13th ICCRTS
"C2 for Complex Endeavors"

Title of Paper: A Useful Methodology for Cost-Benefit Evaluations of Cognitive Process Improvements in Complex C2 Endeavors

Topic(s):

1. C2 Concepts, Theory and Policy
2. Assessment Tools and Metrics
3. Cognitive and Social Issues

Name of Author(s):
Edmundo O. Acosta, PhD
Wesley L. Nolden, II, PhD
Thomas V. Gross, MA

Point of Contact: Edmundo O. Acosta, PhD

Name of Organization: Air Mobility Command

Complete Address:
Edmundo O. Acosta, PhD
HQ AMC/A3RB
402 Scott Drive
Unit 3A1
Scott AFB IL 62225

Telephone: (618) 229 4697

E-mail Address: edmundo.acosta@scott.af.mil

A Useful Methodology for Cost-Benefit Evaluations of Cognitive Process Improvements in Complex Command and Control (C2) Endeavors

Edmundo O. Acosta, Ph.D., Wes Nolden, Ph.D., and Tom Gross, M.A.

ABSTRACT

Proposed solutions to identified C2 gaps can be at a disadvantage in the fierce competition for scarce dollars because they are often considered "soft" benefits (*e.g.*, augmenting human cognition to improve performance). This paper describes a straightforward method to quantify and express "soft" benefits in monetary terms. Within a conventional cost-benefit structure, the proposed approach offers a tool to demonstrate "soft" cognitive improvements in "hard" dollars.

This methodology is in use to quantify soft benefits of the Work-Centered Interfaced Distributed Environment (WIDE), a proposed enhancement to the Global Decision Support System. Evaluative experiments (specific to WIDE) demonstrate soft cognitive improvements in measurable values. These metrics are then transformed into dollar values, and incorporated into the benefits portion of the cost-benefit structure. In addition, other potential soft benefits from WIDE are quantified and monetized through cost-estimating techniques. Cost-Benefit Ratios and Return-on-Investment calculations are easily generated.

This cost-benefit approach is a tool for advocates to (1) frame discussions of C2 solutions, (2) produce quantified responses to "what-if" challenges, and (3) to argue for the funding of "soft" proposals in "hard" dollar terms

Introduction

Capabilities based planning (CBP) is the process of looking at operations and acquisition in light of desired military effects. It means that the desired military effects of an operation or mission are considered first and then the capabilities required to achieve those effects are reviewed and analyzed. It is a strategy to task, top-down approach to developing required capabilities to support the achievement of desired Joint warfighting effects.

The functional analysis to achieve the CBP goals is comprised of three major components. First is the Functional Area Analysis (FAA) which identified operational tasks, conditions, and standards needed to accomplish the required military objectives defined by needed capabilities.(1) Once these capabilities have been identified and set down in a capabilities list, the process moves to the Functional Needs Analysis (FNA).(2) The FNA assesses the ability of current and programmed capabilities to accomplish the tasks and identifies any deficiencies. Finally, the Functional Solutions Analysis (FSA) uses an operationally based assessment of doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) approach to solve the identified capability gaps or deficiencies. It is within the FSA that a cost benefit evaluation is accomplished. As part of

the CBP process, the cost benefit evaluation allows decision makers to evaluate a proposed solution to an identified capability deficiency with an eye toward achieving capability goals that provide the greatest return on investment.

Within the C2 realm, many of the solutions are what may be called "soft" solutions. The reason they are called "soft" is because often the improvements are in time efficiency, behavioral improvements, and other areas of work that are less easily measured than, say, the efficiency of a new aircraft engine. Combined with appropriate investigative measurement, cost benefit evaluations can provide solid rationale for C2 system investment by presenting the financial case for "soft" solutions. This paper will present WIDE and the Global Response and Synchronization (GRS) application as technologies that improve C2 operator performance in areas that could be called "soft" solutions. Evaluation of these improvements provides data for economic analysis that reinforces this particular technology as a positive solution for current mobility C2 shortfalls.

Discussion

Overview of the WIDE and GRS Applications:

WIDE provides individual and distributed team work-centered user interface clients that support mobility operations with special emphasis on collaboration across functional and supervisory positions. The goal is to increase situational awareness during mission planning and execution to allow the team to self-synchronize and ensure a highly coordinated effort. GRS provides functionality that directly supports WIDE and enables it to operate in its most effective fashion. Therefore, for the rest of this paper the authors will often refer to WIDE/GRS as a combined solution since the estimated economic benefits were calculated based on both applications being transitioned together.

WIDE/GRS has been developed in three spirals, two of which have already been presented to Air Mobility Command (AMC). GRS will be included as part of the third Spiral. During Spiral 1, the Air Force Research Laboratory (AFRL) developed and demonstrated within WIDE mission and sortie timeline displays using the emerging Work-Centered Support System (WCSS) cognitive-based analysis and user interface design approach. Interviews and observations of Tanker Airlift Control Center (TACC) personnel (Seniors, Duty Officers, Deputy Directors of Operations, Controllers, and Mission Planners) were used to provide an understanding of the cognitive work involved in mission planning and execution. The cognitive decision making requirements were analyzed to determine efficient visual representations for monitoring and replanning work. In the timeline displays, views of the missions, sorties, and their resource constraints were visually mapped to a common timescale that is updated with real-time Mobility Air Forces (MAF) mission, location, and resource, data. Intelligent agents were used to demonstrate automation assistance in mission planning and execution situational awareness. Intelligent agents used business rules for monitoring the data for factors that may affect the mission plan and alert the operator to exceptions through the visualization. Mission execution personnel are alerted to problems in context and are able to see the factors affecting mission viability and offer possible solutions. They are able to perform "what-if" simulations to identify the repercussions of any changes to the mission plan.

Spiral 2 built upon the Spiral 1 functionalities and used the WCSS approach to develop and demonstrate work-centered visualizations to support dynamic aircraft reallocation decisions. These are decisions associated with the in-system select where the TACC operators must select a resource to save a mission. An enhanced Spiral 1 functionality was developed to determine the best choice while minimizing the ramifications of AMC's overall operations.

Spiral 3 has most recently been demonstrated at AMC and continues to build on the first two spirals and use the WCSS approach to develop and demonstrate work-centered visualizations to support dynamic resource reallocation decisions across multiple missions. Spiral 3 will support replanning multiple missions simultaneously and provide visualizations to analyze the impact of the many changes permeated through the overall plan.

Human Factors in C2:

To more fully understand why WIDE is so effective and presents such a radical improvement in C2 capability it is important to understand why human factors consideration is so vital. The following discusses the underlying cognitive processes for much of C2 and suggests that assistance with these processes is critical to effective C2 activity.

Situational awareness (SA), attention span, working memory, workload, and critical errors are all aspects of human cognition, behavior, and information processing that play important and complex roles in C2 operations. For example, each of the three levels of situational awareness: perception, comprehension, and projection are directly and dynamically involved in the C2 operator's environment. Referred to in three levels, SA is key to the operator's successful mission control.

Level 1 SA involves seeing the relevant data. It simply means the operator is looking at what is most appropriate. (3)

Level 2 SA involved the ability of the operator to understand, or adequately comprehend what is being presented. (4)

Level 3 involves the ability to look forward with the ability to understand the future situation and its consequences. (5)

Working multiple global missions at once, the C2 operator must be able to form an accurate picture of what is happening with each mission, understand this information, and determine how it relates to the mission plans, and also be able to anticipate problems, or other critical future events that could negatively affect the success of one or more missions. This is quite challenging in the C2 operator's environment which is replete with almost constant distractions that present challenges to attention span and working memory. The result of this high cognitive workload environment is often decision errors that cause significant problems with mission progress and success. Any technology that will improve

situational awareness, enhance attention span and working memory, decrease actual and perceived workload, as well as reduce critical errors will dramatically improve mission success and, it is assumed, reduce cost and save money. The question is how does one prove it? How does one connect the dots from improvement in cognitive behavior and financial benefits realized from that improvement? One begins with the research on behaviors which demonstrates improvement with the new technology.

AFRL Evaluation Research on WIDE:

Evaluation of WIDE Spiral 1 was accomplished by Dr. Emilie Roth and a team of behavioral scientists working with AFRL (7). For Dr. Roth and her colleagues, a key objective of a work-centered evaluation was to assess whether the proposed design concepts, as embodied in the prototype, have the positive effects predicted by the system developers (i.e., to evaluate the hypothesized model of support). The specific anticipated benefits being analyzed included:

a. A decrease in time to recognize impacts of mission changes during execution.

b. A decreased number of errors in replanned missions in execution.

The evaluation tested these hypothesized benefits by comparing performance of execution cell personnel in the TACC using the timeline with their performance using their current legacy system on comparable scenarios. The key performance parameter success criteria to be established by the evaluation were:

a. User acceptance (via post-test questionnaire): 60% participant acceptance established as a minimum requirement, 90% as the objective.

b. Improved mission-related SA: Level 2 SA (comprehension of the current situation) was established as a minimum requirement. Level 3 SA (the ability to project impact on future sorties and missions) was established as the objective.

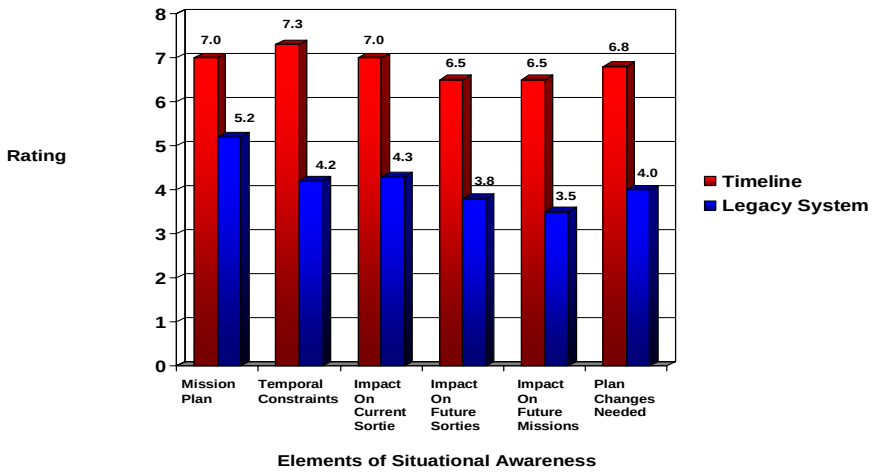
The study participants consisted of twelve experienced members of the execution cell within the TACC, which is AMC's global C2 management facility. These participants were given several scenarios using both their legacy system or WIDE. There were two phases in the test scenarios:

a. An "initial call" which highlighted aspects of a mission problem. Subjects were asked to evaluate the repercussions, or "broken glass" resulting from, the problem. The term "broken glass" refers to problems with additional missions that would possibly result from a solution.

b. Subjects were given a proposed solution and asked to evaluate whether the recommended solution eliminated the problem(s), or perhaps introduced new difficulties to the current problem set (broken glass).

Following each condition, the subjects completed a National Aeronautics and Space Administration (NASA) Task Load Index (TLX) workload rating form and an SA self-report rating form for that test condition.

The results demonstrated statistically significant improvements in response time between the existing legacy system and the WIDE timeline. Errors were also found to be reduced with WIDE vice the legacy system. Mean SA ratings were higher for WIDE than the legacy system and included some Level 3 SA. Additionally, WIDE exceeded the established key performance parameters objectives. 90% of the users found WIDE acceptable and agreed it improved Level 3 SA. Finally, perceived workload was lower at a statistically significant level with WIDE as opposed to the legacy system. The graph below highlights the results of the improvements in SA.



For the evaluation of WIDE Spiral 2, Dr. Roth and her team focused on a more complex cognitive problem: reallocation of aircraft to support real-time dynamic replanning of missions. Projected benefits for Spiral 2 included:

a. Increased SA for viable courses of action (COAs) for short notice missions.
b. Increased effective resource allocation decisions.
c. Minimize the negative impacts of reallocation decisions ("broken glass").

Similar protocols were followed for the Spiral 2 research including subjects using both the legacy system and the WIDE Resource Candidate (ReCaD) displays (8). The results demonstrated 100% of the subjects rated ReCaD as acceptable (objective was 60% as minimum and 90% as objective). Improvements in situational awareness and decision quality were documented as was a positive impact on a variety of C2 operator positions within the TACC.

Importance of Measuring "Soft" Benefits:

While one may intuit that improvement in these cognitive processes associated with C2 operations will produce benefits, actual measurement demonstrates the validity of this assumption. However, in today's fiscally constrained environment one must go beyond demonstration of these benefits to adequately justify acquisition consideration and investment.

Connecting the Operational and Fiscal Dots:

In order to prove the financial benefit of acquiring a technology that demonstrates the above-mentioned human cognitive and mission-related improvements, there are challenges that need to be overcome. While there are identified, plausible benefits from WIDE timeline functionality, they are improvements in areas such as situational awareness and reduced critical errors. Even though these improvements are definitely important and speak directly to C2 needs that were identified in the MAF C2 FNA, they are difficult to quantify from a cost/benefit perspective.

In many other areas, benefits are more easily calculated because they result from what might be called "hard improvements." For example, a cost/benefit calculation might be done on a new jet engine to determine the financial benefit received from improved fuel economy. The engine can be tested and the improvement in terms of reduced fuel use documented in hard numbers. Thus, a cost/benefit calculation is rather simple because the demonstrated benefit is easily seen via the test of equipment and is presented in numbers resulting from the engine test. In the case of C2 benefits, the improvements are not always immediately evident. How, for example, does improvement in situational awareness translate into dollars saved? This was the challenge faced by the investigators.

In order to perform a cost/benefit calculation on WIDE/GRS functionality, "soft" improvements from this functionality must be identified. This identification was realized from analysis of the capabilities needs, i.e., what the MAF should be doing better and its importance, and how documented improvements to such things as situational awareness related to the capabilities/needs. The source for these improvements was the above-mentioned study by Dr. Roth. Each of the areas which WIDE/GRS functionality was found to improve could be translated into some dollar savings. For example, the ability for mission managers to retask aircraft more quickly can result in more efficient tasking and fewer delays according to subject matter experts (SMEs) who were interviewed for the cost benefit evaluation. This can be translated into actual dollars per flying hour saved assuming eliminating or mediating one delay can result in the savings of one flying hour (as projected by SMEs). Using this type of premise, soft improvements can be translated into dollar cost savings or cost avoidance.

Unfortunately, no objective research evidence is known to be available which will validate these assumptions beyond SME inputs. it argues for additional research to be done concerning how efficiencies in planning and execution can positively affect airlift mission success.

The benefits and costs of the proposed WIDE/GRS solution were systematically identified and roughly quantified in dollar terms. An organizing structure was prepared to display and compare the dollar benefits and costs throughout an eight year period. This structure allows for the calculation of Benefit/Cost (B/C) ratios and Return on Investment (ROI) values.

Case Study: A Tailored Cost-Benefit Approach

Purpose of the Cost-Benefit Calculation:

Within the CBP C2 community, WIDE/GRS functionality has been identified as a promising candidate solution for improving mission planning and management activities. Before any cost-benefit calculations were done, consensus impressions were that WIDE functionality would offer significantly better situational awareness, and thus lead to better performance in areas such as decision-making, coordination, and synchronization.

The main purpose of the cost-benefit calculation was to evaluate these consensus impressions, by specifying and quantifying the expected impacts of WIDE/GRS, in dollar terms. Does WIDE/GRS make financial sense, consistent with expected improvements in "situational awareness"? At each round of quick and rough calculations, WIDE/GRS showed impressive positive dollar impacts. The consensus impressions were reinforced, in financial terms.

Conventional Cost-Benefit Evaluations:

Even though WIDE/GRS poses various "soft" benefits, conventional cost-benefit practices provide a useful structure for systematically presenting costs and benefits. Once specified and captured, the calculations are mostly straight-forward. At a generic level, the structure includes four blocs, to display information about the:

Period of Performance
Costs
Benefits
Summary Calculations.

Of course, nuances such as discounting and present value, along with the selection of inflation factors, play important roles in formal cost-benefit analyses (also known as economic analysis). This paper, however, deals with the "first cut" version of the study. Its emphasis is on how we managed to specify the ethereal benefits more concretely, which allowed us to quantify impacts in conventional dollar terms.

The use of the conventional cost-benefit structure also provides a template for other users who face similar problems in advocating proposed solutions which are characterized by "soft" benefits.

Unique, Tailored Features of this Calculation:

At least two features make this study somewhat unusual. First, a brainstormed list was the essential step to eventually specify three "soft" benefits (to Mission Managers, to Tails during Operations, and to Aerial Port Activities). Second, results from experiments (using an early version of WIDE/GRS, with actual mission planners and managers) provided data to help quantify WIDE/GRS's impacts on behavior and performance.

Mission Managers -- Specifying the benefits enough to quantify their impacts was the first major issue. The technique of brainstorming an extensive listing of potentially positive impacts was used. Close scrutiny of the list indicated that most of the benefits were associated with a particular set of activities… by mission managers! It became apparent that WIDE/GRS could provide mission managers with solutions much more quickly than the mission managers could generate manually (as in the status quo). This specified the type of benefit more concretely, and allowed for gathering estimates for the amount of time that WIDE/GRS would save for each activity. Along with data and assumptions regarding frequencies of occurrence of the activities, and estimates of the time costs of mission managers, "soft" benefits were credibly quantified into dollar terms. These savings of hours and minutes on individual activities grow to large dollar impacts when multiplied by the approximately 60,000 missions that AMC has flown annually in recent years.

Tails, during Operations -- Discussions around the brainstormed list led easily to the possibility that improved planning and mission management through "soft" WIDE/GRS benefits could prevent at least some delays! This resultant benefit was specified as "Tails, during Missions." Tails and Flying Hours could be saved. With data and assumptions about frequencies of delays, and costs of Flying Hours, large dollar savings again result from the many missions flown each year.

Aerial Port Activities -- Similarly, personnel and expensive Materiel Handling Equipment (MHEs) at Aerial Ports can also be managed more effectively.(9) Idle time waiting to unload/load unexpectedly late aircraft is reduced by WIDE/GRS's improvements to the retasking activity (thus, fewer late arrivals). With Halverson MHEs ($640,000 each) and Tunners ($1.7 million), and multiple personnel assigned per load event, idle time is expensive (and quantifiable). The authors suggest that even more dollar savings could be calculated.

Sources -- After "soft" benefits are identified and specified more concretely (as above), a following task for the analyst (and proponents) is to get answers to the question, "So what?" In terms of time or dollars, how much impact does a proposed solution like WIDE/GRS have? A numerical value is called for, preferably in terms of time and/or dollars (or $/Hr). Credible numerical values of a proposed solution's positive impacts can provide powerful rationale for acquiring the solution. Conventional sources include historical data, analogy, inputs from Subject Matter Experts (SMEs), and placeholder guesstimates. Data values from any of these usual source types can be valuable and persuasive.

WIDE/GRS developers (AFRL) delivered an extraordinary source of data values. They conducted surveys of performances by mission managers…*with* a prototype WIDE vs. *without* WIDE. The results demonstrated impressive improvements *with* WIDE. Response times were quicker, critical errors were fewer, situational awareness was greater, and perceived workloads lower. These results were consistent with data values that were gleaned from historical data and from SMEs. These fortuitous experimental findings reinforce the credibility of SME input values, and thus confidence in the calculations.

Calculation Results:

Actual values of inputs and results are not included in this paper. However, the dummy values do represent the relationships and conclusions of the calculations.

Costs to transition/implement WIDE/GRS were expectably frontloaded, and relatively low because it is an application to be incorporated into an existing system. A risk area, as usual, lies in the integration of the necessary data exchanges. Development and procurement costs are borne by AFRL, and thus not included in the Cost-Benefit calculations.

The three types of benefits yield positive time and dollar impacts from the first year, and depend on the number of sorties/missions flown. Because of the numerous missions, the dollar value of benefits overwhelms costs almost immediately, and continues to dominate throughout the period of performance.

The consistently favorable benefit-to-cost ratios presented (with representative dummy values) begin at more than 1 in the first year, and soon increase to more than 30. The Return on Investment values (net accumulated benefits) also surge in year 3, and likewise climb to over 30. WIDE/GRS clearly appears to make solid financial sense.

Afterwords

More Benefits are Out There -- We noticed that there were additional benefits to be had beyond those in the three categories (to Mission Managers, to Tails during Operations, and to Aerial Port Activities) that we initially specified and quantified. Further reductions in errors, delays and in time requirements might be achieved in several more areas. Crew Management (and Availability), for example, would benefit from fewer delays in operations. Even customers might benefit, by the lessening of Customer Wait Times (again, through WIDE-enabled fewer delays). The dollar value of Fuel Savings (fewer Flying Hours, from fewer diverts or delays) can be quantified and highlighted. Each of these additional types of benefits is quantifiable, and is a candidate to be included in future versions of cost-benefits for this and other C2 solutions.

A particularly expected valuable benefit from WIDE/GRS lies in its capability to immediately generate and present “broken glass” (*i.e.*, the multiple delays or cancellations of other missions which result from an initial retasking). Thus, Mission Managers will be able to see and evaluate the secondary and tertiary impacts of alternative retasking choices. Future benefit-cost calculations will address the enormous dollar implications of “broken

glass." All C2 operators are now able to handle increased numbers of missions that are of more significant complexity than they were able to effectively manage in the past.

Benefits Already Addressed:

Mission Managers
Tails, during Operations
Aerial Port Activities

Candidate Benefits for Future Inclusion:

Crew Management & Availability
"Broken Glass"
Customer Wait Time
Fuel Savings

Other Benefits Possible with Additional Research – This paper has thus far mainly discussed benefits that are reactionary in nature. That is, they are obvious results of changes in user behavior as a result of the introduction of a technology that supports their cognitive work. Given the improvements that have been documented via AFRL's research, it would lead one to consider how the C2 process could be affected by the introduction of a technology that improves the operator's ability to handle work of more significant cognitive complexity.

C2 capabilities and processes have been suggested in MAJCOM and Air Force Master Capabilities Lists based on current technology and a human - computer interface that has not kept pace with research into technologies that enhance the cognitive aspects of work. It is worth consideration for research to be done that would investigate how C2 processes could be improved based on the technological improvements in the human - computer interface. For example, can planning tasks be expanded based on a system's ability to support the planner? Is it possible to erase the planning/execution gap and make the actions seamless as they transfer one to another? Can strategic level planning be expanded to include collaboration between actors in real time that would result in a strategic level planning document that could immediately be morphed into operational and tactical plans? These questions and other should be considered for additional research opportunities.

This Approach is Do-able by Others -- Future Cost-Benefits exercises for C2 solutions may be carried out by any proponent. A rough, quick, initial version may use the standard template, and the "list" approach to specifying "soft" benefits. Finally, quantification in dollar terms is accomplished through data (especially time and $/Hr), SME inputs, and experimental results (if available). Please let us know what you find.

References

1. Office of Aerospace Studies (2005). Functional Solution Analysis Handbook. Office of Aerospace Studies, Air Force Materiel Command, Kirtland AFB, NM.

2. Ibid.

3. Ibid.

4. Endsley, M.R. (1995). Toward a Theory of Situation Awareness. *Human Factors*, 37(1), pp. 32-64.

5. Ibid.

6. Ibid.

7. Roth, Emilie., Stilson, Mona.,Scott, Ronald., Whitaker, Randall., Kazmierczak, Tom., Thomas-Meyers, Gina., and Wampler, Jeffrey (2005). Work-Centered Design and Evaluation of a C2 Visualization Aid.

8. The primary purpose for the Resource Candidate Displays (ReCaD) is to improve the ability of operators managing mission execution to perform dynamic replanning in support of short notice requirements. The planner or person in execution will use new search functions and displays that include a tabular presentation of possible aircraft resources (resource candidates). It includes a coordinated map showing the geographic location of possible aircraft tails and an expanded Multi-Mission Detail Timeline visualization that enables individuals to examine mission details and explore the ramifications of redirecting resources to support the short notice requirement.

9. Materiel handling equipment (MHE) refers to the family of large wheeled vehicles which are used for the movement and storage of materiel within a facility or a site. MHE range in size and capacity from a wheeled pry-bar used to lift one side of a 100 lb. box all the way up to the 25,000 pound capacity (Halvorsen) and 60,000 pound capacity (Tunner) cargo loaders. These loaders are used to transport cargo between aircraft and storage/staging areas and are the primary method of loading and unloading cargo aboard a variety of AMC aircraft and AMC-contracted commercial aircraft. Both loaders are

capable of transporting a variety of types of cargo including palletized cargo, shipping containers, airdrop platforms, and rolling stock (e.g., vehicles, carts, etc.). Both loaders are also designed to be transported by air on C-5 and C-17 aircraft and can be moved be surface on a truck, rail or ocean vessel. (Tom Gross, SME at HQ AMC/A3R; 14 March 2008.)

GLOSSARY

AFRL	Air Force Research Laboratory
AMC	Air Mobility Command
B/C	Benefit/Cost
C2	Command and Control
CBP	Capabilities Based Planning
COA	Course of Action
DOTMLPF	Doctrine, Organization, Training, Leadership, Policy, and Facilities
FAA	Functional Area Analysis
FNA	Functional Needs Analysis
FSA	Functional Solutions Analysis
MAF	Mobility Air Forces
MHE	Materiel Handling Equipment
NASA	National Aeronautics and Space Administration
ReCad	Resource Candidate Displays
ROI	Return on Investment
SA	Situational Awareness
SME	Subject Matter Expert
TACC	Tanker Airlift Control Center
TLX	Task Load Index
WCSS	Work-Centered Support System
WIDE	Work-Centered Interface Distributed Environment