DATA COMMUNICATIONS POSSIBILITIES FOR THE DEPLOYABLE REMOTE CONSOLIDATED AERIAL PORT SUBSYSTEM

THESIS

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The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

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Presented to the Faculty of the School

of Systems and Logistics

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Preface

This research used a design methodology to systematically derive a mobile data communications system for the deployable Remote Consolidated Aerial Port Subsystem. From over 1500 candidate systems, one was chosen as the "best." Very Small Aperture Terminals (VSAT), the chosen solution, offer an exciting new prospect for mobile air transportation data collection.

I would like to thank those who helped me along the way. Col James Winter, for steering me to this topic. Lt Col Dick Peschke for introducing me to Ostrofsky's methodology and then helping me through the entire thesis process. Capt Kevin Moore for helping me gather information at HQ MAC and providing many useful office notes on the concept of deployable Remote CAPS. Finally, but not least, I wish to thank my wonderful wife Judy whose encouragement, patience and editing skills helped keep me on track.

John T. Rausch

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Abstract

This research's purpose was to determine the optimal candidate system for data communications with deployable Remote CAPS. The process also established justification for the selection. A formalized methodology based on Benjamin Ostrofsky's *Design, Planning, and Development Methodology* was used for the process.

After a needs analysis of the problem, which is a lack of a mobile data communications system for MAC air transportation units, a feasibility study was completed which formulated the candidate systems to solve the problem. Finally, a preliminary activities phase evaluated each candidate system according to end user based criteria.

The candidate system selected was the Very Small Aperture Terminal (VSAT) technology. This data communication method will allow mobile data communications links throughout the world. Also the costs of the VSAT technology are not prohibitive as compared to standard satellite communications. The small size adds the portability that is required for mobile operations.

Recommendations for further research include analysis of total VSAT field systems required, analysis of host computer/hub terminal requirements, analysis of cost/benefits, and analysis of design specifications requirements.

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I. *INTRODUCTION*

General Issues

In today's world, computer systems like the Military Airlift Command's (MAC) Consolidated Aerial Port Subsystem (CAPS) (18), provide the ability to control large operations. CAPS operations run 24 hours a day, seven days a week, on a year-round and a worldwide basis (4). In CAPS, thousands of pieces of cargo are being tracked at any one time (20). The increasing demands placed on these computer systems have driven the development of new data communications technologies (24:71). Additionally, the use of microcomputers as smart terminals has been an integral component of the evolution of computer systems, specifically computer based information systems (14:77).

No longer are computer systems confined to the corporate headquarters or the manufacturing plant. Networks now tie together large geographic areas. The nodes of these networks communicate and feed each other data. This is the source of all the data which becomes information from which operational decisions are made (8:6). The typical corporate manufacturing plant computer system now updates the geographically separated headquarters computer system on a regular basis. Headquarters inquiries into a plant's status have become simple, local computer queries (24:71).

The military need for information systems is not any less consequential than in the business world. The military often finds the data sources for amassing its information to be spread globally and in locations with poor worldwide communication capabilities (19). The military information systems, which suffer from deficient links to these data sources, must employ the new technologies in communications systems if the goal of complete, accurate, and timely information is to be achieved. General Hansford T. Johnson, Commander In Chief, United States Transportation Command, in a recent statement before Congress alluded to this goal with the following: "The system should be capable of seamless integration of these modes of transportation--land, air, and sea--and would provide comprehensive intransit visibility of cargo and troops from home base to final destination" (11:1). Many military transportation organizations have now dubbed this new push for data collection on cargo and passengers "intransit visibility" or ITV for short (4).

Headquarters MAC/Air Transportation Systems, along with the 322 Airlift Division Deputy Commander for Air Transportation, Col James Winter, wants to use the advances in computer and data communications technology to improve MAC's ability to control and track cargo and passengers in the military airlift system (29). This is the case of MAC's CAPS, a system which is used to control the movement of cargo and passengers at military aerial ports. Successful large military deployments and employments such as Desert Shield/Storm depend on well coordinated and timely transportation information (13:25-26). Additionally, MAC operates a subordinate system, Remote CAPS, which consists of terminals placed at civilized locations where full CAPS implementation is not feasible (18).

Specific Problem

In the future MAC will have a deployable (mobile) version of Remote CAPS (17:1). The terminals will actually be micro computers, which will be expected to function immediately after arrival in environmentally hostile conditions (17). Unlike regular Remote CAPS, deployable Remote CAPS terminals frequently will not have the benefit of a modern telephone line for data communications purposes. Under these situations, data will be slow if not non-existent in movement between the CAPS host computer at Scott AFB and the remote terminal. The specific problem is how to establish a suitable data communications link under these primitive conditions. (29)

Research Objectives

The aim of this research was to find the optimal data communications system for deployable Remote CAPS. This was based on the formulation of potential candidate systems, which were then evaluated with performance criteria developed from consulting with Headquarters MAC on the subsequent investigative questions. A candidate system is defined as a system which fulfills the needs of the project, no matter how well or poorly, as long as it is capable of task completion.

Using the following investigative questions, a single candidate system was identified as being the best choice as compared to its fellow candidate systems. The investigative questions are as follows:

1. Should the communication link be an on-line transaction processing system (actual connection of field site to host computer) or a batch fed system with the communication connection made through an intermediate system or media?

2. What are the methods or the carrier media for establishing the communication link in question one?

3. Which methods give the best performance (speed of data communications) and reliability (number of transmission errors)?

4. Which methods can be operated by the average air cargo specialist in the field without special technical support?

5. Which methods are within MAC's budget?

6. What is the estimated time for a candidate system as defined by answers one through five to be developed and deployed for use?

7. Will the communications hardware for the candidate system fit on a standard military aircraft cargo pallet?

Research Scope

This research identified candidate systems in their prospectively ranked order. Only the deployable Remote CAPS terminals were studied. The actual decision as to which candidate system to be chosen rests with the user (the Military Airlift Command). Candidate systems researched in this thesis must be viable within the bounds of current technology or within the next one to two years.

Research sources for the study are from available literature and from telephone or personal interviews. Due to the time constraints of this study, formal surveys of potential candidate system suppliers were not accomplished. Subsequently, some cost data was approximated.

Conclusion

The Military Airlift Command is on the verge of moving from the slow paper burdened past to paper-less and quick information systems. To facilitate this goal in CAPS, deployable Remote CAPS is a necessity. The difficulty is to determine the "best" solution for deployable Remote CAPS data communications needs. This study uses a formalized methodology to examine these needs and give a structured and thorough recommendation.

II. *Literature Review*

The number of different ways to effect data communications is extensive and expanding yearly. Additionally, the costs associated with these different methods are varied, and adjusting with the declining costs of computer technology (24:71). This literature review discusses the features of various methods, along with the pros and cons of each.

Data Communications Systems

The first area examined was the media or the vehicle which is used to transport the data from the terminal or secondary computer to the host computer. Media can be broken down into two major categories, conducted and radiated. Conducted media include public and private telephone wires, coaxial cables, and fiber optic cables. Radiated media include broadcast radio waves, microwaves (terrestrial), infrared transmission, and satellite transmission (also using microwaves). A third type, storage media, such as magnetic tape or disks can be transported with the proper data message and effect a transfer or communication of data. (26:41)

Conducted media generally offers a lower cost method, especially for users who have access to public telephone lines. Infrequent usage is also a consideration for users, as purchasing or leasing a full-time telephone wire, coaxial cable, or fiber optic cable could be a waste of funds. Additionally, the user must consider the distance and volume of communication the conducted media is expected to carry. Coaxial cable is good only for distances under 10 miles (26:42). Some conducted media can also encounter problems with capacity constraints (limited frequency bandwidths) and electromagnetic interference (26:42). Telephone lines, public or private, can be unsuitable for data communication transmissions if the signals are too wide in bandwidth for the wire media (26:42). Long distance telephone communications can also be too noisy (electromagnetic interference) for data communications (26:42). Finally, but not least, conducted media is not very portable especially for long distance applications.

Radiated media offers many possibilities but the costs involved with radiated media are sometimes prohibitive for the subject application. The initial setup costs of radiated media are significantly more than most conducted media applications (26:48). However, in the long run, radiated media can be highly cost effective as the low operating costs offset the higher setup costs (26:48). The advantages radiated media offer are especially evident with satellite transmission where large geographical areas can be serviced with a single satellite. Other radiated media offer solutions to right of way problems (microwave) and moving vehicle applications (radio waves and infrared)

(26:48). All radiated media suffer from potential signal interference problems, such as weather and line of sight with satellite and microwave (26:48).

A new development worth mentioning is the Very Small Aperture Terminal (VSAT), otherwise known as the microterminal. Satellites launched in the 1980s are using higher receiving and transmitting frequencies, thus allowing for smaller earth station terminal "dishes" (five feet in diameter or less) to be used (21:7-68;23:89). The new frequencies operate in the 14/12 gigahertz range compared to the older style 6/8 gigahertz range, which required the eight to twelve foot in diameter dishes (25:37). The implications of this are that costs are reduced by as much as 10 times the average cost of the larger dishes (7:1105;21:7-68).

Many companies, most notably Federal Express, are employing VSAT in their operations with enormous success (5:19). Federal Express has placed a VSAT at all their service points, even in shopping center parking lots. Most of these VSATs transmit via satellite to a central hub, where the main host computer is located. Each terminal must communicate through the hub to reach another terminal (see figure 1). Other VSAT networks employ a mesh structure and communicate directly with each other instead of through a hub (see figure 2) (4:7-68; 6:89-94; 8:37-43).

Data communication media are not the only consideration when selecting a method of communication. Another

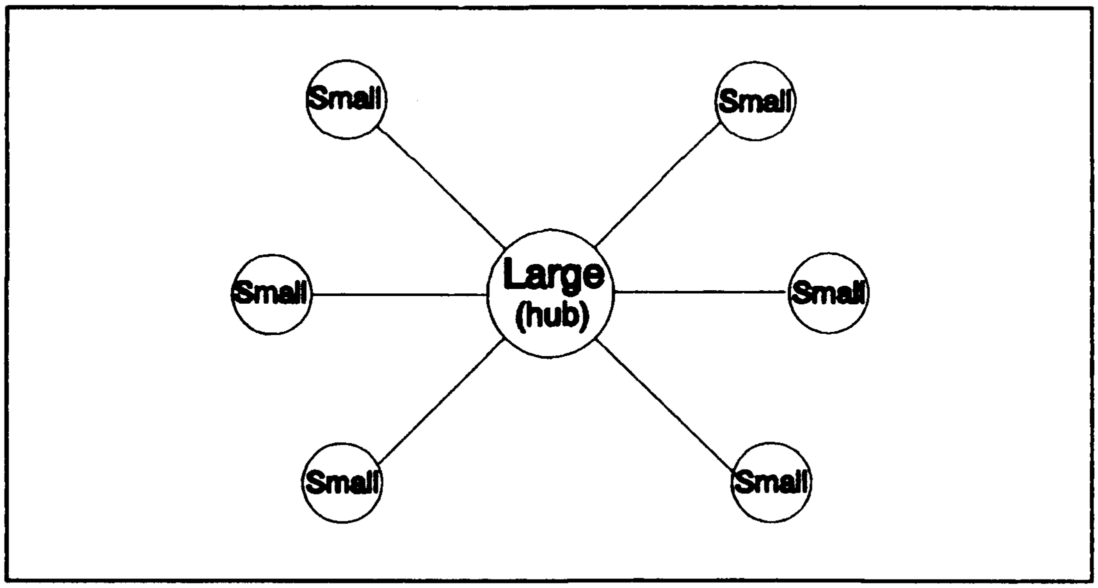

Figure 1 Hub or Star Network (21:20)

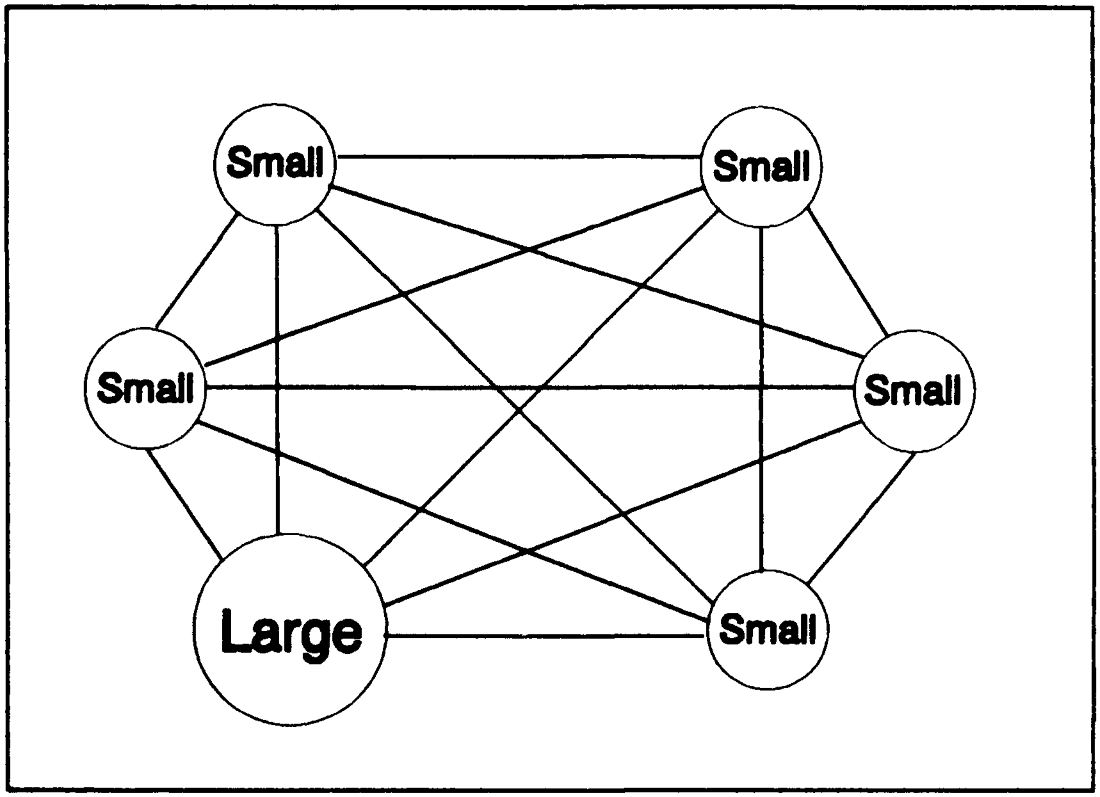

Figure 2 Mesh Network (21:21)

consideration is the configuration of the data communication system. Data communications can be from point to point (via dedicated media) or over a network structure. Additionally, a network structure can establish a real link between the host and terminal, analogous to talking on the telephone. The link may also be in the form of a handed off packet of data, much like sending a letter in the mail. The decision as to the best structure depends on the required data communication's speed, volume, and level of priority demanded by the using computer system (26:247-275).

Finally, cost is a consideration, especially in budget constrained times. Most communication systems are measured for cost on a monthly basis per site. Typically costs for data communications service over a distance of 2500 miles are widely varied. Private phone lines would cost approximately $53,916 per month, Satellite C-band service approximately $10,094 per month, A packet switching service approximately $31,403 per month, and a VSAT service approximately $1812 per month (21:91-103;23:89-94). All these costs are based on leased equipment, buying the equipment would add to the cost. Additionally, shorter communication runs bring the cost of phone lines and packet switching down dramatically. Runs of 200 miles are $1256 and $7383 per month respectively (21:91-103). The various satellite services do not change costs with distance covered as this does not increase equipment costs.

Conclusion

Selection of the communications media and structure is a complicated task if the using computer system is demanding of transmission speed, capacity, error protection, costs, priorities, etc. However, if the system is not demanding instant communication, data communication via mailed storage media could be a viable and cost effective alternative. Additionally, the selection can be further complicated by hybrids of the different methods, a sort of mixing and matching over different parts of the communication path. The selection of a data communications system for deployable Remote CAPS is not a simple problem. Therefore a structured methodology must be used to select candidates and evaluate them. The research design methodology developed by Benjamin Ostrofsky of the University of Houston, Houston, Texas, provides an excellent vehicle to accomplish this goal.

III. Methodology

Using available sources of literature and personal interviews, the first two steps of Ostrofsky's *Design, Planning, and Development Methodology* were performed. These were the "Feasibility Study" and the "Preliminary Activities" (22:17) This methodology has subsequent phases which were not accomplished for this research.

Ostrofsky's methodology is based on earlier work on design morphology by Morris Asimow and on systems engineering by Arthur Hall (22:3) Figure 3 illustrates the phases of the project life, a systems concept, where the project is designed and planned from a basic need statement to the retirement of the system. The first part or the "primary design-planning" phases include the two phases accomplished in this research and the "detail activities." Since the feasibility study and the preliminary activities are the phases used in this study, they are discussed in detail later in this chapter. The detail activities were used to generate and organize the implementation plans for the "optimal candidate system" (22:155). The second part or the "production-consumption" phases include the "production" phase, the "distribution" phase, the "consumption/operation" phase and the "retirement" phase (22:8). The production-consumption phases are defined as follows:

Production—the operations which manufacture the system elements or product.

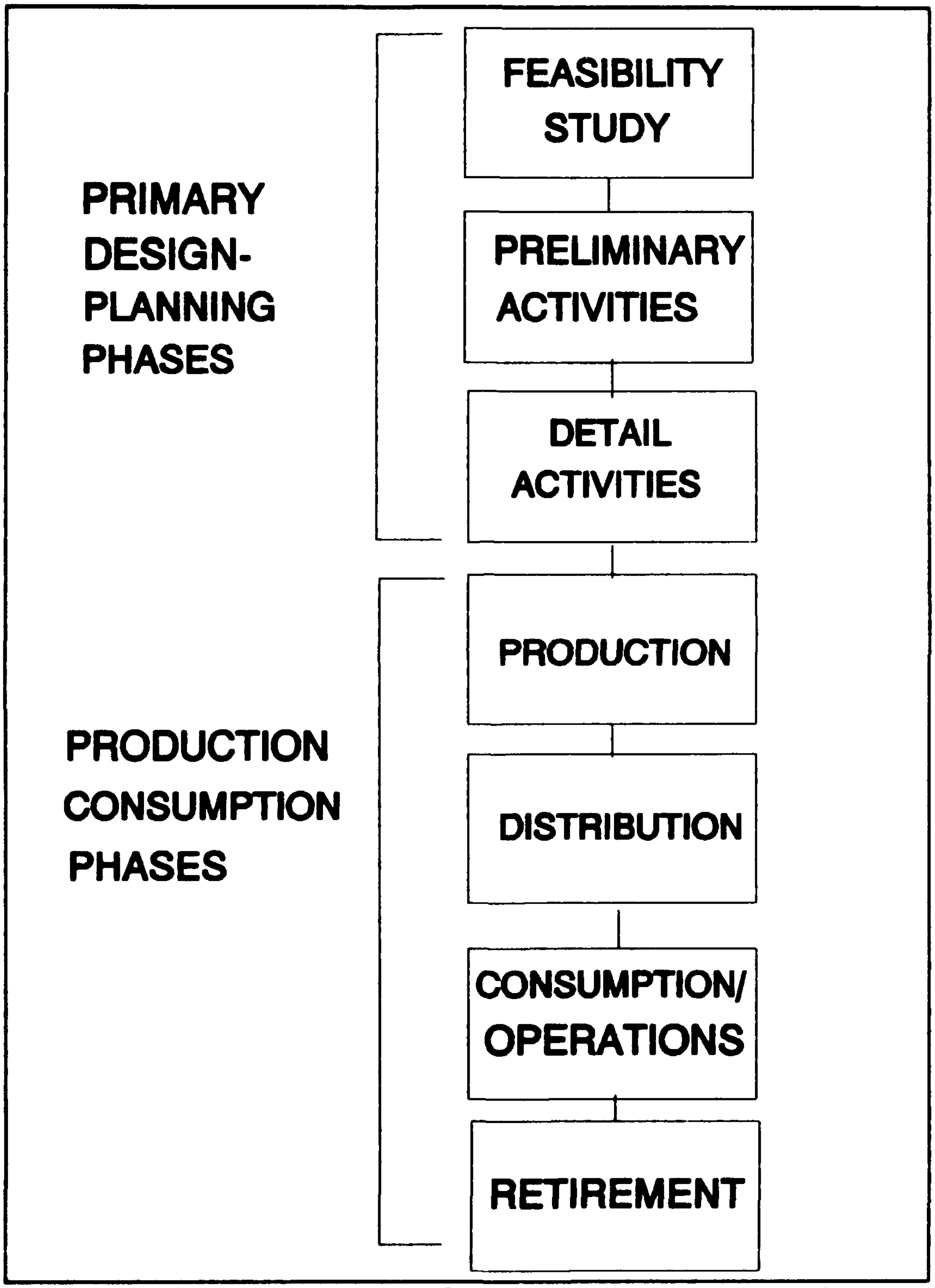

Figure 3 Phases in the Life of an Activity (22:18)

Distribution—the operations which transport the raw materials into the production facility, and to the consumer's site.

Consumption/Operation—the use of the system elements/product by the consumer. Products that are considered an operation make this phase a monitoring of that operation.

Retirement—the operation which places the system into a permanently dormant condition (9:87;22:8-13).

The Feasibility Study

Each step in Ostrofsky's methodology is iterative in that a particular step was repeated until all known options were exhausted. A feasibility study consists of four steps as illustrated by figure 4. The feasibility study starts with an analysis of the "primitive needs". Then the "needs analysis" ensures the project is worthy of further expenditure of developmental resources (22:31). It also provides a basis and a direction for the following activities.

The next step involves the "identification of the problem" (22:36). This stage takes the needs defined from the needs analysis and places them in the framework of the production-consumption phase. Inputs and outputs are formulated with respect to the needs of the system. These inputs and outputs have two types each: intended/environmental for inputs and desired/undesired for

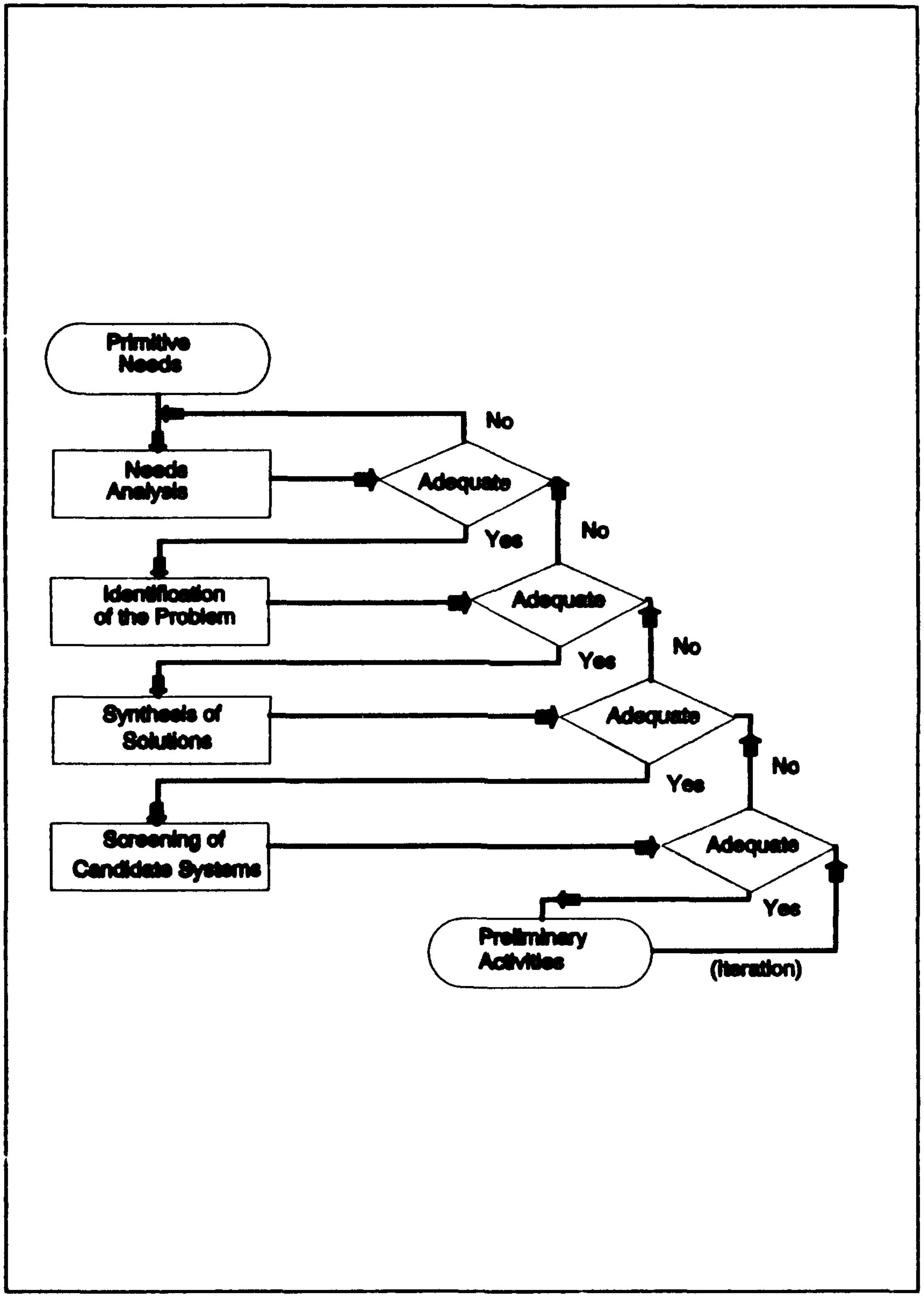

Figure 4 Feasibility Study Activities (22:28)

outputs. Figure 5 illustrates the concept of an input/output matrix used for formulating the inputs and outputs. By doing this, the designer ensures the activities of the primary design phases are associated with the

	INPUTS		OUTPUTS	
	Intended	Environmental	Desired	Undesired
Production				
Distribution				
Consumption/ Operation				
Retirement				

Figure 5 Input/Output Matrix (22:36)

production-consumption phases.

The third step, or the synthesis of solutions, is where a set of potential solutions to the specific problem was formulated. Each solution is termed a "candidate system." Candidate systems are made up of components, some of which may be shared by rival candidate systems. All the different combinations from each component category or concept make up a set of feasible solutions. For example, a feasible system for concept 1 has three components and each component has multiple solutions. The multiplication of each component category gives the total number of candidate systems, i.e., 3x2x4=24 candidate systems (22:45). Figure 6 illustrates the relationships between concepts, subsystems and the resulting candidate systems.

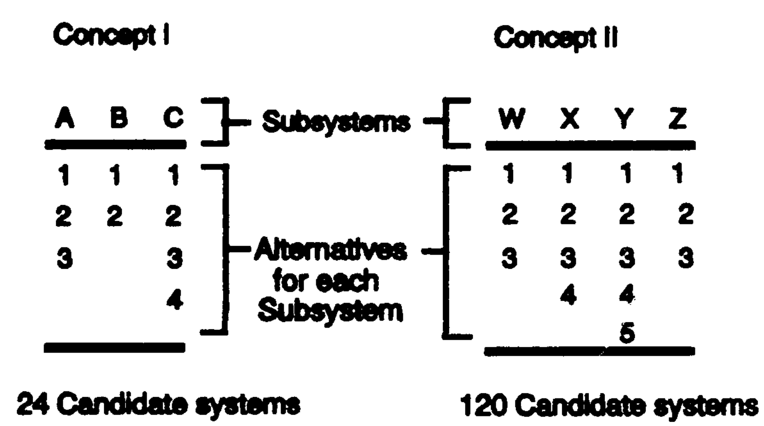

Figure 6 Definitions of concept and candidate system in synthesis of alternatives (22:48)

The last step in the feasibility study is the "screening of candidate systems" (22:55). Here, those candidate systems which were not physically, economically or financially feasible were eliminated from the list of candidate systems. If any doubts exist over eliminating a candidate system it should not be eliminated (22:55). This could be especially true of systems with long development times as a questionable candidate may become more feasible over time. A good example is the declining costs of micro-chip technology, where a candidate system using a micro-chip may have been too expensive at the start of development, but by the end of the development it is competitive with other alternatives.

Preliminary Activities

This portion of the research evaluated the candidate systems produced from the Feasibility Study. A flow diagram of the preliminary activities is illustrated in Figure 7. The preliminary activities' multiple steps are designed to find the "best" solution or as Ostrofsky states, "identify the optimal candidate system from the set of candidates already defined" (22:69). The optimal candidate system should not be confused with the "optimum candidate system" which is the theoretically favored according to the defined criteria (22:71). Rarely does the designer-planner find the optimum, but instead the optimal candidate system from the list of candidate systems. The main reason for this is because the list of candidate systems may not include the optimum candidate for reasons of oversight or obscurity.

The "preparation for analysis" groups comparable candidate systems together for establishing the advantages and disadvantages of each set (22:71). By doing this the interactions within the optimization process are defined.

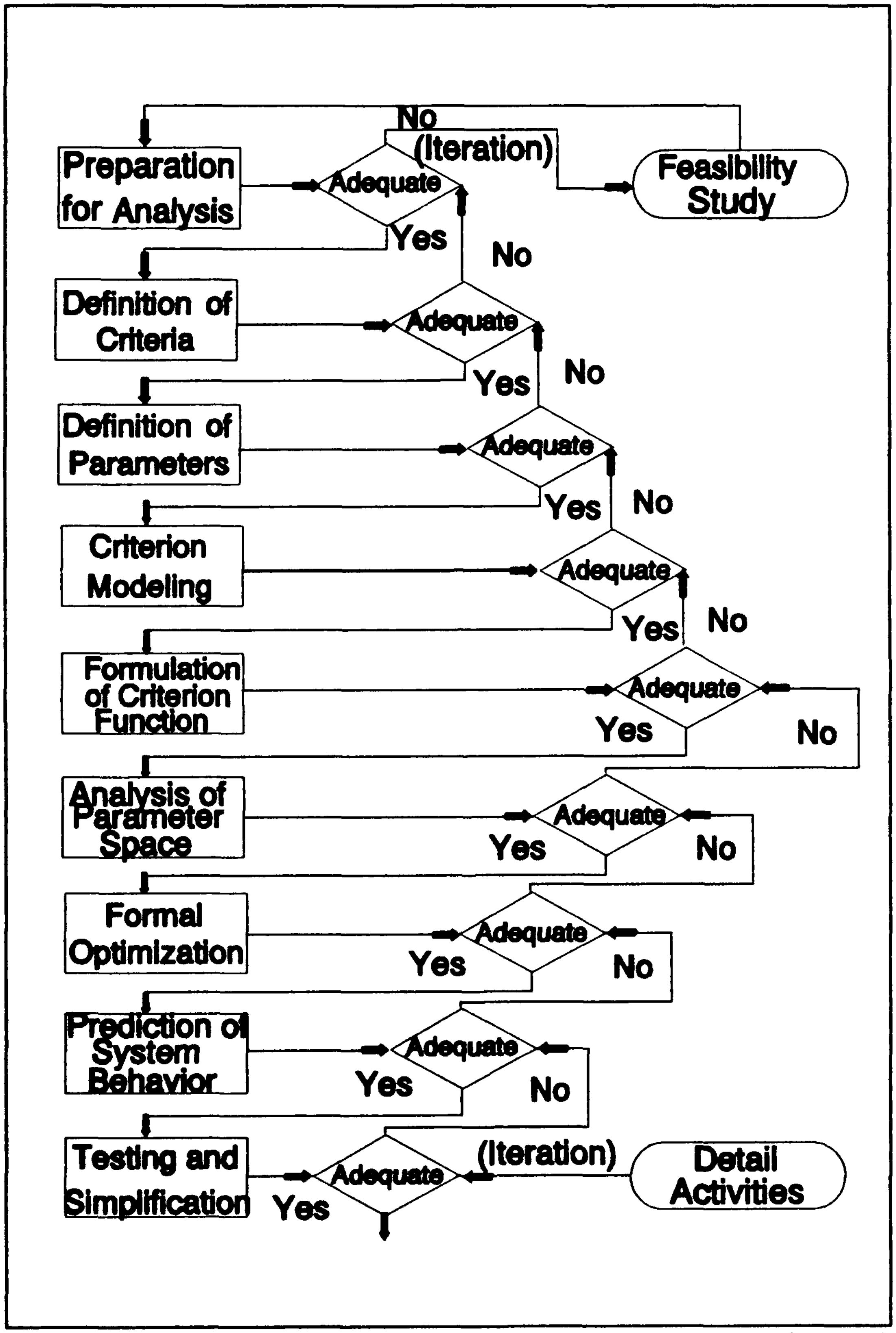

Figure 7 Preliminary Activities (22:68)

Eventually, the information gained was used to help detail the formulation of the criteria used to evaluate the different candidate systems.

The next step in Ostrofsky's methodology is the "definition of criteria" (22:80). Evaluation criteria were based on the needs of the user, in this case MAC's needs for deployable Remote CAPS. Criteria were given relative weights to ensure the that the results were fair. Additionally, the criteria were used for both desired and undesired measurements.

Each criterion needs to have parameters for the purpose of establishing measurable elements. The "definition of parameters" is designed to perform this function (22:86). The use of parameters allowed each criterion to have elements that can be directly, indirectly or not measurable. By breaking the criterion into elements, the analysis was assured that the most basic quantifiable measurements are made before interactions cloud the relationships and skew the results.

"Criterion modeling" involves the building of each criterion's mathematical function (22:95). At this step the designer-planner formulates out of the respective parameters the functions, whose relationships form each criterion. Ostrofsky emphasizes the fact that the resulting scale will be a cardinal scale, where intervals between successively ranked candidate systems are constant.

Ostrofsky states that this will allow a ranked order of candidate systems to be produced.

The next step, "formulation of the criterion functions," is where the designer-planner established the ranges placed on the parameters and eventually combines the different criteria into a single function (22:107). The result in this study was a single equation that furnished a scaled value for each candidate system. Ostrofsky also discusses the importance in ensuring each criterion is based on the same units of measure for consistency. Ostrofsky suggests using fractions for identifying criterion performance, using the allowable range to achieve this unit-less state.

To ensure the modeling has not embraced any significant hidden relationships, such as interaction between parameters, "analysis of parameter space" was performed (22:118). Because this procedure was done with a computer program, changes in the importance of different criteria can be easily analyzed for sensitivity, compatibility, and stability. This step is intended to reduce risk and uncertainties in the planning and design within the scope of the available resources.

The "formal optimization" is the final step in establishing an optimal candidate system (22:135). Using another computer program built to compare and compute the optimization, the design-planner received the optimal choice. Because the optimization was derived using a computer program, changes in the user's values can be easily changed and recomputed. The user (HQ MAC) now has the capability to make an educated decision for the correct candidate system choice.

The final two steps, the "prediction of system behavior" and the "testing and simplification" are to ensure the optimal candidate system's correctness (22:142-150). The prediction of system behavior deals in the compatibility with the operational environment as defined by the input-output matrix in the feasibility study. Testing and simplification is concerned with the verification of the system attributes. It also is intended to focus further study on the candidate system in order to gain new knowledge and expose any overlooked shortcomings.

Conclusion

Ostrofsky's methodology provided a structured formulation and evaluation of candidate systems. The process yielded a ranked list of solutions. Out of this list an optimal solution yielded the means for a better and educated decision for choosing the "best" system. Subsequently, the justification for the decision can be defended to critics.

IV. Feasibility Study

In recognizing an irrefutable problem of providing mobile communications for Deployable Remote CAPS, the feasibility study's goal is "to synthesize and screen solutions, thus achieving a set of useful solutions to the problem" (22:23). These useful solutions or candidate systems are then evaluated against criteria developed during the preliminary activities. Eventually, one system becomes the choice, but not before all potential schemes are considered.

The feasibility study starts with the user's primitive needs and progresses through four steps: the needs analysis, the identification of the problem, the synthesis of solutions, and the screening of candidate systems. Each step builds on the previous one to produce the final output. Candidate systems are the output which the preliminary activities evaluate and order from most desirable to least desirable.

Needs Analysis

The Military Airlift Command (MAC) has gradually developed its airlift information systems to the point where permanent, fixed air bases are now tied together providing information on a global scale. Individual pieces of cargo can be tracked at any base with access to the Consolidated Aerial Port Subsystem, a capability which greatly enhances logistics in the DOD (16). The power of this information has allowed significant gains in reducing costly inventories, an issue which will attract attention during the forthcoming budgetary reductions (20).

The need for further air transportation data communications to include mobile links was more than evident during Operation Desert Storm/Shield (29). Cargo arrived into a situation unlike the established and permanent bases in Europe and the Far East. To compensate for the lack of data communications on the receiving end, MAC set up Remote CAPS terminals at the deployed sites. Eventually Defense Data Network (DDN) connectivity to the CONUS was established after six weeks, but not before significant amounts of cargo had been airlifted into the region (20;29). The resulting lack of cargo "received" or "not received" information caused confusion and in some cases secondary shipments to replace supposedly "lost" shipments. In times of emergencies the size of Desert Storm, any duplication of effort is wasteful and may have far reaching negative impacts on the logistical support of the operation (29).

The problem of providing air transportation information systems support in deployed locations is a hurdle, which MAC is trying to clear by employing microcomputers at these sites (19). These microcomputers will become the basis of the deployable version of Remote CAPS. The system however, cannot be truly deployable worldwide unless a mobile communications package is also developed. Not every location in the world has a telephone line or DDN connection available (6:53-55). A temporary measure of passing floppy disks will be only partially acceptable as it will not provide the instant data updating capability which is critical to a modern information system (16).

Identification and Formulation of the Problem

In this step of Ostrofsky's methodology, an input/output matrix was used to place the needs in the context of the production-consumption phase. By analyzing the inputs and outputs, the designer-planner gains a better grasp and focus of the problem. He also is able to identify as many characteristic attributes as possible.

The matrix covers both the desired and undesired aspects of the project's life cycle. Undesired aspects can be minimized or eliminated by this advance planning. Desired aspects conversely, can be enhanced when possible and planned to interact positively with environmental inputs. Environmental inputs being those which already exist in the system and are projected to effect the project in each life cycle phase. Tables 1 through 4 cover the phases of production, distribution, consumption/operation, and retirement.

Synthesis of Solutions

The synthesis of solutions used three basic approaches to the problem each with elemental functions or subsystems. The different combinations of subsystems from each concept

Table 1 *Production Activity Analysis*

INPUTS			
	Intended		*Environmental*
1.	Highest quality product	1.	US manufactured
2.	State of the art technology	2.	Commercially available
3.	Reasonable cost		
4.	User friendly		
5.	Durable in austere environments		
6.	Uses small or micro components		
7.	Worldwide usage		

OUTPUTS			
	Desired		*Undesired*
1.	Maintainable system	1.	Foreign material sources
2.	Low production costs	2.	Limited availability
3.	Production on schedule	3.	Cost overruns
4.	State of art system	4.	Geographical limitations
5.	Compatible with current equipment		

amounts to the number of candidate systems synthesized.

This produced the following number of candidate systems:

Concept I

A B C D E F G F
3 x 2 x 4 x 2 x 2 x 2 x 2 x 3 = 1,152 candidate systems

Concept II

A B C D E F G F
3 x 3 x 2 x 4 x 2 x 2 x 2 x 3 = 1,728 candidate systems

Concept III

A B C D E
3 x 5 x 2 x 2 x 3 = 180 candidate systems

Table 2 *Distribution Activity Analysis*

INPUTS

Intended	*Environmental*
1. Acceptance of product by MAC	1. Budgetary allocation
2. Integration with Deployable RCAPS	2. Distribution of Deployable RCAPS
3. High MTBF for hardware	
4. Low MTTR for hardware	
5. Short training time	

OUTPUTS

Desired	*Undesired*
1. Quick implementation to the field	1. Quick obsolescence
2. Full distribution	2. Partial distribution
3. Long service life	

Total candidate systems for all three concepts = 3,060

Tables 5 to 7 illustrate the different subsystems for each concept. However, it should be noted that a screening of these lists had to be accomplished as some combinations were infeasible for physical, economic or financial reasons. Additionally, the listings included some questionable approaches, but the purpose of this study was to evaluate all approaches and not to risk discarding the optimal candidate system prematurely.

Screening of Candidate Systems

As mentioned in the synthesis of solutions, the solutions must be screened to eliminate those which are

Table 3 *Consumption/Operation Activity Analysis*

INPUTS

Intended	*Environmental*
1. Trained users	1. Operating location
2. Deployable RCAPS terminal	2. Weather
3. Host computer	
4. Airlift movement	
5. Mobile equipment	
6. Reliable	

OUTPUTS

Desired	*Undesired*
1. Data flows smoothly	1. Data flow interrupted
2. Data correct	2. Data incorrect
3. Helps logistics effort	3. Creates dependance on it
4. User acceptance	
5. Low operating costs	
6. Low maintenance costs	
7. User installation	

definitely infeasible. Ostrofsky states that care should be maintained here as: "many projects are developed over long time periods, and as time progresses during a development additional knowledge and resources are gained which often make candidate systems feasible which might not have been earlier" (22:57). The first elimination is for those components which are physically incompatible, the second for economic worthwhileness and the third for financial feasibility.

Physical Realizability. Because many components of the system are developed separately, some may need to be eliminated for incompatibility. For Concept II, component

Table 4 *Retirement Activity Analysis*

INPUTS

Intended	*Environmental*
1. Disposal according to DOD norms	1. Obsolescence
2. Recycle into second life	2. CAPS retired

OUTPUTS

Desired	*Undesired*
1. Reused for other uses	1. Retired prematurely
2. Complete recycling of material	2. Material un-disposable
3. Provides information for a superior successor	

B1 is incompatible with component F2. The reason for eliminating this group is because twisted pair applications do not offer a reliable data communications media above 9600 Bps. Just this elimination alone caused a reduction of net candidate systems by 192. Concepts I and III were found not to contain any combinations of physical incompatibilities.

Economic Worthwhileness. This screening is to reduce the pool of candidate systems from any candidates which will not provide an acceptable return on investment. In order for this to happen, an investment in a candidate system would have to exceed the value to which is placed on the benefits gained from the system. All of the components of Concept II are economically infeasible as they all require extensive investments in twisted pair wire, coaxial cable, or fiber optic cable. Since the system is to be mobile, the

Table 5 *Concept I Candidate Systems*
Radiated Media (21:4-7;26:48-59)

A. Communication Capability
   1. Send only
   2. Receive only
   3. Send and receive

B. Transmission Frequencies
   1. 6/8 GHZ
   2. 14/12 GHZ

C. Message Transmission
   1. Virtual circuit
   2. Virtual circuit packet switching
   3. Message switching
   4. Datagram packet switching

D. Setup
   1. User capable
   2. Specialist assistance

E. Procurement
   1. Purchased
   2. Leased

F. Satellite Time
   1. Government owned
   2. Commercial lease

G. Transmission Security
   1. Secure
   2. Non-secure

F. Speed of Transmission
   1. 9600 Bps
   2. >9600 Bps
   3. 9600 Bps send/>Bps receive

costs of rigging vast stretches of conducted media for a moving asset are uneconomical. This elimination reduced the net candidate systems by another 1536.

Financial Feasibility. This final screening offers no incompatibilities. The remaining candidate systems are fully feasible under the user's current budget. However,

Table 6 *Concept II Candidate Systems Conducted Media* (26:41-48)

A. Communication Capability
   1. Send only
   2. Receive only
   3. Send and Receive

B. Media Type
   1. Twisted pair wire
   2. Fiber optic cable
   3. Coaxial cable

C. Transmission
   1. Digital
   2. Analog

D. Message Transmission
   1. Virtual circuit
   2. Virtual circuit packet switching
   3. Message switching
   4. Datagram packet switching

E. Setup
   1. User capable
   2. Special assistance

F. Procurement
   1. Purchased
   2. Leased

G. Transmission Security
   1. Non-secure
   2. Secure

F. Speed of Transmission
   1. 9600 Bps
   2. >9600 Bps
   3. <9600 Bps

later as in many Department of Defense projects, the possibility exists of a financial constraint which could eliminate one or more of the remaining candidate systems. The total number of candidate systems has thus been reduced by a total of 1728 possibilities. The remaining count is 1332.

Table 7 *Concept III Candidate Systems Storage Media* (26:10-11)

A. Communication Capability
   1. Send only
   2. Receive only
   3. Send and receive

B. Type of Storage
   1. Magnetic tape
   2. 5.25 Floppy disk
   3. 3.5 Floppy disk
   4. Punch cards
   5. Compact disk

C. Procurement
   1. Purchased
   2. Leased

D. Transmission Security
   1. Secure
   2. Non-secure

E. Time of Transport
   1. US mail
   2. With every shipment
   3. On a scheduled basis with a shipment (batch)

Summary

The feasibility study refined the needs of the user for a mobile data communications system. It then proceeded to establish the limitations and expectations through the input/output matrixes. Finally, a list of candidates was synthesized and screened for feasibility. This produced a product for the preliminary activities to evaluate for the formal optimization, and find the "best" candidate.

V. *Preliminary Activities*

The feasibility study resulted in the formation of many candidate systems. The "Preliminary Activities" section's purpose is to find the "best" solution, or according to Ostrofsky: "identify the optimal candidate system from the set of candidates already defined" (22:71). Subsequently, Asimow wrote the importance of this step is that: "the most promising one must be identified" and "adopted as the design concept for the project" (2:24). The preliminary activities are meant to evaluate only those candidate systems which fall within the parameters developed from the needs of the future user and not to evaluate candidate systems which fall outside those boundaries.

Preparation for Analysis

Although some candidate systems were eliminated in the screening of candidate systems during the feasibility study, 1332 possible candidate systems remain. The more candidate systems remaining, the bigger the difficulty in subjectively evaluating all of them. However, the more systems evaluated the better are the chances of finding an optimal solution.

The preliminary activities allows new knowledge to arise about the set of candidates and their positions of suitability among themselves and with the needs analysis. Ostrofsky states that the analysis gives results for the following objectives.

1. An increasing awareness of the nature of the criteria to be met by the emerging system.

2. An increasing knowledge of the nature of the candidate systems for a given concept and the qualities of each concept in the broad domain of possible concepts available to meet the needs defined. (22:74)

Ostrofsky suggests grouping candidate systems together which have comparable attributes. This helps facilitate the accomplishment of the previously mentioned objectives. Tables 8 to 10 identify the advantages and disadvantages of each grouping within a particular concept. This helps ensure the criteria for the evaluation are proper and given adequate consideration.

Definition of Criteria

Each candidate system has particular attributes, which can be evaluated with criteria. The scale that results from the combination of criteria into a measurement tool can be used to compare each candidate system against the others. Criteria can be almost anything desired, even abstract concepts such as "ease of use" or "user satisfaction." Ostrofsky states that criterion development should not leave out any elements which are crucial to identifying the optimal candidate system (22:80). If that happens, the criterion will have no effect on the choice for the optimal candidate system.

The subsequent criteria were selected for their ability to meet the original requirements indicated in the feasibility study.

Table 8 *Concept I Grouped Candidates by Attributes*

Type of Candidate	*Advantages*
Very Small Aperture Terminal (Ku-band)	1. Small ground station size. 2. Independent of local communication infrastructure. 3. Offers global communication. possibilities. 4. Light weight equipment offers portability. 5. Provides medium for a virtual circuit to host computer. 6. Continuing operations cost relatively small.
	Disadvantages
	1. Initial equipment cost expensive. 2. Requires satellite service. 3. Extensive user training maybe required. 4. Inclement weather may interrupt service.
	Advantages
C-band Terminal	1. Uses frequencies common in 1970s and early 1980 era satellites. 2. Most government satellites also use C-band. 3. Offers higher communication speeds than Ku-band. 4. Independent of local communication infrastructure. 5. Offers global communication possibilities. 6. Provides medium for a virtual circuit to host computer.
	Disadvantages
	1. Very expensive. 2. Requires long lead time for setup. 3. Equipment bulky and heavy. 4. Requires extensive technical expertise. 5. Inclement weather may interrupt service

Table 9 *Concept II Grouped Candidates by Attributes*

Type of Candidate	*Advantages*
Conducted Media (Virtual circuit)	1. Lower costs than satellite service when used on an infrequent basis. 2. Inclement weather has minimal effect. 3. Requires minimal equipment at terminal location. 4. Users need minimal technical training. 5. Equipment is small and portable. 6. Offers virtual circuit to host computer.
	Disadvantages
	1. Not available at every global location. 2. Transmission quality lines not available at all global locations. 3. Media easily destroyed by hostile action.
	Advantages
Conducted Media (Packet switching)	1. Lower costs for service. 2. Inclement weather has minimal effect. 3. Requires minimal equipment at terminal location. 4. Users need minimal technical training. 5. Equipment is small and portable.
	Disadvantages
	1. Not available in many global locations. 2. Transmission quality lines not available at all global locations. 3. Media easily destroyed by hostile action. 4. Does not offer virtual connection to host computer. 5. Requires many intermediate nodes to handle data packets.

Table 10 *Concept III Grouped Candidates by Attributes*

Type of Candidate	*Advantages*
Storage Media	1. Very low cost. 2. Easy for user to operate. 3. Virtually unaffected by weather. 4. Independent of local communication services. 5. Low impact on DOD communication facilities. 6. Small equipment size and weight.
	Disadvantages
	1. Slow data communications interchange. 2. No virtual circuit to host computer. 3. Media subject to damage in transit. 4. Media is limited in storage capacity.

Costs. Costs are the expenses for hardware, transmission, maintenance and host computer connectivity. The budget constraints placed on the user are important considerations as limited resources will have a large impact upon selection.

User Friendliness. As the end user of the product is not intended to be a electronic and computer expert, the degree of user friendliness is highly important. The users could find themselves in a remote area with limited technical assistance available. The degree which a candidate system can help the user along depends upon built in help features, field manuals, the complexity of the system and training required for users.

Portability. Portability is the ease of with which a candidate system can be packed up and moved to another location. It is subject to the size and weight of the equipment. The smaller and lighter the equipment, the higher the portability.

System Availability. System Availability is based on whether or not the system is operable when needed (26:461). Average failure times of equipment components and the average subsequent repair times are considered in projecting system availability.

Response Time. Response Time is the time required for data to flow from the terminal site to the host or main computer. The need for quick and timely information in the military airlift system compels this time to be as short as possible.

Criteria Relative Importance

Because the study includes several criteria, each must be weighted according to its relevance. Each criterion may not be of equal significance and to ensure proper differentiation weighted values are essential.

The rating values are in table 11 and are labeled a'(i). These could be derived from many sources of information, and according to Ostrofsky "even an intuitive evaluation" can generate a choice closer to the optimum candidate system than using equally weighted criteria (22:84). The criteria in this study were weighted by soliciting individuals at Headquarters MAC for their perceptions on the deployable remote CAPS data communications system requirements.

The instrument used was the questionnaire in Appendix A (1:54). An interesting observation was that statistically, a significant difference was produced by the two groupings of officers and noncommissioned officers. A Wilcoxon Signed Rank Test produced a p value of only 0.2860 that the two populations could be the same (15:959;27:211). Appendix B contains the complete results of the test.

To formulate the ratings, the majority consensus for the five criteria was used. Each criterion was given a value between zero and ten. The ratings were then normalized by calculating the portion of the summed criteria ratings each criterion represents. Notice that the sum of these portions equals one.

Table 11 *Criteria and Relative Weights*

Criterion, x(i)	*Rating, a' (i)*	*Weight a(i)*
x1: Cost	7	a1: 0.18
x2: User Friendliness	9	a2: 0.24
x3: Portability	8	a3: 0.21
x4: System Availability	8	a4: 0.21
x5: Response Time	6	a5: 0.16
		1.00

Definition of Parameters

Each criterion once established must be measured according to its parts or elements. These elements are parameters and provide the quantitative evaluation of each candidate system. Some criteria can be directly measured, but more abstract criteria require submodels to facilitate proper measurement. The relationships among the criteria must be comprehended in order to obtain realistic and measurable criterion elements. Ostrofsky states that although measurable criterion elements are a goal, not all criterion elements maybe measurable with "current resources but which are considered as contributors to the meaning of the criterion" (22:88).

Table 12 lists each criterion and associated elements or parameters. Each element is assigned an alphabetic letter code which represents the type of parameter the element corresponds to in table 13. Ostrofsky recommends the inspection of each element for "consistency and completeness" (22:90). This ensures that the proper and minimal number of elements are used to describe the criteria. Any redundancies will cause the number of comparisons made during the formal optimization phase to increase astronomically, which can cause excessive computation time to occur.

The following list defines each element.

Y1: **Primary hardware costs.** This parameter includes costs of purchasing or leasing equipment such as modems,

Table 12 *Criteria, Elements, and Parametric Codes*

Criterion	*Elements*	*Code*
x1: Costs	Primary hardware costs	a
	Transmission costs	a
	Maintenance costs	a
	Host computer connection costs	a
x2: User Friendliness	Complexity of software	a
	Complexity of setup	d
	Training hours	a
	Manuals and help features	a
x3: Portability	Size of hardware	a
	Weight of hardware	a
x4: System Availability	MTBF (Mean Time Between Failure)	a
	MTTR (Mean Time To Repair)	a
x5: Response Time	Speed of Transmission (Bps)	a
	Processing (batch or on-line)	a

Table 13 *Code Definitions*

Code	*Type of Element*
a	Directly measured.
b	Measured from a model that includes some of the a's.
c	Completely included in other elements.
d	Not measurable within existing resources.

satellite dishes, and disk drives.

Y2: **Transmission costs.** Costs associated with transporting data from point a to point b. Could be mailing costs for disks, satellite time, or telephone line costs.

Y3: **Maintenance costs.** The costs of maintaining any necessary equipment.

Y4: **Host computer connection costs.** The costs of implementing system at the host computer site.

Y5: **Complexity of software.** This parameter deals with the ease of use for the system user. Is the software easy to use or hard to use?

Y6: **Training hours.** This parameter measures how many hours it is estimated to take the average worker to be trained on using the system.

Y7: **Manuals and help features.** Does the system have reference guides available with it? Does it have on-line help information in the software?

Y8: **Size of hardware.** The estimated dimensions of the system's equipment destined for field use.

Y9: **Weight of hardware.** The estimated weight of the system's equipment destined for field use.

Y10: **MTBF (Mean Time Between Failure).** This parameter is a measure of the average amount of time between failure in the system's equipment.

Y11: **MTTR (Mean Time To Repair).** This parameter is a measure of the average time required to repair a failed component to full operation.

Y12: **Speed of Transmission (Bits per second).** How fast is the data transmission.

Y13: **Processing.** This parameter measures the quickness of the communications response. Is the system an on-line connection to the host computer or does the data flow in batches.

Criterion Modeling

The established set of criteria and parameters can now be modeled into functions which emulate the desired measurement. This allows the criteria, which are not directly measurable, to be measured through a function utilizing the measurable parameters of each criterion. The equations will be combined later into a single criterion function.

Costs. Quantitatively, this is the summation of all the costs for the system's purchase, operation and maintenance. As costs climb so does the graph. The values produced simply represent the maximum costs allowable by the user. The graph of the function is illustrated in figure 8. The criterion is defined by the following elements:

Y1: Primary hardware costs
Y2: Transmission costs
Y3: Maintenance costs
Y4: Host computer connection costs

The resulting linear function for the criterion is:

X1 = (Y1 + Y2 + Y3 + Y4)

User Friendliness. This is one of the more abstract measurements. The degree of ease of use to individuals can be perceived differently . The criterion is defined by the following elements:

Y5: Complexity of software
Y6: Training hours
Y7: Manuals and help features

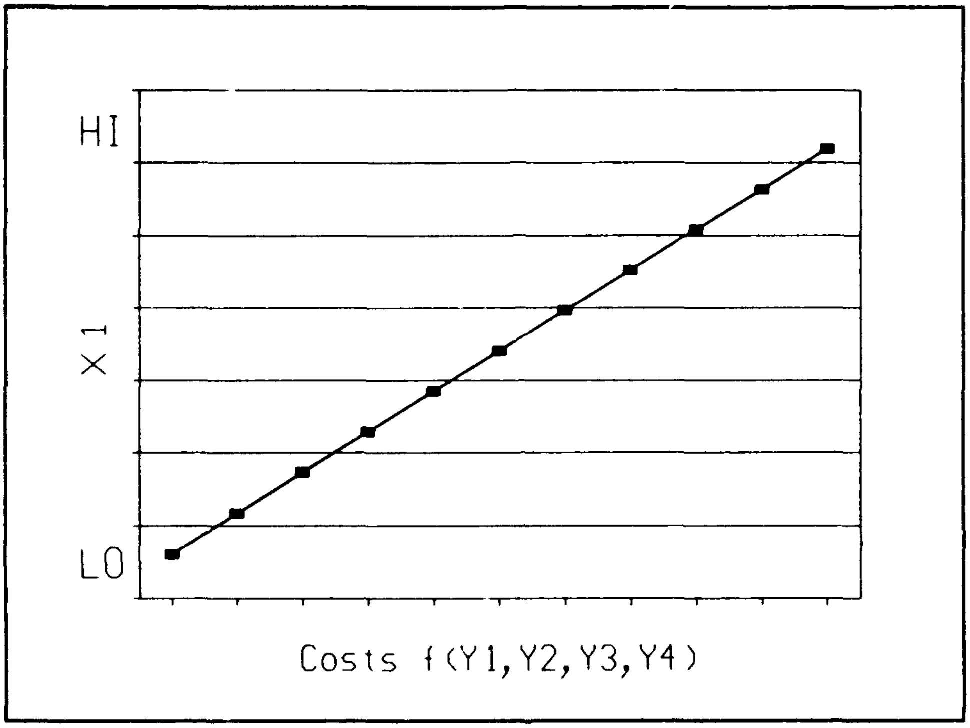

Figure 8 Criterion X1

The complexity of the software and the availability of manuals and help features are measured on a scale from zero to one, with one being fully present and "user friendly". These are then summed and divided by the training hours required, as to produce a function that declines in value as training hours increase. This then gives worse values as more training is required to operate the subject system. The resulting equation is:

X2 = (Y5 + Y7) / Y6

The graph of the function is shown in figure 9.

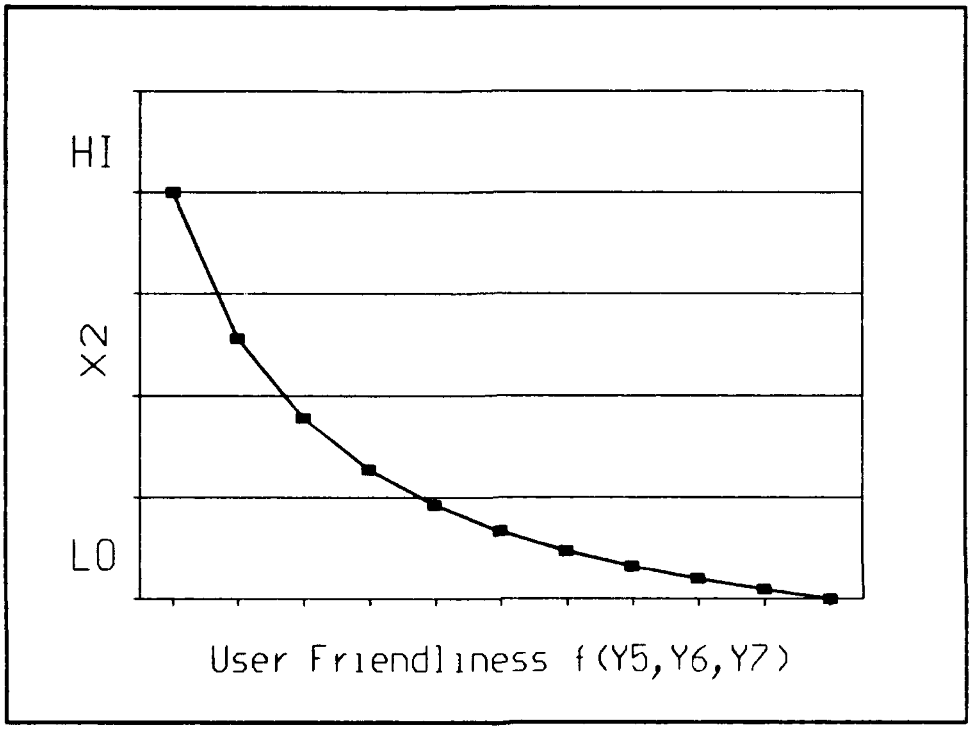

Figure 9 Criterion X2

Portability. To the user of the system, portability measures the ease with which the equipment can be packed up and moved. The function is simply the inverse of the product of the weight and size, which produces declining values with increasing weight and size. The lower the value, the less favorable the system. The criterion is defined by the following elements:

Y8: Size of hardware
Y9: Weight of hardware

The equation which results is:

$$X3 = 1 / (Y8 \times Y9)$$

Figure 10 illustrates the graphed function.

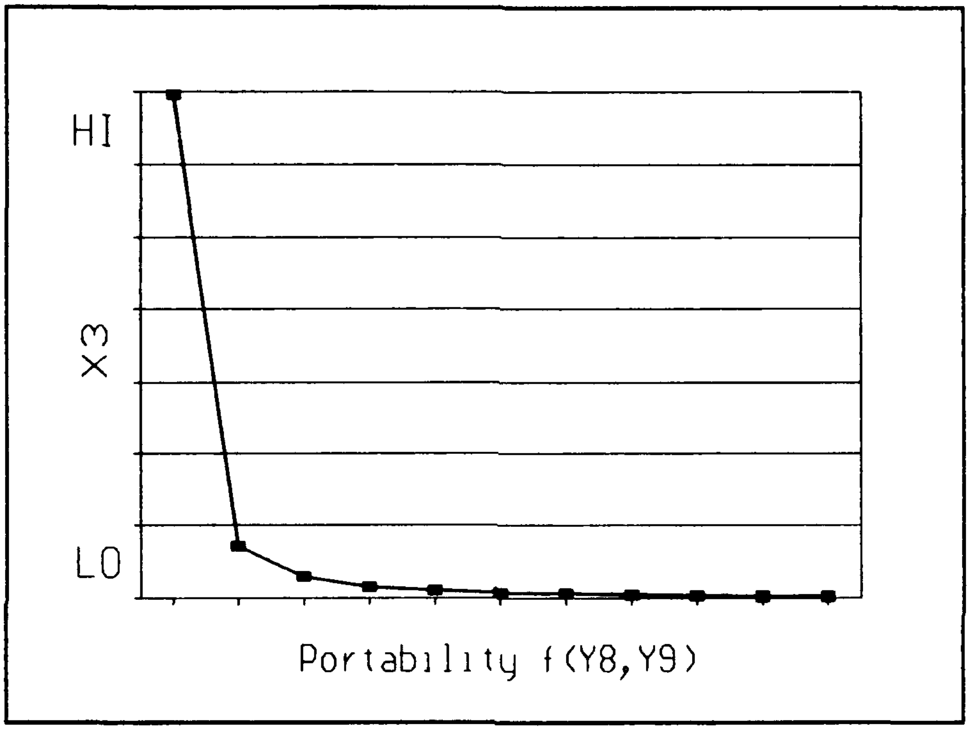

Figure 10 Criterion X3

System Availability. System Availability to the user describes the availability of the system at any user selected time. The criterion is made up of the following two elements:

Y10: MTBF (Mean Time Between Failure)
Y11: MTTR (Mean Time To Repair)

The function normally used to describe system availability is a probability function, such as:

$$A(t) = [a / (a + b)] + [b / (a + b) e^{-(a + b)t}$$

Where a = 1 / (MTTR), b = 1 / (MTBF), e is the natural logarithm, and t is the time interval (26:462). The resulting function gives the frequency of availability during a specified time period. David Stamper states however, that when the time interval increases "the exponential term approaches zero and becomes insignificant" (26:462). The higher the value, the more desirable the system. The equation then can become simplified as:

$$X4 = Y10 / (Y10 + Y11)$$

The resulting graph is represented by figure 11.

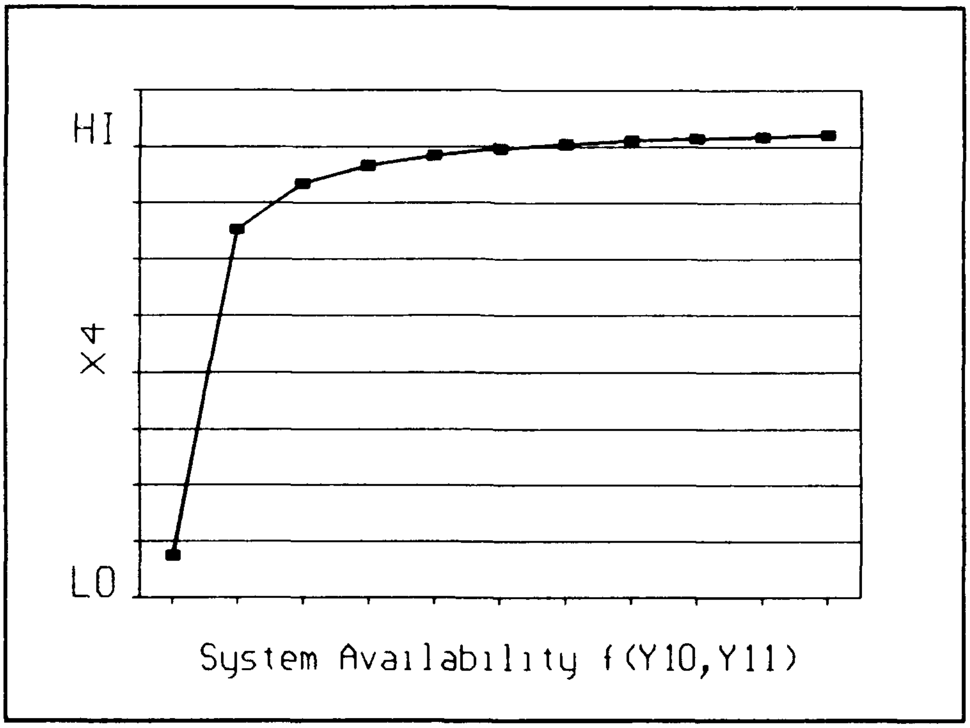

Figure 11 Criterion X4

Response Time. This last criterion is meant to measure the time used to communicate between the host computer and the field terminal. Because the user placed more emphasis on speed of transmission than processing time, the function uses only the full weight of the transmission speed measurement and the fractional of transmission speed to processing time. The higher value is more desirable. The criterion used the following elements:

Y12: Speed of Transmission
Y13: Processing

The resulting equation is:

X5 = Y12 + Y12 / Y13

Figure 12 pictures the graph which results from this function.

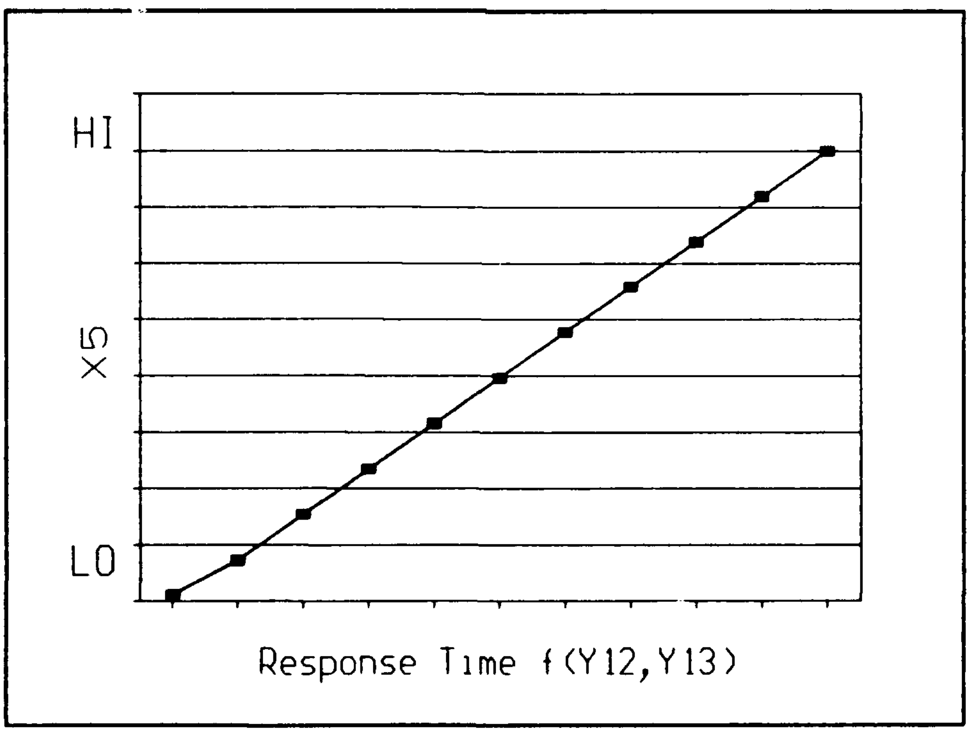

Figure 12 Criterion X5

Formulation of the Criterion Functions

The parameters must be bounded to limit the range of considerations to that which is desired. Using information from Capt Moore (20), the questionnaire results, and current trends in data communications (21:91-103; 23:89-94), the ranges found in table 14 were established. The ranges reflect the preferred outcome of the eventual user, the Military Airlift Command. It should be noted that the wider the range of the parameters, the more candidate systems that will be considered; and the narrower the range the fewer. Therefore the formulations of parametric ranges are exceptionally important.

Table 14 shows the acceptable range for each parameter and by using these values in the proper criterion functions, a similar table (table 15) was constructed for each criterion. The minimum and maximum parameter values were placed into each criterion function, yielding the associated minimum and maximum criterion values.

Combining Criteria into a Single Function. Using the values from table 15, the a single criterion value function (CVF) was fabricated. The individual criterion values must also be made unitless to allow them to be combined (22:114). This was accomplished by identifying each criterion as a fraction of the total allowable range. The subject units then cancel each other out and leave the value unitless. Additionally, the values must be multiplied by the appropriate criterion relative weight figures (table 11).

Table 14 *Range of Parameters Y(k)*

	Parameter Y(k)	*Y(k) Min*	*Y(k) Max*	*Mean*
Y1:	Primary hardware costs	$5,000	$10K	$7,500
Y2:	Transmission costs	$500	$1,000	$750
Y3:	Maintenance costs	$100	$1,000	$550
Y4:	Host computer connection costs	$500	$50K	$25,250
Y5:	Complexity of software	0	1	0.5
Y6:	Training hours	8	40	24
Y7:	Manuals and help features	0	1	0.5
Y8:	Size of hardware (c.i.)	3,600	27K	15.3K
Y9:	Weight of hardware	4 lbs	200	102
Y10:	MTBF (Mean Time Between Failure)	540 hrs	16,640	8,590
Y11:	MTTR (Mean Time To Repair)	1 hr	6 hrs	3.5
Y12:	Speed of Transmission (Bps)	9600	50K	29,800
Y13:	Processing (seconds)	10	43200	21605

Table 15 *Range of Criteria x(i)*

	Criterion x(i)	*Min*	*Max*	*Mean*
x1:	Costs	6,100	62,200	34,150
x2:	User Friendliness	0.0	0.25	0.125
x3:	Portability	0.1852	69.4444	34.8148
x4:	System Availability	0.9890	0.9999	.99445
x5:	Response Time	9600.22	55,000	32,300.11

This ensures the criterion receives the proper emphasis in relation to the other criterion. It also provides a criterion value between one and zero. The criterion function template in the equation below, performed both the removal of units and the relative weighing.

$$CF(\alpha) = \sum_{i=1}^{n} a(i) \left[\frac{x(i)-x(i)\min}{x(i)\max-x(i)\min}\right] \quad (1)$$

and

$$0.0 \leq CF(\alpha) \leq 1.0$$

CF(α) = Criterion value for each α (candidate system)
n = Number of individual criteria
a(i) = Relative weight assigned to ith criterion
x(i) = ith criterion value
x(i)min = Minimum value for ith criterion
x(i)max = Maximum value for ith criterion (10:63)

When the criterion range values are placed in the equation, the following criterion function (CF) occurred.

```
CF=0.18*[{(Y1+Y2+Y3+Y4)-6100}/56100]
   + 0.24*[{(Y5+Y7)/Y6}/0.25]
   + 0.21*[1,000,000*(1/(Y8*Y9)-.1852)/69.2592]
   + 0.21*[{(Y10/(Y10+Y11))-.9890}/ 0.0109]
   + 0.16*[{(Y12+(Y12/13))-9,600.22}/45,399.78]
```

Note that criterion X3 was multiplied by 1,000,000., this was done simply to avoid working with a very small decimal number.

Analysis of the Parameter Space

Interactions among the criteria can have an adverse influence, therefore an analysis of the parameter space was accomplished. Although a complete understanding may not be realistic, a limited amount is fully realizable. The selections of criteria, which are based on many different premises, had not been evaluated for interactions between themselves. Ostrofsky provides a synopsis of this process with his statement: "the accuracy of the entire activity is dependent on many facets of the situation which may not be included in the quantification process" (22:119).

Sensitivity Analysis. In order to observe the rate of change or sensitivity of the parameters, two computer programs were used. The first one, the Single Value Sensitivity Analysis, used the code in Appendix D to vary one parameter by a small and fixed amount of five percent (10:94;12;52). The mean of each parameter range was used as a constant for starting the analysis. The minimum and maximum parameter values were not used because of the significant probability of causing extreme sensitivity reactions.

Table 16 contains the results of the Single Value Sensitivity Analysis. Each initial parameter was used in computing the criterion function value (CFV), then the difference in the CFV was noted after each parameter was changed by five percent. The rate of change for the criterion function as related to changes in each parameter was consequently made possible.

The results indicated that parameters Y4 (host computer connection costs) and Y12 (speed of transmission) had the largest percentage change in the CFV. Additionally, these two parameters are the most sensitive to changes with regards to the CFV. This finding indicates that changes in these two parameters should be evaluated carefully because they have the greatest influence on the CFV. Parameter Y6

Table 16 *Single Value Sensitivity Analysis*

Y(k)	*CFa*	*Yk mean*	*Δ Yk*	*CF'a*	*Δ CFa*	*%*
Y1	.4063	7500	7874.99	.4075	.0012	.29
Y2	.4063	750	787.49	.4064	.0001	.02
Y3	.4063	550	577.50	.4064	.0001	.02
Y4	.4063	25250	26512.50	.4103	.0040	.99
Y5	.4063	0.5	0.525	.4073	.0009	.24
Y6	.4063	24	25.19	.4044	-.0020	-.47
Y7	.4063	0.5	0.525	.4073	.0009	.24
Y8	.4063	15300	16065	.4062	-.0001	-.03
Y9	.4063	102	107.09	.4062	-.0001	-.03
Y10	.4063	8590	9019.50	.4067	.0003	.09
Y11	.4063	3.5	3.67	.4059	-.0004	-.10
Y12	.4063	29800	31290	.4115	.0052	1.29
Y13	.4063	21605	22685.25	.4063	-.0001	-.01

(training hours) also had a significant effect on the CFV and should be handled with care.

The second analysis, Multiple Values in a Sensitivity Analysis, took the Single Value Sensitivity Analysis a step further by varying the parameter values over a range of five percent increments. Appendix E contains the computer program used to produce the analysis evaluations in Appendix F (3:147;10:95). Table 17 summarizes the results and as before, parameters Y4 and Y12 had the most significant effect on the CFV, augmenting the findings of the Single Value Analysis.

Compatibility Analysis. "Compatibility is the orderly, efficient integration and operation of elements in the system" according to Ostrofsky (22:291). This analysis ensures subsystems would operate together in a useful order. By examining those parameters with the least effect on the

Table 17 *Sensitivity Range Summary*

Y(k)	*Least Percentage Change in CFα*	*Greatest Percentage Change in CFα*
Y1	0.29	1.63
Y2	0.02	0.16
Y3	0.02	0.11
Y4	0.99	5.50
Y5	0.24	1.35
Y6	0.51	2.87
Y7	0.24	1.35
Y8	0.02	0.13
Y9	0.02	0.13
Y10	0.09	0.57
Y11	0.09	0.54
Y12	1.29	5.85
Y13	0.00	0.01

total CFV, a list was compiled of those parameters which in the name of system compatibility requirements can be changed first without a large effect on the CFV.

Analysis of Tables 16 and 17 indicate the following parameters to be the least sensitive:

Y2: Transmission Costs
Y3: Maintenance Costs
Y8: Size of hardware
Y9: Weight of hardware
Y13: Processing

Should changes be required in the parameters to meet system compatibility, this list will offer the most logical considerations. They offer the least effect on the CFV and hence reflect the best starting point for parameter changes.

Stability Analysis. A system can be designed to meet the many requirements of the field, but ensuring the success of a system in its environment is difficult to do without a stability analysis. Ostrofsky gives a good example of this:

> A bridge can be designed to withstand certain temperatures, loads, and wind gusts. However, in certain combinations of values of both temperature and wind gust system, harmonic vibrations may be established which can cause the bridge to collapse under proper conditions. From the perspective of the design space, then, it is desirable to understand the interaction effects of the Y(k). If not, these effects can cause the system to fail in operation. (22:129)

Ostrofsky depicts these system interactions in an "m+1" Euclidean space, where m is the total number of parameters (22:129). In this case, the data communications system becomes a 14 dimensional surface. The added dimension being the criterion function itself. The interactions between parameters each have 13 levels. However, such a depiction is inordinately complex and beyond the scope of a standard analysis.

Easier to understand is the 3-dimensional concept, where stable interactions are hills, and less stable interactions are valleys. Mathematically, these correspond to the maximum CVFs and the minimum CVFs respectively. Other reasonable CVFs are depicted by flatter sheer planes in between the hills and valleys. Ostrofsky maintains that having an understanding of the shapes will aid in the awareness of "conditions which might cause failure or major malfunctions" (22:129).

The criterion function in this study was created mathematically instead of by measured observations. The function itself is an arbitrary performance indicator and therefore the function cannot be employed outside of its design space to examine system performance. The function is consequently restricted unless the criteria and subordinate parameters are re-evaluated for this purpose.

Even though it seems that much of the system's success is left to chance, the careful analysis and development of a predictive function greatly reduces the probability of failure or problems. Subsequently, the designer will be better prepared to appraise difficulties and recommend modifications.

Formal Optimization

This was the final step in choosing an optimal candidate system. The candidate system, which is computed to have the highest CFV compared to all the other CFVs considered, is the one chosen. This combining of parameter values so that each candidate system receives an optimal value is what Ostrofsky calls "optimization within a candidate system" (22:134). Ostrofsky states that this is done to ensure that a candidate system is measured in its "best light" (22:134).

To accomplish the optimization, a computer program in Appendix G was run on the Air Force Institute of Technology's VAX/VMS computer for one hour and fifteen minutes (10:95;28:147). The mainframe computer was necessary because the computer memory required was beyond the capabilities of the author's one megabyte 286 PC. The computer compared 6,250,000 combinations of parameter values and outputed the top five, which are listed in Table 18.

Table 18 *Optimization of CFV*

Y(k)	*1st*	*2nd*	*3rd*	*4th*	*5th*
Y1	10000	10000	10000	10000	10000
Y2	1000	1000	1000	1000	1000
Y3	1000	820	1000	640	1000
Y4	50000	50000	50000	50000	50000
Y5	1	1	1	1	1
Y6	8	8	8	8	8
Y7	1	1	1	1	1
Y8	3600	3600	3600	3600	3600
Y9	4	4	4	4	4
Y10	16640	16640	10200	16640	16640
Y11	1	1	1	1	2
Y12	50000	50000	50000	50000	50000
Y13	10	10	10	10	10
CFVs	.99995	.99955	.999396	.998972	.99897

The top CFV's parameter values were then used to evaluate the best candidate system from those identified in the feasibility study. The top CVF of .99995 indicates a candidate system from Concept I should be picked. The subsystems A3, B2, C1, D1, E1, F1, G1, and F2 are the best fit to these parameters.

The candidate system which could result from this is composed of Very Small Aperture Terminals which communicate through a central hub. The central hub would also contain the host computer. The system would be mobile and user friendly, allowing the user to set up and operate it. Additionally, the system would provide a virtual circuit to the host computer. Complete field manuals and on-line help features would be present in addition to not more than 8 hours of user training. MTTR to repair would be one hour and MTBF would be approximately two years.

This system would provide the instant access to CAPS database information that the Military Airlift Command desires. Not only in cases of sites with DDN connectivity, but also in isolated conditions. The setup time would be minimal and done with manpower already deployed at the site for the purpose of airlift operations. Communications support personnel could then be eliminated, making less of a demand on deployed resources and also saving time in reaching full operational communication capability.

This completes the formal methodology development for this research. The system cho en will satisfy the goals and needs identified at the start of the study. However, that is not to say the eventual system will be the one identified here. Changing environments, such as funding, supported associated systems, new technologies, or new military strategies could change the needs and therefore change the choice of a best system.

Summary

The Preliminary Activities purpose was to select and define criteria which are considered to make up the character of the candidate system. These criteria were then weighted as to their relative importance to the user. Thus the more important criteria had more influence in the choice of a candidate system.

To quantify the criteria, parameters were formed to place boundaries on the criteria ranges. These parameters were used in forming functions for each criterion and these criteria functions in turn were combined into the final and single criterion function.

Sensitivity, compatibility, and stability analysis ensured the criterion function was performing as required and offered information for low impacting, future criteria changes. The formal optimization yielded the highest criterion function value possible within the defined parameter ranges. The parameter values from the highest criterion function value then provided the basis for determining the correct candidate system.

Ostrofsky's methodology offers further system development with the Detail Activities of the Design Methodology, but this is beyond the scope of this research. If such a project was started, it should be only after a complete review of system capabilities.

VI. *Conclusions and Recommendations*

This research was accomplished for the purpose of providing the Military Airlift Command (MAC) with an answer to the problem of providing deployable Remote CAPS with a mobile data communications system. The rapidly changing field of commercial data communications offers possibilities, but not any solutions aimed specifically at mobile military data communications. In spite of this, candidate systems were found and evaluated.

The methodology provided not only a structure or guide to accomplish the research, but also acted as a stimulating lesson in systematic thinking. The process can not profess to be fool proof and find an optimum output. The process did however, find an optimal solution.

The feasibility study assessed MAC's needs and studied them in relation to MAC's strategies, limitations, and operations. Candidate systems were synthesized in accordance with these concepts. The candidates then were screened for continuing research and evaluation.

The preliminary activities designed criteria to evaluate the candidates. Consideration was given to MAC's emphasis of the different criteria and therefore weighted each one as a fraction of one. Inputs from MAC and researched sources provided ranges for parameters, the basis of measurement for the criteria. A criterion function was built and analyzed for parameter sensitivity, subsystem compatibility, and subsystem stability. Formal optimization yielded a result which provided the basis for evaluating the candidate systems and choosing the "best" candidate.

Conclusions

Although the methodology produced five criteria and 13 associated parameters, careful consideration of unmeasurable factors must be kept in mind when quantifying the "best" choice. These abstract parameters can cause significant unknown interactions. Additionally, measurable parameters are sometimes difficult when establishing minimums and maximums. Because these minimum and maximum ranges played a significant role in the creation of the criterion function, it is unfortunate that more precise values could not be amassed.

Additionally, the computer program used for formal optimization was initially designed to make 8.04×10^{24} comparisons. This would have required the computer to make over 2.6×10^{17} comparisons per second just to complete in one year. The requirements had to be cut down and the comparisons were reduced to a manageable 6,250,000.

The chosen candidate system was Very Small Aperture Terminal (VSAT) technology. VSATs are relatively new to data communications and provide options not available a few years ago. The small size and small terminal costs allow each data communications site to be equipped with a mobile satellite dish for under $10,000 (21:51). Additionally, VSATs can be managed from a central hub, which can also contain the host computer.

Recommendations

If total intransit visibility of military cargo, from supply location to the end user at field sites (or vice versa) is to become a reality, mobile VSAT technology must be employed. Otherwise there will always be a data reporting time gap when DDN connectivity is not available for any CAPS site, remote or otherwise. MAC's deployable Remote CAPS concept of operations for sites without DDN connectivity is to use floppy disks for data transfer until a CAPS station with DDN connectivity is reached. This solution is a concern which must be clarified for air transportation information systems to make the shift to current technology and to provide a worldwide global network. However, if the instant updating of air transportation data systems is not a "top" priority, then the floppy disk concept will operate satisfactorily.

Should VSAT technology be pursued, replication of this research may be done with refined criteria and associated parameters. This would strengthen the validity of this study. Additionally, a more detailed and technical analysis of the problem would help.

Future Research. Future studies of this topic could include analysis of total VSAT field systems required, analysis of host computer/hub terminal requirements, cost/benefit analysis, and analysis of design specifications required. The further use of Ostrofsky's methodology is not necessary to do future research, but is recommended. The subsequent phases of Ostrofsky's methodology provide an excellent progression in future development.

Summary

The study provided a step by step process for finding the optimal candidate system. Each phase relied on the previous one for inputs and each phase provided outputs for the next. Eventually a criterion function was formulated and provided a quantifiable way to help select the "best" candidate system.

Although the need for a mobile data communications system was validated, the type of system used to solve the need may or may not be VSAT technology depending on the further necessity of MAC. Additional research needs to be accomplished in determining the direction and goals of intransit visibility in supporting military operations. The bottom line should be: Is the information gained from the data worth the cost?

Appendix A: *HQ MAC/XORS Questionnaire*

Deployable Remote CAPS
Data Communications Staff Interview Questionnaire

Purpose: This study is being conducted to determine what you feel is the best system to provide data communications between the CAPS hosts and the impending deployable Remote CAPS terminals. It should take less than 5 minutes to complete this questionnaire. The results of this survey may have a bearing on the development and procurement of deployable remote CAPS.

All answers to the questionnaire should be based on your experience with the CAPS and air transportation operations. Your answers will be combined with those of other staff members and will be used for an analysis at the completion of the survey.

Your cooperation in completing this questionnaire will be greatly appreciated and will provide valuable information which may be used for decision-making processes on the development of deployable remote CAPS.

Donald A. Woodworth

DONALD A. WOODWORTH, JR., COL, USAF
Chief, Systems Division
Dir of Resources, DCS/Ops & Trnsp

DEPLOYABLE RCAPS COMMUNICATIONS QUESTIONNAIRE

1. Mark the title which best describes your current status:

   ( ) Officer (AFSC 6054)
   ( ) Officer (AFSC 6016)
   ( ) Officer (AFSC other)
   ( ) NCO (AFSC 605XX)
   ( ) NCO (AFSC other)

2. Do you have experience with CAPS?

   ( ) No
   ( ) Yes (1 year or less)
   ( ) Yes (1-3 years)
   ( ) Yes (3-5 years)
   ( ) Yes (5 years or more)

3. Do you have field experience with deployed operations (MAPS type operations)

   ( ) No
   ( ) Yes

For the following question please circle one response only for each item (note: 4a and 4b and so on are considered separate items). The scale is as follows: no importance as a 1, little importance as a 2, some importance as a 3, important as a 4, very important as a 5.

4. If a deployable communications system was designed for deployable RCAPS which of the following would you consider important?

   A. On-line transaction processing (Actual connection from field to host) 1 2 3 4 5

   B. Batch-fed processing (connection is intermittent or through intermediate system or media) 1 2 3 4 5

   C. Reliability (number of transmission errors) 1 2 3 4 5

   D. Speed of transmission (greater than 9600 Bps) 1 2 3 4 5

   E. Capability of being setup for operation by the average 605XX 1 2 3 4 5

   F. Compactness of the system (small enough to fit in suitcase sized containers) 1 2 3 4 5

G. Data communications security	1	2	3	4	5
H. Two-way transmission (field to host and host to field)	1	2	3	4	5
I. Government owned as compared to leased	1	2	3	4	5

Circle one response only in the following questions.

5. The monthly operational cost of the system should be...

   A. Less than $500.00 per site

   B. $500.00 to $1000.00 per site

   C. $1000.00 to $2000.00 per site

   D. __________ (fill in value) per site

6. The initial equipment costs or start-up costs should be...

   A. Less than $5000.00 per site

   B. $5000.00 to $10,000.00 per site

   C. $10,000.00 to $20,000.00 per site

   D. __________ (fill in value) per site

7. The system should be constrained to use existing DOD communication networks (DDN).

   A. Yes

   B. No

8. Under the current concept of operations, deployable RCAPS would use floppy disks to transfer data when a communications line is not available. Is this acceptable as a permanent solution?

   A. Yes

   B. No

9. ______________________ Name and Office Symbol
(optional)

10. Comments:

Thank you for your time.

Appendix B: *Tabulated Questionnaire Results*

Response range: 1 (little importance) to 5 (very important)

4. If a deployable communications system was designed for deployable RCAPS which of the following would you consider important?

	1	2	3	4	5
A. On-line transaction processing	0%	14%	0%	36%	50%
B. Batch-fed processing	7%	21%	21%	29%	21%
C. Reliability	0%	0%	0%	14%	86%
D. Speed of transmission	0%	7%	36%	14%	43%
E. Capability of being setup for operation by the average 605XX	7%	0%	7%	0%	86%
F. Compactness of the system	0%	14%	7%	29%	50%
G. Data communications security	0%	7%	36%	21%	36%
H. Two-way transmission	0%	0%	7%	21%	71%
I. Government owned as compared to leased	7%	14%	43%	14%	21%

One response only in the following questions.

5. The monthly operational cost of the system should be ...

A. Less than $500.00 per site 0%

B. $500.00 to $1000.00 per site 50%

C. $1000.00 to $2000.00 per site 29%

D. _________ (fill in value) per site* 21%

6. The initial equipment costs or start-up costs should be...

   A. Less than $5000.00 per site 7%

   B. $5000.00 to $10,000.00 per site 43%

   C. $10,000.00 to $20,000.00 per site 14%

   D. __________ (fill in value) per site* 36%

7. The system should be constrained to use existing DOD communication networks (DDN).

   A. Yes 29%

   B. No 71%

8. Under the current concept of operations, deployable RCAPS would use floppy disks to transfer data when a communications line is not available. Is this acceptable as a permanent solution?

   A. Yes 57%

   B. No 43%

*Question 5d. received fill in values between unknown to $5,000.

Question 6d. received fill in values between unknown to $50,000.

Appendix C: *Questionnaire Results Statistical Comparison*

```
STATISTIX 3.1
ID: SURVEY

WILCOXON SIGNED RANK TEST FOR NCO - OFFICER

SUM OF NEGATIVE RANKS                                      -20.50
SUM OF POSITIVE RANKS                                       45.50

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P VALUE)         0.1431

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION             1.067
TWO TAILED P VALUE FOR NORMAL APPROXIMATION                0.2860

TOTAL NUMBER OF VALUES WHICH WERE TIED    4
NUMBER OF ZERO DIFFERENCES DROPPED        0
MAX. DIFF. ALLOWED BETWEEN TIES     1.0E-0005

CASES INCLUDED 11   MISSING CASES 0
```

Appendix D: *Source Code for Single Value Sensitivity Analysis*

```
10 REM---------------------------
20 REM SOURCE CODE, VERSION 1.1
30 REM SENSITIVITY ANALYSIS
40 REM FOR GRADUATE THESIS
50 REM
60 REM WRITTEN IN GWBASIC VER 3.0
70 REM (C) 1985 FRANK OSTROWSKI
80 REM 1989 R. CRAIG HAM
90 REM---------------------------
100 DIM Y(13), OLDY(13)
110 LPRINT "****   SENSITIVITY ANALYSIS AT 5%    ****"
120 FOR I=1 TO 13
130 Y(1)=7500:Y(2)=750:Y(3)=550:Y(4)=25250
140 Y(5)=.5:Y(6)=24:Y(7)=.5:Y(8)=15300:Y(9)=102
150 Y(10)=8590:Y(11)=3.5):Y(12)=29800:Y(13)=21605
160 GOSUB 320
170 OLDY(I)=Y(I)
180 Y(I)=Y(I)*1.05
190 OLDCF=CF
200 GOSUB 320
210 CFFDIFF=CF-OLDCF
220 CHANGE=(CFDIFF/OLDCF)*100
230 OLDCF=INT(OLDCF*10000)/10000
240 OLDY(I)=INT(OLDY(I)*10000)/10000
250 Y(I)=INT(Y(I)*1000)/1000
260 CF=INT(CF*10000)/10000
270 CFDIFF=INT(CFDIFF*10000)/10000
280 CHANGE=INT(CHANGE*100)/100
290 LPRINT "Y";I,OLDCF, OLDY(I),Y(I),CF,CFDIFF,CHANGE
300 NEXT I
310 END
320 CF1+.18*(((Y(1)+Y(2)+Y(3)+Y(4))-
6100/56100)+.24*(((Y(5)+Y(7))/Y(6))/.25)
330 CF2=CF1+.21*((1000000*1/(Y(8)*Y(9)))-
.1852)/69.2592+.21*(((Y(10)/(Y(10)+Y(11)))-.989)/.0109)
340 CF=CF2+.16*(((Y(12)+(Y(12)/Y(13)))-9600.22/45399.78)
350 RETURN
```

Appendix E: *Source Code for Multiple Values in a Sensitivity Analysis*

```
10 REM---------------------------
20 REM SOURCE CODE, VERSION 2.0
30 REM MULTIPLE PERCENTAGE RUN
40 REM SENSITIVITY ANALYSIS
50 REM FOR GRADUATE THESIS
60 REM WRITTEN IN GWBASIC VER 3.0
70 REM (C) 1985 FRANK OSTROWSKI
80 REM 1989 R. CRAIG HAM
90 REM----------------------------
100 LPRINT "****   SENSITIVITY ANALYSIS   ****"
110 DIM Y(13),OLDY(13)
120 FOR I=1 TO 13
130   GOSUB 500
140   GOSUB 460
150   LPRINT "Y(";I;")","MEAN VALUE = ";Y(I)
160   LPRINT "INITIAL CF VALUE = ":Y(I)
170   LPRINT :LPRINT "Yj + %Yj     CFV        CHG. CFV   %CHG"
180   PCT=1.05
190   OLDY(I)=Y(I)
200   FOR LOOP=1 TO 5
210     GOSUB 500
220     GOSUB 460
230     OLDY(I)=OLDY(I)*PCT
240     Y(I)=OLDY(I)
250     OLDCF=CF
260     GOSUB 460
270     DIFFCF=CF-OLDCF
280     CHANGE=(DIFFCF/OLDCF)*100
290     OLDCF=INT(OLDCF*10000)/10000
300     OLDY(I)=INT(OLDY(I)*10000)/10000
310     Y(I)=INT(Y(I)*10000)/10000
320     CF=INT(CF*10000)/10000
330     DIFFCF=INT(DIFFCF*10000)/10000
340     IF Y(I)>100 THEN Y(I)=INT(Y(I))
350     CHANGE=INT(CHANGE*100)/100
360     LPRINT Y(I),CF,DIFFCF,CHANGE
370 NEXT LOOP
380 IF PCT=.95 THEN 410
390 PCT=.95:GOSUB 500
400 GOTO 190
410 LPRINT :LPRINT
420 IF I/3=INT(I/3) THEN LPRINT CHR$(12):LPRINT "****
SENSITIVITY ANALYSIS  ****"
430 NEXT I
440 END
450 REM
460 CF1+.18*(((Y(1)+Y(2)+Y(3)+Y(4))-
6100/56100)+.24*(((Y(5)+Y(7))/Y(6))/.25)
```

```
470 CF2=CF1+.21*((1000000*1/(Y(8)*Y(9)))-
.1852)/69.2592+.21*(((Y(10)/(Y(10)+Y(11)))-.989)/.0109)
480 CF=CF2+.16*(((Y(12)+(Y(12)/Y(13)))-9600.22/45399.78)
490 RETURN
500 Y(1)=7500:Y(2)=750:Y(3)=550:Y(4)=25250
510 Y(5)=.5:Y(6)=24:Y(7)=.5:Y(8)=15300:Y(9)=102
520 Y(10)=8590:Y(11)=3.5):Y(12)=29800:Y(13)=21605
530 RETURN
```

Appendix F: *Computer Output of Multiple Values in a Sensitivity Analysis*

```
****  SENSITIVITY ANALYSIS  ****
Y(1)      MEAN VALUE = 7500
INITIAL CF VALUE = .4063339
Yj + %Yj         CFV          CHG. CFV        %CHG
7874           0.4075          0.0012          0.29
8268           0.4088          0.0024          0.6
8682           0.4101          0.0037          0.93
9116           0.4115          0.0051          1.27
9572           0.4129          0.0066          1.63
7125           0.4051         -0.0013         -0.3
6768           0.4039         -0.0024         -0.58
6430           0.4029         -0.0035         -0.85
6108           0.4018         -0.0045         -1.1
5803           0.4008         -0.0055         -1.34

Y(2)      MEAN VALUE = 750
INITIAL CF VALUE = .4063339
Yj + %Yj         CFV          CHG. CFV        %CHG
787            0.4064          0.0001          0.02
826            0.4065          0.0002          0.06
868            0.4067          0.0003          0.09
911            0.4068          0.0005          0.12
957            0.4069          0.0006          0.16
712            0.4062         -0.0002         -0.03
676            0.4060         -0.0003         -0.06
643            0.4059         -0.0004         -0.09
610            0.4058         -0.0005         -0.11
580            0.4057         -0.0006         -0.14

Y(3)      MEAN VALUE = 550
INITIAL CF VALUE = .4063339
Yj + %Yj         CFV          CHG. CFV        %CHG
577            0.4064          0.00007         0.02
606            0.4065          0.0001          0.04
636            0.4066          0.0002          0.06
668            0.4067          0.0003          0.09
701            0.4068          0.0004          0.11
522            0.4062         -0.0001         -0.03
496            0.4061         -0.0002         -0.05
471            0.4060         -0.0003         -0.07
447            0.4060         -0.0004         -0.09
425            0.4059         -0.0004         -0.1
```

**** SENSITIVITY ANALYSIS ****

Y(4) MEAN VALUE = 25250

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
26512	0.4103	0.004	0.99
27838	0.4146	0.0083	2.04
29230	0.4191	0.0127	3.14
30691	0.4237	0.0174	4.29
32226	0.4287	0.223	5.5
23987	0.4022	-0.0041	-1.0
22788	0.3984	-0.0079	-1.95
21648	0.3947	-0.116	-2.85
20566	0.3913	-0.151	-3.7
19537	0.3880	-0.184	-4.52

Y(5) MEAN VALUE = .5

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
0.525	0.4073	0.0009	0.24
0.5512	0.4083	0.002	0.5
0.5787	0.4094	0.0031	0.77
0.6076	0.4106	0.0043	1.05
0.6379	0.4118	0.0055	1.35
0.4750	0.4053	-0.001	-0.25
0.4512	0.4043	-0.002	-0.48
0.4286	0.4034	-0.0029	-0.71
0.4071	0.4026	-0.0038	-0.92
0.3867	0.4018	-0.0046	-1.12

Y(6) MEAN VALUE = 24

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
25.1999	0.4044	-0.002	-0.47
26.4598	0.4026	-0.0038	-0.92
27.7827	0.4008	-0.0055	-1.35
29.1718	0.3992	-0.0071	-1.75
30.6303	0.3976	-0.0087	-2.14
22.8000	0.4084	0.0021	0.51
21.6600	0.4106	0.0043	1.06
20.5770	0.4129	0.0066	1.63
19.5481	0.4154	0.0091	2.24
18.5706	0.4180	0.0116	2.87

**** SENSITIVITY ANALYSIS ****

Y(7) MEAN VALUE = .5

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
0.525	0.4073	0.0009	0.24
0.5512	0.4083	0.002	0.5
0.5787	0.4094	0.0031	0.77
0.6076	0.4106	0.0043	1.05
0.6379	0.4118	0.0055	1.35
0.4750	0.4053	-0.001	-0.25
0.4512	0.4043	-0.002	-0.48
0.4286	0.4034	-0.0029	-0.71
0.4071	0.4026	-0.0038	-0.92
0.3867	0.4018	-0.0046	-1.12

Y(8) MEAN VALUE = 15300

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
16064	0.4062	-0.0001	-0.03
16888	0.4061	-0.0002	-0.05
17711	0.4060	-0.0003	-0.07
18597	0.4059	-0.0004	-0.09
19527	0.4059	-0.0005	-0.11
14535	0.4064	0.0001	0.02
13808	0.4065	0.0002	0.05
13117	0.4066	0.0003	0.07
12461	0.4067	0.0004	0.1
11838	0.4069	0.0005	0.13

Y(9) MEAN VALUE = 102

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
107	0.4062	-0.0001	-0.03
112	0.4061	-0.0002	-0.05
118	0.4060	-0.0003	-0.07
123	0.4059	-0.0004	-0.09
130	0.4059	-0.0005	-0.11
96.9	0.4064	0.0001	0.02
92.055	0.4065	0.0002	0.05
87.4522	0.4066	0.0003	0.07
83.0795	0.4067	0.0004	0.1
78.9255	0.4069	0.0005	0.13

**** SENSITIVITY ANALYSIS ****

Y(10) MEAN VALUE = 8590
INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
9019	0.4067	0.0003	0.09
9470	0.4070	0.0007	0.17
9943	0.4074	0.001	0.26
10441	0.4077	0.0013	0.34
10963	0.4080	0.0016	0.41
8160	0.4059	-0.0005	-0.11
7752	0.4054	-0.0009	-0.21
7364	0.4050	-0.0014	-0.33
6996	0.4045	-0.0018	-0.44
6646	0.4040	-0.0023	-0.57

Y(11) MEAN VALUE = 3.5
INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
3.6749	0.4059	-0.0004	-0.1
3.8586	0.4055	-0.0009	-0.2
4.0515	0.4050	-0.0013	-0.31
4.254	0.4046	-0.0017	-0.42
4.4667	0.4041	-0.0022	-0.54
3.325	0.4067	0.0003	0.09
3.1587	0.4070	0.0007	0.18
3.0007	0.4074	0.0011	0.27
2.8506	0.4077	0.0014	0.35
2.708	0.4081	0.0017	0.43

Y(12) MEAN VALUE = 29800
INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
31289	0.4115	0.0052	1.29
32854	0.4170	0.0107	2.64
34497	0.4228	0.0165	4.07
36222	0.4289	0.0226	5.57
38033	0.4353	0.0290	7.14
28310	0.4010	-0.0053	-1.3
26894	0.3960	-0.0103	-2.53
25549	0.3913	-0.0150	-3.69
24272	0.3868	-0.0195	-4.8
23058	0.3825	-0.0238	-5.85

**** SENSITIVITY ANALYSIS ****

Y(13) MEAN VALUE = 21605

INITIAL CF VALUE = .4063339

Yj + %Yj	CFV	CHG. CFV	%CHG
22685	0.4063	-0.0001	-0.01
23819	0.4063	-0.0001	-0.01
25010	0.4063	-0.0001	-0.01
26261	0.4063	-0.0001	-0.01
27574	0.4063	-0.0001	-0.01
20524	0.4063	0.0	0.0
19498	0.4063	0.0	0.0
18523	0.4063	0.0	0.0
17597	0.4063	0.0	0.0
16717	0.4063	0.0	0.0

Appendix G: *Source Code for Multiple CFV Comparisons*

```
10 REM -----------------------------
20 REM SOURCE CODE , VERSION 1.0
30 REM CRITERION COMPARISON
40 REM FOR GRADUATE THESIS
50 REM WRITTEN IN BASIC VER 3.4
60 REM (C) 1985 BY FRANK OSTROWSKI
70 REM 1989 R. CRAIG HAM
80 REM------------------------------
90 REM
100 DIM Y(20),OLDY(20),RESULT(10,20),TOP(5)
110 FOR Y1=5000 TO 10000 STEP 1000
120 FOR Y2=500 TO 1000 STEP 100
130 FOR Y3=100 TO 1000 STEP 180
140 FOR Y4=500 TO 50000 STEP 49500
150 FOR Y5=0 TO 1 STEP 1
160 FOR Y6=8 TO 40 STEP 8
170 FOR Y7=0 TO 1 STEP 1
180 FOR Y8=3600 TO 27000 STEP 4680
190 FOR Y9=4 TO 200 STEP 39.2
200 FOR Y10=540 TO 16640 STEP 3220
210 FOR Y11=1 TO 6 STEP 1
220 FOR Y12=9600 TO 50000 STEP 40400
230 FOR Y13=10 TO 43200 STEP 8638
240 GOSUB 530
290 IF CF>TOP(1) THEN TOP(1)=CF\V=1\GOTO 350
300 IF CF>TOP(2) THEN TOP(2)=CF\V=2\GOTO 350
310 IF CF>TOP(3) THEN TOP(3)=CF\V=3\GOTO 350
320 IF CF>TOP(4) THEN TOP(4)=CF\V=4\GOTO 350
330 IF CF>TOP(5) THEN TOP(5)=CF\V=5\GOTO 350
340 GOTO 390
350 GOSUB 570
390 NEXT Y13
400 NEXT Y12
410 NEXT Y11
420 NEXT Y10
430 NEXT Y9
440 NEXT Y8
450 NEXT Y7
460 NEXT Y6
470 NEXT Y5
480 NEXT Y4
490 NEXT Y3
500 NEXT Y2
510 NEXT Y1
520 GOTO 750
530 CF1=0.18*(((Y1+Y2+Y3+Y4)-6100)/56100)
535 CF2=CF1+0.24*((Y5+Y7)/Y6)/0.25
540 CF3=CF2+0.21*((1000000*1/(Y8*Y9))-.1852)/69.2592
545 CF4=CF3+0.21*(((Y10/(Y10+Y11))-0.9890)/0.0109)
```

```
550 CF=CF4+0.16*(((Y12+(Y12/Y13))-9600.22)/45399.78)
560 RETURN
570 RESULT(V,1)=Y1
580 RESULT(V,2)=Y2
590 RESULT(V,3)=Y3
600 RESULT(V,4)=Y4
610 RESULT(V,5)=Y5
620 RESULT(V,6)=Y6
630 RESULT(V,7)=Y7
640 RESULT(V,8)=Y8
650 RESULT(V,9)=Y9
660 RESULT(V,10)=Y10
670 RESULT(V,11)=Y11
680 RESULT(V,12)=Y12
690 RESULT(V,13)=Y13
740 RETURN
750 PRINT "CANDIDATE SYSTEM ANALYSIS RESULTED IN THE
FOLLOWING"
760 PRINT "TOP CHOICES"
770 FOR XX=1 TO 5
780 PRINT "CHOICE ";XX;" CFV = ";TOP(XX)
790 PRINT \PRINT "CANDIDATE VALUES"
800 FOR YY=1 TO 13
810 PRINT "Y(";YY;") = ";RESULT(XX,YY)
820 NEXT YY
830 PRINT \PRINT
840 NEXT XX
850 END
```

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Vita

Captain John T. Rausch was born on 1 December 1961 in Iowa City, Iowa. He graduated from high school in La Crosse, Wisconsin, in 1980 and from the University of Wisconsin-Madison in 1984 with a Bachelor of Science degree in Geology and Geophysics. He also completed the Air Force Reserve Officer Training Corps program at the University of Wisconsin, receiving his commission and distinguished graduate status on 20 May 1984. Captain Rausch completed basic transportation officer training at Sheppard AFB, Texas with honors and was first assigned to the 3rd Mobile Aerial Port Squadron, Pope AFB, North Carolina in June 1985. He held positions there as ATOC duty officer and vehicle management officer. Upon assignment to the Netherlands in June 1987, he was the vehicle maintenance officer for the 486th Transportation Squadron, Woensdrecht AB. Closure of the base one year later, brought Captain Rausch to Rhein Main AB, Germany as the detachment commander for Detachment 2, 7300 Materiel Squadron. In May 1990 he entered the School of Systems and Logistics, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. He is married to the former Judith M. Henry of Belmont, Wisconsin.

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13. ABSTRACT *(Maximum 200 words)* This research's purpose was to determine the optimal candidate system for data communications with deployable Remote CAPS. The process also established justification for the selection. A formalized methodology based on Benjamin Ostrofsky's Design, Planning, and Development Methodology was used for the process. After a needs analysis of the problem, which is a lack of a mobile data communications system for MAC air transportation units, a feasibility study was completed which formulated the candidate systems to solve the problem. Finally, a preliminary activities phase evaluated each candidate system according to end user based criteria. The candidate system selected was the Very Small Aperture Terminal (VSAT) technology. This data communication method will allow mobile data communications links throughout the world. Also, the costs of the VSAT technology are not prohibitive as compared to standard satellite communications. The small size adds the portability that is required for mobile operations. Recommendations for further research include analysis of total VSAT field systems required, analysis of host computer/hub terminal requirements, analysis of cost/benefits, and analysis of design specifications requirements.

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