communications value problem is a Decision Analysis philosophy known as Value-Focused Thinking; it's underlying value assessment concepts and methodology are described in Chapter 2. Chapter 3 then applies Value-Focused Thinking to the communication architecture problem and develops the Communications Architecture Value Model, and includes a logical description of the complete model. Finally, in Chapter 4, the model is demonstrated by applying it to a hypothetical communications acquisition case study. The operational values of two competing architecture solutions are assessed using the Communications Value model, and the results are analyzed and interpreted. Although the decision scenario is hypothetical, the exercise demonstrates how DOD can ensure that future communication architecture decisions adequately identify, prioritize, and meet operational requirements. The development and exercise of the Communications Value model in this paper demonstrates how, by applying the model, decision-makers can ensure their communications architecture decisions address *all* relevant operational factors, and subsequently maximize overall operational value. Finally, Chapter 5 summarizes the research, draws conclusions, and examines the limitations of the methodology. Suggestions for follow-on study are also presented.

Notes

[1] Force XXI…America's Army of the 21st Century, Office of the Chief of Staff, Army, 17. This vision paper describes the results of Prairie Warrior '94, an exercise where Army Command and General Staff College wargamers learned that by equipping forces with advanced digital communications capability, "we saw clear gains in fighting effectiveness of netted and digitized forces." Smaller, "digitized" forces dominated larger, better-equipped "non-digitized" forces; the smaller force could dominate larger areas than conventional divisions can control today.

[2] Alan D. Campen, *The First Information War* (AFCEA International Press, Fairfax, VA, 1992), *ix*.

[3] Joint Publication 6-0. *Doctrine for Command, Control, Communications, and Computer (C4) Systems Support for Joint Operations*, 30 May 1995, I-7.

[4] In the absence of credible means to define the value of communication system capacity (or throughput), the rule of thumb seems to be "buy all you can afford," as experience shows that we consistently consume and saturate all available circuits (Campen). Commanders now demand instant transfer of information between command and control entities, and the associated data products are becoming larger and more perishable. In addition, access to detailed information is demanded at lower and lower echelons of the warfighting forces. A good example is the Army's Force XXI plan to "digitize the battlefield" and allow all commanders to share a coherent picture of the battle space to enhance situational awareness.

The Army is not alone in its desire for increased situational awareness for operators and decision-makers. The Air Force recently demonstrated the ability to deliver pertinent threat data imagery in aircraft cockpits, and we currently employ unmanned aerial vehicles such as Predator to provide live video of activity over the horizon in Bosnia.

Notes

These increased data requirements translate directly to increased communications bandwidth requirements. Despite this escalating demand for higher resolution, higher throughput, and more immediate transfer of products to more users, there are currently no means to assess whether a higher capacity communications system or architecture will satisfy the operator's requirements.

[5] GAO Report from WWW. Defense Communications: Performance Measures Needed to Ensure DISN Program Success (Letter Report, 11/27/96, GAO/AIMD-97-9).

[6] "Defense Information Systems Agency (DISA) Defense Information Systems Network (DISN) Architecture. Summary," 16 Jun 97; on-line, Internet, 7 January 1998, available from http://www.disa.mil/disnarch.html.

[7] "Defense Information Systems Network (DISN) Architecture" Document; on-line, Internet, 7 January 1998, available from http://www.disa.mil/disnarch.html. Table 4-3, 4-4-8.

[8] I have been repeatedly told by decision-makers that operational users do not care how a communications system works, why it works, or how tough it was to make it work - they just want it to work.

[9] During this research effort, I've spoken with representatives of AFSPC/XR, SMC/XRE, OSD/PA&E, HQ AF/AFSAA, USSPACECOM/J6S, the Space Warfare Center, the Air University Space Chair, and the AF Space BattleLab. While they each agree that we need to better understand how communications capability affects the warfighter, they also agree that the issue has just been too difficult to resolve; the studies they've seen seem to lack a clear, quantitative evaluation of communication value.

[10] Campen, *The First Information War*, 136.

[11] Point paper on System Effectiveness Analysis Simulation (SEAS), SMC/XRE, Lt Gregoire, undated. This model is a statistical characterization of combat outcome, using a Force-on-Force campaign model sensitive to variations in satellite communication service performance parameters (communication delay, target location error, target location update rate, target detection probability). For each parameter variation, the campaign model is run hundreds of times to gain a statistical understanding of the subsequent effects on measures of outcome (platforms destroyed by force, casualties by force, casualties by type (hostile or fratricide)).

[12] THUNDER summary of revisions, version 6.4 and 6.5, Nov 97.

[13] JWARS Briefing to the 65th Military Operations Research Society (MORS) Symposium, Prototype Lessons Learned and Future Directions, 12 Jun 97, by LTC Terry Prosser, OSD/PAE.

[14] I also reviewed the CJCS Universal Joint Task List (Chairman, Joint Chiefs of Staff Manual CJCSM 3500.04A, *Universal Joint Task List v3.0*, 13 Sept 96) for communications tasks and performance measures. While the document defines some communications tasks and respective performance measures, it does not address why they are important or the relative importance of the tasks.

Chapter 2

Value Assessment

Communications architecture decision-makers currently make acquisition decisions based upon some assessment of the ability of architecture alternatives to satisfy operational requirements. While specific system performance requirements may be well defined by operators, architecture requirements are not. Agencies such as DISA are left to develop architecture requirements based upon their best understanding of what commanders and operators "value" in communications support. But without thorough analysis of what aspects of communications the users deem valuable, there is no way of determining how well the architecture decisions are supporting the warfighter. When these operational value criteria are identified and quantified, the acquisition agencies and developers can develop and field the most operationally valuable system possible. Operational value, then, must be well defined for both the decision-maker and the warfighter's benefit.

Values are principles used for evaluating alternatives.[1] Decision-makers are often forced to make complex, difficult decisions based upon these assessments of what is most valuable to them or their organization.[2] The operations research field addresses this type of decision problem with a philosophy known as Value-Focused Thinking (VFT). VFT is a technique that compels the decision-maker to specify his/her values first, then identify alternatives that satisfy those values. With an unconstrained set of alternatives from which to choose, the decision-maker enjoys the freedom of discovering and possibly choosing non-traditional or new ways of solving his problem. Clearly, this type of constraint-free thinking can help decision-makers think outside of the military communications' "stovepipe" or traditional biases.[3]

Fundamentals of Value-Focused Thinking

The VFT approach is built upon a mathematical technique known as Multi-Objective Decision Analysis, which uses objectives and supporting tasks established by the decision-maker to construct a hierarchy framework as shown in Figure 1. This set must be collectively exhaustive, containing all the activities important to the decision-maker, and mutually exclusive from tasks that support other objectives. This "purity" in the model avoids duplication and overlap, which could result in inaccurate value scores.[4]

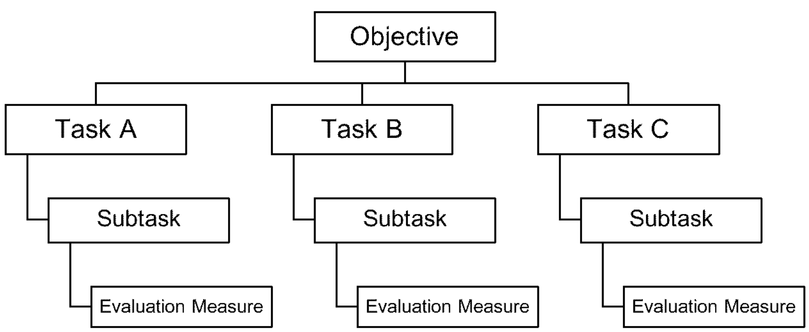

Figure 1. VFT Hierarchy

Once the objectives and tasks are compiled, evaluation measures are assigned to the lowest level subtasks. Evaluation measures define the ability of a system to achieve a specific task.[5] An example evaluation measure for the task "transmit" might be the system's "range," which quantifies the ability of the system to transmit over long distances. Evaluation measures form the foundation for scoring operational value; thus a value function is created for each evaluation measure. These value functions are derived from decision-maker or operator inputs, typically by interviewing a small panel of operational experts.

Application of VFT to the Communication Value Problem

Using this VFT technique, the analyst can build a value model without the constraints of current buzzwords and biases. Based upon communications tasks and desired evaluation measures the operators and analysts define up front, the model captures *what* operators want from communication activities without bias towards technology or *how* the service is provided. The decision-maker can then create architecture alternatives that, when scored using the operational value functions, are compared against their respective costs. The VFT value modeling technique helps the acquisition decision-maker develop the best communications architecture to meet operational requirements.

Notes

[1] Ralph L. Keeney, *Value-Focused Thinking* (Cambridge, MA: Harvard University Press, 1992), 6.

[2] Operations researcher Ralph Keeney describes two primary methods of assessing value to support decisions: Alternative-Focused Thinking and Value-Focused Thinking. Alternative-focused thinking focuses on identifying alternatives, specifying relevant values, then evaluating the alternatives and selecting the one best satisfying the stated values. This approach forces the decision-maker to choose from a constrained set of alternatives, all of which may be poor solutions in comparison to his or her values.

[3] Two highly praised studies applied VFT to address seemingly impossible research questions: the AF Chief of Staff-sponsored SPACECAST 2020 and Air Force 2025 studies. The 1994 SPACECAST 2020 study conducted by Air University (AU) identified the most significant technologies the DOD should invest in to meet our 21st century defense needs. The SPACECAST analysis team gathered inputs from many sources including our military forces, NASA, civilian and military universities, the film industry, and science fiction enthusiasts. The team organized these diverse inputs into the most promising and most vital technology groups, rank-ordered the results and presented their

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findings to the Air Staff. Similarly, in 1995, AU was tasked by the Air Force Chief of Staff to conduct a one-year study to "…generate ideas and concepts on the capabilities the United States will require to possess the dominant air and space forces in the future." The AF 2025 research team used VFT to brainstorm the requirements for a future air and space force, identify the key tasks and their supporting evaluation measures, and define the operational values for each of these tasks and force qualities. The result was a much-acclaimed value model (Foundations 2025) accepted by the AF Chief of Staff to frame force planning decisions shaping our 21st century air and space force.

An interesting AFIT thesis by Bruce Rayno revisited the SPACECAST 2020 methodology, specifically looking at the very simplistic value functions. After constructing concave, convex, linear, and S-curve value functions for the SPACECAST model, he confirmed the results of the SPACECAST team. Although not decisive proof, Rayno's results hint that for the purpose of identifying the best solution or decision, precision and resolution in the value functions may not be as important or necessary as attention to detail in model construction (mutually exclusive and collectively exhaustive).

[4] For this reason, I could not use the abundant military and commercial communication organization or mission area hierarchies as a framework for the communications model; they aren't constructed with mutual exclusivity in mind, and thus cannot work mathematically.

[5] Lt Col Jack A. Jackson, Lt Col Brian L. Jones, and Maj Lee J. Lehmkuhl, "An Operational Analysis for ***Air Force 2025***: An Application of Value-Focused Thinking to Future Air and Space Capabilities," Research Paper (Maxwell AFB, AL: Air University, 1996), 13.

Chapter 3

The VFT Communications Model

The first step in applying VFT to the communications problem was to identify all activities involved in communications operations. A small team, including two VFT experts, met to brainstorm and create the set of activities listed in Table 2.[1] The team attempted to include any communication activities from data or message generation, through any baseband data processing, to transmission, relay, reception, conversion back to baseband, and dissemination to intended parties. This list compares favorably to activities listed in current communications literature by Roddy and Campen.[2]

Table 2. Communication Activities

DIGITIZE	COMPRESS	INTERLEAVE	CONNECT	IDENTIFY INTRUDERS
ENCRYPT	INTERROGATE	REPEAT	NETWORK	TRANSMIT/SEND
BROADCAST	INTERFACE	INTEGRATE	DEFEND	POINT-TO-POINT CALL
SURVIVE	EXPLOIT ENEMY	CORRUPT	DESTROY	ROUTE MESSAGE
PRIORITIZE	CATEGORIZE	DISSEMINATE	DISTRIBUTE	CONFIRM RECEIPT
STORE	QUEUE	RELAY	COORDINATE	OPTIMIZE PATH
VALIDATE	INJECT	DEINTERLEAVE	DECOMPRESS	A->D CONVERSION
DECRYPT	PROCESS	COLLECT	RECEIVE	D->A CONVERSION
PROTECT	INTERCEPT	AUTHENTICATE	DENY	AVOID DETECTION

The next step in the model construction was to arrange these 45 activities into affinity groups, or sets of communication actions that are somehow related to each other.[3] The affinity groupings, depicted in Figure 2, adhere to the mutually exclusive and collectively exhaustive rules, thus facilitating more accurate value assessment.

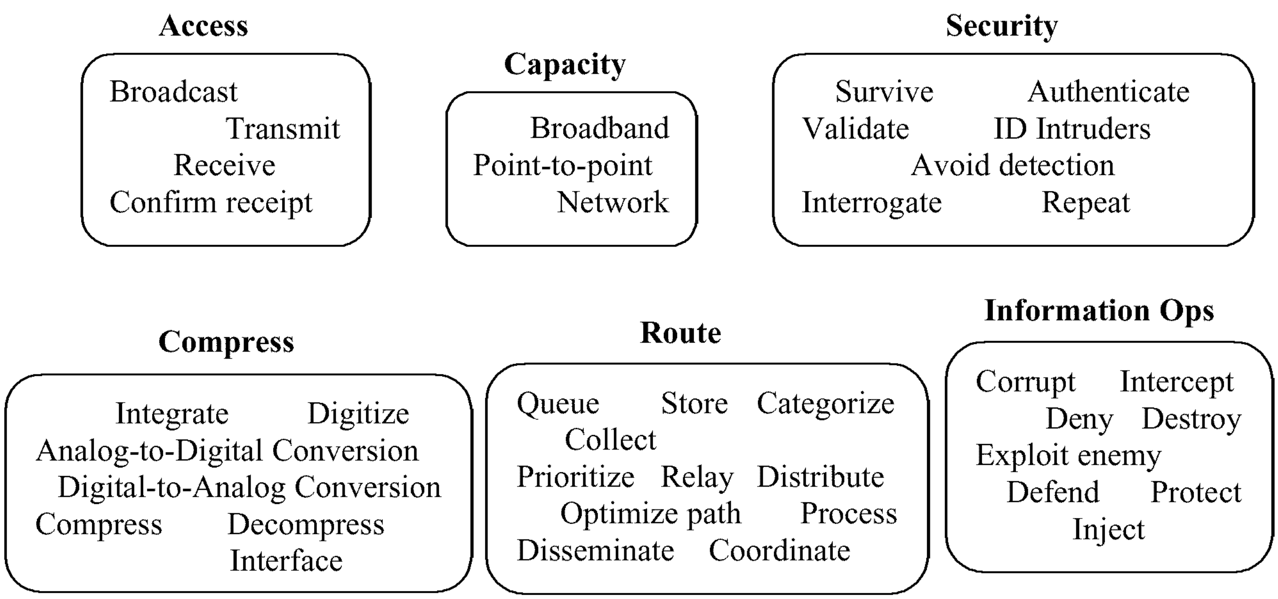


Figure 2. Communications Affinity Groupings

The six affinity groups include all of the communication activity verbs.[4] Under this organization in Figure 2, three groups—access, capacity, and security—describe ***what*** communication systems provide to the operator. The last three groups, compress, route, and information operations, describe ***how*** communication is accomplished with current systems. Recall that the operator is not interested in *how* the communication is accomplished, but rather in the fact that the architecture provides *what* he needs. Using this operational criterion, the last three affinity groups were excluded from the final model framework, leaving the access, capacity, and security groups to form the foundation for the Communications Value model.

The brainstorming exercise also identified 24 evaluation measures (or adjectives) that describe communications system performance, as listed in Table 3. A few of the measures were combined in the model for clarity, but the list is essentially complete. This list also compares favorably with a Naval Electronic Systems Command document which compiled communications systems measures of effectiveness obtained from over 50 naval communications acquisition programs.[5]

Table 3. Communications Evaluation Measures

ERRORS	RELIABILITY	RANGE/DISTANCE	GLOBAL
MOBILITY	SURVIVABILITY	COVERAGE	COMPLETE
CAPACITY	MULTI-CHANNEL	REDUNDANCY	VERSATILITY
SECURE	AVAILABILITY	THROUGHPUT/BANDWIDTH	SPEED
ACCESSIBILITY	INTEROPERABILITY	EASE OF OPERABILITY	COST
DISTANCE	MULTI-SPECTRAL	INTELLIGIBILITY	MULTIPLEX

Communications Value Model Structure

Next, the affinity group *tasks* and *subtasks*, and *evaluation measures* were organized to build the final communications architecture value model as depicted in Figure 3. This portion of the paper describes each of the model's key communication tasks in detail. The model is organized into tiers that are generally defined by the following terms:

- **Task** - the high-level name of an affinity group, describing the group's major activity
- **Task Group** - a set of subtasks; usually distinguishes considerations that would affect the weighting of the subtasks
- **Subtask** - the supporting tasks defined in the affinity groupings; collectively, they define the high-level task
- **Evaluation Measures** - the measure of merit, defining the degree of accomplishment of the subtasks; other terms used for evaluation measure are measures of performance, metrics, attributes, or force qualities

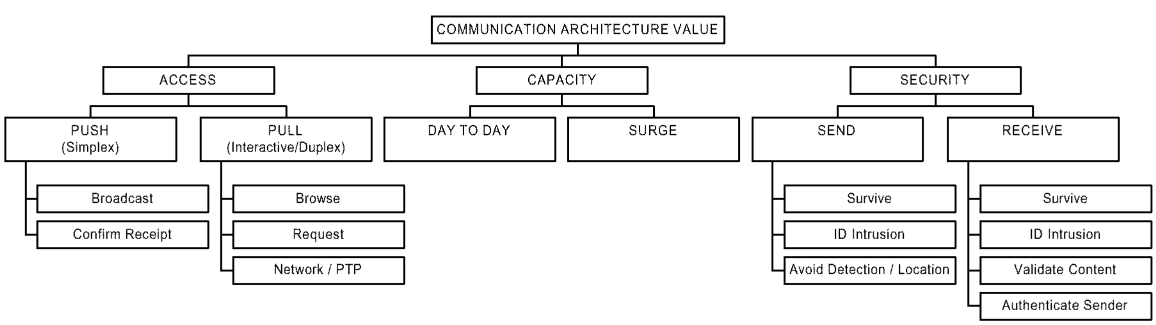


Figure 3. Communication Architecture Value Model

Provide Access

The first task identified in the communication value model is to provide communication *access* to the operator. Access is defined as the ability of an operator to contact and exchange information with another operator or system, when required. Modern communication architectures include systems that provide access for both information *push* (simplex) and information *pull* (interactive or duplex), which require significantly different communications protocols. The subtasks and evaluation measures associated with push systems are not necessarily the same as those used for pull systems, so the access task is broken out into two task groups, as seen in Figure 4. The emphasis for future systems seems to be favoring information pull to conserve bandwidth and storage capacity necessary for large information products.[6]

The information push and pull tasks are completely described by their supporting subtasks. Two subtasks, information *broadcast* and *confirm receipt* of information, define the information push task. Broadcast is a common means of pushing information, but there is also a requirement to verify the intended parties received the information. For information pull, two of the subtasks are providing the ability to *browse* and successfully retrieve products from databases, as well as *request* specific products on demand (without the need to browse). The browse and request subtasks are similar to Internet browsing and fax-on-demand services, respectively. The last subtask for information pull is to provide *network* and *point-to-point* communications, describing the ability to join and communicate with groups of operators. A point-to-point call is simply a networked communications between only two operators.

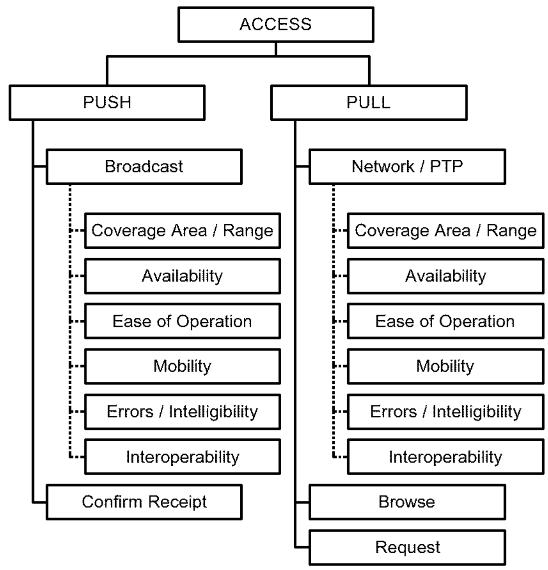


Figure 4. Provide Access

Evaluation measures and value functions, as described in Chapter 2, characterize tasks and subtasks. For the access task, six of the 24 communications evaluation measures listed in Table 3 characterize the performance of a broadcast or network system:

- The system's coverage area (line of sight through global coverage)
- Range (can we reach back to rear operations?)
- Availability of the communication link, satellite, or terminal (including weather and maintenance outages)
- Mobility of the user equipment
- Ability to receive the message correctly (bit error rate for digital systems, and intelligibility for analog systems)
- Interoperability of the architecture components with each other, to include transfer of data between commercial and government systems

These evaluation measures are aligned under the broadcast and network subtasks shown in Figure 4. The confirm receipt, browse, and request subtasks are each defined by a single evaluation measure, listed in Appendix A with all of the model's evaluation measures and associated value functions.

Provide Capacity

The second task of communications systems is to provide capacity to the user. Capacity is usually defined as the ability of a system or architecture to handle multiple simultaneous users and large data products. Capacity is operationally valuable not just to meet current day to day requirements, but also in the ability to grow or surge to meet historically ever-increasing requirements. The ability to provide communications capacity *today* is valuable to the operator, but of possibly greater value is the ability to expand this capacity *tomorrow*. The Communications Value model captures both the *day to day* and *surge* capacity by breaking capacity into two task groups as seen in Figure 5.

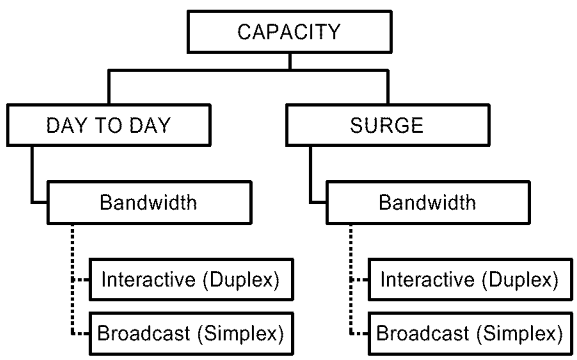


Figure 5. Provide Capacity

There are no subtasks associated with capacity; the only two evaluation measures used to assess capacity are the bandwidth available for use in simplex and duplex modes. Capacity is the single measure traditionally used to define relative communications architecture performance, but the Communications Value model allows the decision-makers and operators to fully define their values and preferences beyond a single measure.

Provide Security

The third communications task is to provide security for operations or operational information. Security is the ability of the architecture to protect the operator, the communications link, and the information passed over the link. As seen in Figure 6, security can be provided for both message transmission and reception; some systems provide security on the transmit side, the receive side, or both. For this reason, *send* and *receive* define two distinct task groups.

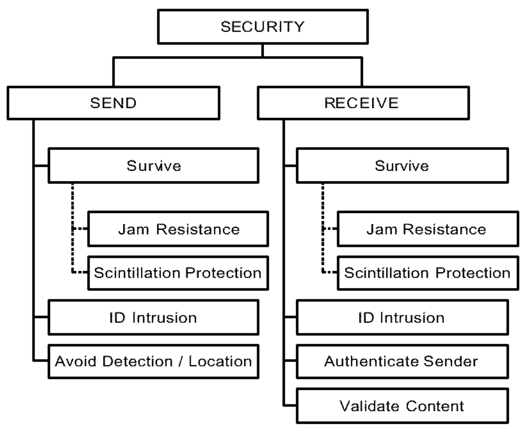


Figure 6. Provide Security

The three subtasks for *send* security are the survival of the signal, the identification of intruders attempting to disrupt communications, and the avoidance of detection by enemy or monitoring forces. Signal survival is important for C2 and force direction communications, and is measured by a system's ability to endure jamming attempts and nuclear scintillation upsets during message transmission. The ability to detect and identify intrusion on the transmitted link provides a measure of security above simply just verifying transmission to the proper, intended message recipient. Detection avoidance is critical to stealthy and special forces that must protect their presence and location information; long or powerful transmissions may reveal the location of the operator.

On the *receive* side of the security breakout in Figure 6, the subtasks are similar to those for *send*. Survival of the communication link through jamming attempts and scintillation is important for various message recipients, similar to the case for the send portion of the model. The identification of intruders is also important to the message recipient, as is the ability to authenticate the source of the message and the content of the transmission.

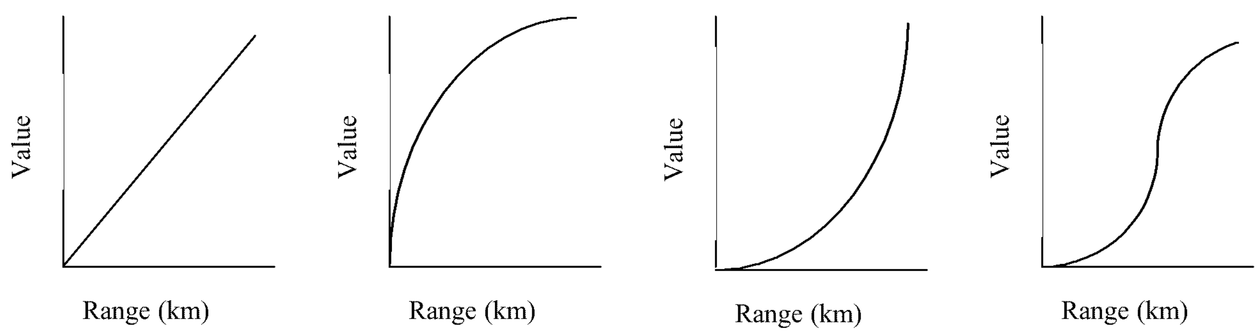
The three communications tasks (access, capacity, and security) with their respective task groups, subtasks, and evaluation measures comprise the complete Communications Value model structure. This hierarchy defines only those communications activities valued by the operators, and forms the foundation for analysis of competing architecture alternatives.

Communication Value Model Review

While there is no means to truly "validate" a value model, during the course of model development, several Air Force operational and management personnel reviewed this model structure for clarity and completeness.[7] On each occasion, the reviewers were introduced to Value-Focused Thinking fundamentals, the model's purpose, and the model's structure; they all confirmed the completeness and organization of the model hierarchy. All of their substantive comments were helpful, and either addressed in the model or, due to their scope, included in my suggestions for further research. Due to time constraints, these reviews constitute the full review process for this model to date.

Evaluation Measures and Value Functions

With the model structure in place, the next step was to develop value functions for each of the evaluation measures used in the model. Each value function relates the architecture's performance, in terms of a single evaluation measure, to operational value. Value functions are also known as scoring functions; evaluation measures may also be called force qualities, measures of merit, or measures of effectiveness. Evaluation measures can be either qualitative or quantitative, and their relationship to value is captured in a simple plot as pictured below.



a) Linear Value Function

b) Diminishing Value Function

c) Increasing Value Function

d) Increasing then Diminishing Value Function

Figure 7. Possible Value Functions[8]

Value functions may take forms in addition to those shown in Figure 7 (step functions, logarithmic, piece-wise linear, etc.), but if the relationship between the evaluation measure and value is clearly established, the value function will identify the evaluation measure's "return to scale" and adequately support the value model.[9] The X-axis of the value function covers the range of possible system performance scores, and the value or Y-axis indicates value scores ranging from 0 to 1, 0 to 10, or 0 to 100. Ideally, these value functions are elicited from operators who provide the shape and structure of the curves or graphs during interviews or surveys.[10] However, due to the scope of this research project, interviews were not used. Instead, notional value functions for each evaluation measure approximate the performance-to-value relationship. These value functions are included in Appendix A, and can be quickly modified by follow-on researchers or analysts applying the Communications Value model to actual decision problems.

Model Weights

The final step in model development was to assign weights to each task, subtask, and evaluation measure. The tasks most important to the operator are assigned higher weights than those less critical, but the task weights must sum to one. In this case, the weights might be 0.4 for access, 0.35 for capacity, and 0.25 for security. In the same fashion, the weights of the task groups are assigned and must sum to one under each task. The last weight assignments are for subtasks and evaluation measures; the sum of all subtask weights under each task group must equal one, and the sum of all evaluation measure weights under a subtask must also equal one. This simple weighting process allows the analyst to not only assess value derived from performance (evaluation measures), but also capture the relative value of various evaluation measures and tasks to most accurately represent the total value of the system or architecture.

The combined use of Multi-Objective Decision Analysis and VFT approach proved very successful in developing the Communications Value model. The VFT process facilitated bottom-up construction of the hierarchy defining communications architecture operational requirements, while avoiding traditional biases towards defining and measuring *how* communications systems work. Multi-Objective Decision Analysis, applied to the model hierarchy, provided the mathematical relationships within the model and facilitated the quantification of operational value. While VFT required very thoughtful identification and organization of communications tasks, the effort was necessary to ensure the model accurately captured operational value. This powerful combination of Decision Analysis tools can be successfully applied to many other difficult decision problems involving value.

Notes

[1] I met with two VFT experts, Greg Parnell and Maj Dave Taylor, USAFR, on 2 Dec 97 to discuss the VFT approach and brainstorm the military communication process.

[2] Colonel (retired) Alan D. Campen, USAF, "Gulf War's Silent Warriors Bind US Units via Space," *Signal*, August 1991, 81. Dennis Roddy, *Satellite Communications*. (Englewood Cliffs, NJ: Regents/Prentice Hall, 1989), 97.

[3] My first attempt at organizing these tasks followed the fundamental communications block diagram, a very basic structure: *Transmit* Conversion (from baseband to RF/Light frequency), *Mode* of Transmission (network, broadcast, or point-to-point), Message *processing and routing* (at any node between transmit and receive), *Receive* Conversion (RF/Light frequency back down to baseband), and *Information warfare* functions (deny/exploit/corrupt, etc). The most obvious affinity groupings relate to the sequence of communication actions, starting with the processing of baseband signals (information). For digital communications, the information is initially sampled (A-D conversion); in both the digital and analog cases, the data is compressed, encrypted, and sometimes interleaved. The data package is then modulated on a radio frequency or light wave carrier frequency, possibly amplified, and transmitted over wire, cable, or through air/space. The receiver, whether a relay node or end-user, performs the transmit process in reverse order (from demodulation to decompression and D-A conversion) to reproduce the baseband data. This process then falls into five neat nodes/groupings: baseband conversion, transmit, relay/route, reception, and reconversion to baseband.

While this model reflects the traditional block diagramming of the communications process, it does not lend itself to accurate value measurement. First, the decision-maker and operator are not interested in the detailed communications process, but in the ability of the system or architecture to satisfy their values; this model does not focus on values. Secondly, when we attempt to build a mathematically correct (mutually exclusive and collectively exhaustive) framework within this structure, the model fails due to the repetition of the communication actions inherent in the transmit, receive, and relay nodes.

See also Jack A. Jackson, LtCol USAF, Brian L. Jones, LtCol USAF, Lee J. Lehmkuhl, Maj USAF, Research Paper. An Operational Analysis for ***Air Force 2025***: An Application of Value-Focused Thinking to Future Air and Space Capabilities, 29.

[4] 45 verbs came out of the brainstorming activity, but five were eliminated or absorbed by other tasks, resulting in this final list of 40 tasks.

Notes

[5] United States Naval Electronic Systems Command, Command, Control, and Communications (C3) Measures of Effectiveness (MOE) Handbook, Interim Draft, PME 108, 30 Jun 1980.

[6] Interview with Maj Virginia Ashpole, former DISA communication engineer. On Jan 5, 1998.

[7] Maj Virginia Ashpole, communications officer and former DISA engineer; LtCol Tom Clark, USAF, Air University Space Chair; Col John Gorman, USAF, command pilot; LtCol Bruce Crownover, USAF, former DISA officer; LtCol Jeff Garner, USAF, space operator.

[8] Lt Col Jack A. Jackson, Lt Col Brian L. Jones, and Maj Lee J. Lehmkuhl, "An Operational Analysis for ***Air Force 2025***: An Application of Value-Focused Thinking to Future Air and Space Capabilities," Research Paper (Maxwell AFB, AL: Air University, 1996), 14.

[9] Craig W. Kirkwood, *Strategic Decision Making: Multi-Objective Decision Analysis with Spreadsheets* (Belmont, CA: Wadsworth Publishing, 1997), 61.

[10] Major Dave Taylor, USAFR, Single Dimensional Value Function Elicitation Primer, (HQ AFSPC/XR, Dec 97), 2.

Chapter 4

Demonstration: Communication Architecture Decision

Despite the apparent simplicity of the Communications Value model, its application and utility are best demonstrated by case study. This chapter demonstrates the application of the model to a hypothetical architecture decision problem.

Chapter 1 included discussion of DISA's method to select the best alternative from three candidate DISN architectures. Unfortunately, DISA's published analysis does not provide sufficient architecture detail for this value model exercise. In the absence of an actual architecture decision case study, using a Decision Analysis tool known as the strategy generation table can create the spectrum of options available to DISA or any decision-maker. The strategy generation table is a framework "within which all imaginable combinations can be screened easily to determine the most appropriate candidates."[1]

Strategy Generation Table for Communication Architectures

Although not a complete or validated list of alternatives, Table 4 provides a notional example of a strategy generation table listing the possible choices from which we might choose an architecture. For this limited demonstration, assume:

1. The current fielded communications architecture relies exclusively on military-owned and operated satellites and terminals for long haul communications.

2. New CJCS OPLANS rely on 24-hr global communication coverage for strategic communications requirements, each user requires data rates of T1 (1.5Mbit/sec) or less. Assume the NCA and CINCs must accommodate up to 100 polar users consuming a total of 100Mbit/sec of communications circuits, apportioned among voice, multimedia, and broadcast services operating at top secret classification or below.
3. The current architecture only provides the requested capability from 65 degrees North latitude to 65 degrees South latitude, with no polar coverage.
4. The decision-maker needs to provide coverage for the polar regions, and must choose candidate solutions from the choices listed in Table 4.

Note that in this simple hypothetical case, the value of the existing baseline architecture is not assessed; rather, the exercise focuses on determining which alternative architecture will satisfy the new requirements and provide the best value per dollar spent.[2] This simplified exercise demonstrates how the Communications Value model can be adapted and applied to real-world acquisition decisions.

Table 4. Notional Communications Architecture Strategy Generation Table

Acquisition Type	Terminal Type	System Concept	Frequency Band	Coverage	Control Segment	User Interface	Expansion	Connectivity
New satellite development	Fixed	User pull	HF/VHF	65N-65S	Existing	Proprietary	Surge On-demand	DOD
Terminal Mod	Deployed	System push	UHF	Theater	Contractor	Gov't spec	Add'l terminals	Com'l
Com'l lease	Both	Duplex	SHF	Global	Combined	Non-proprietary	Com'l lease	Both
		Network	EHF	Polar			Redesign / New buy	
			Fiber					
			Laser					

The table depicts the difficulty of making communication architecture decisions, as there are over 93 thousand possible combinations of these system parameters.[3] The decision-maker can choose one or more system features from each column, but note that not all combinations of the parameters are feasible or even make sense.

For demonstration purposes, only two alternatives from the table are considered. The first alternative, defined in Table 5, is the development of a polar adjunct satellite communication system, including development of a new satellite, launch of at least three polar-orbiting satellites, and the modification of existing ground control stations or design and construction of a separate ground segment to support the polar constellation.

Table 5. New Development Alternative

Acquisition Type	Terminal Type	System Concept	Frequency Band	Coverage	Control Segment	User Interface	Expansion	Connectivity
New satellite development	Fixed	User pull	HF/VHF	65N-65S	Existing	Proprietary	Surge On-demand	DOD
Terminal Mod	Deployed	System push	UHF	Theater	Contractor	Gov't spec	Add'l terminals	Com'l
Com'l lease	Both	Duplex	SHF	Global	Combined	Non-proprietary	Com'l lease	Both
		Network	EHF	Polar			Redesign / New buy	
			Fiber					
			Laser					

The second alternative, described in Table 6, is to procure leased capacity from commercial sources, possibly from a global cellular service such as Motorola's Iridium constellation. This alternative does not require government satellite development or launch, but may require some development of gateways and a scheme to gain the required bandwidth from the cellular-based (and, therefore, distributed capacity) constellation. In addition, the government would need to secure a reserved capacity from the contractor to meet wartime or worst case requirements. Although this commercial alternative may at first glance appear to be the favored choice (in terms of cost alone), keep in mind the need to first assess the operational value obtained from the alternative systems, and then compare the value obtained to system cost.

Table 6. Commercial Lease Alternative

Acquisition Type	Terminal Type	System Concept	Frequency Band	Coverage	Control Segment	User Interface	Expansion	Connectivity
New satellite development	Fixed	User pull	HF/VHF	65N-65S	Existing	Proprietary	Surge On-demand	DOD
Terminal Mod	Deployed	System push	UHF	Theater	Contractor	Gov't spec	Add'l terminals	Com'l
Com'l lease	Both	Duplex	SHF	Global	Combined	Non-proprietary	Com'l lease	Both
		Network	EHF	Polar			Redesign / New buy	
			Fiber					
			Laser					

With the two alternative strategies defined, the next step is to assign weights throughout the model, based upon the operational requirements stated in the assumptions.

Value Assessment

The operational value of the two alternative architecture solutions is now scored using a weighted value model. For this demonstration scenario, notional weights are assigned to each of the communications tasks, subtasks, and evaluation measures as depicted in Figures 4, 5, 6, and 7. Actual values should be derived from operational decision-maker input, and they may vary significantly from this test case.

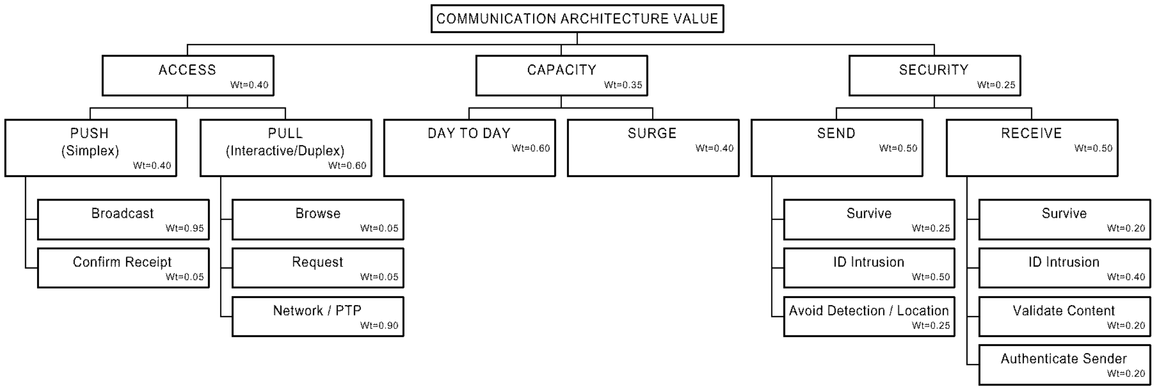


Figure 8. Communications Value Model Weighting (to subtask level)

Communication task and subtask weights are shown in Figure 8. Based on the stated scenario assumptions, access is assumed to be the most important task with a weight of 0.40. Capacity is the next highest priority task, arbitrarily weighted at 0.35, followed by security at 0.25; the sum of the task weights is one. Weights assigned in branches of the tasks and subtasks follow the same convention, summing to one beneath each successive level. Values assigned to evaluation measures are shown in Figures 9, 10, and 11.

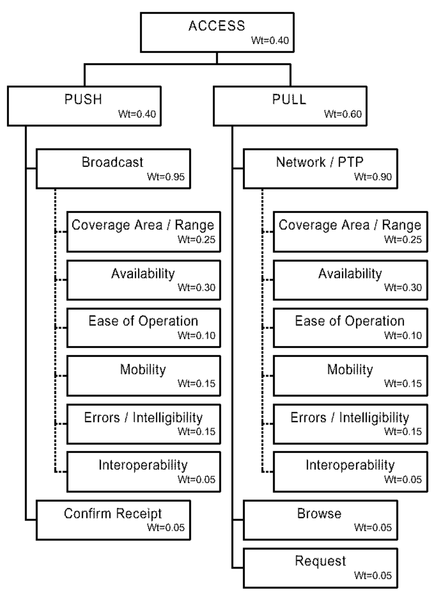


Figure 9. Weights for Access Task

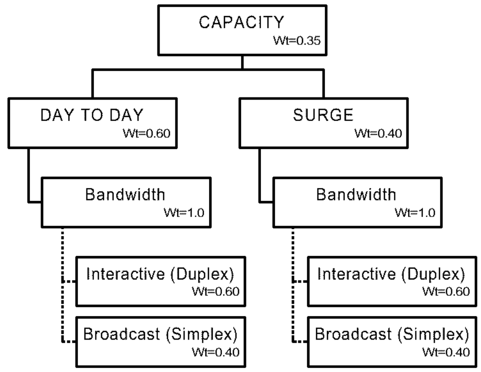


Figure 10. Weights for Capacity Task

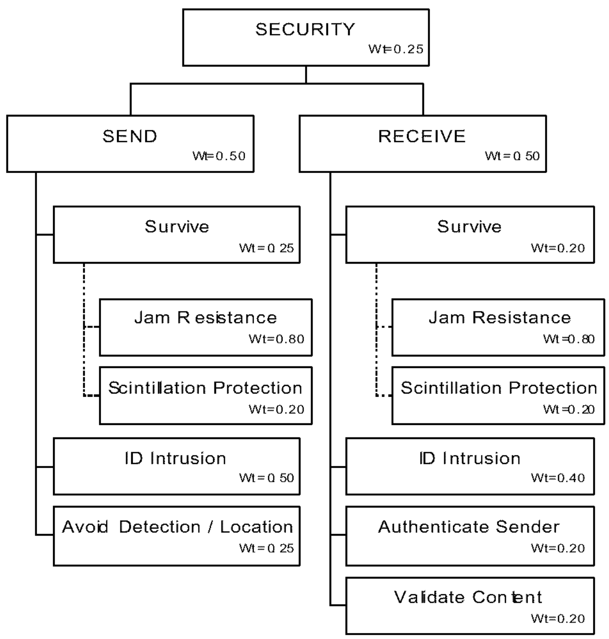


Figure 11. Weights for Security Task

The final value assessment step involves scoring the alternatives against value functions, derived from operational decision-maker input.[4] This section describes only two of the 25 functions required for the Communications Value model; the remaining value functions are outlined in Appendix A.

Under the task of providing access via push (simplex) techniques, the evaluation measure of availability can be related to operational value by the straightforward value function in Figure 12.

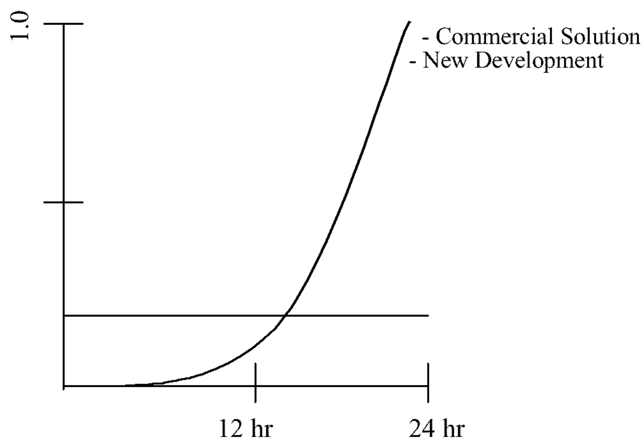


Figure 12. Availability Value Function

The availability value function captures the increasing value of alternatives that provide greater than 12-hour availability, averaged over all seasons of the year and through all weather conditions. Systems operating at super high and extremely high frequencies (SHF and EHF) might experience signal outages during severe rainfall, where commercial ultra-high frequency (UHF) systems do not experience such attenuation. In our example, the polar solution is susceptible to low elevation angles (atmospheric attenuation) and summer humidity (water absorption), so it may only provide 96 percent or better availability and obtains a value of 0.90. The commercial UHF cellular system, benefiting from a denser satellite constellation and less vulnerable frequency band, should provide better than 99 percent availability; its value is scored at 1.0.

A more complex example of a value function is the evaluation measure of jam resistance, found under the security task. The ability of a system or architecture to resist attempts to jam a modulated signal is inherently difficult to define and measure. In this case, it may be appropriate to assess performance by simply identifying the probability that data integrity is lost if a jamming attempt is made on the communications link. This macro view of anti-jam performance in Figure 13 may be easier for decision-makers to assess.

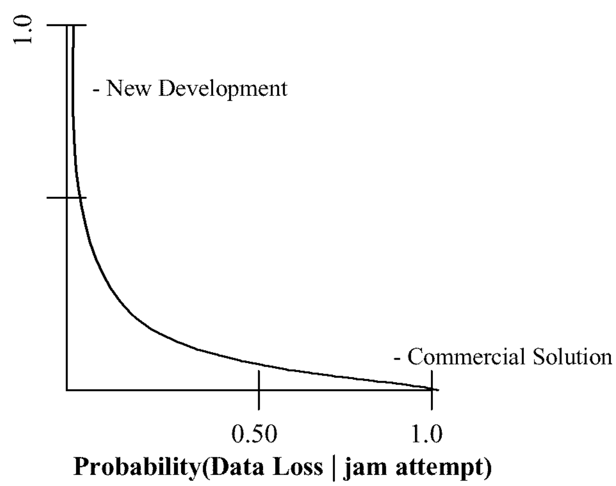


Figure 13. Jam Resistance Value Function

Evaluation measure value functions are developed using a variety of probability functions, step functions, curves, and charts; the remaining examples used for this demonstration are listed in Appendix A.

Alternative Comparisons

Applying the Communications Value model outlined in this chapter and the value functions listed in Appendix A, the two architecture solutions to the polar coverage demonstration yield the architecture values shown in Figure 14. Although the new development architecture value is almost 10 percent higher than that of the commercial alternative, the decision-maker still has to compare the architecture costs to determine which system in which to invest.

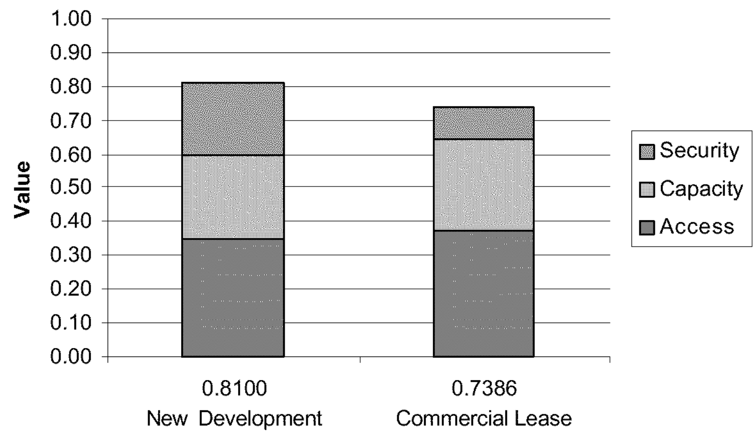


Figure 14. Communication Architecture Values

These values were derived from the weighted Communications Value model; the detailed scoring is shown in Table 7 in Appendix A. The new development alternative frequently scores lower than the commercial architecture in the access and capacity tasks, but excels in the security task based on these notional weights and scoring functions. The next step is to plot these alternative values against a feasibility parameter such as acquisition cost or cost of transition, to reveal the cost of obtaining the anticipated operational value. For this demonstration, the value scores are simply compared to the estimated cost of fielding the alternative solutions.

The shaded area in Figure 15 shows the region where the alternatives would provide more value and/or cost less than the existing system. Within this cost and value space, the decision-maker must search for alternative solutions. Given the hypothetical requirements earlier in this chapter, the commercial lease solution appears to contribute to the best architecture. However, if communication security and survivability are weighted as top priorities (and the model weights were so adjusted), the new development solution may be well worth the additional cost, far surpassing the value of the commercial lease alternative.[5]

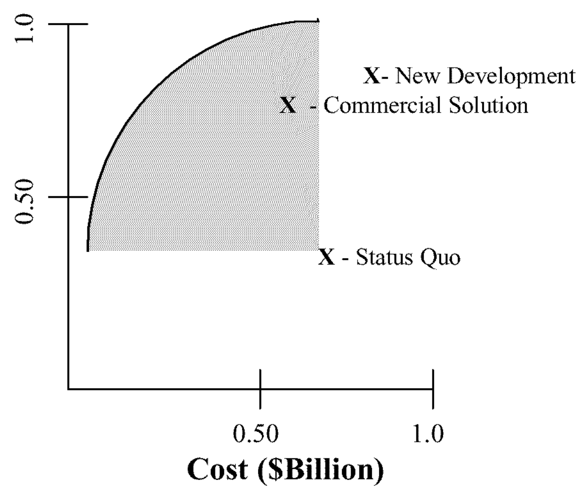


Figure 15. Cost vs. Value Comparison[6]

While this demonstration assessed the value of two potential alternatives, the power of Value-Focused Thinking can be best realized by designing a third alternative. With operational value previously defined and weighted, it is possible to create a third communications architecture alternative that maximizes operational value. Referring back to Figures 9, 10, and 11, the most valuable (and heavily weighted) tasks and evaluation measures for this scenario are to:

- Provide information pull access, with excellent coverage and availability
- Provide generous capacity, including both day to day and surge capabilities
- Detect and identify communication link intruders

An acquisition decision-maker can provide this type of quantified value analysis to potential communication system vendors, focusing new development on what operators value most. This type of value definition can greatly increase the potential for overall architecture value, as they are true "requirement definitions."[7]

Summary of Demonstration Results

The application of the Communications Value model to a hypothetical decision problem demonstrated the value assessment methodology developed in Chapter 3. The demonstration results suggest three primary observations:

- Communications value can be assessed for the purpose of architecture alternative comparison.
- The Communications Value model, including operator-assessed weights and value functions, can reveal the relative operational value of several alternative architectures.
- To best assess value for entire architectures, the evaluation measure value functions must address desired performance and associated value at the *architecture level*, not the individual *system* level. If these functions are developed at only the system level, the model will only apply to specific system values.

The decision scenario, strategy generation table, model weights, and value functions used for this demonstration are notional, and must be tailored and modified before application to any decision problems. This demonstration merely serves as a proof of the communications architecture value assessment concept.

Notes

[1] Robert T. Clemen, *Making Hard Decisions - An Introduction to Decision Analysis,* (Boston, MA: PWS-Kent Publishing, 1991), 157.

[2] In a real decision case, the existing architecture value and cost baseline would have to be assessed in order to make a valid acquisition decision from among the alternative solutions (and there is always the option of doing nothing, which is the baseline). While a baseline assessment is of utmost importance in a real case, it is omitted here due to research scope limitations. A notional baseline value and cost is assumed later in the chapter to demonstrate how to use the exercise results to make a decision.

[3] The actual number of combinations, if we can only choose one feature from each column, is 93,312. The problem becomes even more complex if we consider the selection of more than one feature from each column. Regardless of the number of possible combinations, this strategy generation table reveals the complexity of communications architecture decisions.

Notes

[4] Again, the nature of this exercise allows us to use notional value functions.

[5] This was likely the case with the Milstar survivable communications system. The National Command Authority's emphasis on uninterrupted communications through a nuclear laydown scenario provided the foundation for a low-capacity but highly survivable worldwide SATCOM system. With the current emphasis on tactical communications capacity, however, follow-on Milstar satellites have greatly increased capacity with much less emphasis on survivability.

[6] The cost and value score of the status quo system is purely hypothetical. Costs associated with the alternatives are very rough estimates. The purpose of the plot is only to demonstrate the use of the value assessment results.

[7] In recent years, DOD has increased the emphasis on stating acquisition requirements as baselines, or simply stating our minimum acceptable performance requirements. By paying contractors to develop systems that meet performance "minimums" without insight into what our operators value most, DOD is missing the opportunity to maximize operational value. Supplying vendors with this sort of value definition and weighting early in the acquisition cycle has the potential to yield noticeable cost and performance benefits.

Chapter 5

Conclusions and Recommendations

The purpose of this project was threefold: to demonstrate assessment of the operational value of complex systems, to build a robust communications architecture value framework useful for acquisition decisions, and to demonstrate modification and application of the value model to specific communications architecture decision problems. These objectives were successfully met by applying the decision analysis technique of Value-Focused Thinking to address the spectrum of communication activities and create the Communications Value model. The model includes supporting tasks and the set of critical evaluation measures that must be measured to define communication performance and value in operational terms. The model is unbiased towards the type of user, technology or medium of communication; the model is capable of capturing the operational value of all types of modern military communications.

To demonstrate its utility, the communications model is applied to a notional architecture decision scenario. The paper demonstrates how to structure the value model, build value functions, assess weights and score and interpret architecture values. The exercise results suggest that the model can not only assess the value of known alternatives, but also provide insight into alternatives that *could be solicited* in order to improve the architecture's operational value. The power of the VFT perspective is that it provides the decision-maker with unconstrained solutions; with the operational value structure defined before the solicitation of alternatives, developers can focus on maximizing value rather than simply maximizing performance.

However, the most significant contribution of this research is that it provides a single quantitative Communications Value model, defining the complete set of communications tasks that operators deem essential and valuable in warfighting. To date, no such model had existed, despite GAO emphasis on development of such a tool. The Communications Value model developed here provides the foundation for construction of a defense communications architecture optimized to meet the operational needs of all DOD users.

Recommendations

There is great potential for this tool to provide the foundation for further wargaming and communication modeling and simulation efforts. This potential can be greatly enhanced by follow-on research in several critical areas:

- Several communications and operational experts have already reviewed the Communications Value model, but it could benefit from more extensive review to ensure that tasks, subtasks, and evaluation measures are complete and aligned accurately.
- The current defense communications architecture value should be assessed as a baseline. Alternative values and cost analyses will benefit from comparison to a real baseline, which is not defined today in terms of operational value.
- The development risk of proposed communications architectures should also be assessed. Assessing probability distributions on each of the scores can do this. The result is a range of possible architecture scores that reveal development risk.

The Communications Value model answers the acquisition decision-maker's need for an operational value analysis tool for communications architectures. Properly adapted and applied to future architecture decisions, the model can help decision-makers build the most useful and robust communications architecture possible.

Appendix A

Additional Demonstration Details

This appendix includes the notional value functions used to score the alternatives for the communications architecture model demonstrated in Chapter 4. Tables 7 and 8 show the Excel spreadsheets summarizing the weights and value scores for the competing architectures. The next section includes each of the value functions used to score the model, including the rationale for their respective scores. These nineteen value scoring functions are derived from notional performance and value assessments, obtained with minimal operator or system expert input; they merely demonstrate the type of functions necessary to apply the model to actual decision scenarios.

Table 7. Weighting and Scoring Summary

		ACCESS 0.40															
		Push 0.40							**Pull** 0.60								
		Broadcast 0.95						**Confirm Rcpt** 0.05	**Network / PTP** 0.90						**Browse** 0.05	**Request** 0.05
	Weights	Coverage 0.25	Availability 0.30	Ease of Ops 0.10	Mobility 0.15	Error Rate 0.15	Interoperability 0.05		Coverage 0.25	Availability 0.30	Ease of Ops 0.10	Mobility 0.15	Error Rate 0.15	Interoperability 0.05		
Alternative																
New Development	0.3504	1.00	0.90	0.75	0.80	0.85	1.00	0.20	1.00	0.90	0.75	0.80	0.85	1.00	0.80	0.90
Commercial Lease	0.3712	1.00	1.00	0.75	1.00	0.95	1.00	1.00	1.00	1.00	0.75	1.00	0.95	1.00	0.20	0.40

		CAPACITY 0.35			
		Present 0.60		**Future** 0.40	
	Weights	Duplex BW 0.60	Simplex BW 0.40	Duplex BW 0.60	Simplex BW 0.40
Alternative					
New Development	**0.2450**	1.00	1.00	0.25	0.25
Commercial Lease	**0.2744**	1.00	1.00	0.50	0.40

		SECURITY 0.25								
		Send 0.50				**Receive** 0.50				
		Survive 0.25				Survive 0.25				
	Weights	Jam 0.80	Scintillation 0.20	ID Intruder 0.50	Avoid Detect 0.25	Jam 0.80	Scint 0.20	ID Intruder 0.50	Auth Sender 0.25	Validate 0.20
Alternative										
New Development	0.2146	0.85	0.95	0.85	0.80	0.85	0.95	0.85	0.9	0.9
Commercial Lease	0.0929	0.15	0.05	0.25	0.40	0.15	0.05	0.25	0.9	0.9

Table 8. Value Scoring Results

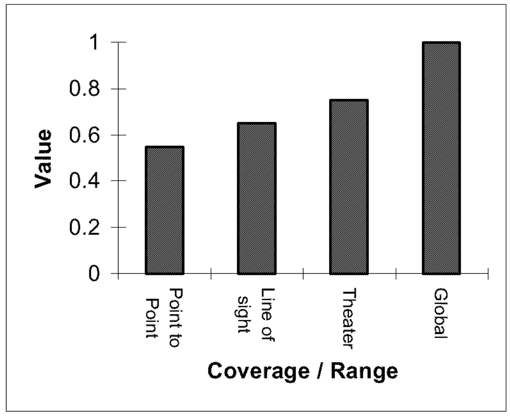
Total Comm Value Score	
New Development	0.8100
Commercial Lease	0.7386

Architecture Access Scoring Summary

The eight scoring functions for architecture access are depicted in Figure 16. By complementing existing **coverage** with polar capabilities, both the commercial and new development alternatives were assessed to resolve current architecture's the coverage problem, and thus were assessed values of 1.0. The values are the same for both information push and pull operations.

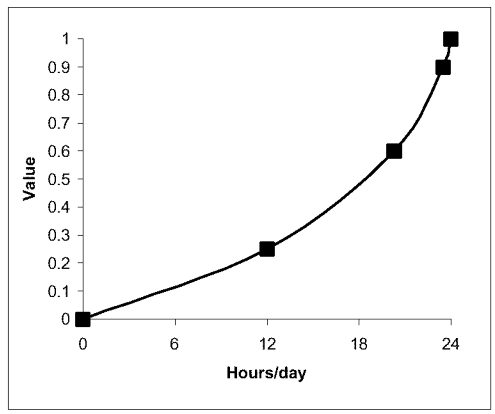
Coverage Area / Range

Value	Area/Range
0.55	Point to Point
0.65	Line of sight
0.75	Theater
1	Global



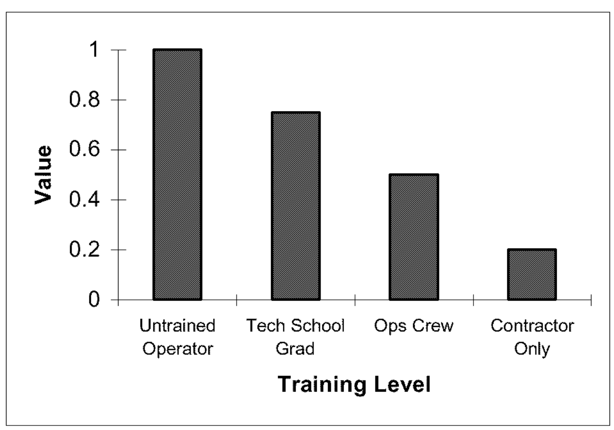
Availability

Value	Hours/day
0	0
0.25	12
0.6	20.3
0.9	23.5
1	24



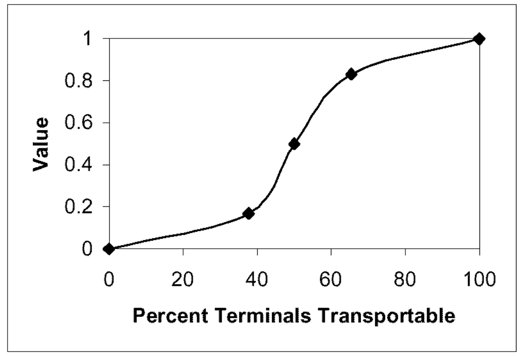
Ease of Operation

Value	Training Required
1	Untrained Operator
0.75	Tech School Grad
0.5	Ops Crew
0.2	Contractor Only



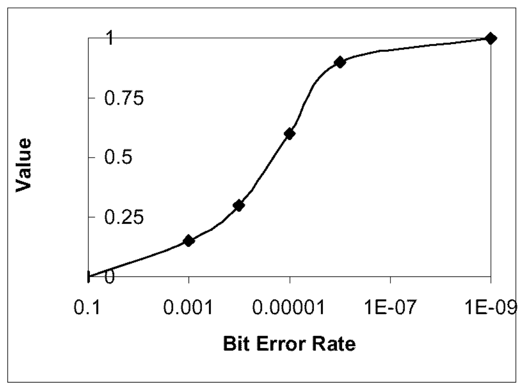
Mobility

Value	Percent Terminals Transportable
0	0
0.169	37.7
0.5	50
0.832	65.4
1	100



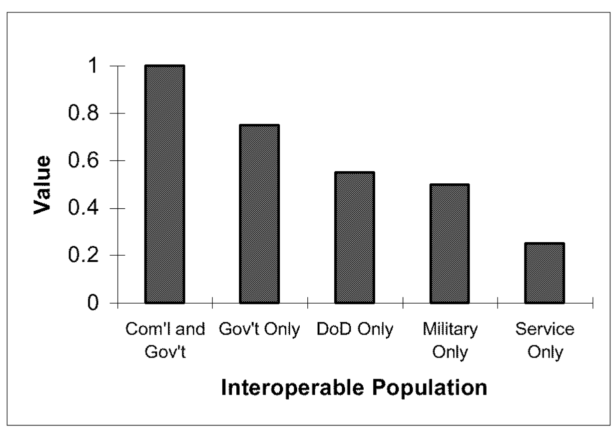
Errors / Intelligibility

Value	Bit Error Rate	Percent Intelligibility
0	0.1	50
0.15	0.001	75
0.3	0.0001	85
0.6	0.00001	90
0.9	0.000001	95
1	1.00E-09	100



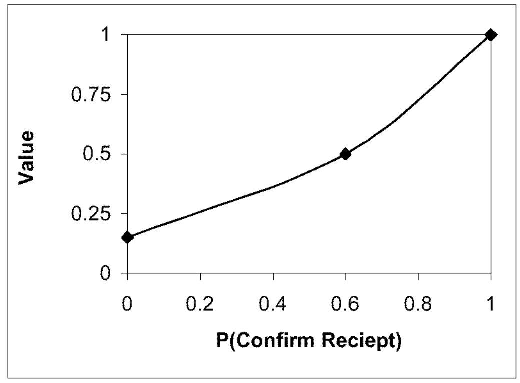
Interoperability

Value	Interoperable Population
1	Com'l and Gov't
0.75	Gov't Only
0.55	DoD Only
0.5	Military Only
0.25	Service Only



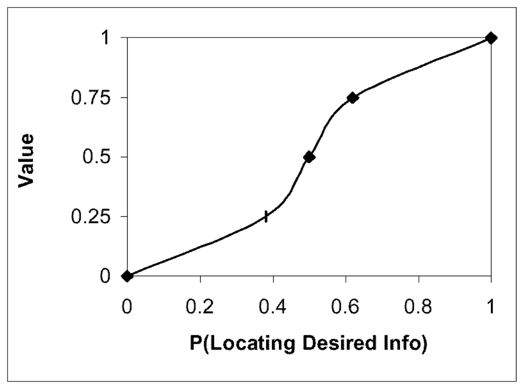
Confirm Receipt
(or Ability to Confirm)

Value	P(Confirm receipt)
0.15	0
0.5	0.6
1	1



Browse

Value	P(Locating Desired Info)
0	0
0.25	0.38
0.5	0.5
0.75	0.62
1	1.00E+00



Request

Value	P(Retrieving Requested Info)
0	0
0.25	0.38
0.5	0.5
0.75	0.62
1	1.00E+00

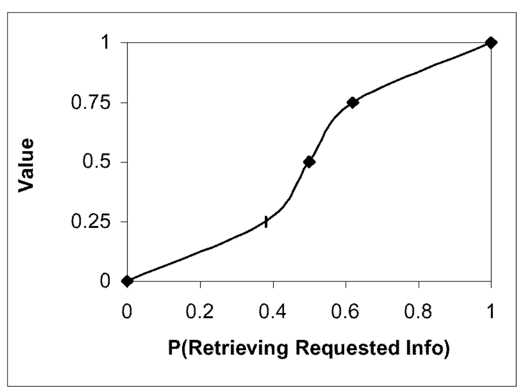


Figure 16. Value Scoring Functions for Architecture Access

Depending on the types of orbits and inclinations selected, **availability** of the new development system in the polar regions is likely to experience periodic low elevation angles, and at EHF/SHF frequencies in summer months, atmospheric attenuation may cause signal degradation and possible loss of satellite signal tracking. This periodic degradation may amount to 30 minutes per day in July and August, resulting in a value of 0.9 for the new system. The commercial system, operating in the UHF spectrum and with a much more populated satellite constellation, is not expected to encounter any significant outages and is assessed a value of 1.0.

Ease of operation for both architecture alternatives is likely to require a trained, enlisted operator. For the commercial system, this operator would administer the government secure communications gateway node into the commercial system; for the new development system, the user could not communicate with the satellite without interfacing through a ground terminal establishing the desired communication network. This terminal would require at least one trained operator, with an associated value of 0.75 for both architectures in information push and pull operations. The need for constellation maintenance and control operations from a ground station was not considered for this assessment.

Approximately 60 percent of the terminals for the new development alternative were assumed to be transportable; all of the commercial solution terminals were considered to be transportable. These assessments yielded **mobility** values of 0.80 and 1.0, respectively. These architecture assessments would obviously depend upon the percentage of transportable terminals in the current architecture; for this demonstration, all terminals in the current architecture were assumed to be transportable.

The **errors/intelligibility** assessment was based upon the frequency spectrum utilized by the respective architecture alternatives. The commercial system operates in the UHF band, which has very high signal survivability in most weather conditions; its bit error performance was rated very near 10^{-9}, with an associated value of 0.95. The new development (EHF/SHF) option assumes a potential for degradation due to rain and high humidity, and was assessed a slightly lower performance level (0.85). Of course, this weather effect is seasonal and most problematic in the mid-latitudes. The problem can be overcome by using larger antennae or higher output power from the satellites or terminals. Without the bad weather assumption, the new development option would score as high or higher than the commercial option.

Both alternatives were assessed to be fully **interoperable** with all government or commercial users who are likely to utilize the architecture, based upon adherence to common interface standards and non-proprietary signal and message structures. With full interoperability, values are assessed as 1.0.

The probability that a broadcaster could **confirm receipt** by the intended message recipient was assessed as very low (just above zero) for the new development system, due to the anticipated simplex architecture structure (similar to most non-interactive television or radio systems today). In contrast, the commercial alternative is based upon a duplex architecture, and the capability to verify receipt exists (probability equal to one).

For information pull, the ability to **browse** and locate desired information is similar to Internet browsing: the user searches databases to find and retrieve the desired information. If he is occasionally successful at retrieving desired information, the system is more useful than if it is rarely successful. For the new development case, the probability of the user finding and retrieving the desired information on a given attempt was assessed a probability of about 0.65. The commercial alternative probability of retrieval was assessed much lower, about 0.30, due to the potential classification and security interface problems between commercial and secure military systems. If the interfaces were perfected and transparent to operators, there would be little difference between the alternatives.

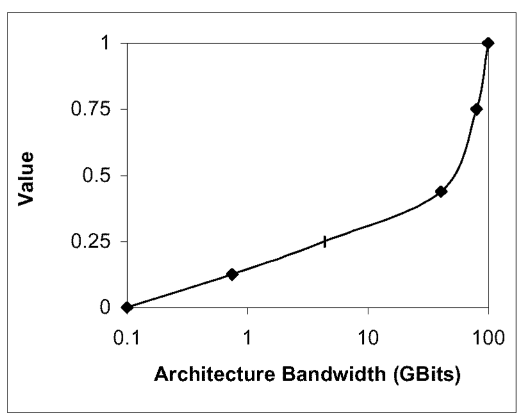
The ability to **request** and receive desired information is similar to the browse and retrieve function, except that the user must know and ask for specific information products, rather than browsing through menus. With the higher knowledge level, the probability of obtaining the desired information with the new development system is assessed much higher (probability of 0.90) than it was for the browse function. The commercial system lags the new development alternative for the same reason as the browse function, but is also rated higher (0.45) due to the higher knowledge level.

Architecture Capacity Scoring Summary

The four scoring functions for architecture capacity are depicted in Figure 17.

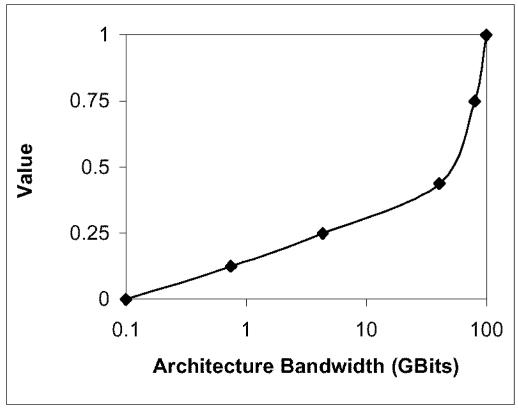
Present Simplex BW

Value	Architecture Bandwidth (GBits)
0	0.1
0.125	0.75
0.25	4.365158322
0.439	40.73802778
0.75	80
1	1.00E+02



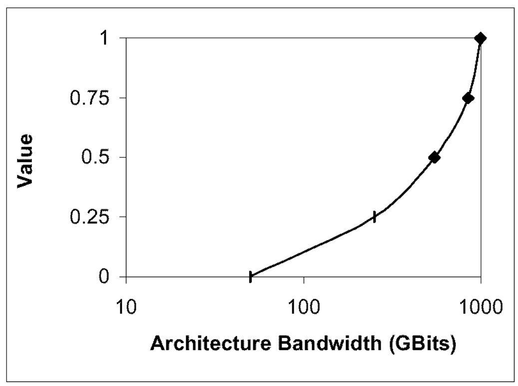
Present Duplex BW

Value	Architecture Bandwidth (GBits)
0	0.1
0.125	0.75
0.25	4.365158322
0.439	40.73802778
0.75	80
1	1.00E+02



Surge Simplex BW

Value	Architecture Bandwidth (GBits)
0	50
0.25	250
0.5	550
0.75	850
1	1.00E+03



Surge Duplex BW

Value	Architecture Bandwidth (GBits)
0	50
0.25	250
0.5	550
0.75	850
1	1.00E+03

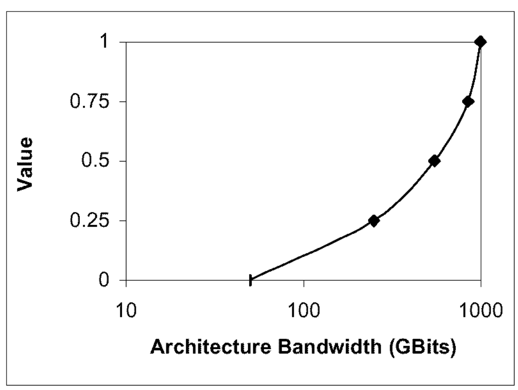


Figure 17. Value Scoring Functions for Architecture Capacity

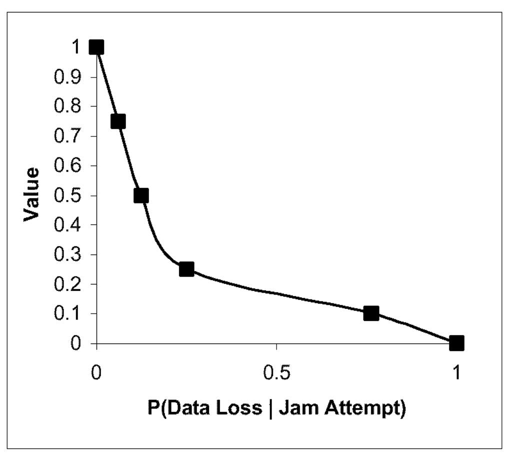
Both the commercial and new development alternatives are assessed to provide 100-gigabit **current bandwidth** capabilities in both **duplex** and **simplex** modes, yielding values of 1.0. This performance assumption is not based on any currently known system capabilities, and cannot be defended as a realistic assessment. Whatever performance baseline we choose for the "day to day" system, the value functions for growth or surge capabilities are based on the assumption that an order of magnitude increase will be required for both the simplex and duplex modes. In the case of surge capability, the new development system is assessed to have less growth potential than the commercial, due to the commercial architecture's inherent excess capacity. However, the commercial system's growth capacity is assessed to be slightly less for the simplex case than for the duplex, due to the likelihood that the system's duplex architecture has some limitation on the number of simplex circuit configurations available.

Architecture Security Scoring Summary

The six scoring functions for architecture security are depicted in Figure 18.

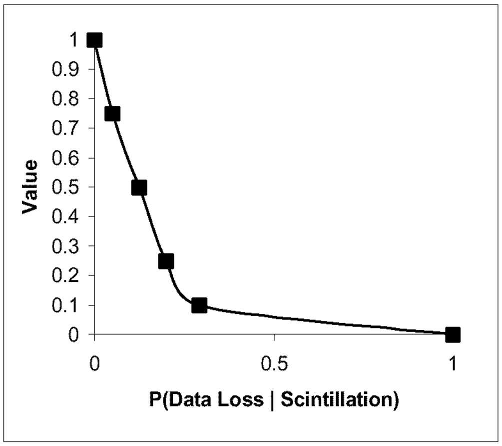
Jam Resistance

Value	P(Data Loss | Jam Attempt)
0	1
0.1	0.764
0.25	0.25
0.5	0.125
0.75	0.06
1	0



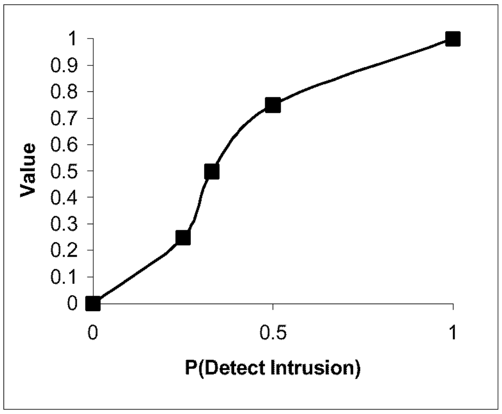
Scintillation Protection

Value	P(Data Loss | Scintillation)
0	1
0.1	0.293
0.25	0.2
0.5	0.125
0.75	0.05
1	0



ID Intrusion

Value	P(Detect Intrusion)
0	0
0.25	0.25
0.5	0.33
0.75	0.5
1	1



Authenticate Sender

Value	P(Authenticate)
0	0
0.25	0.66
0.5	0.828
0.75	0.92
1	1

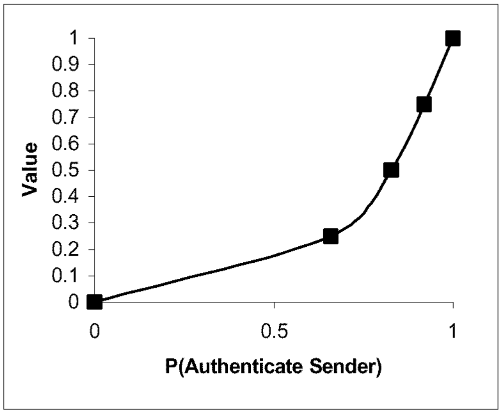


Figure 18. Value Scoring Functions for Architecture Security

The **jam resistance** of the new development system is assumed to be more robust than that of the notional commercial system due to its higher frequency and narrow bandwidth. An adversary would have to use a high power, wideband jamming system in close proximity to the receiver or transmitter to have a reasonable probability of jamming the EHF/SHF system. The commercial system, due to its less robust signal structure, would have a much higher probability of being jammed given a jam attempt by an adversary. These probabilities yield associated values of 0.85 and 0.15, respectively.

The likelihood that **scintillation** would disrupt communications is again a factor of frequency and digital signal structure. The EHF/SHF system is much less prone to atmospheric and nuclear scintillation, especially with the digital techniques employed in current strategic systems. The UHF commercial system may employ reasonable signal protection measures, but still be affected by virtue of its location in the frequency spectrum. These assumptions yield values of 0.95 for the new development and 0.05 for the commercial architectures.

The ability of the architecture to **identify intrusion** is imperative in modern scenarios. The commercial system is assumed to be able to detect an intrusion attempt in one out of four cases, with an associated value of 0.25. The new development system could be expected to recognize intrusion attempts seventy percent of the time, equivalent to a value of 0.85. These performance assessments are not based on any factual system data.

The probability that either architecture can **authenticate** a sender's identity is expected to be very high, near 0.95. This performance level equates to a value of 0.9 for both the commercial and new development architectures.

Similarly, the probability that both systems can **validate** the message content as being complete and unaltered should be very high, also about 0.95. This probability correlates to a value of 0.9 for both alternatives.

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