AN ANALYTICAL TOOL TO ASSESS
AEROMEDICAL SYSTEMS
FOR THE DEPARTMENT OF DEFENSE

THESIS

Scott A. Wilhelm, Major, USAF

AFIT/GOR/ENS/98M-27

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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AN ANALYTICAL TOOL TO ASSESS AEROMEDICAL EVACUATION SYSTEMS FOR THE DEPARTMENT OF DEFENSE

THESIS

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Scott A. Wilhelm, B.S., M.S.

Major, USAF

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AN ANALYTICAL TOOL TO ASSESS AEROMEDICAL EVACUATION SYSTEMS FOR THE DEPARTMENT OF DEFENSE

Scott A Wilhelm, B.S., M.S.
Major, USAF

Approved:

Lt Col Jack A Jackson, Jr. - Advisor
Assistant Professor of Operations Research
Air Force Institute of Technology

16 Mar 98
date

Dr William Cunningham - Reader
Associate Professor of Logistics Management
Air Force Institute of Technology

date

PREFACE

The results of this research will be reaccomplished for the decision-maker. As of this writing, updated data on modifications and costs, is expected from engineers assigned to assist me on this project. However, I don't expect this data to alter the conclusions reached.

Value-Focused Thinking is but one aspect of Decision Analysis (DA). The true value of this discipline is its applicability to everyday life. Individuals who can internalize the concepts of DA will make better decisions. Period. Isn't that the purpose of Operations Research?

I'd like to thank some people that made my efforts at AFIT, and in life, a success:

- my father, Jerry Wilhelm, whom I'm still proud to call my hero;
- my mother Christa Wilhelm, who may just possibly be the best human being on the planet;
- my wife Tracee, who is the personification of my heart and soul; and
- my sons Alex and Ian, who have already made my time on this world a success.

I'd also like to acknowledge the invaluable assistance of my thesis committee, Lt Col Jack Jackson and Dr. William Cunningham. I wanted the ball to run with it, and they gave it to me. I think I did a good job with it and hope you agree.

Finally, I would like to acknowledge some of my peers. Jeff, Gene, Tom, Dave, Tim, and Thuan made up possibly the most unique and impressive study group ever created at AFIT. I wouldn't have survived the first term without them. To John, Don, Tom, Joe, Dan, and Larry, my comrades-in-arms from the "Barney Wars": Adversity provides the true test of your character. You all passed with flying colors.

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Abstract

The research was commissioned by, and conducted for, the HQ AMC Surgeon General to assist him in making a hard decision. Should the McDonnell-Douglas C-9A Nightingale be replaced, and, if so, with what? Using tools based in Keeney's Value-Focused Thinking methodology, the SG's values for this decision were quantified, alternatives that addressed these values were generated, and those alternatives were evaluated using his values to suggest preferred alternatives.

An Analytical Tool to Assess Aeromedical Evacuation Systems for the DOD

I. Introduction

1.1 Statement of the Problem

The Air Mobility Command Surgeon General (HQ AMC/SG), commissioner of this study and the ultimate decision-maker, directed the evaluation of all potential methods of meeting Department of Defense (DOD) theater aeromedical evacuation requirements. A planning horizon for the study was set at 2010.

1.2 Background

Department of Defense Instruction (DODI) 6000.11 (1993:3) directs that the Commander in Chief, United States Transportation Command (USCINCTRANS) shall, in coordination with the Assistant Secretaries of Defense (SECDEF) for Force Management and Personnel and for Health Affairs,

> ...establish a global network system to assist in the command and control of intertheater medical regulating and aeromedical evacuation (AE) and offer in-transit visibility of Uniformed Services' patients in both peace and

> contingency (military and civilian) operations. That system shall integrate the processes and ISS [information support systems] for medical regulating, the assignment of AE aircraft, and the assignment of AE medical crews and equipment to aid in the seamless intertheater movement of patients. That centralized global system shall include CONUS and other active theaters and shall offer decentralized execution, to the supported geographic Unified and Specified Commands, in both peacetime and contingency (military and civilian) operations.

Joint Pub 4-02 (1995:I-4) , "Doctrine for Health Services Support in Joint Operations," is even more specific, assigning responsibility for patient aeromedical evacuation from the theater directly to USCINCTRANS and the mission to Air Mobility Command (AMC). Additionally, the supporting Air Force component is tasked to provide tactical, or theater, aeromedical evacuation from the combat zone. This translates into an AMC requirement to provide aeromedical evacuation capability on both a tactical and strategic, or inter-theater, level.

Currently, AMC accomplishes this mission through the use of several assets, used in conjunction:

- *McDonnell Douglas C-9A Nightingale*. The C-9 is the only air asset dedicated to the AE mission.

- *Civil Reserve Air Fleet (CRAF)*. CRAF assets augment military airlift during war/contingency. The Boeing 767 provides AE support through the CRAF.

- *Retrograde airlift*. Non-dedicated airlift assets are used as available to supplement the AE role. Primarily the C-130 is used at the tactical level, and the C-141 and C-17 at the strategic level.

1.3 Research Objectives

The objective of this thesis is to recommend to HQ AMC/SG the best option for meeting theater AE requirements by:

- Thoroughly identifying HQ AMC/SG value objectives;
- Identifying evaluation measures (EM) for assessing objective attainment;
- Generating alternatives to obtain these objectives;
- Assessing each alternative's effectiveness in meeting objectives by scoring each evaluation measure;
- Recommending an alternative, based upon HQ AMC/SG guidance and assumptions; and
- Conducting sensitivity analysis to determine how changes in requirements and assumptions affect that recommendation.

1.4 Thesis Overview

Chapters II and III review the literature relevant to this study. This includes official policies and directives within the Department of Defense on aeromedical evacuation, and the theories of decision analysis and value focus thinking.

Chapter IV addresses the methodology used in this study and presents the decision analysis model created, using this methodology, to analyze the AE problem.

Chapter V presents the results of the model, and discusses possible changes in these results identified through sensitivity analysis of the study's requirements and assumptions.

Chapter VI introduces cost into the model and the methodology, and Chapter VII presents updated results and a cost-benefit analysis.

Chapter VIII provides specific conclusions and recommendations to HQ AMC/SG, and suggests future research based upon analysis results.

Numerous appendices display more detailed information on a variety of topics.

II. A Review of the Literature Pt. 1

2.1 C-9A Roadmap

The 1997 Air Mobility Master Plan (AMC, 1997) identified two deficiencies that will significantly impact the long-term viability of the C-9A Nightingale as the primary dedicated theater aeromedical asset. These deficiencies were the current avionics package will not meet planned Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) navigation and separation standards, and an eroding logistics support base due to the retirement of DC-9s by civil carriers worldwide.

AMC's short-term plan is to upgrade the C-9A with such systems as the Global Positioning System (GPS) and the Traffic Collision Avoidance System (TCAS) to ensure continued access to optimum airspace. However, its long-term plan is to obtain a follow-on commercial derivative for the aeromedical role, while preparing to field non-developmental aircraft in the event that the civil logistics support structure inhibits mission capability. This research is the initial study in determining a follow-on aircraft.

2.2 Health Service Support

The mission of Health Service Support (HSS) is not just one of compassion; it serves a true warfighting role. By minimizing the effects of injuries and disease on unit effectiveness, HSS preserves the combatant commander's warfighting capability on land, sea and air. HSS accomplishes its mission through phased levels of health care, and a proactive patient movement system between those levels (Joint Pub 4-02, 1995:v, Joint Pub 4-02.2, 1996:v). The levels, or echelons, of care are:

Echelon I: Care administered at unit level; includes self-aid, buddy care and emergency life-saving measure.

Echelon II: Care administered by HSS personnel.

Echelon III: Clinical care administered in a medical treatment facility (MTF).

Echelon IV: Recovery phase care.

Echelon V: Convalescent and rehabilitative care provided in CONUS.

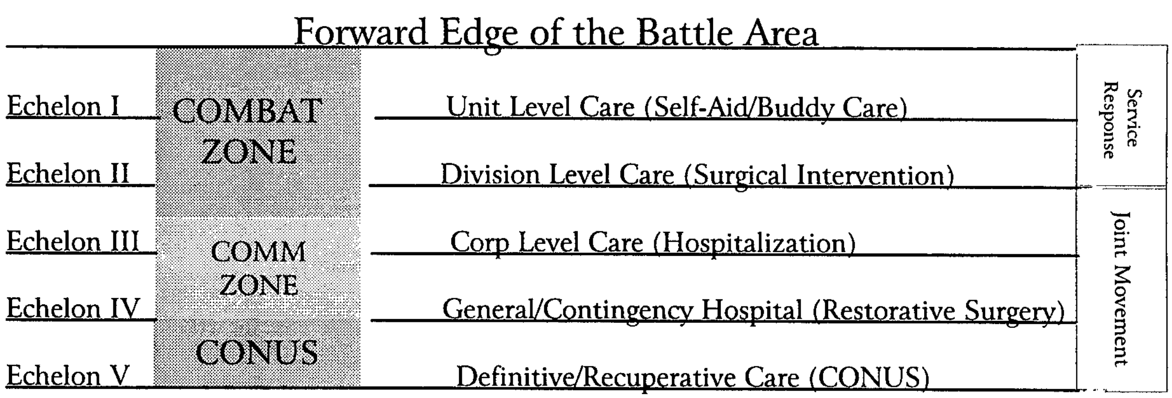

Figure 2-1 Echelons of Care

Notice in Figure 2-1 that echelons of care do not necessarily coincide with the three Operations Zones defined below: the Combat Zone, Communication Zone, and CONUS.

Aeromedical evacuation directives apply to transport between and within the different echelons of care, but Operations Zones that the echelons of care are located in dictate different AE capabilities. Survivability and runway requirements are more important in an AE asset the deeper into the Combat Zone it must operate. Conversely, range and speed become more important in assets bridging the gap between the Communication Zone and the CONUS.

The Operations Zones (Op-Zones) are defined (AFD 317, 1996: 8-9) as:

Combat Zone (Op-Zone 1): 1) That area required by combat forces for the conduct of operations. 2) The territory forward of the Army rear area boundary.

Communications Zone, or COMMZ (Op-Zone 2): Rear part of theater of operations (behind but not contiguous to the combat zone) which contains the lines of communications, establishments for supply and evacuation, and other agencies required for the immediate support and maintenance of the field forces.

CONUS (Op-Zone 3): United States territory, including the adjacent territorial waters, located within North America between Canada and Mexico.

2.3 Evacuation Responsibilities

The general evacuation responsibilities are also seen in Figure 2-1. Respective service component commands are responsible for patient movement from the point of injury, through Echelon I, to Echelon II. Some services provide dedicated air and ground evacuation assets, but may rely on opportune lift. Service components also normally assume responsibility for movement within Echelon II, or from Echelon II to Echelon III. However, there are exceptions where joint AE assets are required. For example, the Marine Corps has no medical capability above Echelon II and depends upon other services for medical care beyond this point (Joint Pub 4-02.2, 1996: II-7).

Unless Echelon III medical infrastructure does not exist, in which case evacuation from Echelon I or II may be required directly to Echelon IV or V, joint movement responsibilities normally begin at Echelon III. Movement within Echelon III, and from Echelon III to Echelon IV, is typically considered the intra-theater, or tactical, AE requirement assigned to U.S. Transportation Command (USTRANSCOM) and to AMC. The current trend, however, is to move this requirement further forward into the Combat Zone. USTRANSCOM assumed movement responsibility for Army component evacuation between Echelons II and III after Operations Desert Shield/Storm highlighted deficiencies when that distance exceeded 200 NM (ST 8-10-HCAA, 1996: iii). Subsequent movement from Echelon IV to Echelon V is USTRANSCOM's inter-theater, or strategic, requirement.

USTRANSCOM tasks AMC to provide both the intra-theater capability, which will be controlled by the theater commander during war, and the inter-theater capability, which AMC will manage through the Tanker Airlift Control Center (TACC). The C-9A Nightingale is currently AMC's dedicated intra-theater aeromedical evacuation asset, and its replacement is the focus of this research.

2.4 Intra-theater Airlift Resources

Although the C-9A is the only dedicated intra-theater AE asset, it is not the only asset available. The Lockheed C-130 Hercules will assume a large AE burden during war. Along with the C-27 Spartan and aircraft not normally assigned to the AE mission (C-21, C-12, rotary assets, etc), a theater-assigned transport may be used at the combatant commander's discretion for the AE role. The C-130 is considered the primary aircraft for patient movement within and from the Combat Zone and can operate as either opportune, retrograde, or preplanned AE. The C-9A primarily operates within the COMMZ under a low threat level (Joint Pub 4-02.2,1996: B-A-8).

Total replacement of the C-9A would remove 18 aircraft, each capable of carrying 40 litter or ambulatory patients (or a combination of the two) over 2000 NM at speeds of 500 mph, from those resources, as well as the only dedicated intra-theater AE assets (Joint Pub 4-02.2, 1996: B-A-8). Any replacement should provide these basic capabilities.

2.5 Requirements for an Airlift Aircraft

The prospective replacement of the C-9A provides the opportunity to identify and solve C-9 shortfalls, particularly in light of a potentially expanding mission. The Air Force has identified minimum standards for AE aircraft in peacetime, which include:

1. Sufficient aircraft insulation to reduce noise and increase warmth.
2. Adequate heating facilities.
3. Flexible litter and comfortable seating arrangements to permit placement of patients according to their conditions.
4. Adequate space for in-flight treatment of litter patients. The vertical distance between each loaded litter must not be less than 21 inches.
5. Galley facilities for storage and preparation of in-flight meals for patients.
6. Suitable hand-washing and latrine facilities for patients.
7. Pressurization capability to maintain cabin altitude of between 8000 and 8500 feet when at cruising altitude. (AFI 41-301,1996:11)

However, these provide but a starting point. Capability expected from a replacement is highly dependent upon a large number of assumptions about the nature of the opponent the United States can expect to fight, which forces will be used in the conflict, and which resources will be available. Changes in the international political landscape have made the previously expected scenario of mass casualties in a European conflict between superpowers highly unlikely. Planners now expect to fight varying numbers of major regional conflicts (MRC). The scenario for the 1993 Bottom-Up Review involved two MRCs (the Korean Peninsula and the Persian Gulf) nearly simultaneously (AMC, 1997: 5-16; 12). HQ AMC/CC can be expected to base wartime requirements for intra-theater AE on such a scenario.

III. A Review of the Literature Pt. 2

3.1 Decision Analysis

HQ AMC/SG has a hard decision to make. He can decide to keep and operate the C-9A as it is, or modify it in any number of ways; he can also elect to replace it with one of any number of alternative aircraft at any time during the planning horizon.

A number of characteristics make his decision hard. Common issues include the very complexity of the decision. Usually there are inherent uncertainties, particularly regarding the different alternatives. If the decision-maker could see the future based upon the selection of each alternative, the decision may be quite easy. Often there are multiple, but conflicting objectives. Success in one area may limit or stop progress in another. Sometimes so many elements of the decision exist that it is difficult to simply remain aware of them all, much less focus on the elements that are truly relevant to the decision. Finally, conclusions are very dependent upon the perspectives involved. Even in the case of a single decision-maker, slight changes in perspective from one day to the next may lead to dramatic changes in recommendations (Clemen, 1997:9). At least some, if not all, of these elements affect the C-9A decision.

The discipline of decision analysis was developed to deal with these hard decisions. It contains the theory and methodology needed to systematically analyze hard, complex decisions. This systematic approach, shown in Figure 3-1, incorporates a decision-maker's preferences, values and attitudes towards risk to identify preferred alternatives. (Howard, 1983: 7).

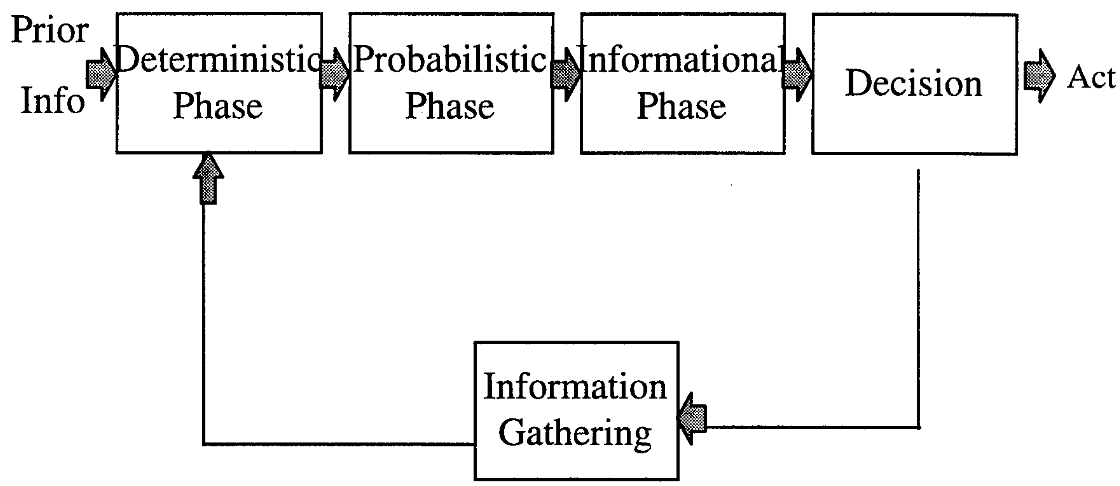

Figure 3-1: The Decision Analysis Cycle (Howard, 1983:9)

3.2 Value-Focused Thinking

One shortcoming of this approach is that, while it helps the decision-maker solve decision problems, it does not aid in identifying decision opportunities. Keeney (1992: vii) criticized previous decision analysis literature for failing to address this key aspect of making good decisions. In order to make better decisions, decision-makers must have better alternatives. He asserted that previous literature centered on a reactive solution process he termed *alternative-focused thinking.* Alternative-focused thinking assumed crucial activities, such as identifying the decision problem, specifying objectives, and creating alternatives, had already taken place and focused on actions to be taken afterward. The external imposition of a decision problem preceded comparison of alternatives, also typically imposed externally, before any attention had been given to the objectives. This, Keeney claimed, was the equivalent of putting "the cart of identifying alternatives before the horse of articulating values." (1992: vii-viii)

Keeney emphasizes that it is the values themselves that are fundamentally important to the decision process. The alternatives are only relevant as means to achieve these values. He terms this "values first" approach *value-focused thinking* (VFT). This changes the emphasis of the decision from one of decision *problem* to one of decision *opportunity* (Keeney, 1992: viii). Simply put, VFT is the process of determining what you want, then figuring out how to get it.

VFT transforms the decision analysis cycle into the flowchart in Figure 3-2:

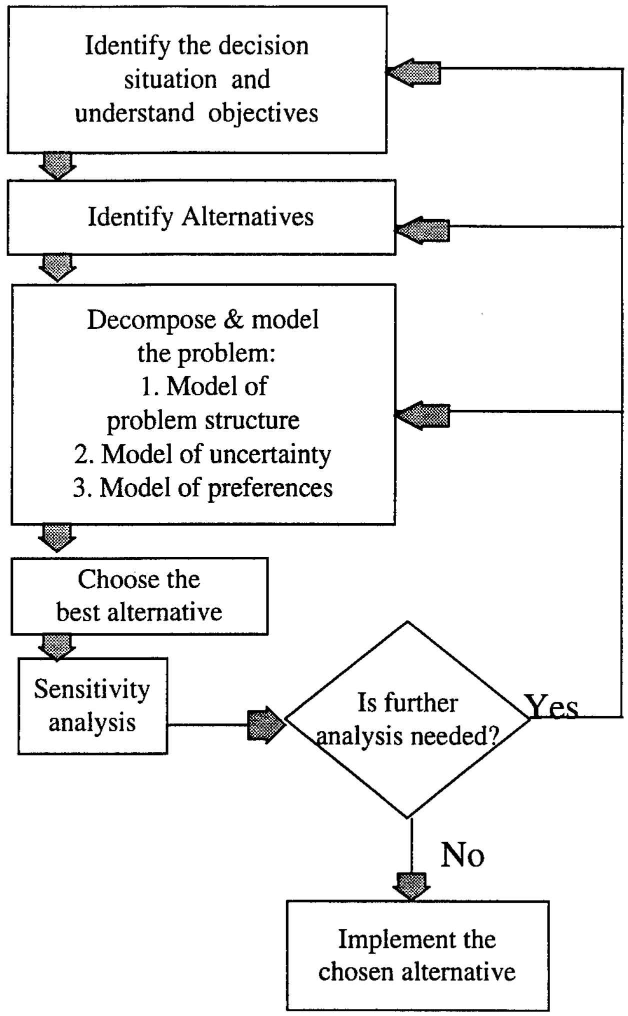

Figure 3-2 Decision Analysis Process Flowchart (Clemen, 1997:6)

3.3 Thinking About Values

Values are principles used to evaluate alternatives. These values may be based in ethical principles, traits, or characteristics that are considered important, or simple guidelines to distinguish preferences between choices (Keeney, 1992:6-7). Values, as Clemen (1997:19) articulates, "refer to things that matter to you." Objectives, on the other hand, are specific, measurable things that one hopes to achieve. All relevant objectives together support the values. Eventualy this means the values must be decomposable into individual evaluation measures. This characteristic of decomposability will be discussed further in Section 3.4.

Properly identifying one's values requires constraint-free thinking (Keeney, 1992:6-7). Constrained thinking, although easier, ultimately offers little advantage over alternative-focused thinking. If the identification of values is unnecessarily constrained, then the potential alternatives will also be unnecessarily constrained. The key is to identify everything that one hopes to achieve in the decision context. This "wish list" need not even be likely; it is simply an acknowledgement of what is important.

3.4 The Value Hierarchy

Keeney (1992) and Clemen (1997) specifically differentiate between values and objectives, but then occasionally use the terms inconsistently. As stated above, the objectives taken together make up the values. The *values* we have are the *reason* our objectives are important. Our fundamental objectives are those values in qualitative form, and provide a foundation for quantitative analyses. The qualitative structure is called the value hierarchy. The quantitative scales derived from them are the evaluation measures (EM).

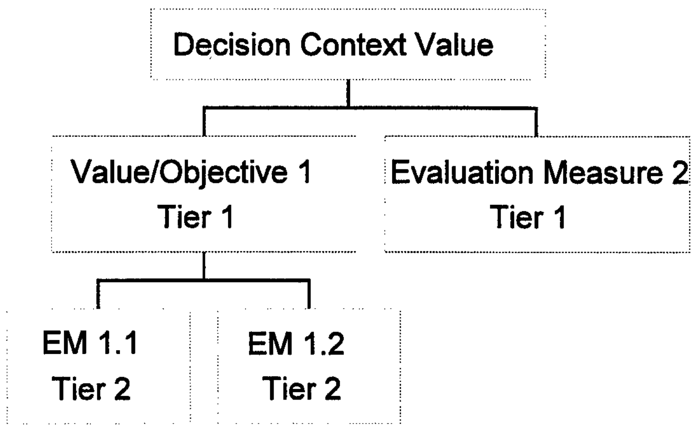

Figure 3-3 Decomposibility in a Value Hierarchy

To simplify understanding of the construction of a value hierarchy, reference Figure 3-3. Decision-maker values will be qualitatively expressed by an overall objective that represents those values within the particular decision context. This overall objective must be decomposable into evaluation measures that are quantifiably measurable. This decomposition occurs through any number of successively lower levels, or tiers, but eventually must decompose into individual evaluation measures that act as a measuring scale for attainment of the objective. Evaluation measures may appear at any level, but the lowest tier of any branch of the tree-like hierarchy must end with an EM. These evaluation measures are the scales on which alternatives will be scored to determine individual attainment of an objective. Kirkwood (1997:13-16) discusses other hierarchy representations. This research uses the structure discussed above.

3.5 Properties of Value Hierarchies

Value hierarchies have both necessary and desirable properties: (Kirkwood,1997:16-18)

Value Hierarchies MUST be:

- Decomposable
- Non-redundant, or mutually exclusive
- Complete, or collectively exhaustive

Value Hierarchies SHOULD be:

- Operable
- As Small as Possible

The desirable properties relate to communication between the analyst and the decision-maker(s). A smaller hierarchy is inherently more easily communicated to interested parties. Similarly, the property of operability means that the hierarchy is understandable to those whose values it reflects.

The necessary properties insure that not only can individual objective attainment be measured, but also that a procedure exists to combine evaluation measures in order to rank alternatives by degree of overall objective attainment.

Decomposability has already been discussed. Another necessary property is completeness. If the hierarchy is not collectively exhaustive, the analysis will not consider everything that is relevant to the decision. Conversely, if the hierarchy is not mutually exhaustive, some evaluation measures will receive greater weight than intended or "double-counted". Since overall rankings are typically a weighted sum of scores for each evaluation measure, it is obvious that a redundant evaluation measure will receive additional weight at each point it appears in the hierarchy (Kirkwood, 1997, 16-17).

3.6 Evaluation Measures

With a proper value hierarchy developed, the lowest level objectives are all evaluation measures. Evaluation measures allow the analyst a method for measuring attainment of the objective on the preceding tier. They do this by providing a measurement scale on which alternatives can be scored and compared. Kirkwood (1997:24-25) proposes that the scales used may be either natural or constructed scales, and either direct or proxy scales. A natural scale is one that has a common interpretation to all, and is typically in general use. Profit measured in U.S. dollars in a good example for business decisions.

A constructed scale is one that has been created specifically for a particular decision when a natural scale is either unavailable nor inappropriate and can take many forms.

A direct scale, as the name implies, directly measures performance. Again, profit can serve as an example, or consider freezing point in degrees Celsius or pressure in psi. A proxy scale, in contrast, measures performance through an associated objective. The use of the Dow Jones Industrial Average as an indicator of the health of the stock market is a perfect example. Typically, natural-direct scales would be the most preferred, but such scales are often not possible or the most appropriate.

No matter the type of scale used, it must have several properties (Kirkwood, 1997: 28). While being an accurate and complete measurement of a particular objective, an evaluation measure should also be easily understood by the parties involved. Kirkwood warns that overly ambiguous scales only serve to impede the communication process. Ideally, scales should pass what he terms the *clairvoyance test.* If the future could be seen with no uncertainty, could scores be unambiguously assigned to the outcomes attributed to the selection of each alternative?

3.7 Generating Alternatives

Keeney (1992:198) maintains "the mind is the sole source of alternatives." Often, a number of alternatives will already be on the table for any given decision-making opportunity. They may have been generated through institutional biases, politics, or any number of other reasons, and will normally need to be included in any analysis. The key is to overcome cognitive biases that stem from the way humans think and process information. Keeney (1992: 198-240) and Kirkwood (1997: 44-51) both suggest numerous techniques for stimulating unconstrained thinking to generate alternatives for a given decision.

To supplement the initial alternative set, a strategy generation table is particularly useful, especially when alternatives are made up of groups of characteristics. Within each group is two or more possible characteristics, which can potentially be combined with any characteristic from any other group.

In Figure 3-4, a teenager is considering whether or not to continue to live at home with his parents, or trade-off the financial burden of self-support for the "freedom" he associates with living away from his parents. For whatever reason, the teenager has screened his alternatives to the following groups of characteristics: setting, type home, ownership and furniture. These characteristic groups can now be used to create alternatives that support a particular strategy. The highlighted alternative supports the "Move Out" strategy and consists of renting a furnished apartment in the city on a month-to-month basis. Obviously all combinations will not be relevant; only one alternative will support the "Live at Home" strategy. Similarly, perhaps the city in question has zoning laws against mobile homes within city limits. In this case, no alternatives involving mobile homes in an urban environment need be considered.

In the example above, the teenager had already screened a number of potential alternatives. Screening criteria are important for several reasons (Kirkwood, 1997: 46). Often even a relatively mundane decision can have a staggering number of alternatives. Consider a decision of what to order on a pizza. If the pizzeria offers 15 separate ingredients, a total of $2^{15} = 32,768$ separate alternatives exist. If the customer must always have sausage, but would never consider putting anchovies on a pizza, then the alternatives have already been dramatically reduced to $2^{13} = 8192$, an elimination of 24,576 possible alternatives. Screening criteria are particularly useful for reducing both analysis time and cost, which in this case would have been wasted on analyzing alternatives that have no impact on the decision made.

Strategy	Setting	Type Home	Ownership	Furniture
		Apartment	Buy	
Live at Home	Urban			Furnished
		Mobile Home	Lease	
				Unfurnished
Move Out	Rural	Townhouse	Month-to-Month	
		Single-Family Home		

Figure 3-4 Strategy Generation Table

3.8 Developing Value Functions

The identification of evaluation measures provides a set of scales for measuring attainment of a particular objective. Let's assume that the teenager in the previous example developed a value hierarchy that included the evaluation measure "Proximity to Work". Say that teenager defined a scale to score proximity in miles from his residence to his place of employment. In order to convert the score an alternative receives on that scale to a meaningful figure for use in a value model, the teenager must develop a single-dimensional value function (SVF).

The single-dimensional value function in Figure 3-5 converts the score an alternative receives on the "Proximity to Work" scale to a common unit

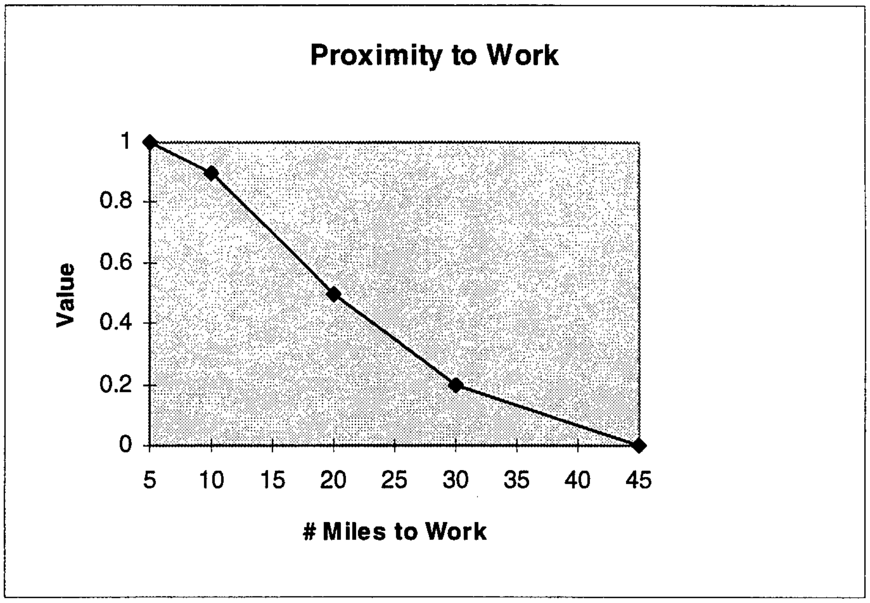

Figure 3-5 Single-Dimensional Value Function

usable in a value model. From the SVF, we see that an alternative scores full value if the residence is five miles or less from his workplace. Very little value is lost as alternatives move further away up to ten miles, where the teenager still receives 90% of the full value an alternative can provide for this evaluation measure. Value received drops off in a piece-wise linear fashion until the distance reaches thirty miles. The teenager still receives some value from an alternative that is thirty miles away, although it is only 20%. Zero value is reached once an alternative is forty-five miles, or further, from work. The common unit provided by the SVF will be termed *value*.

Converting individual evaluation measures into a common unit is valuable for several reasons. As Keeney (1992:129) puts it: "Essentially they all boil down to the same thing." This conversion allows both the analyst and decision-maker to more easily consider trade-offs between alternatives that score highly in different areas. With all evaluation measures now in terms of value toward attainment of the overall objective, alternatives can now easily be compared through the use of a weighting system, which will be discussed in Section 3.10.

Kirkwood (1997:60) additionally notes that the single dimensional value function itself addresses varying returns to scale. Consider profit. An individual's first dollar of profit may be considerably more valuable than his twenty billionth dollar of profit, earned long after he has fulfilled all of his material desires.

Thus the single dimensional value function is important for understanding and accurately representing the true value of each incremental increase (or decrease) of an individual metric and doing so in a common unit. A value function can take one of a number of shapes, the most common being linear, piece-wise linear, and exponential, but its most important characteristic is that it accurately reflect the decision-makers satisfaction with the attainment of a given objective. It provides a function that converts scores over a given range to a score on a given value scale. A more common value scale, and the one used in this thesis, is a scale from zero to one representing 0% - 100% of the possible value achievable for a given metric.

3.9 Multi-Attribute Value Functions

The multi-attribute value function consolidates values obtained by the single-dimensional value functions into an overall value provided by an alternative. The methodology followed equates this overall value to the degree of attainment of the overall objective identified in the value hierarchy.

A multi-attribute value function may take a variety of forms. The most common, and the one applicable to this research, is the additive value function. Other types of functions are discussed further in Kirkwood (1997: 227-262). Using an additive value function, the overall value of an alternative is the sum of the values it attained from each of the evaluation measures multiplied by the weight assigned to that evaluation measure by the decision maker. For example, consider a decision with two evaluation measures *Size* and *Color,* weighted at 0.6 and 0.4 respectively. If an alternative scores 0.8 value for Size and 0.2 for Color, its overall score using an additive value function would be: $(0.6)(0.8) + (0.4)(0.2) = 0.56$. Weights are discussed in Section 3.10.

Evaluation measures must meet independence considerations in order for the additive value function to be a valid model. Kirkwood (1997: 238-243) defines two independence requirements. The first, mutual preferential independence, requires that for any two evaluation measures are *seperable.* In other words, for any two two evaluation measures X_i and X_j the rank ordering of alternatives with common levels for one of the evaluation measures does not depend on these levels. Take, for example a decision to buy a car. Two evaluation measures may be *Body Style* and *Color.* If a red car will always provide a given amount higher value than a yellow car, no matter the score for Body Style, then these attributes display preferential independence. If, on the other hand, red is preferred in a 2-door coupe, but yellow provides greater value in a station wagon, then preferential independece, and therefore mutual preferntial independence, does not hold. Mutual preferential independence may be determined by testing preferential independence of (n-1) pairs of evaluation measures (Kirkwood, 1997: 239), or may be assumed in most applications. Clemen (1996: 585) concludes the additive value model is reasonable for most situations lacking uncertainty, even when independence does not hold, and is also a useful approximation in extremely complicated, multi-attribute situations.

3.10 Weights

All of the steps already discussed are part of developing a value model. Section 3.9 discussed development of a mathematical expression that combines all of the evaluation measures in such a way as to accurately represent a given alternative's attainment of the overall objective. This additive value function took the form $\sum w_i V(x_i)$, where w_i is the weight assigned to evaluation measure *i* and $V(x_i)$ is the value provided by an alternative based upon its score on evaluation measure *i.* Thus, an integral part of this process is to determine weights for each evaluation measure.

Conceptually, this weight is "equal to the increment in value that is received from moving the score on that evaluation measure from its least preferred level to its most preferred level" (Kirkwood, 1997: 68). Practically, consider an evaluation measure called Time as part of a decision value hierarchy, with a range of scores from one hour, which earns a value of 1.0, to 10 hours, which returns zero value. Say that the weight assigned to Time was 0.2, meaning that 20% of the overall objective's value was contained in Time. This weight means that a reduction in time from 10 hours to 1 hour would increase the overall value attained by 0.2.

One very common value model is simply the sum of the weighted values for a given alternative. A job acceptance decision example may have three objectives under Salary, Location, and Free Time, with weights respectively equal to 0.6, 0.1, and 0.3. An alternative's overall score would be the sum of the value it scored under salary multiplied by 0.6, the value it attained under Location multiplied by 0.1, and so on. Obviously, assigned weights must sum to one to ensure completeness.

3.11 Analysis

The value model is a tool; it cannot replace a decision-maker. At this point, its true value as a tool has yet to be realized. With the value model developed, and the alternatives individually scored, what remains is hard analysis. Sensitivity analysis must be conducted on all potentially relevant figures. Any figure that, given another value, might change the recommended decision is a relevant figure. These typically include weights, but may also include the probabilistic scores for individual alternatives or even the range of values considered.

Typically, unless one alternative dominates all others across all ranges of values, a decision-maker can at best hope to see his field of truly good potential decisions reduced to a few alternatives with guidance about conditions that favor one alternative over another.

3.12 ... The Rest of the Story

This discussion has but touched the surface on an ever-increasing ocean of theory and considerations written on the subject of Decision Analysis and Value-Focused Thinking. Many of these considerations, such as utility theory, attitudes towards risk, addressing uncertainty, etc., are particularly important but go well beyond the capabilities of this review. Keeney (1992:130) reminds us that a value model should complement our intuition by providing insight into a complex decision. As long as it does that and makes logical sense within the decision context, it can be a valid model and a useful tool. Additional information may be found in Howard (1983), Keeney (1992), Clemen (1997), and Kirkwood (1997).

Concepts that are particularly relevant to this research effort will be dealt with during the analysis section to provide greater understanding of how the principles of Value-Focused Thinking were used to evaluate aeromedical evacuation opportunities.

IV. Theater AE Value Model

4.1 Methodology

Chapter III identified numerous steps that were followed sequentially to develop a theater AE model that translates HQ AMC/SG values and assumptions into decision recommendations. These steps are:

- Identify HQ AMC/SG value objectives and structure them as a value hierarchy;
- Identify evaluation measures for each objective that cannot be further decomposed;
- Generate alternatives that attain the objectives;
- Score each alternative against each evaluation measure;
- Determine overall objective attainment achieved by each alternative, and rank them accordingly; and
- Perform sensitivity analysis to identify how changes in assumptions affect their ranking.

4.2 Value Hierarchy

The value hierarchy presented was coordinated through the Surgeon General's staff and through AMC's Studies and Analysis Flight. The importance of AMC's concurrence is highlighted by Figure 4-1.

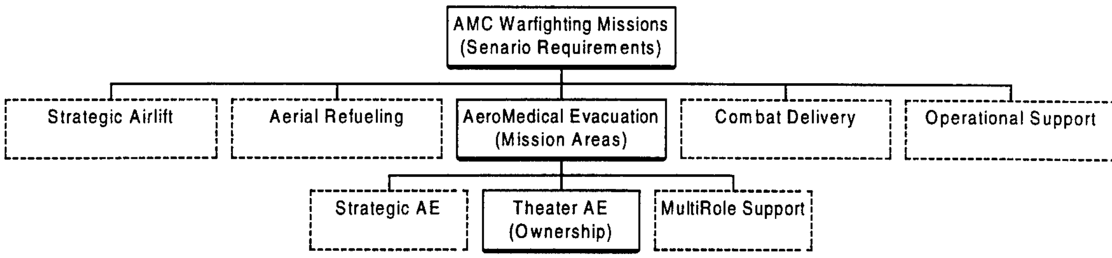

Figure 4-1: AMC Mission Hierarchy

The aeromedical evacuation mission is but one mission that AMC assumes responsibility for under the USAF Global Reach vision. Since SG is a subordinate office within AMC, and must compete for funding within that structure, the decision-maker must at least give consideration to the values of those whom he must justify his decision to. The coordinated value hierarchy shown in Figure 4-2 was confirmed by HQ AMC/SG as the value hierarchy to be used for this research. It is consistent with the decision-maker's desire to replace and expand the C-9A's current capabilities.

The hierarchy is also consistent with Kirkwood's requirements of completeness, non-redundancy, and decomposability, and the desired trait of operability. The hierarchy is faulted only in its size, although often hierarchies can later be reduced in size. This reduction may occur after weights are

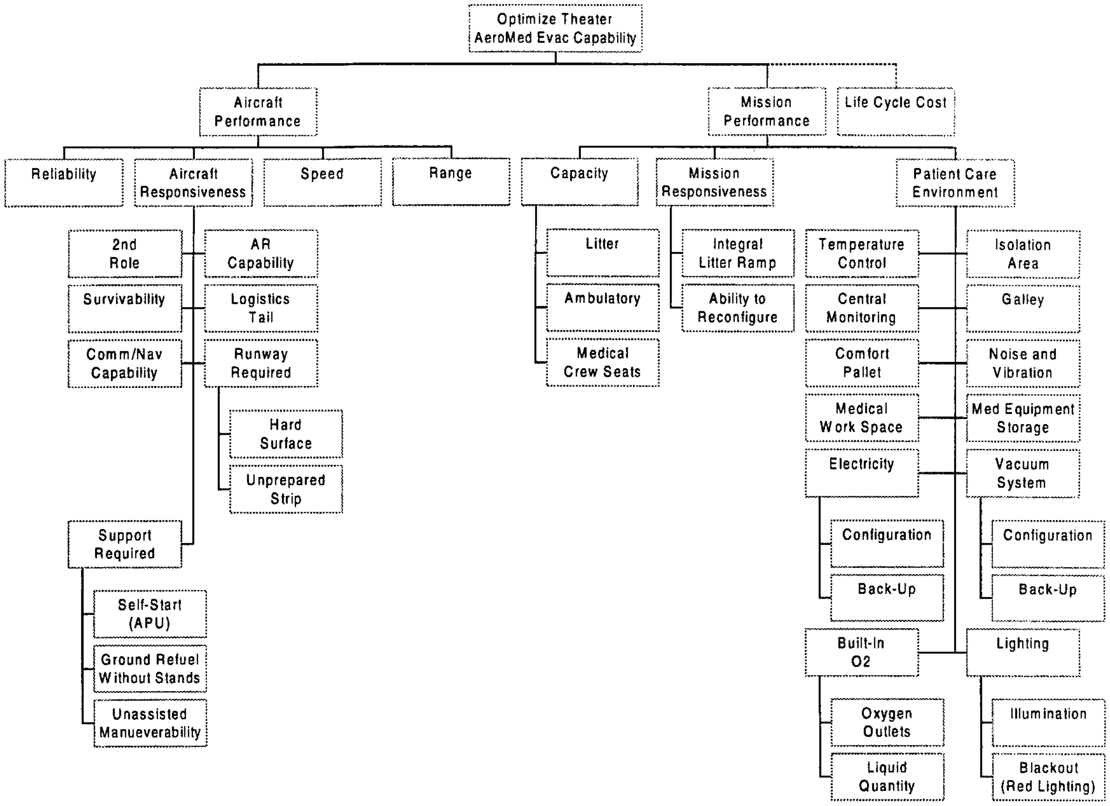

Figure 4-2: Value Hierarchy for Theater AE Decision Opportunity

assigned and analysis determines that a particular evaluation measure has been assigned such small weight that alternative performance for this evaluation measure in no way affects the overall ranking. Initially, however, the hierarchy produced 34 separate evaluation measures. These will serve to guide both the alternative generation process and scoring of alternatives to assess attainment of the objective "Optimize Theater Aeromedical Evacuation Capability".

4.3 Evaluation Measures

Each of these evaluation measures can be measured to determine an alternative's attainment of that particular metric. General definitions of the evaluation measures are discussed below; actual scales and corresponding single-dimensional value functions may be found in Appendix A. The first tier beneath the overall objective contains the sub-objectives that define aircraft performance and those that define mission performance for the decision-maker. These are further decomposed into the following:

AIRCRAFT PERFORMANCE

- **Reliability:** Reliability is measured by mission-capable rate (MCR), a common metric used in AMC which is essentially a measure of an aircraft's availability on a 24-hour basis after accounting for both scheduled and unscheduled down times.

- **Speed:** Speed is measured by cruise mach. Aircraft that cruise at lower levels and use true airspeed will be scored at no-wind mach conversion.

- **Range:** Range is measured in nautical miles under a cargo load of 25,000 pounds, without aerial refueling.

- **2nd Role:** Aircraft primary role is aeromedical evacuation. Additional value is obtained from an aircraft which can also be used by combatant commanders to airlift passengers and cargo.

- **AR Capability**: Can the aircraft be aerial refueled?

- **Survivability:** Additional value is obtained from an aircraft that can operate in advanced threat environments. Threats are defined: "*Low*": small arms fire; "*Medium*": small arms fire and limited surface-to-air

(SAM) missile capability; "*CBN*": chemical, biological, and/or nuclear threat.

- **Logistics Tail:** The logistics tail is measured by the short tons of support equipment that must be forward deployed per aircraft.

- **Comm/Nav Capability:** Value is obtained from a Global Air Traffic Management (GATM) compliant asset. GATM compliance for all AMC aircraft is currently AMC's (1997, iv) third highest acquisition priority, and will determine future airspace accessibility. *Telemedicine* capability for the medical crew provides additional value. Lemme (1997: 1-2) defines telemedicine in terms of availability and transmission speed of medical information to medical personnel in a battlezone.

- **Runway Required, Hard Surface:** How many feet of dry runway is required for takeoff and landing?

- **Runway Required, Unprepared Strip:** Does the aircraft have unprepared strip landing capability?

- **Self-Start:** Does the aircraft have an auxiliary power unit (APU) which allows engines to be started without external support?

- **Ground Refuel Without Stands:** Can ground personnel refuel the aircraft without the use of stands?

- **Unassisted Maneuverability:** Aircraft maneuverability is defined by its turning radius, or feet required to execute a 180 degree turn on the ground.

MISSION PERFORMANCE

- **Capacity, Litter:** Litter capacity is measured by the number of litters, spaced 21 inches apart that can be carried.

- **Capacity, Ambulatory:** How many seats for ambulatory patients are there?

- **Capacity, Medical Crew Seats:** Crewmembers may fill ambulatory seats, but ambulatory patients may not be seated in some seats authorized for crewmembers. How many such seats are there?

- **Integral Litter Ramp:** Can litter patients be loaded using a ramp integral to the aircraft?

- **Ability to Reconfigure:** Aircraft may have capability to partially or fully reconfigure, and may possess this capability only when on the ground or also when in flight.

- **Temperature Control:** Can the aircraft maintain temperatures between 75 degrees and 85 degrees Fahrenheit? This implies both a heating and cooling capability.

- **Isolation Area:** The aircraft may provide varying levels of patient isolation capability: general privacy, isolation of fluids such as blood and saliva, and complete aerosol isolation.

- **Central Monitoring:** This capability ranges from a simple "*call bell*" system which allows patients to signal for assistance to full *telemetry* capability, which would provide direct monitoring of patient vital information at a central console.

- **Galley:** Value is measured by what can be refrigerated: medicine, food, and/or blood; and whether or not a sink is available.

- **Comfort Pallet:** How many latrines are available? One is necessary for patients, with a second highly desirable to keep aircrew isolated from potentially contagious patients.

- **Noise and Vibration:** Noise and Vibration is measured in decibels.

- **Medical Work Space** and **Medical Equipment Storage**: Both are measured in cubic feet as a percentage of current C-9A capacity.

- **Electricity, Configuration:** Most aircraft operate on 110 Volt, 400 Cycle power. Since medical equipment requires 110/60, configuration is measured as the number of 110 Volt, 60 Cycle outlets available as a percentage of patient positions. Medical crews can provide a cycle conversion capability from 400 to 60 cycles, making a 110/400 system acceptable with a zero value score (the same as a 110/60 configuration with zero outlets).

- **Vacuum System, Configuration** and **Built-In O_2, Oxygen Outlets**: Both are also measured as the number of ports/outlets as a percentage of patient positions.

- **Electricity, Back-Up** and **Vacuum System, Back-Up**: Do back-up systems exist in the event of primary system failure?

- **Built-In O_2, Liquid Quantity:** Liquid quantity is measured in liters.

- **Lighting, Illumination:** Patient area illumination measured by lux rating.

- **Lighting, Blackout:** Does a red lighting capability exist?

Each evaluation measure has two important characteristics, a measurable scale on which to score alternatives and a function that converts these scores to the common unit *value*. Important to the creation of the scales are the scores at which minimum, usually zero, value and full value occur. Equally important is a determination of whether scores below minimum value are acceptable, or whether an alternative should be disregarded for such a score.

4.4 Generating Alternatives

A strategy generation table is useful here to identify alternatives for consideration.

Strategy	Financing	Age	Type
Replace Keep & Modify	Buy Lease None	New Used	See Table 4-2 for Alternatives

Table 4-1 C-9 Alternative Generation

Strategy generation initially identified the options of buying alternative aircraft used rather than new, or leasing rather than buying either new or used aircraft. Further research eliminated these options from the alternatives list. Although Warren (1991:12-13) concludes in his analysis for the "Acquisition of Customized Commercial Aircraft" that the best option for the particular decision opportunity he considered involved the purchase of used aircraft, he failed to address a major problem with the purchase of used aircraft. Having conducted multiple aircraft purchase studies for the Air Force, Watters (1997) asserts that inconsistent configurations found in multiple aircraft buys of used aircraft ultimately make their purchase cost-prohibitive. USAF standardization and safety requirements dictate duplicate configuration on fleet aircraft. However, commercial manufacturer purchases yield aircraft that are modified to the buyer's specifications. Each used aircraft available for purchase tends to be configured differently than every other available aircraft, thus requiring *individual* modification to bring it to a USAF standard. Additionally, this discussion assumes that used aircraft of the size desired are available for purchase. Searches for used aircraft that met the screening criteria discussed below could not find appropriate quantities of an aggregate of these aircraft, much less of an individual aircraft type. A similar problem was noted in the USAF's VC-X Requirements Trade-Off Study (VC-X Program Office, 1992: ii, 38) to consider replacements for the VC-137.

The lease of such assets provided a different, but no less restrictive problem. The C-32A Insurance Meeting, held in August 1997 between government, manufacturer and insurance company representatives, highlighted the necessity for the purchase of government aircraft over any lease option (Watters, 1997). Leasing requires insurance that the government is prohibited from providing, and is prohibitively expensive. Such insurance requirements additionally place operating restrictions on the aircraft that are inconsistent with the Air Force mission. These conclusions were true for aircraft intended for the peacetime transportation of distinguished visitors (DV); in the case of theater aeromedical evacuation, the theater of operations is likely to expand into hostile or combat environments and thus the mission is even less tolerant of externally imposed operating restrictions. Consequently, replacement alternatives for the C-9A were limited to the purchase of new aircraft.

The alternative "type" should include any aircraft that can meet the objectives quantified by the evaluation measures and pass a set of screening criteria. Screening criteria may be explicitly directed by the decision-maker, or the analyst may interpret these from the evaluation measures and their single-dimensional value functions. The primary screening criteria used for Civilian Off-the-Shelf (COTS) aircraft were range, passenger capacity, production window, and country of origin.

A set of civil aircraft alternatives was relatively easy to screen. Major aircraft manufacturers target their product lines to specific markets; these markets are typically defined by range and passenger-carrying capacity. Typically, aircraft designed for similar markets have similar or near-identical attributes. Using these market criteria, in conjunction with specifications from evaluation measures, numerous civil aircraft were eliminated from consideration.

The evaluation measure "Range" encompassed alternative scores from a minimum of 2000 nautical miles (nm) to a full value score of 3600 nautical miles. Since a score less than 2000 nm was considered unacceptable by the decision-maker, aircraft with ranges below 2000 nm were not considered. On the high end, however, aircraft with ranges as high as 6000 nm were considered.

In general, larger aircraft have longer range. They also tend to have higher passenger capacity, which *normally* equates to higher patient capacity, but tend also to require longer runways and are more expensive to operate. So, while a Boeing 747 possesses capabilities well beyond the full value scores for range, litter and patient capacity, it would contribute no greater value for those evaluation measures than would a Boeing 767, which also exceeds those full value scores but with a higher score for runway required and a lower operating cost. With COTS aircraft screened for range and passenger capacity, alternatives that would cease production during the planning horizon were eliminated. Production runs that ended prior to a planned aircraft buy would necessarily place those aircraft alternatives in only a *used* category and would increase support difficulties throughout the aircraft's useful life. Both U.S. and foreign manufacturers were considered, although only foreign manufacturers based in strongly allied countries were considered to ensure continued access to spare parts in times of war. This restriction did not eliminate any of the major global manufacturers' aircraft from consideration.

To the civil aircraft remaining from this screening process were added select military aircraft that survived a similar screening process. Although the retirement of the Lockheed C-141B from the inventory offered an easy and inexpensive, if only temporary, replacement option, it was removed from consideration based upon the conclusions of the Service Life Extension study (USAF-SAB, 1994) which raised serious doubts about the structural integrity of the C-141B fleet. Alternative generation produced the new aircraft purchase options in Table 4-2. Note that an alternative to keep and modify the C-9A exists.

Boeing 737-600	Boeing 757-200	Airbus 319
Boeing 737-700	Boeing 757-200F	Airbus 320
Boeing 737-700 IGW QC	Boeing 757-300	Airbus 321
Boeing 737-800	C-17 Globemaster	Future Large Aircraft
Boeing 737-900	McDonnell-Douglas 17	C-130J Hercules
Boeing Business Jet	C-9A (keep & modify)	

Table 4-2 Initial Alternatives List

4.5 Scoring Alternatives

Now the alternatives are scored against the evaluation measures generated from the value hierarchy. Each alternative will score somewhere along the measure's scale. This score is then converted into the common unit *value* by the scoring function. It is again useful to note that both the measurement scale and the value function were solicited directly from the decision-maker, from overall values that belonged solely to him. The scores, however, can come from a variety of sources.

This is particularly true if scales are subjective in nature, but may also be true for more objective measures, particularly if strong disagreements exists regarding measurement interpretation methods. Numerous sources were used for the scoring of alternatives in this study, which can be referenced in the Appendix B. Those sources included:

- manufacturer representatives,
- USAF System Program Office (SPO) representatives,
- *Jane's All the World's Aircraft 1997,* and
- manufacturer sales, technical and performance manuals.

4.6 Determining an Alternative's Total Value

A simple additive value function with slight modification was used for the C-9A replacement decision. The value of an alternative equaled the sum of the values attained by that alternative from each of the evaluation measures multiplied by the weight assigned to that evaluation measure by the decision maker.

The modification used for the C-9A decision is a boolean expression termed "GO" which indicates whether an alternative meets all GO/NO-GO criteria specified by the decision-maker. For example, the decision-maker specified that any acceptable alternative must have a self-start capability. If an alternative does not have that capability, not only does it score zero for the evaluation measure "Self-Start", but its associated boolean term "GO" also becomes a zero. This boolean is multiplied times the alternative's sum of weighted values to obtain an overall value for the alternative. The value function for the C-9A decision may be expressed as:

$$Go \; * \; \sum w_i \, V(x_i)$$

where w_i is the weight assigned to evaluation measure *i*
$V(x_i)$ is the value assessed from evaluation measure *i*
"Go" is 1 if the alternative passes all GO/NO-GO criteria, 0 otherwise

4.7 Sensitivity Analysis

Ranking of alternatives based upon the value they provide according to the value function above highlight the relative levels of goal attainment expected. Each ranking is a snapshot recommendation based upon the specific parameters used as input values. More important to a decision-maker is that a recommended alternative be robust and maintain its recommended position across a wide range of input values or scenarios. Sensitivity analysis provides insight into the robustness of a recommended alternative.

Sensitivity analysis is not limited to particular approaches. Its intent is to identify assumptions that, if altered, will cause a change in the recommended alternative. One common target of sensitivity analysis is the weight scheme assigned by the decision-maker. Since the weighting process is such a subjective one, sensitivity analysis of evaluation measure weights allows the decision-maker to have confidence that slight modifications of the weights assigned will not change a recommended alternative. If these modifications alter the recommedation, then the decision-maker knows either to place particular emphasis on the assignment of weights or that two or more alternatives may be so similar in the level of value they provide within the decision space that any of them would be an acceptable choice.

Sensitivity analysis is also useful to address differences in opinion within the decision-maker's staff on the scoring of alternatives, or uncertainty involving their scores. If a decision-maker's attitudes towards risk are incorporated, these attitudes may also be the subject of sensitivity analysis. Essentially, any aspect of the decision process that may reasonably be expected to have some value other than input should be the subject of sensitivity analysis, answering the question "How does the ranking of alternatives change as Input A varies?"

V. Results (Cost Exclusive)

5.1 Alternatives Considered

Two aircraft were removed from the initial alternatives list (Table 4-2) prior to scoring. The Boeing Business Jet is sold only for Distinguished Visitor (DV) or corporate business transport, and thus unavailable to the USAF as an aeromedical aircraft. However, the B737-700 IGW QC is essentially the same aircraft, with a cargo door, a strengthened floor and cargo handling system added, and is available as a commercial airline. The B737-700 IGW QC was recently purchased by the U.S. Navy (USN) to replace their C-9B DV transport aircraft.

The Future Large Aircraft (FLA) was also eliminated from consideration. Though the FLA is a concept aircraft planned by Airbus's military division to compete with the C-130J, its capabilities and costs proved too uncertain for realistic evaluation within this study.

Additionally, it should be noted that results in this chapter will be identical for the B757-200 and B757-200F. The 200F is the freighter version of the 200, and presented no changes in performance. Any difference between the two alternatives would be in acquisition and modification costs.

5.2 Overall Value

Using the value model, it is a simple matter to rank the alternatives using weights provided by the decision-maker. The portion of overall value contributed by each evaluation measure is determined by weight assigned to that evaluation measure multiplied by the value obtained from the alternative's score for that evaluation measure. Alternative scores and evaluation measure weights are contained in Appendix C. Figure 5-1 shows the alternative rankings by the value provided towards the overall objective to "Optimize Theater Aeromedical Capability" exclusive of any GO/NO-GO criteria. Value contributed by "Aircraft Performance" and "Mission Performance" sub-goals are annotated.

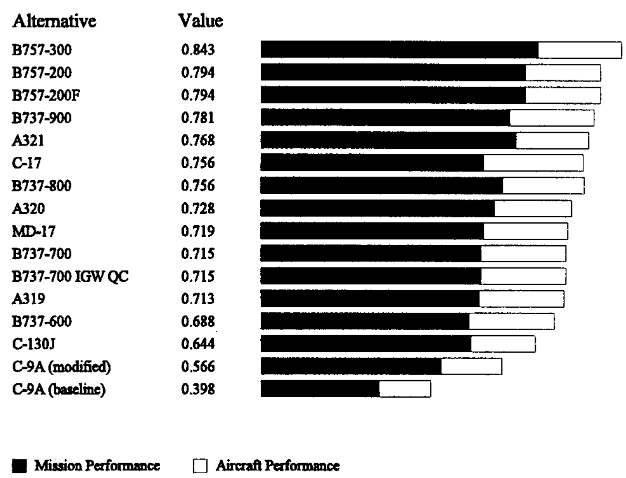

Figure 5-1 Alternative Ranking at Base Weights (exclusive of GO/NO-GO criteria)

The Boeing 757-300 is clearly preferred at the base weights. However, when GO/NO-GO criteria are applied, the B757-300 fails the "Hard Surface" requirement. Any alternative requiring more than 8000 feet was considered unacceptable; the B757-300 required 8200 feet. The B757-300 is the only aircraft to fail any of the GO-NO criteria, and is thus considered unacceptable. Nevertheless, due to its unique nature as the otherwise highest ranked alternative and the possibility that the decision-maker might want to reconsider the "Hard Surface" issue, the B757-300 was carried as a possible alternative throughout the remainder of the analysis.

Does this ranking make sense? Based upon the weights given, and the variances in alternative scores for the evaluation measures most heavily weighted, they do. The evaluation measures related to "Capacity", most notably that of "Litter Capacity", and "Range" impact the alternative ranking the most. This is consistent with SG objectives in that patient care capability, no matter the level of quality that can be provided, is pointless unless the patients can be put on the aircraft and carried out of harm's way. Those alternatives with the greatest patient capacity scored the highest, with other attributes, most notably "Range", distinguishing between them.

5.3 Sensitivity Analysis

With the elimination of the Future Large Aircraft from consideration, no developing technologies were included in the alternatives list. Thus it was assumed that no uncertainty existed in the scores assigned each alternative for each evaluation measure.

However, rank sensitivity to given weights was tested across all thirty-four evaluation measures and twelve sub-goals. Weights assigned each sub-goal and evaluation measure were varied across all reasonable ranges, with other weights on that tier proportionately increased or decreased based upon the nominal ratios. Although rankings were robust across a wide range of weights, some sensitivities deserve comment.

5.3.1 Impact of Aircraft Performance Weight

As weight on the sub-goal "Aircraft Performance" is increased, C-17 and MD-17 overall value increase relative to other alternatives. The C-17 becomes the preferred (acceptable) alternative with a change in weight on Aircraft Performance from 0.3 to 0.41. It would not surpass the B757-300 until weight on Aircraft Performance is increased to 0.58 (Figure 5-2).

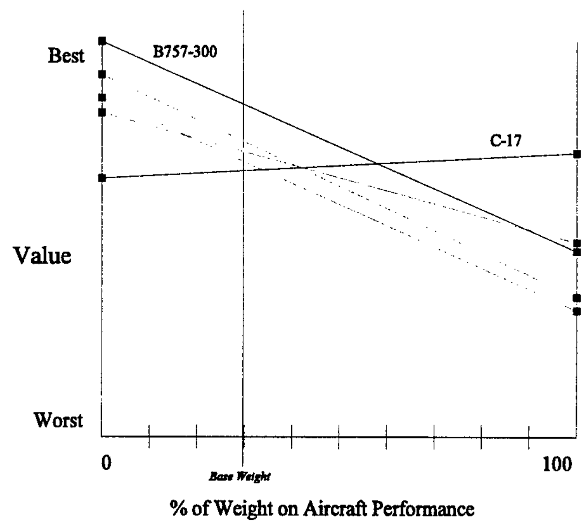

Figure 5-2 Effect of Aircraft Performance Weight on Overall Value

Similar patterns are seen when weight is increased on both Range (Figure 5-3) and Aircraft Responsiveness. The tactical advantages, including greater survivability and unprepared strip and aerial refueling capabilities, and increased range of the C-17 account for this improved value as these weights are increased. The opposite trend occurs as the weight of Reliability, also part of the Aircraft Performance sub-goal, is increased.

However, since the weight of Reliability is smaller than either that of Range or Aircraft Responsiveness, the impact of an increased weight on Aircraft Performance favors the C-17.

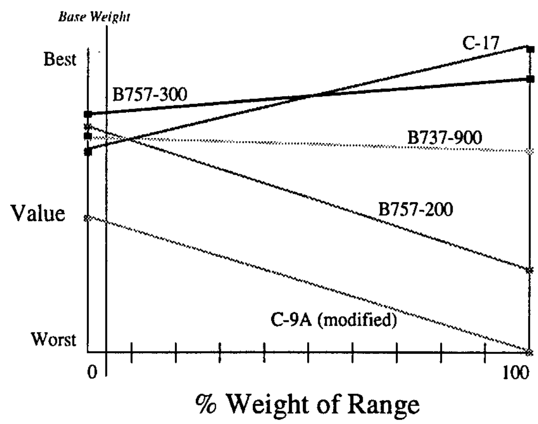

Figure 5-3 Effect of Range Weight on Overall Value

5.3.2 Impact of Mission Performance Weight

Variance in the weight assigned to Mission Performance showed the exact opposite impact of that in Aircraft Performance (Figure 5-4). Since these two criteria are complimentary within the first tier of the model, this result is to be expected.

Rank changes are first noticed as the weight assigned to Capacity is varied. These changes are mirrored when the weight for Litter Capacity, the most influential evaluation measure beneath the sub-goal Capacity, is varied. Not only does the C-17's value decline as weight on Capacity is increased, but so do the smallest COTS aircraft. The B757 series, which experiences small value gain, and the A321 and B737-900, which retain relatively constant value, being to dominate other alternatives. The only notable gains in

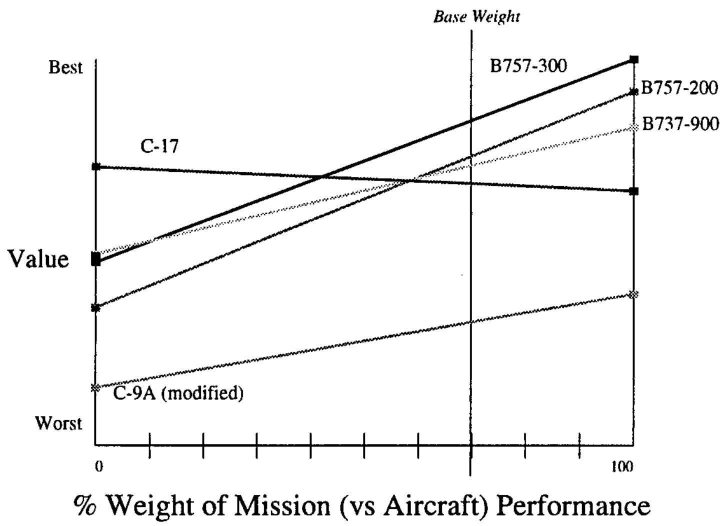

Figure 5-4: Effect of Mission Performance Weight on Overall Value

value occur with the C-130J. The C-130J, however, continues to rank very low and is essentially irrelevant.

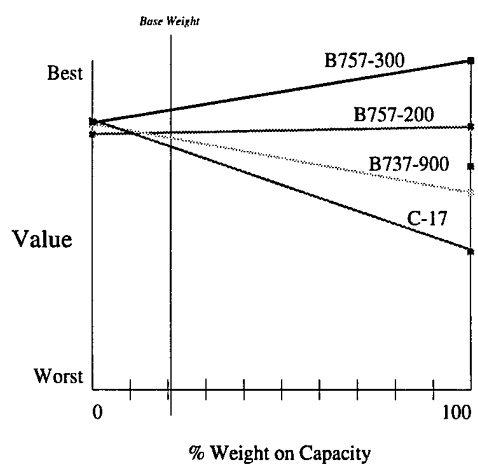

Figure 5-5: Effect of Capacity Weight on Overall Value

The weight assigned to the sub-goal Capacity or the evaluation measure Litter

Capacity would have to decrease by more than one half before the preferred alternative would change to the C-17 (Figure 5-5). This compliments the analysis in Section 5.3.1 and is consistent with the critical nature of the Litter Capacity and Range evaluation measures.

5.4 Conclusions

The tight grouping of values witnessed, particularly by the three Airbus aircraft and the next-generation Boeing 737 aircraft, testifies to a competitive market. In general, larger aircraft score better, primarily due to a larger patient-carrying capacity and longer range. Typically, however, these aircraft will cost more. Cost was not addressed at this level of the analysis, but cost is certainly relevant to alternative selection.

Based solely on aircraft value referenced against the Optimize Theater AE Capability objective, the B757-300 is the preferred alternative. This preference is consistent across all reasonable weighting schemes.

Remember, however, that the B757-300 failed the Hard Surface evaluation measure. If this criterium cannot be changed, the B757-200 or -200F is the next most preferred alternative. Recommendations for these aircraft are not as robust as the B757-300. The value it provides is not dramatically greater than the other alternatives as was the case with the B757-300. Additionally, as weight is increased from 0.045 to 0.082 on the Range evaluation measure, the recommended alternative changes from the B757-200 to the B737-900. The recommended alternative changes again to the C-17 as the weight is further increased to 0.12. These increases are outside the likely range, but are not unreasonable to consider.

Similarly, a decrease in weight assigned to Capacity or Litter Capacity by half, will also cause the C-17 to become the recommended alternative. Again, however, the costs of the C-17 and other alternatives have not been addressed. The C-17 is a specifically designed military aircraft; these aircraft are typically much more expensive to purchase and operate than COTS aircraft.

VI. Cost-Benefit Analysis

6.1 The Cost-Benefit Trade-Off

Analysis thus far has been limited to the value created by benefits. Benefits, however, almost always come at some cost. The tradeoff between what one is willing to give up, or sacrifice, for the benefits to be gained by that expenditure is a major portion of any acquisition decision. A ranking of alternatives for meeting decision-maker needs has been highlighted; now limited resources available to obtain one of those alternatives must be considered.

Each alternative now has a value associated with it, a value that Fabrycky and Thuesen (1980: 13-17) describe as the worth that the decision-maker attaches to the alternative. This value is not inherent in the alternative, but is actually inherent in the regard the decision-maker has for it as captured in the value hierarchy. They further maintain the decision-maker will select the alternative providing the greatest value when money is available and the value of the alternative is equal or greater to the amount of money required to obtain and maintain it.

6.2 Accounting for Cost Preferences

In accounting for the costs of alternatives, Keeney (1992: 323) and Kirkwood (1997: 77) both cite examples wherein a cost evaluation measure is included within the body of the value hierarchy. Essentially it is treated as any other attribute that provides value. Economist Gill (1997: 67) argues against this approach. He maintains that, in accordance with microeconomic theory, cost savings are not a benefit and should be treated separately. Cunningham (1998) and Kent (1997) agree, the latter emphatically stating that "there are benefits and there are costs and never mix the two".

On a practical level, incorporating a cost evaluation measure into the value hierarchy is useful. As mentioned, the cost issue is critical to most management decisions. Additionally, the *value* of money (or other costs such as the cost of human life or environmental degradation) is highly subjective. Certainly it is reasonable to expect a prince and a pauper to value a single dollar differently. Similarly, that dollar potentially has different value to the decision-maker if it is the first dollar, as opposed to the millionth. Incorporating cost into the value hierarchy forces the decision-maker to quantify costs in the common unit Value. However, if the cost evaluation measure is imbedded within the hierarchy, the decision-maker is unable to compare what he is giving up for what he is getting, except on a localized level.

Hale (1995: 3-5) effectively eliminated this problem and incorporated a cost evaluation measure into a value hierarchy the Australian Defense Force used to assess satellite communications systems. Essentially, he created two separate value models, one for system effectiveness and one for cost. He then accomplished two-way analysis to determine tradeoffs between benefits (system effectiveness) and cost.

6.3 C-9A Replacement Costs

Hale's approach was modified for the C-9A decision by inserting another tier just below the overall value objective. Note the current hierarchy in Figure 6-1.

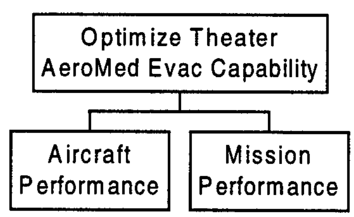

Figure 6-1 Value Hierarchy First Tier

The modification is no more than creating another sub-goal, termed Performance, which the sub-goals Aircraft Performance and Mission Performance will be subordinate to, and pairing it with the evaluation measure Life Cycle Cost on the first tier. The new hierarchy structure is presented in

Figure 6-2.

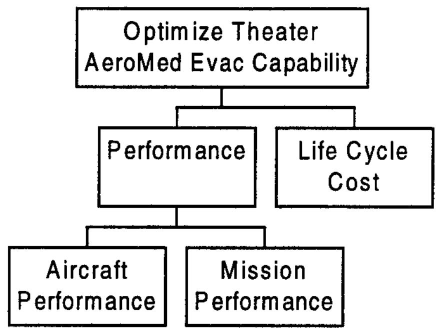

Figure 6-2 Accounting For Cost in the Value Hierarchy

This structure now allows two-way analysis between benefits, here represented by Performance, and costs. Note here that Life Cycle Cost is an evaluation measure, not a sub-goal.

Life Cycle Costs can be further decomposed, since numerous individual costs actually make up the comprehensive term. Life Cycle Cost (LCC) typically includes research and development (R&D), investment, operating, and disposal costs (Gill, 1997: 1). Although these costs are normally accounted for over the full life of a system, this analysis accounts for LCC only through a 25-year life span. It is assumed that SG will replace the chosen aircraft at the end of that period. Since the decision maker values the individual costs for the different phases of the life cycle similarly, a single scale and value function may be used. HQ AMC/SG defined the Life Cycle Cost evaluation measure as the type shown in Figure 6-3.

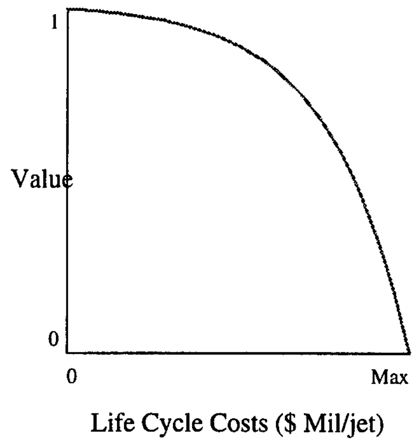

Figure 6-3 Exponential Value Function for Life Cycle Costs

Additionally, the nature of the alternatives generated and the decision context eliminate some normal aspects of LCC from this analysis, namely R&D and disposal costs. Essentially, the LCC of the alternatives include Acquisition costs, made up of purchase, modification, and opportunity (in the case of the "Keep the C-9A" alternative) costs, and Operating and Maintenance (O&M) costs.

6.4 Sensitivity Analysis

Sensitivity analysis is particularly important to the cost-benefit analysis. Gill (1997: 65) points out the poor accuracy record of military cost estimating. This performance history can be traced to a number of reasons that, for our purposes, can be lumped under a single cause: *uncertainty*. Sensitivity analysis on both the expected costs of the alternatives and the weight given costs compared to benefits allows the decision maker to see the impact on the ranking of alternatives when a preferred alternative experiences cost overruns, or changes in the economic climate cause changes in the value placed on money.

VII. Results (Cost Inclusive)

7.1 Updated Results

Results in Chapter 5 were based strictly on the benefits that the alternatives provided, measured by each alternative's overall value. However, the decision-maker cannot select an alternative without regard to its cost (Figure 7-1).

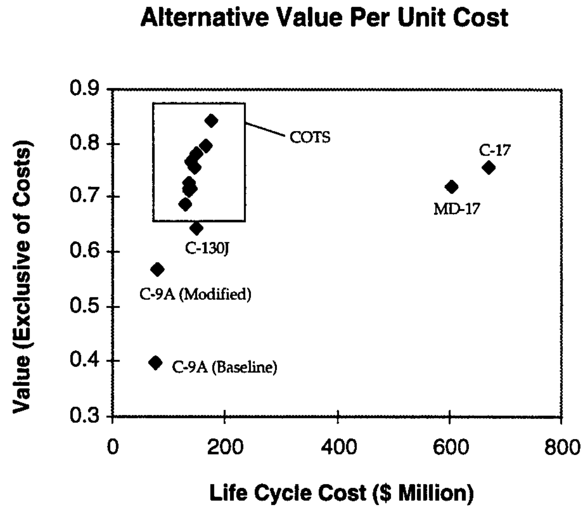

Figure 7-1 Value Provided as a Function of Life Cycle Cost

Incorporating Life Cycle Costs into the value hierarchy as discussed in Chapter 6, reflecting decision-maker preferences (Figure A-28), leads to the ranking of alternatives in Figure 7-1:

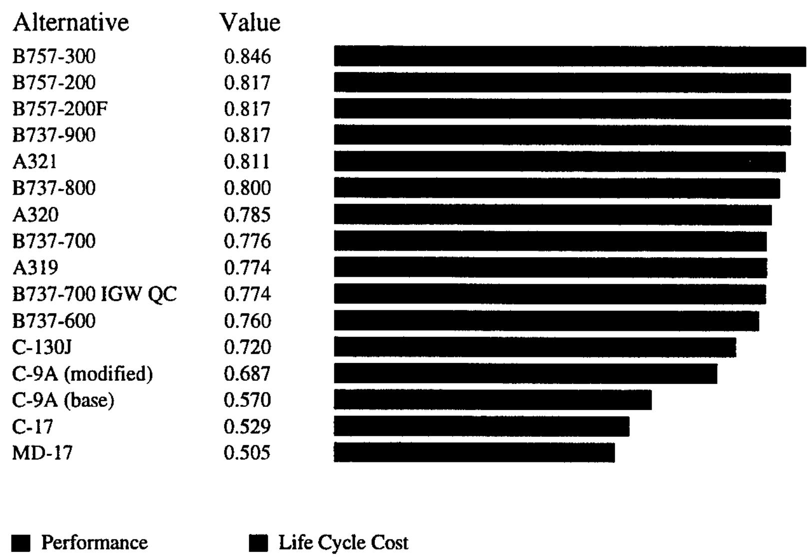

Figure 7-2 Alternatives Ranked at Base Weight (exclusive of GO/NO-GO criteria)

Little change is noted in the ranking of alternatives when the Life Cycle Cost evaluation is added, even with its base weight of 0.3 of the overall objective value. Differences between the B737-700 and B737-700 IGW QC, as well as between the B757-200 and B757-200F, remain trivial. The only notable change from the rankings exclusive of cost information is that the C-17 and MD-17 have dropped significantly in value relative to the other alternatives.

Again, the obvious question is, "Does this make sense?" The competitiveness of the civilian airline market was noted in Chapter 5. This conclusion is supported by alternative cost data. Aircraft competing for the same markets not only score similarly in performance aspects, but are also similar in acquisition, operating and maintenance costs. The larger B757 series aircraft appear to provide an almost linear increase in capability with increased costs. Thus, higher relative value remains consistent between the B757 series and the smaller COTS aircraft.

The enormously increased costs for the C-17 and MD-17, relative to the other alternatives, cause them to be the least recommended alternatives, despite impressive rankings when costs were not included. As long as the greatest weight is assigned to evaluation measures that COTS aircraft are competitive in, such as range and litter capacity, expensive military aircraft cannot be expected to compete. Tactical considerations would have to completely dominate before the C-17 would justify its cost.

7.2 Sensitivity Analysis

Sensitivity analysis was reaccomplished with all evaluation measure weights again. Since all base weights under Performance are now essentially multiplied by 0.7, they impact the overall rankings even less than in the previous analysis, when Performance provided 100% of the overall value. Essentially, overall value was previously equal to (.7)*Mission Performance Value + (.3)*Aircraft Performance Value. Overall value is now represented by (.3)*Life Cycle Cost Value + (.7)*Performance (representing the same combination of Mission and Aircraft Performance values) Value. Change manifests itself in same direction, but with less magnitude. However, the new evaluation measure, Life Cycle Costs, has enormous potential impact on recommended alternatives, carrying a total weight of 30% of overall value..

7.1.1 Sensitivity to Life Cycle Cost Weight

AMC SAF directed that the range of weights for Life Cycle Costs from 0.25 to 0.75 be considered (Figure 7-3). The Boeing 757-300, the best alternative if the Hard Surface criterium is relaxed, blends with and is replaced as the recommended alternative by the smaller COTS aircraft when weight assigned to Life Cycle Costs is increased to 57%. If the B757-300 is eliminated from consideration, differences in value between other COTS aircraft are insignificant within the specified weight range.

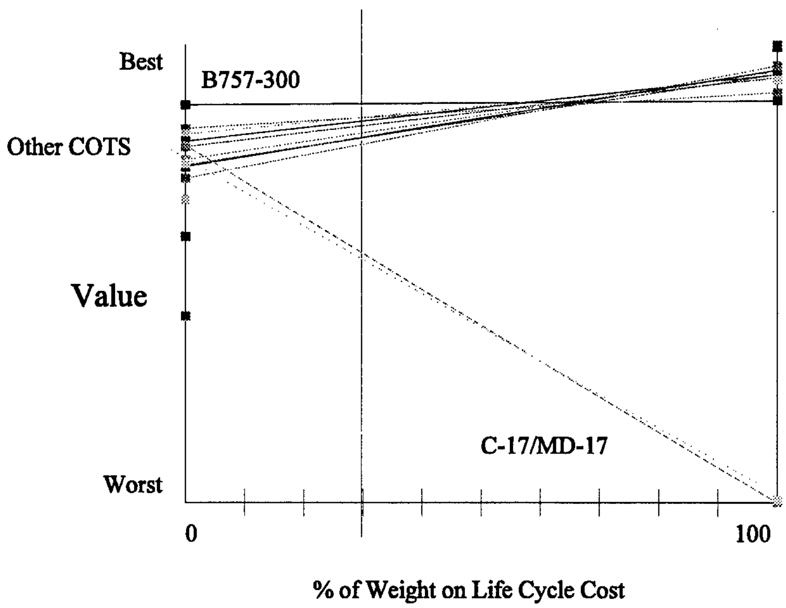

Figure 7-3 Ranking Sensitivity to LCC Weight

Once weight on LCC is increased just outside of the realistic range, approximately 79%, replacement alternatives are just considered too expensive and modification of the C-9A is recommended. At 98% LCC weight, the decision-maker is so concerned about costs that even modification is too expensive and status quo becomes the best alternative.

7.1.2 Sensitivity to Life Cycle Cost Scores

While alternative Performance scores are known, Life Cycle Cost information is, at best, estimated. How much change in LCC can the recommended alternative withstand before it is no longer recommended?

Using the decision-maker's Single-Dimensional Value Function for Life Cycle Costs, scores for the preferred alternatives were varied to determine when a change in recommendation occurred. Using the nominal weight of 0.3 for Life Cycle Costs, an alternative receives 30% of its overall value from the value obtained under that evaluation measure. The B757-300's LCC value would have to decrease from 0.853 to approximately 0.765 before a recommendation occurred, assuming that all other alternative weights remained at their scored levels. This 0.088 decrease in value equates to a LCC increase of thirty three million dollars (18.9%). In other words, if the B757-

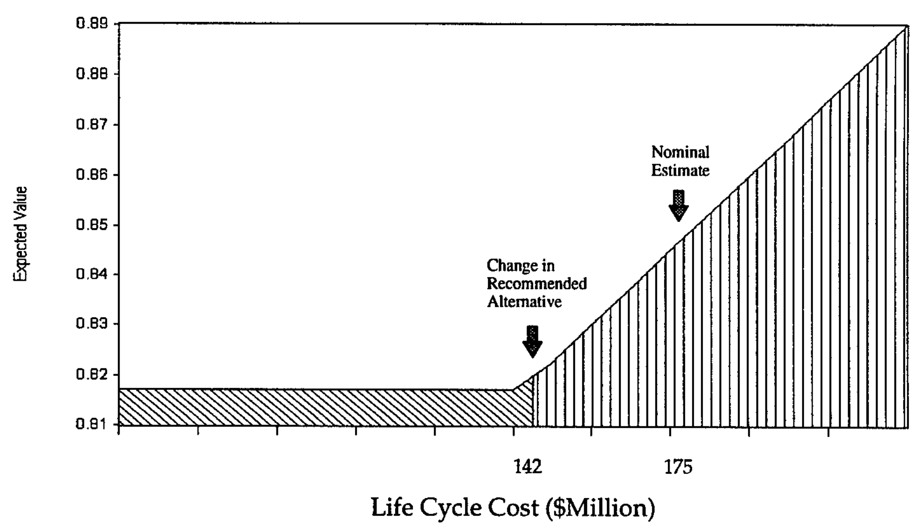

Figure 7-4 Recommended Alternative (B757-300) Sensitivity to LCC

300's life cycle costs increased by less than $33 million, and the costs of the other alternatives remained the same, the B757-300 would remain the preferred alternative using a LCC weight of 30% (Figure 7-4).

Similarly, looking at the most preferred alternative to pass all GO/NO-GO criteria, the B757-200 would only require a LCC increase in excess of approximately four million dollars (2.4%) before the B737-900 became the preferred alternative. The difference in overall value between these two alternatives was so small that relatively little LCC increase was required to generate a change in recommendation (Figure 7-5).

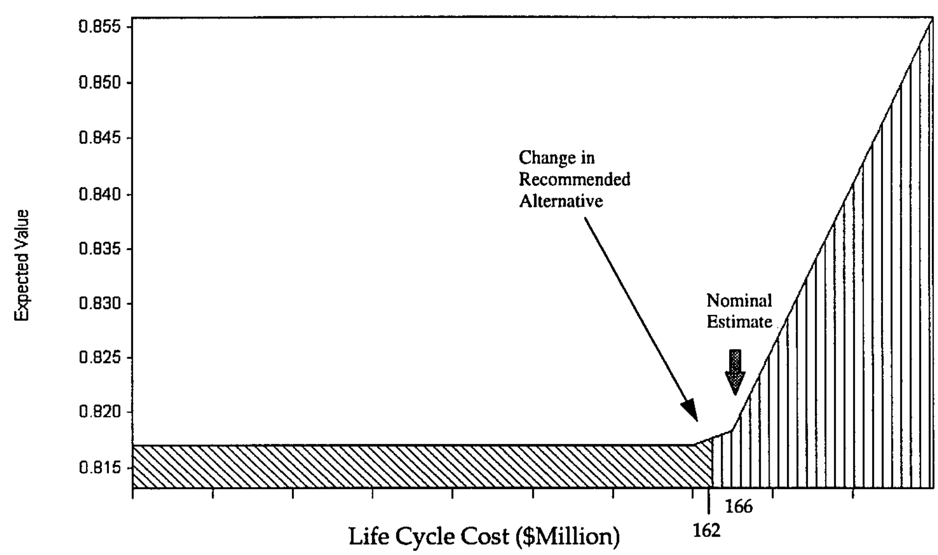

Figure 7-5 Recommended Alternative (B757-200) Sensitivity to LCC

The sensitivity analysis above was predicated on the nominal weights provided by the decision-maker, which gave 0.3 weight to LCC and 0.7 weight to Performance. If LCC weight, relative to Performance weight was increased closer to the opposite extreme, the preferred alternatives would change with approximate LCC increases described in Table 7-1. The B737-900 is representative of the entire class of smaller COTS aircraft and should be read as such in the table.

LCC weight of:	Gives preferred alternative:	LCC increase of approx:	Causes preference change to:
50%	B757-300/B737-900	3.9% / 41.9%	B737-900 / C-9A (modified)
70%	B737-900	3.4%	C-9A (modified)

Table 7-1 LCC Impact With Increased Weights

7.3 Conclusions

The recommended alternatives are only slightly sensitive to the weight assigned to Life Cycle Costs and actual LCC dollars needed for the different alternatives. Does this make sense? Based upon the competitive market for commercial airliners already identified, it does.

The smaller COTS aircraft are so tightly grouped as to be almost indistinguishable. Generally, the larger the aircraft the better the scores. Their range tends to be longer, and they also tend to be able to carry more patients, particularly litter patients. The larger aircraft also cost more, so their preference diminishes as more weight is placed on costs. For the same reason, the B757 series dominates the smaller COTS aircraft until emphasis on costs changes the preferred alterative. Even in this case, the B757 series remains very close in value to the other COTS aircraft.

Aircraft which were outside the costs expected to be incurred by the decision-maker were the most sensitive to LCC weight and uncertainty. The Single-Dimensional Value Function essentially quantified a philosophy of very little value change per million dollars spent within a "target" cost range, but large value gains for substantial savings and large value drops for extravagance. So, as weights changed, very little fluctuation in recommendation occurred between the COTS aircraft. The C-9A benefited from increased cost weights; the C-17 did not.

Increased costs of an alternative due to uncertainty generally meant that another alternative in the same class became slightly more preferred. For example, if the B737-900 was preferred at a given weight, a cost increase might make, say, the A321 slightly more preferred. In reality, however, cost increases for one alternative that targets a particular market will likely also be experienced in other alternatives that target the same market.

General conclusions and recommendations, based upon those from this chapter and those in Chapter 5, are presented in Chapter 8.

VIII Conclusions and Recommendations

8.1 The Aeromedical Evacuation Decision

The AMC Surgeon General commissioned this study to evaluate options to meet future theater aeromedical evacuation requirements. With staff assistance, he quantified his values associated with the decision to Optimize Theater Aeromedical Capability based on 12 sub-goals and 34 evaluation measures. He also provided a mechanism, in the form of Single-Dimensional Value Functions and Evaluation Measure weights, to evaluate trade-offs between the different evaluation measures.

A significant portion of the evaluation measures were directly related to patient care. Virtually none of these attributes are inherent in available alternatives. Aircraft purchases for purposes other than use as commercial air carriers are essentially purchases of an aircraft shell that must be outfitted to its intended purpose. This meant that modifications had to be done to all alternatives to obtain value from those evaluation measures. Thus, as long as the modifications could physically be accomplished on a given alternative, the only differences in value stemmed from the cost of those modifications. Modification costs over a 25-year life cycle were trivial, and had negligible impact on alternative recommendation.

This meant that the distinguishing traits between alternatives would lie in the evaluation measures inherent in the alternative airframes. Of these evaluation measures, most were either too lightly weighted to be significant, or did not provide a source of alternative differentiation in a highly competitive market. The only truly significant evaluation measures in terms of mission and aircraft performance were Capacity, driven primarily by Litter Capacity, and Range. This gave larger aircraft a decided scoring advantage in terms of overall value provided.

Life Cycle Costs were significant only in eliminating very expensive alternatives such as the C-17, and in quantifying the point at which C-9A replacement was not recommended. An apparent willingness on the part of the decision-maker to pay a reasonable market value for a given level of capability meant that LCC had little impact on alternative recommendation.

8.2 The Best (and Worst) Alternative

The only alternative that consistently separated itself from the others was the Boeing 757-300. It provided noticeably better capability in both Range and Litter Capacity over other alternatives. This preference was apparent across all reasonable levels of Performance weights, as well as most expected Benefit-Cost breakdowns.

Unfortunately, the B757-300 also was the only alternative to fail a GO/NO-GO criterium. Its Hard Surface score of 8200 was 200 feet over the maximum acceptable of 8000 feet. This caused the overall value of the B757-300 for this decision to be zero, making it the least preferred of all alternatives.

8.3 Consistency of COTS

If the B757-300 falls from contention, the other COTS aircraft are so tightly spaced that a more generalized statement must be made regarding preferred alternatives. Essentially, any of the other COTS aircraft could be chosen with relatively small differences in value provided. In general, the larger aircraft of the group, particularly the B757-200(F), hold slight advantage, particularly at lower LCC weights. However, since screening criteria selected COTS aircraft on aircraft range and passenger capacity, which correspond directly to the strongly weighted evaluation measures Range and Capacity, all performed well in the analysis.

8.4 Military Aircraft

The C-130J and Future Large Aircraft were originally included in the alternatives list based on their tactical capabilities. The C-17 and MD-17 were included to provide both range and capacity, along with improved tactical capabilities. The relatively poor performance of the C-130J is based upon the low weights given to such evaluation measures as Survivability, Unprepared Surface, and Hard Surface. Although it was not scored, it is assumed that the FLA would have similarly suffered. Of the larger aircraft, the C-17 in particular provided overall high value that was significantly curtailed by its surprisingly low litter capacity. When LCC were considered, however, the extreme expense of the system forced it to the bottom of the alternatives list.

8.5 Keeping the C-9A

It is reasonable that the C-9A, whether modified or not, provided minimal non-cost value. Since the study was initiated to improve upon C-9A capability, the value hierarchy represents a desire to upgrade existing capabilities. Additionally, the C-9A found its three decade-old technology in competition with state-of-the-art aircraft which have not only benefited in the form of increased capability, but also have reduced Operating and Maintenance (O&M) costs.

The C-9's sole advantage occurs when high emphasis is placed on Life Cycle Costs. Although its O&M costs are not substantially better than replacement alternatives, the C-9A has almost no acquisition costs. Since the C-9A is already in the inventory, its equivalent to acquisition cost is the opportunity cost of not selling the aircraft on the open market. The C-9A is essentially only worth its salvage value on the open market, due to the expense that would be incurred to a purchaser to bring the aircraft back in compliance with Federal Aviation Administration (FAA) requirements. Despite these cost savings, they are irrelevant until so much weight is placed on LCC that the acquisition of any alternative is considered unacceptable.

8.6 Recommendations

This study concludes the following recommendations:

- If SG is willing to reconsider the Hard Surface criterium, *and* Congressional funding can be obtained: B757-300;

- If SG is unwilling to reconsider the Hard Surface criterium *and* Congressional funding can be obtained: *Any* COTS aircraft, with particular consideration given to the B757-200(F) B737-900, and A321;

- If a dramatic increase in weight assigned to tactical considerations occurs: Reconsider the C-130J (and FLA, if data is available); and

- If any amount of funding is available: Any alternative considered here, other than the C-17 (or MD-17), is preferred to keeping the C-9A.

Appendix A: Evaluation Measures and Single-Dimensional Value Functions

Each evaluation measure's scale is along the y-axis. A single-dimensional value function transforms alternative scores into the common unit value. Scales range from scores that provide zero value to scores that provide full value at 1.0. Additionally, the decision-maker must decide if a score at or below zero value is acceptable in an alternative.

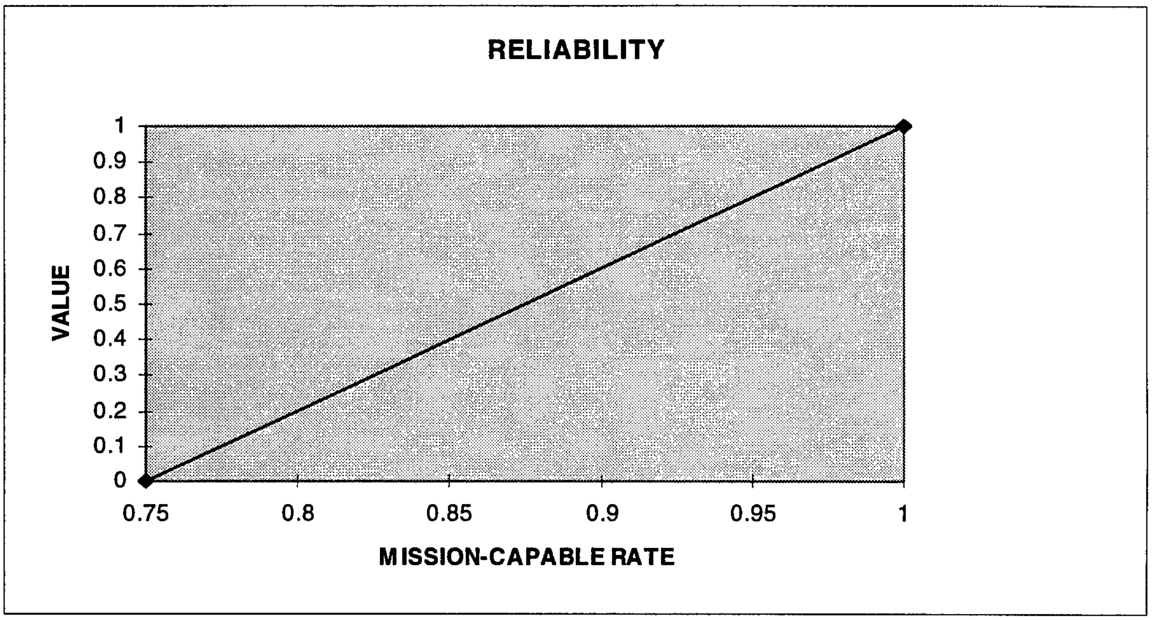

Figure A-1 Evaluation Measure: Reliability.

Zero Value: 0.75 MCR
Full Value: 1.0 MCR

Alternative Acceptable < 0.75 MCR? NO

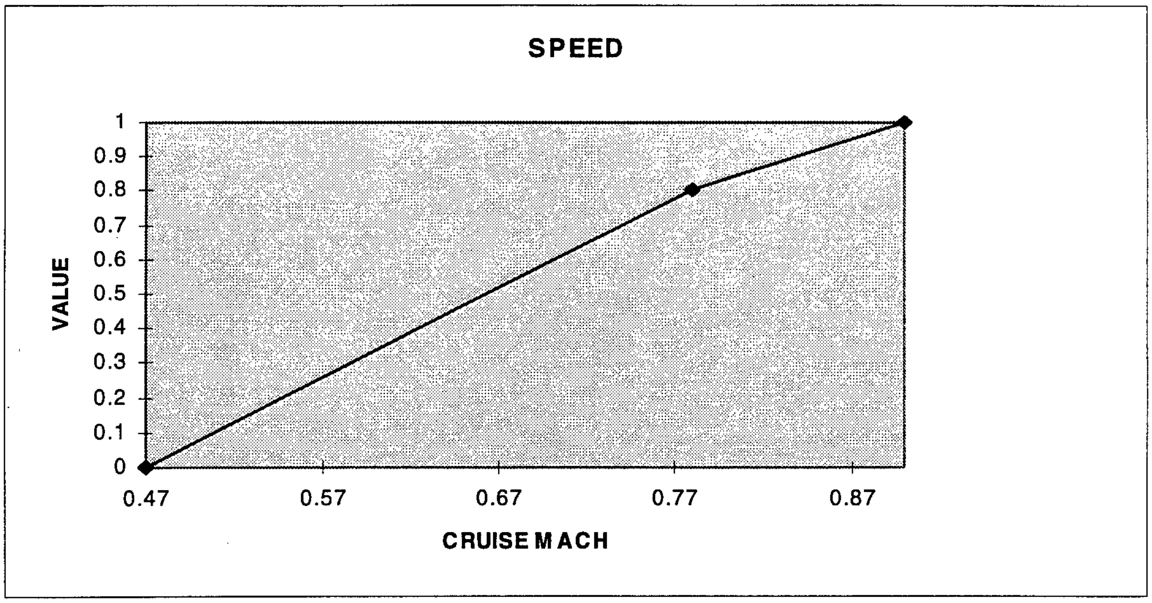

Figure A-2 Evaluation Measure: Speed

Zero Value: M .47
Full Value: M .90

Alternative Acceptable < M .47? YES

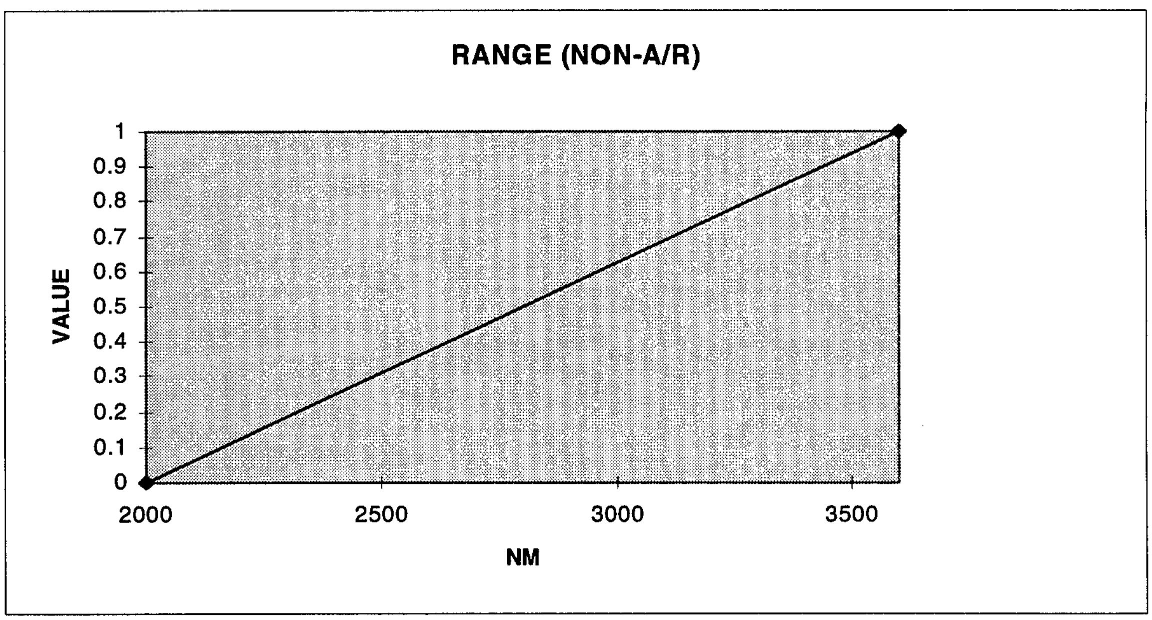

Figure A-3 Evaluation Measure: Range (Non-A/R)

Zero Value: 2000 nm
Full Value: 3600 nm

Acceptable Alternative < 2000 nm? NO

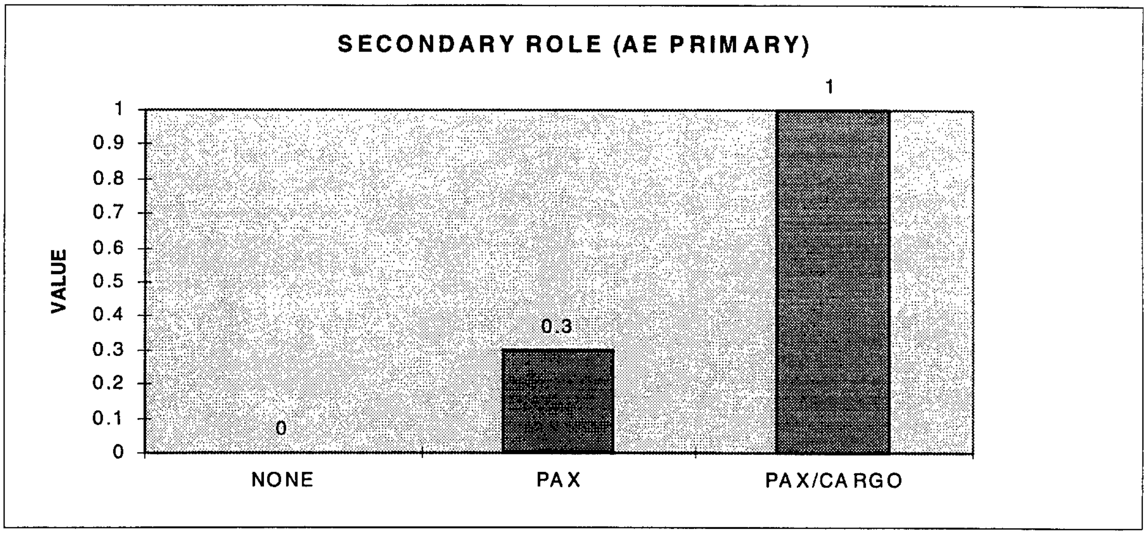

Figure A-4 Evaluation Measure: 2nd Role

Zero Value: None — Alternative Acceptable w/o 2nd Role? YES

Full Value: Secondary Pax/Cargo Role

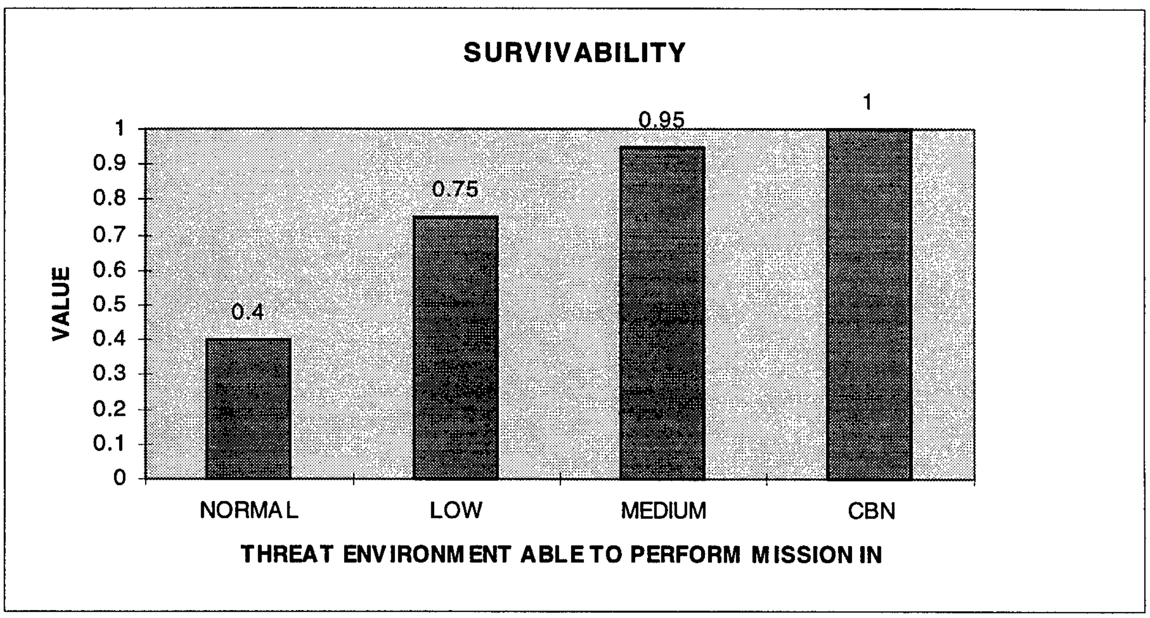

Figure A-5 Evaluation Measure: Survivability

Minimum Value: Normal — Alternative Acceptable < Normal? NO

Full Value: Chemical, Biological, Nuclear

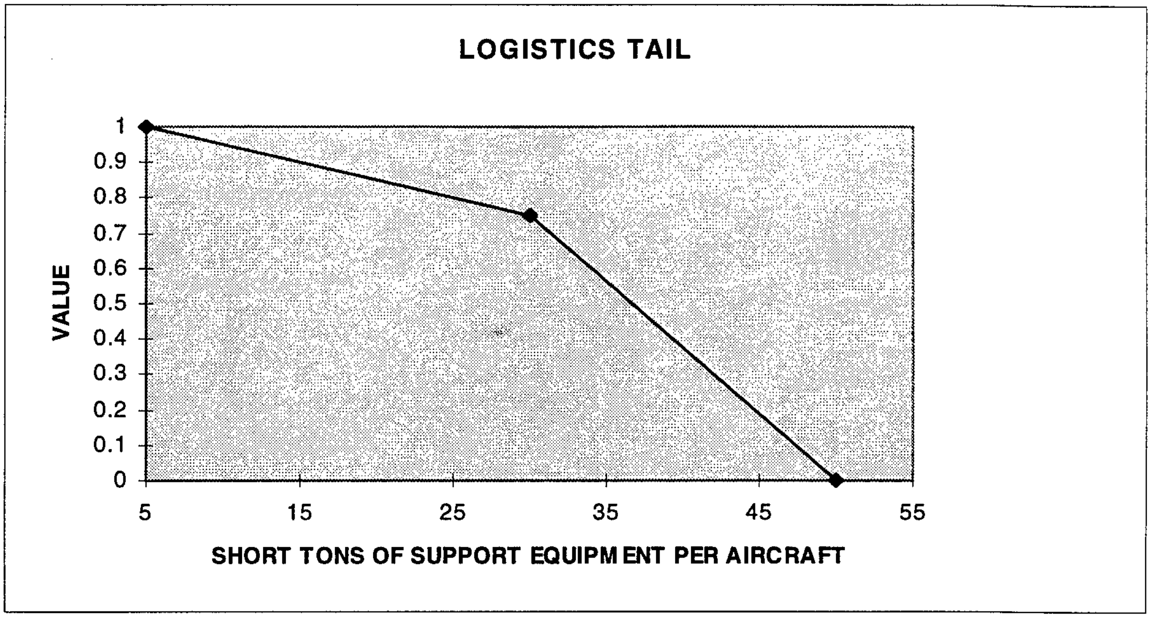

Figure A-6 Evaluation Measure: Logistics Tail

Zero Value: 50 Short Tons Required Alternative Acceptable > 50? NO
Full Value: 5 Short Tons Required

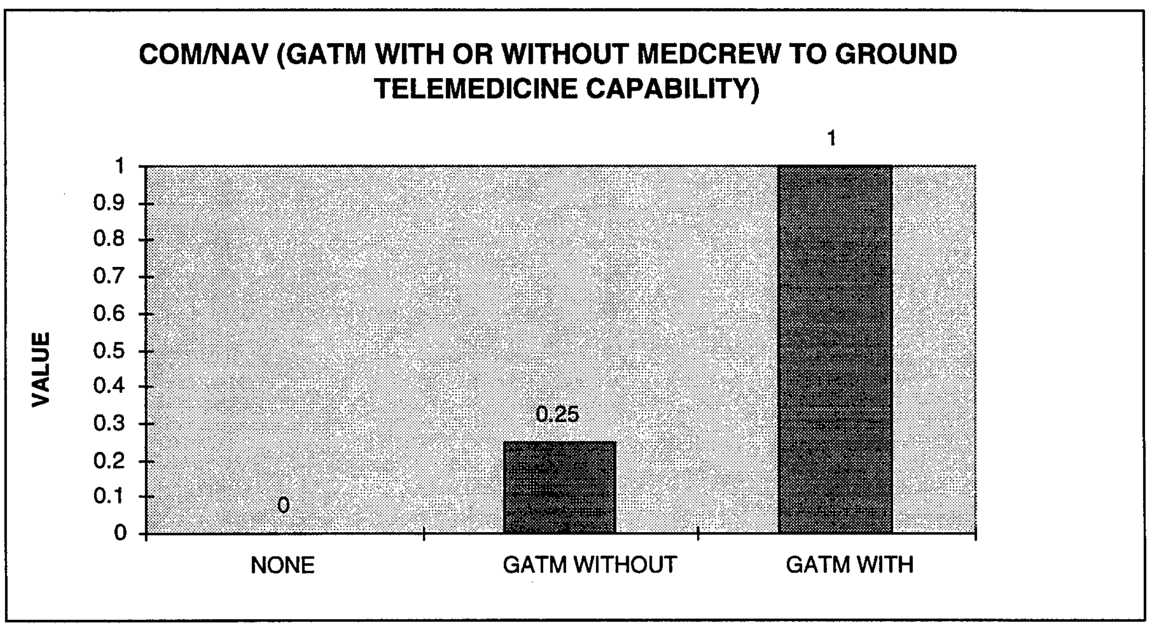

Figure A-7 Evaluation Measure: Com/Nav Capability

Zero Value: Not GATM Compliant Alternative Acceptable w/o GATM? NO
Full Value: GATM/Telemedicine

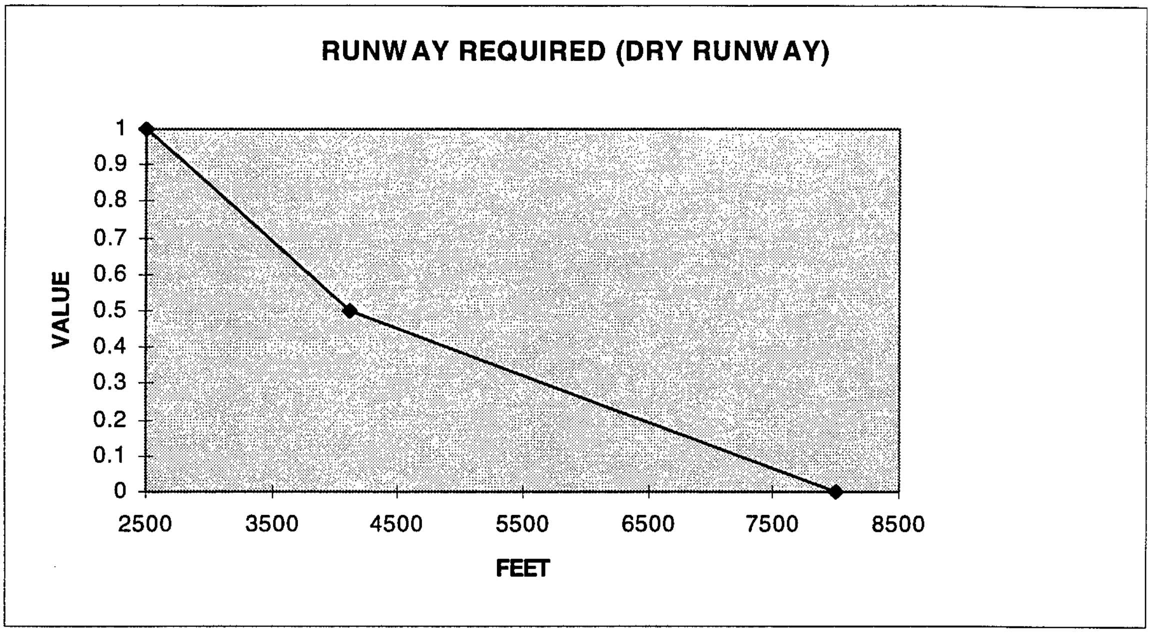

Figure A-8 Evaluation Measure: Hard Surface Required (Dry)

Zero Value: 8000 ft — Alternative Acceptable > 8000 ft? NO
Full Value: 2500 ft

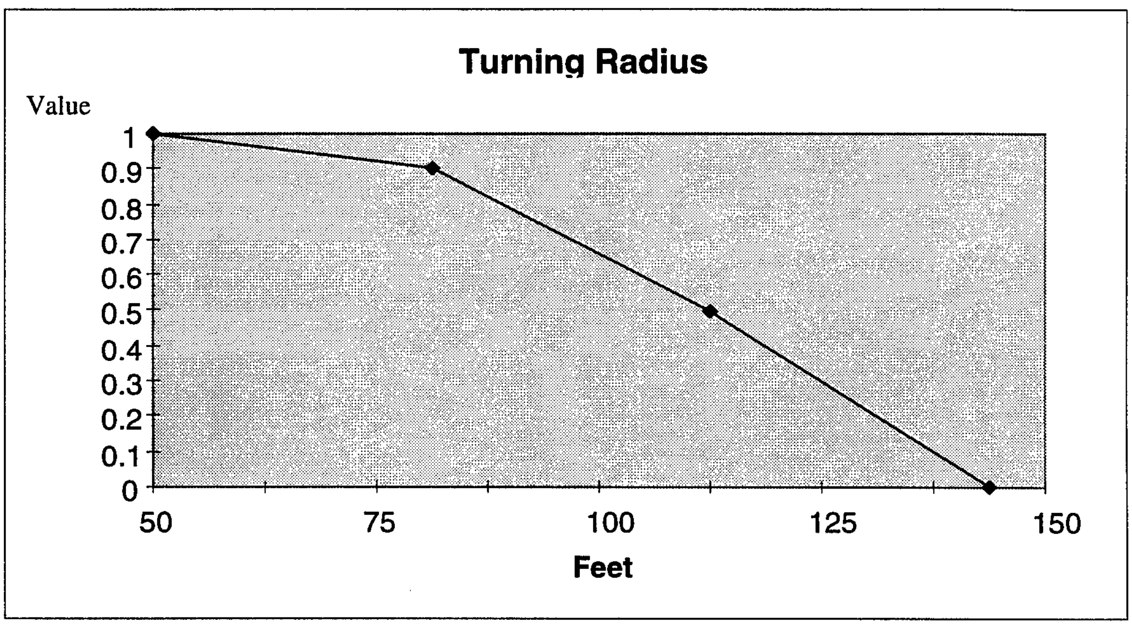

Figure A-9 Evaluation Measure: Unassisted Maneuverability

Zero Value: 150 ft Turn Radius — Alternative Acceptable > 150 ft? YES
Full Value: 50 ft Turn Radius

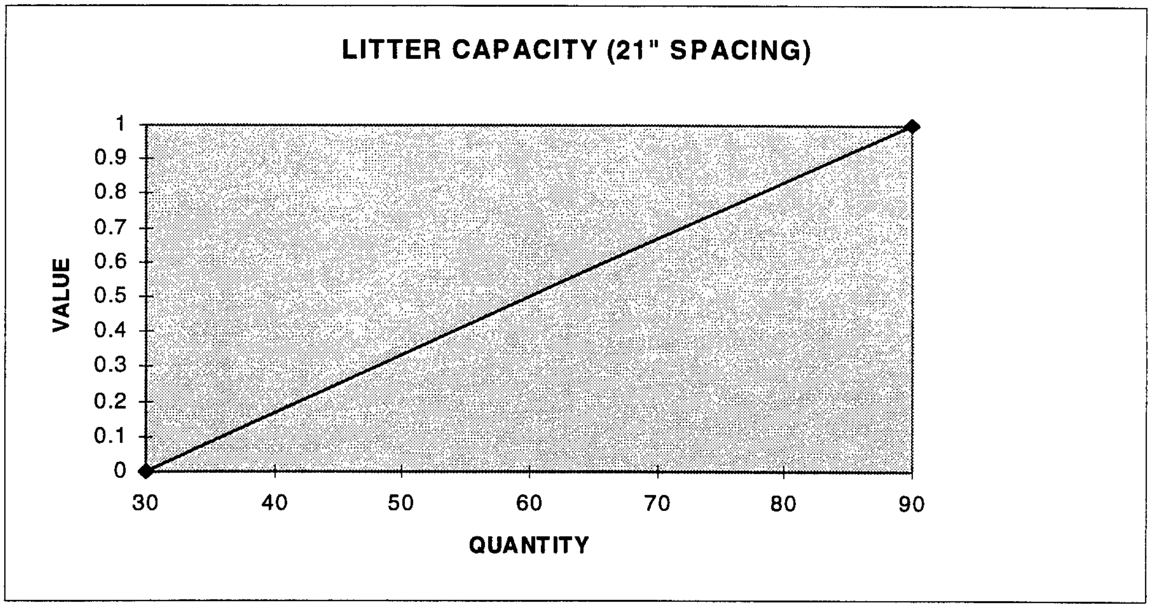

Figure A-10 Evaluation Measure: Litter Capacity

Zero Value: 30 Litters
Full Value: 90 Litters

Alternative Acceptable < 30 Litters? NO

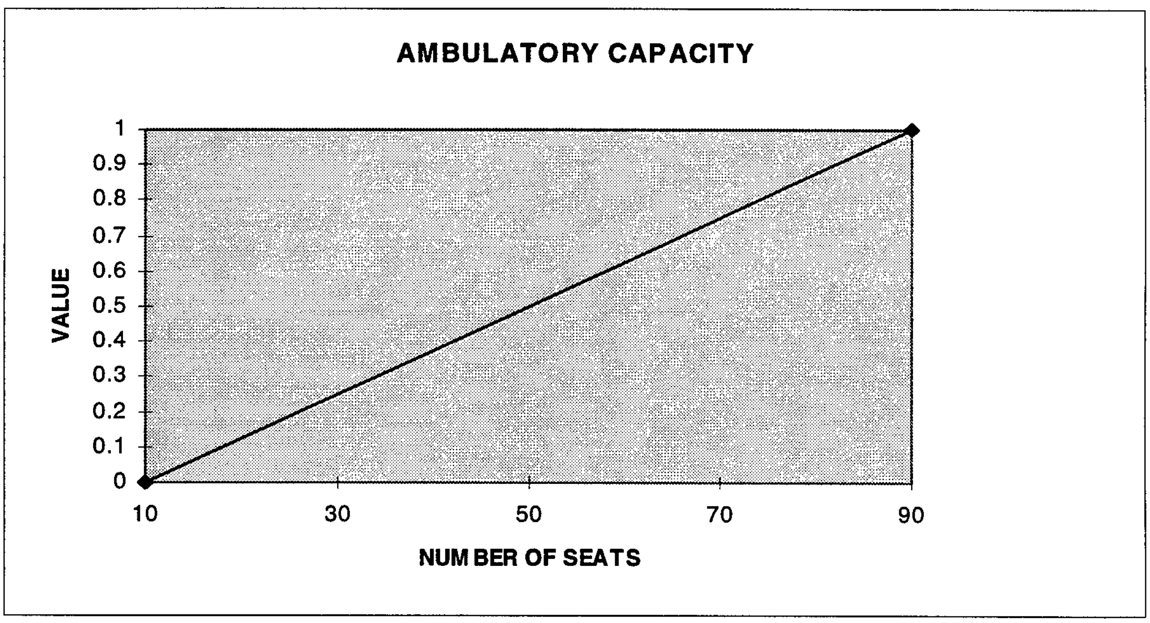

Figure A-11 Evaluation Measure: Ambulatory Capacity

Zero Value: 10 Seats
Full Value: 90 Seats

Alternative Acceptable < 10 Seats? YES

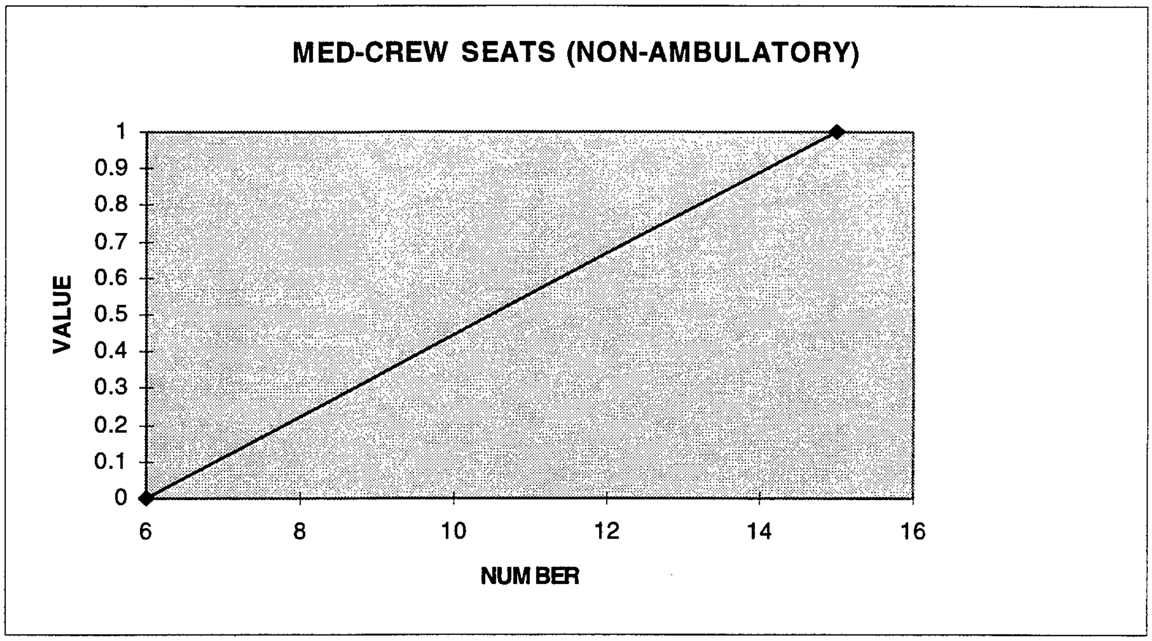

Figure A-12 Evaluation Measure: Med-Crew Seats

Zero Value: 6 Seats
Full Value: 15 Seats

Alternative Acceptable < 6 Seats? YES

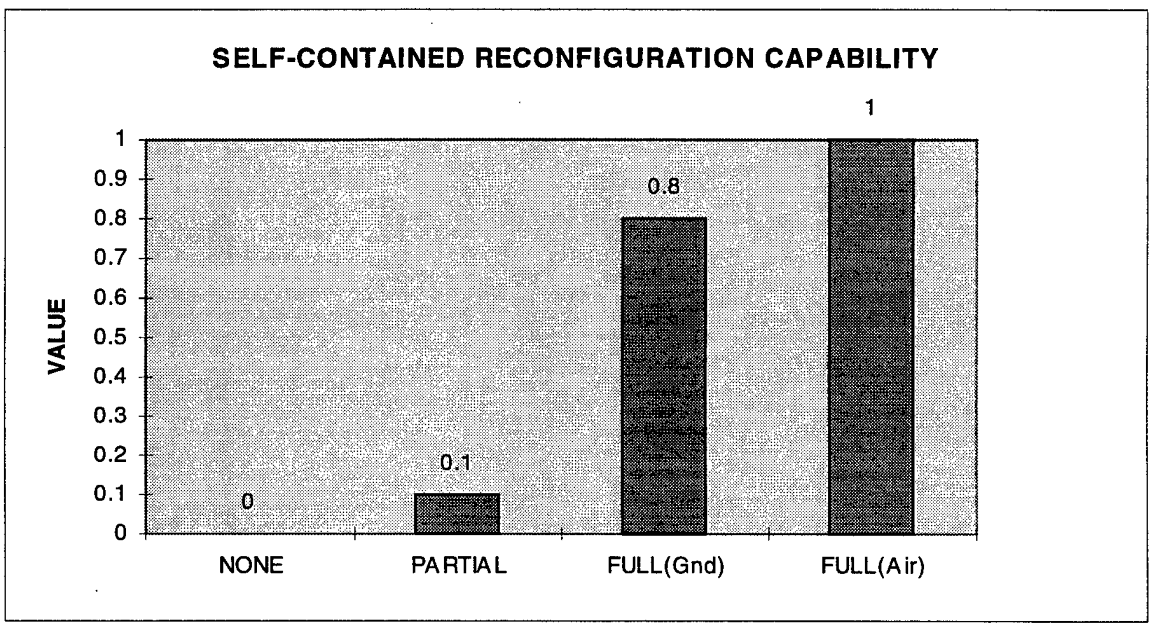

Figure A-13 Evaluation Measure: Ability to Reconfigure

Zero Value: No Self-Contained Ability
Full Value: Full Capability in the Air

Alternative Acceptable w/o Ability? NO

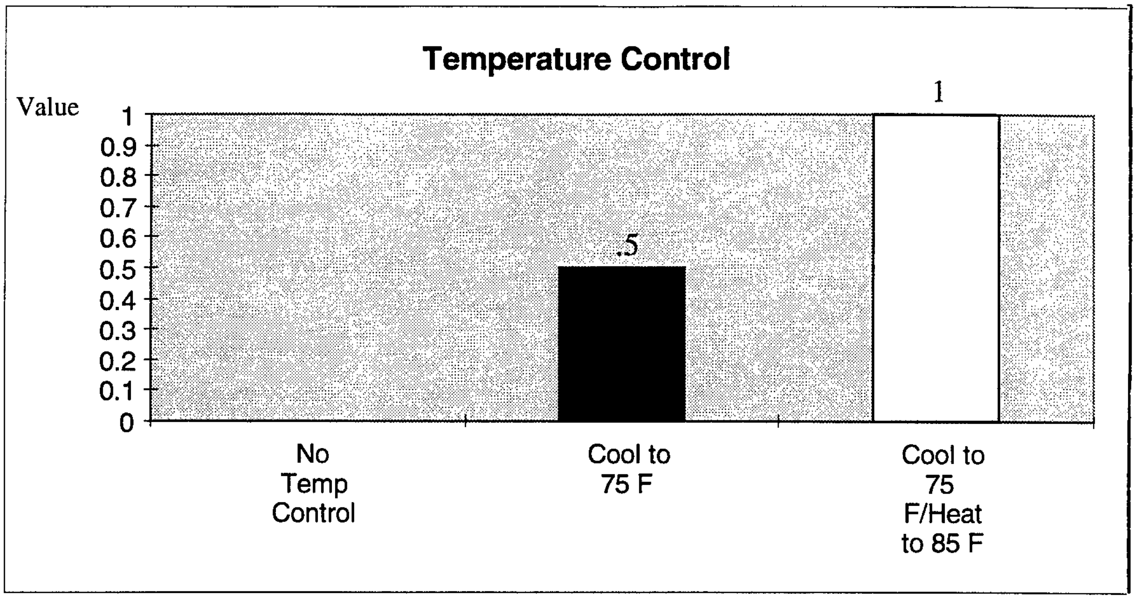

Figure A-14 Evaluation Measure: Temperature Control

Zero Value: None — Alternative Acceptable With None? YES
Full Value: Can Maintain Temp 75-85 F

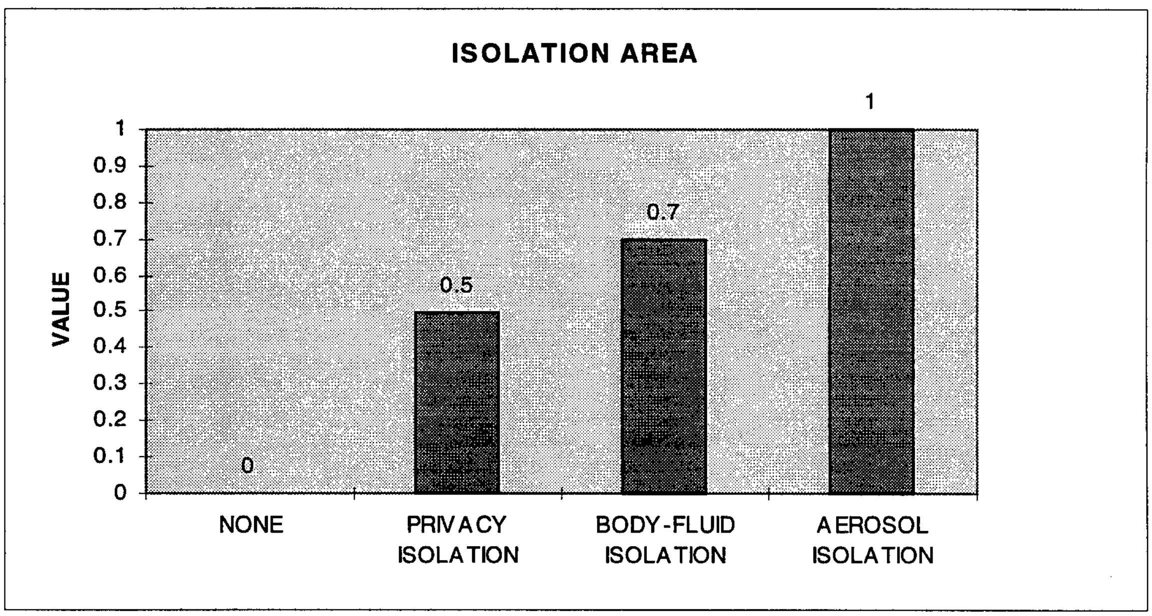

Figure A-15 Evaluation Measure: Isolation Area

Zero Value: None — Alternative Acceptable With None? YES
Full Value: Aerosol Isolation

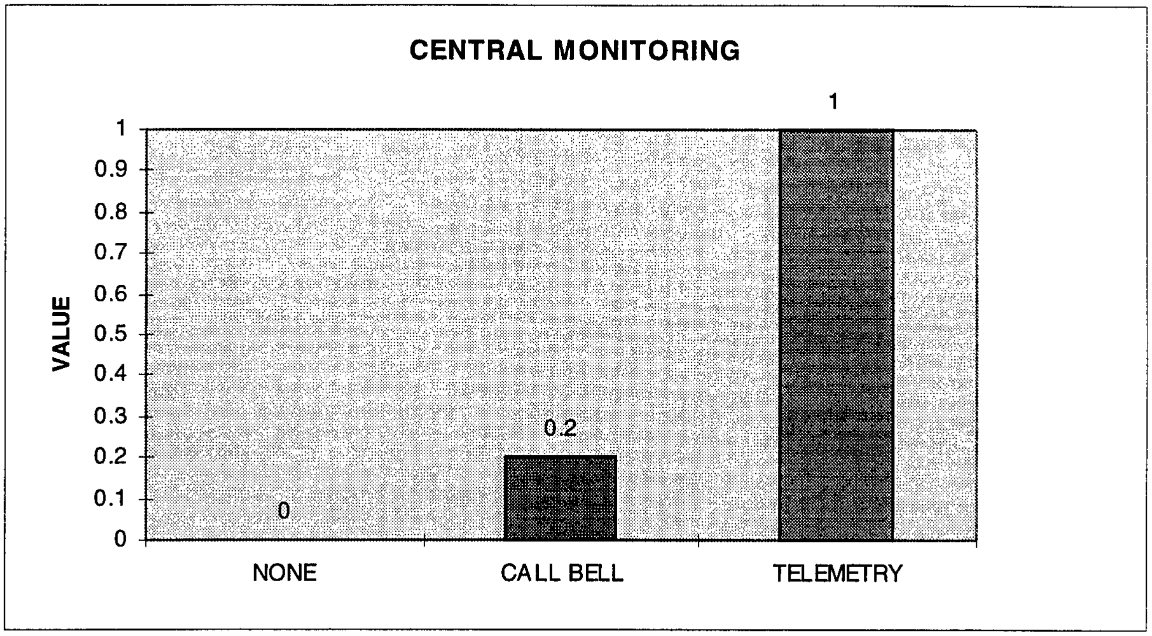

Figure A-16 Evaluation Measure: Central Monitoring

Zero Value: None | Alternative Acceptable With None? YES
Full Value: Telemetry

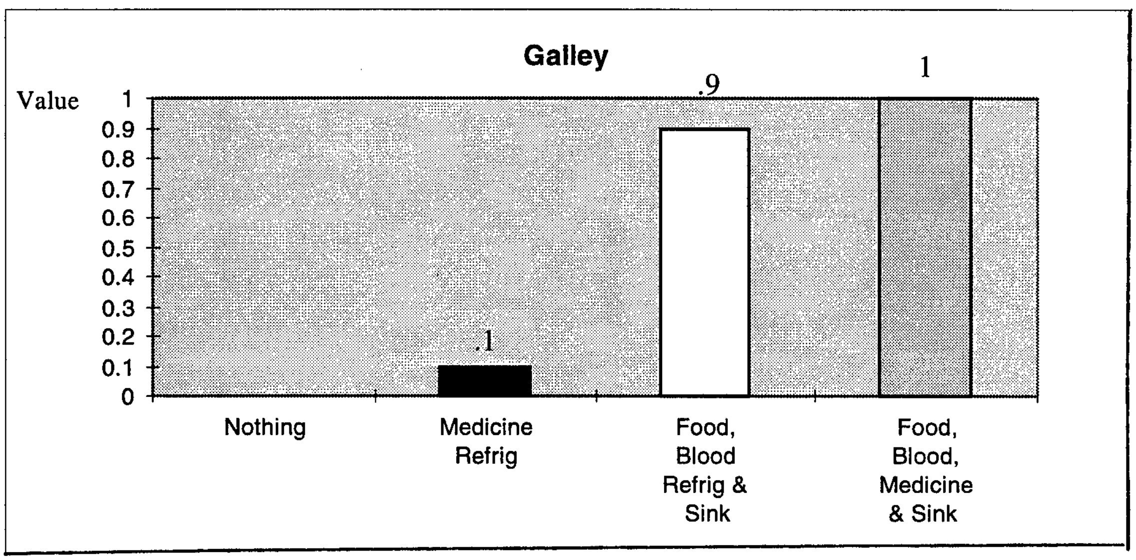

Figure A-17 Evaluation Measure: Galley

Zero Value: None | Alternative Acceptable With None? NO
Full Value: Food, Blood and Medicine Refrigeration

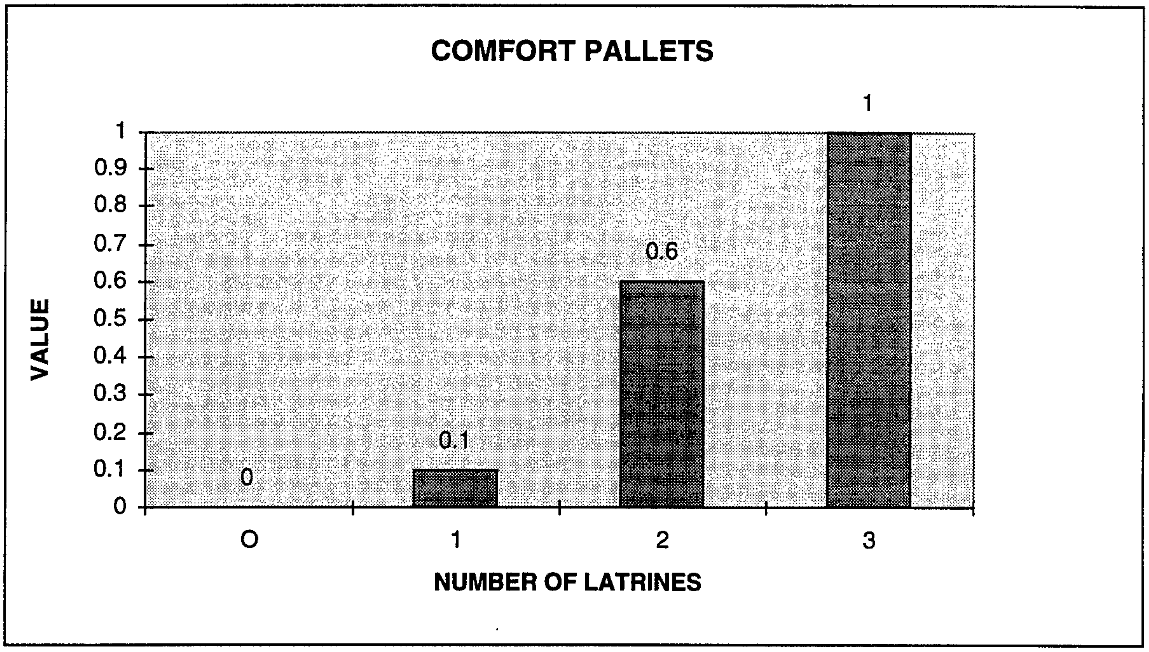

Figure A-18 Evaluation Measure: Comfort Pallet

Zero Value: Zero Latrines

Full Value: 3 Latrines

Alternative Acceptable w/o Latrine? NO

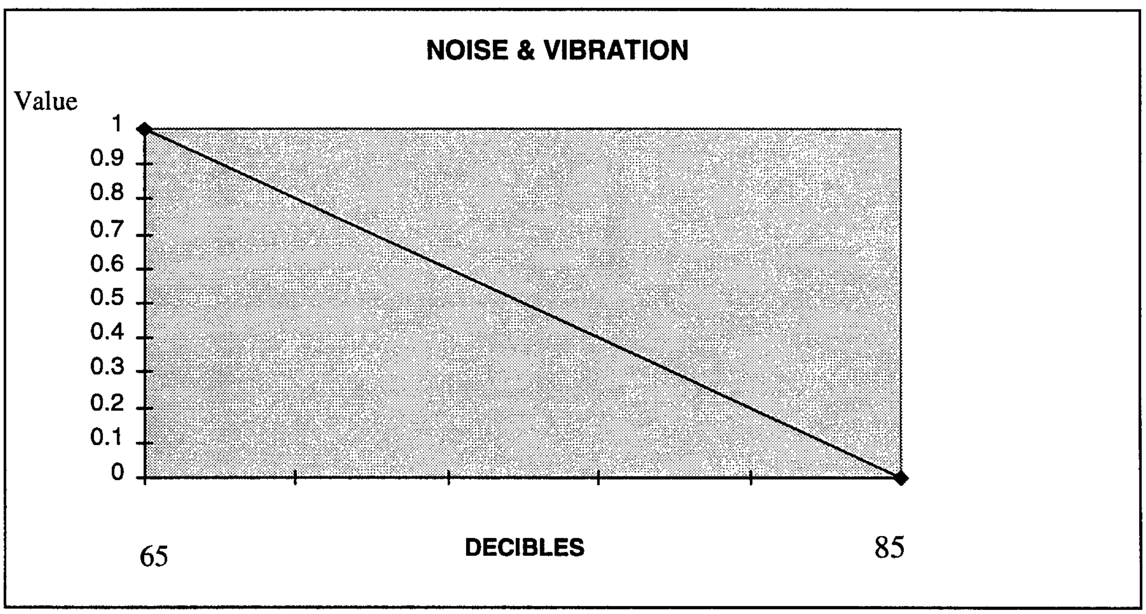

Figure A-19 Evaluation Measure: Noise & Vibration

Zero Value: 65

Full Value: 85

Alternative Acceptable Noise > 85? YES

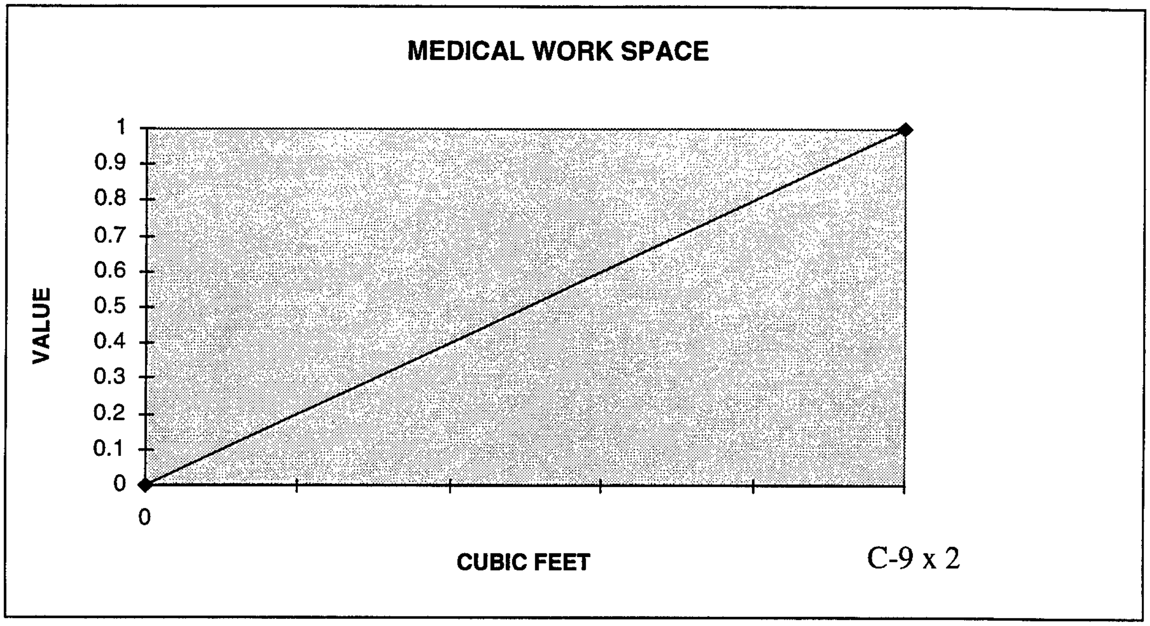

Figure A-20 Evaluation Measure: Medical Work Space

Zero Value: None
Full Value: Twice Cubic Feet of C-9A

Alternative Acceptable w/o Space? YES

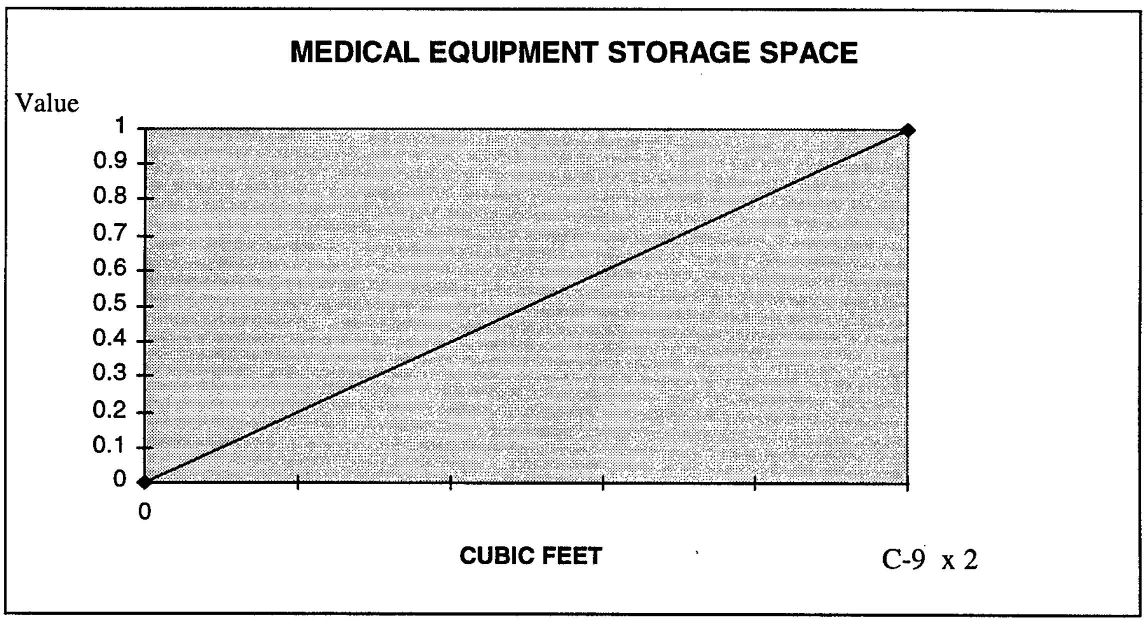

Figure A-21 Evaluation Measure: Medical Equipment Storage Space

Zero Value: None
Full Value: Twice Cubic Feet of C-9A

Alternative Acceptable w/o Space? YES

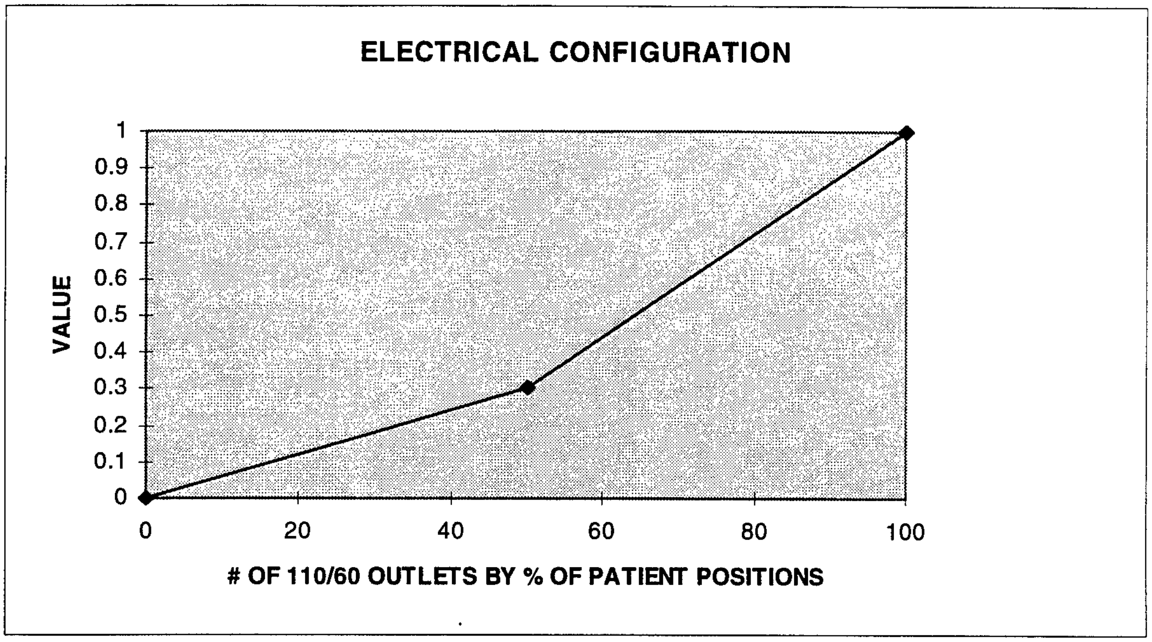

Figure A-22 Evaluation Measure: Electrical Configuration

Zero Value: Zero 110/60 Outlets
Full Value: 100% of Patient Positions

Alternative Acceptable With Zero 110/60 Outlets? Only if 100/400

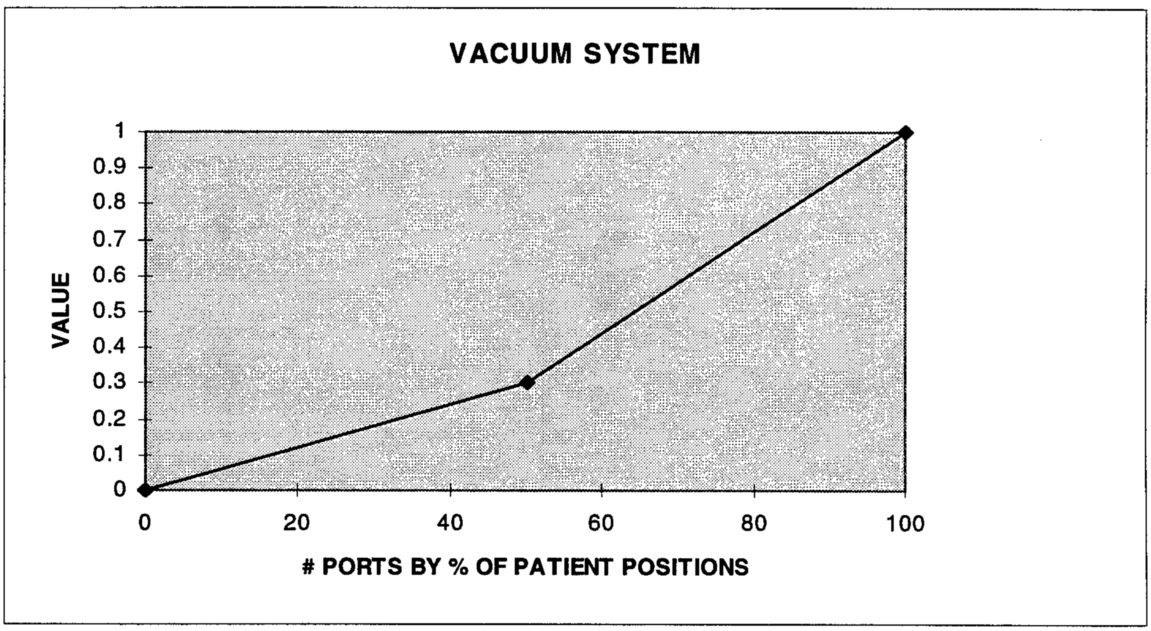

Figure A-23 Evaluation Measure: Vacuum System Configuration

Zero Value: No Outlets
Full Value: 100% of Patient Positions

Alternative Acceptable w/o Outlets? YES

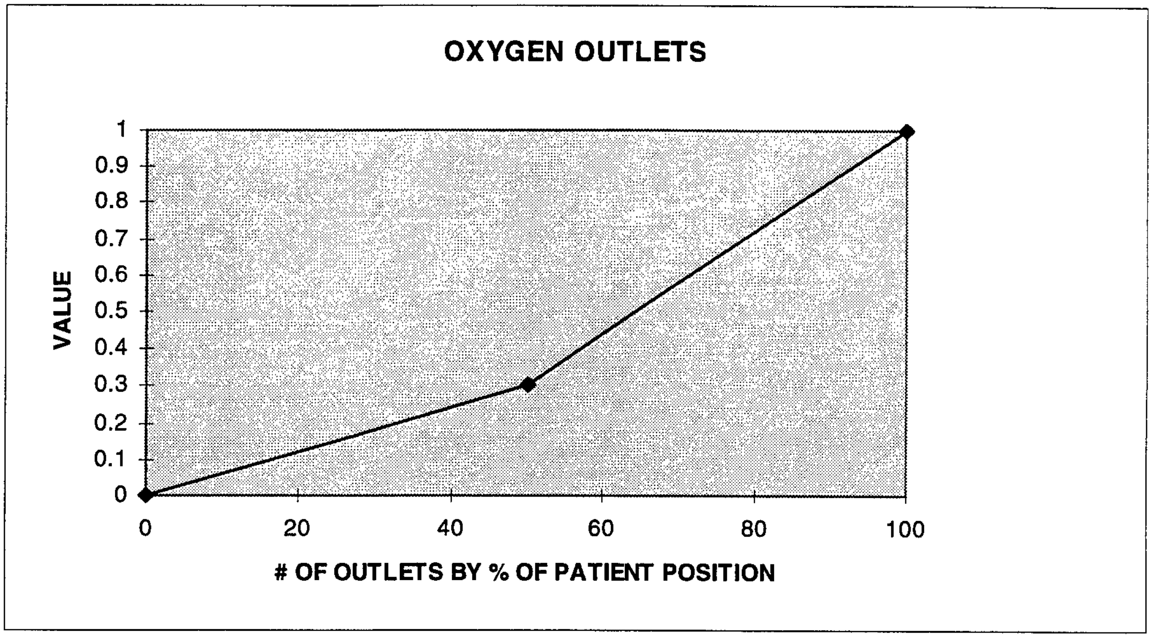

Figure A-24 Evaluation Measure: Oxygen Outlets

Zero Value: No Outlets

Full Value: 100% of Patient Positions

Alternative Acceptable w/o Outlets? NO

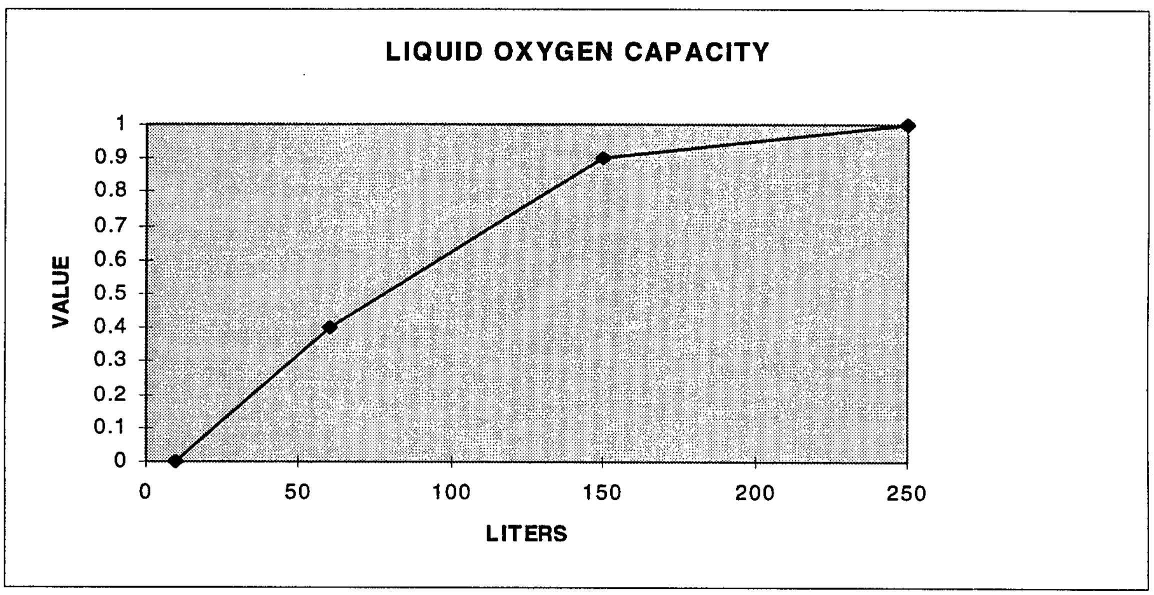

Figure A-25 Evaluation Measure: Liquid Quantity

Zero Value: 5 Liters

Full Value: 250 Liters

Alternative Acceptable < 5 Liters? NO

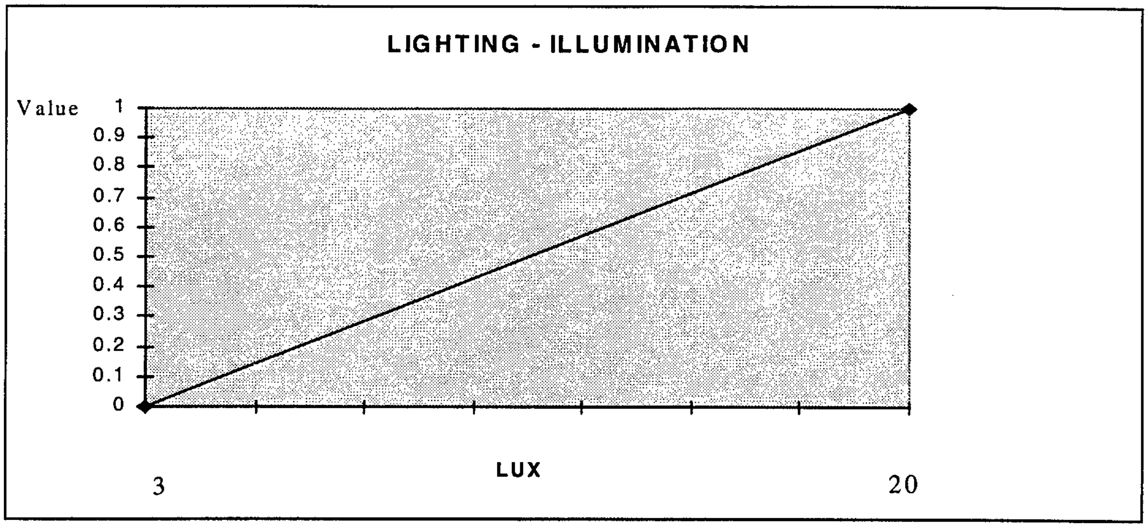

Figure A-26 Evaluation Measure: Lighting Illumination

Zero Value: 3
Full Value: 20

Alternative Acceptable Light < 3? YES

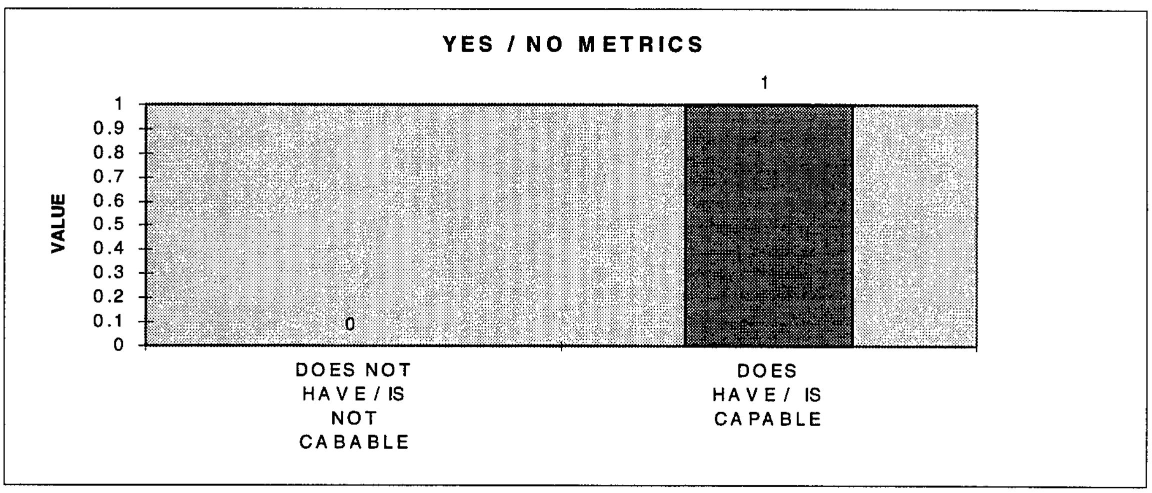

Figure A-27 Zero-One Evaluation Measures

Evaluation Measure	Alternative Acceptable at Zero Level?
Air Refueling Capability	YES
Unprepared Strip Capability	YES
Self-Start Capability	NO
Ground Refuel Capability w/o Stands	YES
Integral Litter Ramp	NO
Electrical System Back-Up	YES
Vacuum System Back-Up	YES
Red Lighting/Blackout	YES

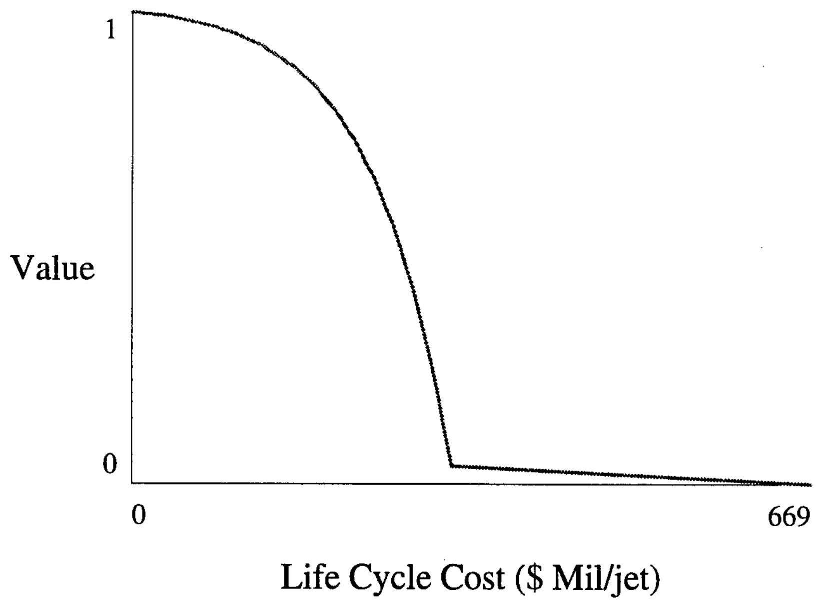

Figure A-28 Evaluation Measure: Life Cycle Cost

Note: Zero value is approached at approximately $ 220 Million The "tail" extending to $669 Million was allowed for computer software purposes. This caused a slightly higher value for the MD-17 (0.0021 higher in overall value) than accurate, but it did not in any way impact the final analysis.

Appendix B: Alternative Scores

Alternative scores are listed for each evaluation measure. Scores are based upon information sources listed in the text. Where conflicts in data existed, the analyst used data most consistent with that expected.

Life Cycle Cost data is the sum of acquisition costs, modification costs, and operating and maintenance costs through a 25-year usage cycle. O& M costs were not corrected for inflation or discount rate, as all alternatives were subject to the same types of costs, and thus will experience the same adjustments. There is no reason to expect purchase methods and timing to be different for any of the alternatives. Since VFT produces a relative ranking of alternatives, this does not affect the analysis.

All alternatives were modified to the maximum extent possible to provide a common configuration for analysis. This meant value differences based upon these modifications were primarily witnessed as differences in LCC value based upon different modifications costs for different alternatives. Further research may be done to determine the preferred level of modification in the chosen alternative.

NAME	Reliability	Range	Speed	Litter Capacity	Ambulatory
C-130J	0.82	3228	0.565	74	74
C-17	0.875	3600	0.77	48	90
MD-17	0.85	3600	0.77	48	90
B737-600	0.99	3230	0.785	43	43
B737-700	0.99	3224	0.785	51	51
B737-800	0.99	2930	0.785	65	65
B737-900	0.99	3200	0.785	70	70
B737-700 IGW QC	0.99	3224	0.785	51	51
B757-200	0.95	2728	0.8	80	80
B757-300	0.95	3485	0.8	90	90
B757-200F	0.95	2728	0.8	80	80
A319	0.95	3550	0.78	50	50
A320	0.95	2950	0.78	60	60
A321	0.95	2600	0.78	74	74
C-9A (base)	0.85	2400	0.78	40	40
C-9A (modified)	0.85	2400	0.78	40	40

NAME	Red Lighting	Vacuum Outlets	Vacuum BU	Temp Control	Isolation
C-130J	Yes	100	Yes	Yes	Privacy
C-17	Yes	100	Yes	Yes	Privacy
MD-17	Yes	100	Yes	Yes	Privacy
B737-600	Yes	100	Yes	Yes	Privacy
B737-700	Yes	100	Yes	Yes	Privacy
B737-800	Yes	100	Yes	Yes	Privacy
B737-900	Yes	100	Yes	Yes	Privacy
B737-700 IGW QC	Yes	100	Yes	Yes	Privacy
B757-200	Yes	100	Yes	Yes	Privacy
B757-300	Yes	100	Yes	Yes	Privacy
B757-200F	Yes	100	Yes	Yes	Privacy
A319	Yes	100	Yes	Yes	Privacy
A320	Yes	100	Yes	Yes	Privacy
A321	Yes	100	Yes	Yes	Privacy
C-9A (base)	No	27.5	No	Yes	Privacy
C-9A (modified)	Yes	100	Yes	Yes	Privacy

NAME	Med-Crew	A/R Capability	Logistics Tail	2nd Role	Survivability
C-130J	6	No	5	Pax/Cargo	Medium
C-17	6	Yes	10	Pax/Cargo	Medium
MD-17	6	No	10	Pax/Cargo	Normal
B737-600	6	No	10	Pax	Normal
B737-700	6	No	10	Pax	Normal
B737-800	6	No	10	Pax	Normal
B737-900	6	No	10	Pax	Normal
B737-700 IGW QC	6	No	10	Pax	Normal
B757-200	6	No	15	Pax	Normal
B757-300	6	No	15	Pax	Normal
B757-200F	6	No	15	Pax	Normal
A319	6	No	10	Pax	Normal
A320	6	No	10	Pax	Normal
A321	6	No	10	Pax	Normal
C-9A (base)	5	No	6.2	Pax	Normal
C-9A (modified)	5	No	6.2	Pax	Normal

NAME	Central Monitor	Galley	Comfort Pallet	Noise/Vibration	Med Work Sp
C-130J	Telemetry	F/B/M + sink	1	98	125
C-17	Telemetry	F/B/M + sink	2	60	200
MD-17	Telemetry	F/B/M + sink	2	60	200
B737-600	Telemetry	F/B/M + sink	3	60	107
B737-700	Telemetry	F/B/M + sink	3	60	127
B737-800	Telemetry	F/B/M + sink	3	60	162
B737-900	Telemetry	F/B/M + sink	3	60	175
B737-700 IGW QC	Telemetry	F/B/M + sink	3	60	127
B757-200	Telemetry	F/B/M + sink	3	60	200
B757-300	Telemetry	F/B/M + sink	3	60	200
B757-200F	Telemetry	F/B/M + sink	3	60	200
A319	Telemetry	F/B/M + sink	3	60	125
A320	Telemetry	F/B/M + sink	3	60	150
A321	Telemetry	F/B/M + sink	3	60	185
C-9A (base)	Call Bell	F/B/M + sink	2	85	100
C-9A (modified)	Telemetry	F/B/M + sink	2	85	100

NAME	Comm/Nav	Hard Surface	Unprep Surface	Self-Start	Gnd Refuel
C-130J	GATM	4470	Yes	Yes	Yes
C-17	Telemedicine	6000	Yes	Yes	No
MD-17	Telemedicine	6000	Yes	Yes	No
B737-600	Telemedicine	6160	No	Yes	No
B737-700	Telemedicine	6700	No	Yes	No
B737-800	Telemedicine	7400	No	Yes	No
B737-900	Telemedicine	7400	No	Yes	No
B737-700 IGW QC	Telemedicine	6700	No	Yes	No
B757-200	Telemedicine	5875	No	Yes	No
B757-300	Telemedicine	8200	No	Yes	No
B757-200F	Telemedicine	5875	No	Yes	No
A319	Telemedicine	5120	No	Yes	No
A320	Telemedicine	7665	No	Yes	No
A321	Telemedicine	7695	No	Yes	No
C-9A (base)	GATM	7200	No	Yes	Yes
C-9A (modified)	Telemedicine	7200	No	Yes	Yes

NAME	Equip Storage	Life Cycle Cost	110/60 Outlets	Electrical BU	Illumination
C-130J	125	150	100	Yes	3
C-17	200	669	100	Yes	20
MD-17	200	605	100	Yes	20
B737-600	107	128	100	Yes	20
B737-700	127	136	100	Yes	20
B737-800	162	146	100	Yes	20
B737-900	175	148	100	Yes	20
B737-700 IGW QC	127	141	100	Yes	20
B757-200	200	166	100	Yes	20
B757-300	200	175	100	Yes	20
B757-200F	200	166	100	Yes	20
A319	125	135	100	Yes	20
A320	150	136	100	Yes	20
A321	185	141	100	Yes	20
C-9A (base)	100	75.5	55	Yes	16
C-9A (modified)	100	80.5	100	Yes	16

NAME	Maneuverability	Litter Ramp	Reconfigure	O2 Outlets	Liquid O2
C-130J	65	Yes	Full(Gnd)	100	150
C-17	85	Yes	Partial	100	150
MD-17	85	Yes	Partial	100	150
B737-600	85	Yes	Full(Gnd)	100	150
B737-700	90	Yes	Full(Gnd)	100	150
B737-800	95	Yes	Full(Gnd)	100	150
B737-900	90	Yes	Full(Gnd)	100	150
B737-700 IGW QC	90	Yes	Full(Gnd)	100	150
B757-200	120	Yes	Full(Gnd)	100	150
B757-300	130	Yes	Full(Gnd)	100	150
B757-200F	120	Yes	Full(Gnd)	100	150
A319	85	Yes	Full(Gnd)	100	150
A320	90	Yes	Full(Gnd)	100	150
A321	95	Yes	Full(Gnd)	100	150
C-9A (base)	72.1	Yes	Full(Gnd)	27.5	25
C-9A (modified)	72.1	Yes	Full(Gnd)	100	150

Appendix C:Evaluation Measure Weights

Figures C-1 through C-3 show the weight breakdown for EMs and subgoals. Weights on a given tier sum to one to ensure completeness. Nominal weights are obtained by multiplying EM weights by the weight for each subgoal it is subordinate to.

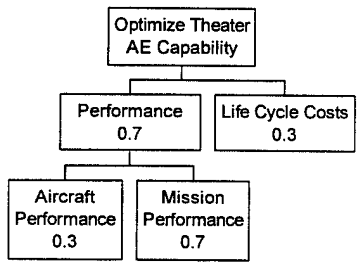

Figure C-1 Upper Tier Evaluation Measures

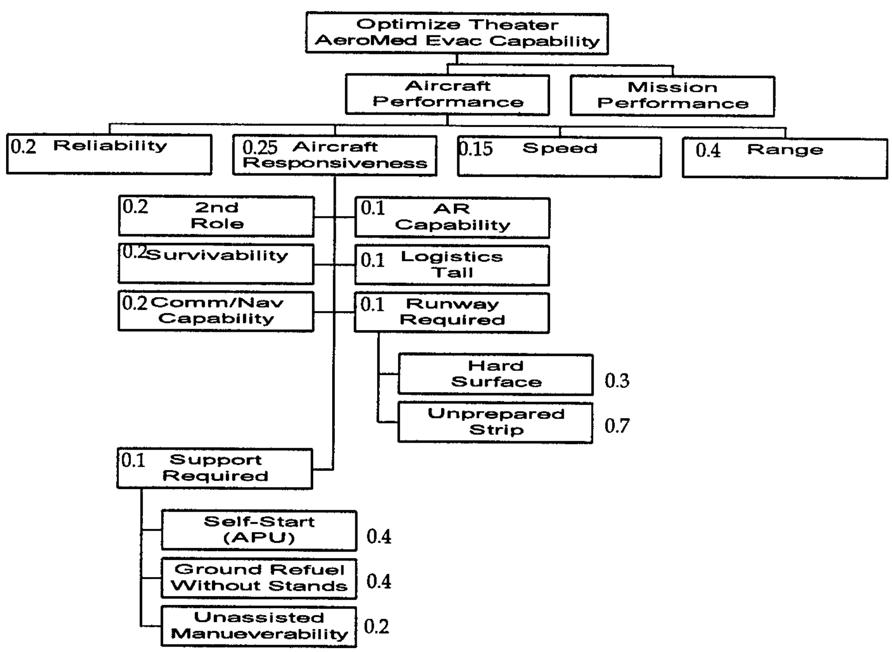

Figure C-2 Aircraft Performance Evaluation Measure Weights

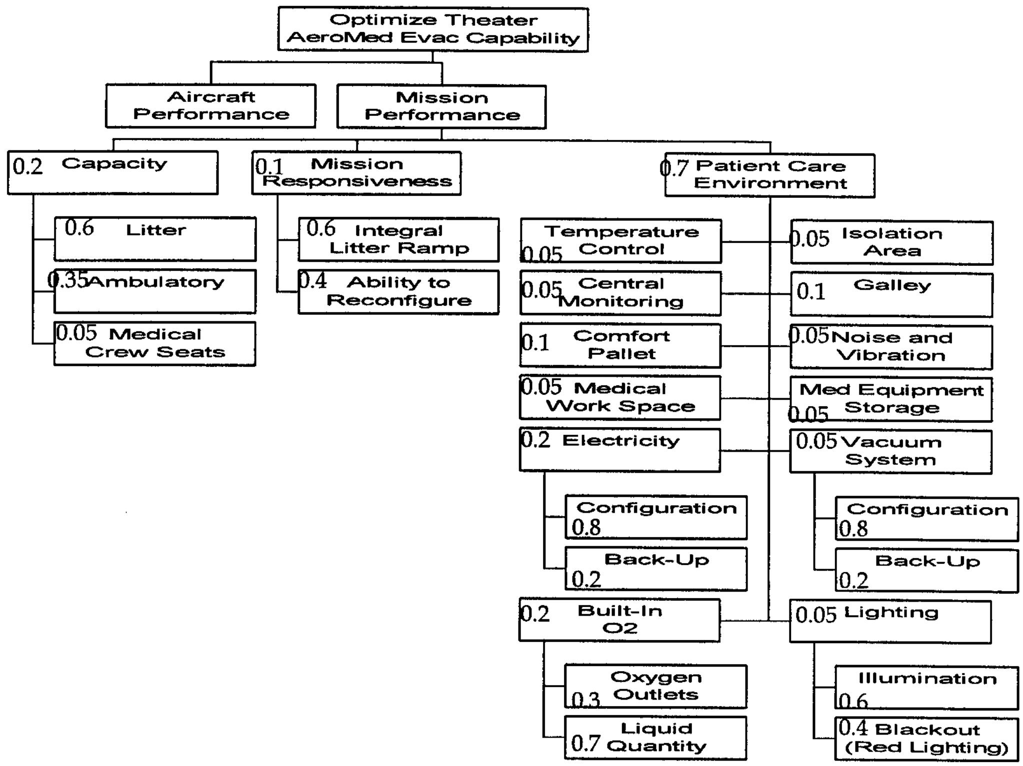

Figure C-3 Mission Performance Evaluation Measure Weights

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Vita

Major Scott A. Wilhelm was born 14 June 1962 at Forbes Field in Topeka, Kansas. He entered Undergraduate Pilot Training following graduation from the U.S. Air Force Academy in 1984 with a major in Computer Science-Systems Software. His first 12 years in service were spent in operational flying, maintaining qualification in the KC-135A, KC-135Q, T-38A, C-141B, and C-21A. Scott represented the U.S. as a special representative to HQ United Nations and earned a MS in International Relations from Troy State University. Upon completion of his MS in Operations Research, he will be assigned to HQ Air Mobility Command as a mobility analyst.

Permanent Address: 621 Woodland Hills
Troy, IL 62294

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Air Force Institute of Technology
2750 P Street
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HQ AMC/SGXP (POC: Major Jim Lorraine)
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DSN 785-6565 x 4335 Com (937) 255-6565 x 4335
E-mail: jjackson@afit.af.mil

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The research was commissioned by, and conducted for, the HQ AMC Surgeon General to assist him in making a hard decision. Should the McDonnell-Douglas C-9A Nightingale be replaced, and, if so, with what? Using tools based in Keeney's Value-Focused Thinking methodology, the SG's values for this decision were quantified, alternatives that addressed these values were generated, and those alternatives were evaluated using his values to suggest preferred alternatives.

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