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Assessing the Organizational Responsibility of Headquarters Under Differing Level of Stress

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Introduction

This paper describes the second in a series of full scale computer aided wargames which have applied a new approach in quantitative measurement of command and control. This new approach incorporates the use of the Headquarters Effectiveness Assessment Tool, which was developed by Defense Systems Incorporated (DSI) of McLean, Virginia, in measuring the responses of headquarters during full-scale exercises and subsequent simulations here at the Naval Postgraduate School (NPS).

The purpose of the Headquarters Effectiveness Assessment Tool (HEAT) developed under contract to Defense Communications Agency (DCA) is to enable a team of internal or external observers to objectively assess and quantify headquarters performance and effectiveness. HEAT combines elements from several different approaches to measuring effectiveness, particularly:

* Headquarters or adaptive control systems
* Effectiveness at military mission accomplishment, and
* Command and control processes as information management systems

The underlying conceptual model of the headquarters process is shown in Figure 1. HEAT provides a means of assigning measures of value to the ongoing processes and subsequently using the aggregates to assess performance. <u>The use of HEAT requires the formation of a plan of action</u>. The HEAT measures are used, thereafter, to quantify adherence to the plan or the adequacy of revisions to the plan.

FIGURE 1

The original applications of the Headquarters Effectiveness Assessment [Ref. 1] Tool (HEAT) were described by one of these authors in a paper given at the San Diego ONR-MIT meeting last year which described evaluation of Exercise Bold Eagle 84 and an NPS laboratory experiment in the fall of '83. Exercise Bold Eagle 84 was a full-scale exercise held at Eglin Air Force Base in October 1984. Prior to the exercise an evaluation team helped the JOINT TASK FORCE 7 staff develop command standards for performance in certain areas of headquarters performance. Of the 8 stated goals of the exercise, three of which were concerned with essential elements of information were examined by the HEAT observer team. They are shown in Figure 2.

FIGURE 2

Our 20 observers collected several thousand data sheets. The subsequent analysis supported observations seen during the exercise regarding staff performance. In summary:

* The staff failed to identify major incongruities between their plan and the events actually occurring.
* Major missions were not accomplished in the planned time frame,
* In general the staff did not provide timely or accurate information on enemy OR own force units according to their own standards.
* The planning and operations failed to establish authoritative and physical connectivity among the participants due in part to lack of modern communications and display equipment.

C2 Laboratory Experiment

HEAT principles were also used in and tested in a month-long command and control experiment in the Naval Postgraduate School (NPS) Wargaming Analyses and Research Laboratory (WAR LAB) during the month of November 1983. The design, conduct and analysis of the experiment was a joint Naval Postgraduate School, Defense Communications Agency and Defense Systems, Inc. effort.

The purpose for conducting the experiment was to attempt to corroborate findings, primarily by the Soviets [Ref. 2], which indicate the command structure supporting a battlefield headquarters influences that headquarters' effectiveness and thus impacts on the speed and correctness of decisions.

The experiment conducted in the War Lab used the Naval Warfare Interactive Simulation System (NWISS) hosted on a VAX 11/780 mini computer. NWISS is a large scale (250,000 lines of code) highly interactive, naval wargame with color graphics. A standard set of military problems were posed to military officer students who performed in distributed roles using several headquarters command structures. The data collection plan permitted use of HEAT Measures in an attempt to corroborate the Soviet findings. The physical design of the experiment closely resembles that reported on later in this paper. Four headquarters were established which simulated responsible headquarters under the Navy's Composite Warfare Commander (CWC) concept at coordination of the Antisubmarine Warfare (ASW), Anti Air Warfare (AAW) and Anti Surface Warfare (ASUW) commander by the Officer in Tactical Command (OTC) who is usually an admiral.

The command modes were restricted to communications via three different command structures, as shown in Figure 2, depending on the individual scenario being presented.

The results of the experiment are shown in Figure 3.

* Star structures are slightly faster than fully-connected structures but not to a statistically significant level.

* (Did not contradict Soviet findings.)

* The fully connected structure was able to reach a decision more often than the star structure but the decision error rate was about the same.

* (Did not contradict Soviets findings.)

* Fully connected structures were always slower to initiate hostilities mistakenly than were other structures.

* (An independent finding.)

Figure 3

In a continuation of sponsorship by the DCA, a second set of experiments was conducted by DSI and NPS. Lessons learned in the previous experiments allowed refinement of experimental design and the application of heat measures.

The war game which is the subject of this paper was designed by the DSI and NPS staffs and conducted in the Wargaming Analysis and Research Center by the faculty and officer-students and staff of the Naval Postgraduate School. While the earlier experiments attempted to study the effects of connectivity on the performance of the Navy's CWC concept, within a battle group, the current studies examined the performance of multiple battle groups as role specialization was varied from functional to geographic. The quantitative assessment of the performance of these headquarters was accomplished using HEAT measures and statistical analyses of times associated with message traffic between headquarters as well as overall exchange ratios.

In earlier work the effectiveness of distinct command structures when faced with equal threats was studied. In these latest experiments the question of effectiveness of a headquarters was studied as both the organizational lines of responsibility and the level of threat varied. The basic organization the major headquarters was as shown in Figure 1 and the physical setup for the experiment in Figure 4. The organization, resembling a basic star, prevented fully connected communications with higher levels of command staff headquarters but supported fully-connected communications between (2) "operational headquarters" (Figure 5). Within the fully-connected portion of the structure two conditions could exist; (1) Geographic organizational lines of responsibility or (2) Functional organizational lines. On the first -each operational headquarters controlled all friendly forces in all major warfare areas in his geographic sector (Figures 6, 7). In the second, shown in Figures 8A, 8B, 9, 10), the separate operational headquarters controlled all assets subordinated to their warfare area regardless of the physical location of the asset in the area of hostilities. Under each scenario, reactions of these headquarters were recorded for later analysis using HEAT measures.

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8A

Figure 8B

Figure 9

Figure 10

The purpose of the experiments was threefold as shown in Figure 11.

Figure 11

Design of the Laboratory Experiment

In current planning the concept of fixed headquarters sites violates the assumption that mobility of the headquarters enhances survivability. The desire for mobility implies that a reduction in the size of the staff is warranted if it is to be mobile. A question then arises which may best be stated; "how small is too small".

To avoid continuous variability in one experimental parameter, however, it is necessary to hold the size of the staff constant at a relatively small number and to increase activity until the staff becomes ineffective. When the point of loss of effectiveness is determined the complimentary questions "How much activity could the small staff handle relative to a large staff" and "Is there a significant difference between the two levels?", can be answered to gain insight in answering the original query. A headquarters size of five persons was determined to be reasonable but small and the central assumption for the experiment was stated as a hypothesis.

Ho: Under increasing levels of activity (stress) a small headquarters organized geographically will show reduced effectiveness.

A second hypothesis.

H1: Under increasing levels of activity (stress) a small headquarters organized functionally will show less effectiveness at all levels than the geographic case, due to the burden of coordination, unless or until the level of activity surpasses the ability of a small staff regardless of organization.

The alternate hypothesis.

Ho: There is no appreciable difference in the level of effectiveness of the small staff due to organization.

Figure 12 is a graphic depiction of these hypotheses.

Figure 12

The experiment was again designed and conducted using the Naval Warfare Interactive Simulation System (NWISS). Military officers who were previously trained in the system comprised the teams. A naval scenario was constructed which involved three carrier battle groups (CVB6) on station simultaneously in the Arabian Sea. A fourth formation, which acted as the center of attention, was a convoy of petroleum tankers in the confined waters of the Strait of Homuz being escorted by two surface units and a submarine detached from the supporting

CVBG's. Each CVBG consisted of a carrier with embarked air wing, five surface combatants, and a support ship. Additional supporting vehicles not dedicated to a specific CVBG were two direct support fast-attack nuclear submarines and land-based maritime air support.

Arrayed against this task force were air and sea forces of the USSR, IRAQ and IRAN. The levels of stimulation ranged from intimidation to provocation to attack. The headquarters was challenged to decide who the enemy was and then to make the appropriate response. To accomplish the tasks each station in the operating units was equipped with four devices; a player terminal, a status board terminal, a graphics display terminal and a communication terminal. Figure 13 shows a representative arrangement. The Commander 7th Fleet (C7F) position played by subjects and the Commander Pacific Fleet (CPF) position, played by the umpire team, consisted of a single communications terminal located in a space where charts were available. The subjects could communicate with the computer and the control team via the player (or order entry) terminal and with other headquarters solely through the communications terminal. Again the CVBG's had the potential for fully-connected comms whereas all traffic to CPR and C7F had to be passed through the OTC.

Figure 13

Forty-five subjects were randomly arranged into three groups and headquarters team membership within each section was also randomly determined. The groups participated in a practice session and six sessions for record as shown in the experimental design shown as Figure 14.

Figure 14

During each three-hour session the players divided responsibility between operating the terminals and being the battle group commander or an observer. Subjects were rotated between sessions to further insure randomness in player's skill and experience. At the beginning of each run the players were presented with the politico-military situation and reminded of established rules of engagement and the functional or geographic organization for that session. Thereafter the wargame was a free-play exercise.

The combination of opposing forces was predetermined by DSI. The combination of these forces and their level of activity was randomly combined with the organization being studied to avoid bias in the data and the opposing forces were prescripted. After game start the actions of the opposing forces were automatically accomplished by the computer according to the script file although control could override the prescript to adjust for actions taken by the CVBG commanders. The prescript helped to guarantee that all teams were exposed to identical threat scenarios for the first 90 minutes of a 2.5 hour session.

The Generation of Data

The NWISS software provides the capacity to collect and file every player position order and the computers response from each headquarters for the entire duration of each session. This capability was utilized to create archival files which were stored for immediate post-game analysis and transferred to tape for later reference. Each session provide four game files (CVG's A, B, C and Control). The control software of the host computer provided the capability to search these files for individual occurrences of interest or combinations of occurrences. In the experimental design phase, once the desired measures of effectiveness were determined, search programs were set up as necessary. Immediate postgame analysis consisted of operating on the four game files with the search files to generate hard-copy results from which HEAT scores could be generated. These were provided to DCA for further analyses by DSI.

In addition, during the work up phase a communication program, COMNET, was written to control the transfer of messages between the communications terminals. In addition to routing the traffic the same piece of software;

1) assigned key times to each message,
2) provided the capability to "jam" a particular terminal,
3) provided the ability to delay transmission
4) allowed the garbling of a percentage of the letters in each message from 10 to 90 percent, and
5) provided a hard copy of each message to each headquarters.

Control could further induce stress in selected sessions through intermittent jamming of one or more stations during the last hour of the session. The garble and delay were not used in this experiment.

All messages were sent to a central file which could be post processed. After being sorted into 1 of 9 categories each message was examined by the analyses section of the software. The differences between the four assigned times provided three statistics for each message: Throughput time, Delay time and Preparation time. By accruing the individual statistics over all messages for each run, session average times and standard deviations were provided. Considering that the average number of messages for a three-hour session was more than 350, the use of mean times for subsequent analyses of the eighteen sessions was justified. The results of the analysis of message times were provided by a student team as a class project and they will be utilized in a forthcoming thesis. [Ref. 3]

In summary, the data package for each session consisted of a selection of measures of effectiveness sorts of the orders issued by the battle group commanders, and a packet of descriptive statistics of times associated with the corresponding message traffic.

Preliminary Analysis of Data

The experiment was completed on 30 October with data reduction continuing til mid-November 1984.

The cursory analyses of message times shows results which support further analysis. In the analysis Throughput Time = Preparation Time + Delay Time. By examining the variability of the average Preparation time statistics and the average Delay time statistics, it was found that the variability in delay times accounted for the majority of the variability required to read and analyze messages waiting in the queue. Delay time would seem to be consistent with decreasing efficiency of the staff. In the worst case long delay times would indicate the failure to respond to orders and queries from outside the command due to collapse of the decision-making function in the headquarters.

For each of the mean statistics it is of interest to determine whether the organizational lines of responsibility effected performance in message handling. The mean times were segregated by geographic or functional organization and the hypothesis selected.

Ho: That the grand mean of the one distribution is not statistically different from the other.

μ o i.e. $\mu g = \mu f$

with

Hl: $\mu g = \mu f$

Given that all data points were themselves mean the resultant reduction is dispersion of the data points caused applicable tests to support Ho. In the process of forming the distributions of means, however, a marked kurtosis or peakedness was discovered for each subset and it could be shown that the mean and standard deviation for the functional organization trials were lower than the geographic trials. The suggested implication is that the functional organization allows the various warfare commanders to concentrate on a single type of prosecution and that the increase in effectiveness overshadows the added burden of coordinating with other battle groups to accomplish the warfare area mission over a wider portion of the globe. Further analysis using more powerful tests on these data is being considered.

A separate analysis of game files from all headquarters was conducted by DSI. Heat measures were applied where applicable and other measures of effectiveness were assesed, i.e. exchange ratios. The anticipated findings are shown in Figure 15.

Figure 15

The results were collected and can be seen by comparison in Figures 16 through 18. An additional assessment of causal linkages between the headquarters is still ongoing as of April 1985 with a final report to be presented to the Defense Communications Agency.

In summary, the most recent effort carried out in the WAR lab produced the results shown in Figures 19 and 20.

The efforts which have been waged currently in the analyses of headquarters effectiveness have developed a new methodology for C2 investigations. That methodology consists of analyses of full scale exercises, wherein many of the key variables are not controlled by the experimenter, coupled with subsequent laboratory experiments wherein the variables are more closely controlled. When the resultant data are analyzed using the same tool, understanding of those results should be enhanced. Movement from the macro to the micro examination of concepts may be a first step in providing confirmation of the existence of and identification of illusive principles of command and control.

Figure 16

Figure 17

Figure 18

Figure 19

Figure 20

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EFFECTIVENESS ANALYSIS OF EVOLVING SYSTEMS*

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ABSTRACT

A quantitative methodology for analyzing the effectiveness of evolving systems that will undergo a series of demonstrations is presented. Emphasis is placed on the design of the demonstration by assessing the effectiveness of alternative system configurations. The system's performance and the mission requirements are described in terms of a finite number of attributes, using a probability distribution and a utility function, respectively. The approach is illustrated through an example based on the development of a network of networks.

1. INTROUDCTION

Consider an organization that is developing a large-scale system such as a large communication network. The completion of this system will take a number of years and require sustained funding. The latter, however, is contingent on (a) the progress made in developing the system, and (b) the prospects it has for meeting the needs for which it is being designed. One way of checking whether these conditions are met is to set up a timetable in which several demonstrations are scheduled. The focus of these demonstrations will be to show that real progress has been made in developing the system, and that the latter will be capable of performning the tasks for which it was designed.

The methodology developed in this paper will help the organization understand better the basic trade-offs and design, with greater awareness of the consequences, demonstrations of the system. More generally, it aims at analyzing the effectiveness of evolving systems, that is, systems that are constantly upgraded as new technologies are made available and as the needs or interests of the various participant groups are redefined.

2. PROBLEM FORMULATION

The specific features of evolving systems affect all aspects of the System Effectiveness Analysis methodology (Bouthonnier and Levis, 1982). Indeed, they appear on the system side, the mission side, and the context, and contribute to the definition of the relevant attributes.

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Figure 1 suggests the intimate interaction between the basic aspects of the methodology. It shows the system-context and mission-context interactions. Also, it sketches the joint contribution of the system, mission, and context, to the definition of the relevant attributes.

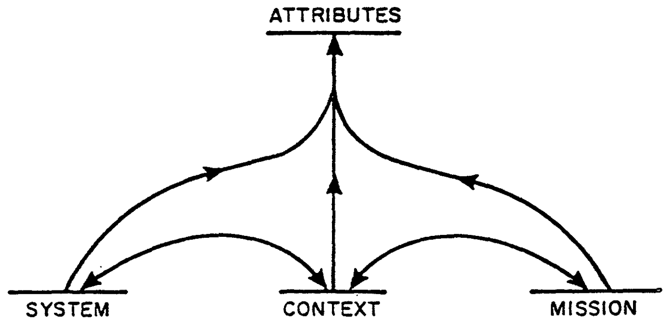

Figure 1. Evolving Systems: The Overall Picture

2.1 The Context

An evolving system typically undergoes a series of demonstrations. Such demonstrations consist, in general, of a succession of stages or events. A stage can be aimed at demonstrating a specific technology, carrying out a given function, or both. The sequence of events and their contents correspond to a scenario. Depending on the scenario adopted, the demonstration will be shaped differently. Hence, the choice of a scenario is a decision variable; the objective is to optimize the effectiveness of the demonstration.

2.2 The System

Let T_j denote the j-th component/technology of the system that is being developed:

$$S_\infty = \{T_1, T_2, \ldots, T_j, \ldots, T_J\} \tag{1}$$

The components T_j can be physical components, i.e., nodes of the network or gates between nets, or even switches, or they can be software implemented on specific hardware.

Since this is an evolving system, at any time t, a component T_j may not be fully operational. If $\lambda_j(t)$ denotes the degree to which T_j is functional, i.e.,

$$0 \leq \lambda_j(t) \leq 1 \tag{2}$$

and if $\underline{\lambda}_j$ denotes a threshold of operability for component j, then S(t) is the subset of S that is operational at time t:

$$S(t) = \{T_j(t) \; ; \; \lambda_j(t) \geq \underline{\lambda}_j\} \quad (3)$$

As time increases, the subset S(t) should expand until, at the end of the project period, it is equal to S_∞ (all component parts are completed). Out of the set S(t), system architectures can be configured that are suitable for demonstration. Not all configurations include all the operational components, and not all configurations are equally effective for the demonstration. These concepts can be stated formally as follows:

Let P(t) be the set of all subsets P of S(t),

$$P(t) = \{P, \; P \subset S(t)\} \quad (4)$$

If S(t) contains $\#T$ elements, then the number of subsets in P(t) is $2^{\#T}$. However, not all of them lead to useful configurations. Let $\tilde{P}(t)$ be the subset of P(t) that merits consideration. It is expected that few non-trivial configurations would be possible at any time. The procedure for determining the set $\tilde{P}(t)$ of useful configurations is sketched out in Figure 2.

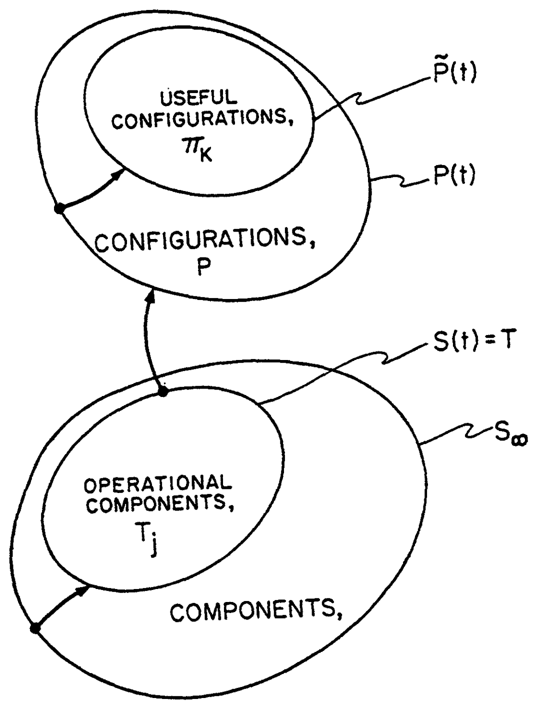

Figure 2. From the Ultimate System S_∞ to the Set $\tilde{P}(t)$ of Useful Configurations

This conceptual framework is applied now to the determination of $\tilde{P}(t)$. Let t_1 be the time at which the design of selected components is fixed so that prototype operational versions can be developed and let t_2 be the time of the proposed demonstration. Then the procedure can be described as follows:

(a) Consult with contractors to determine the components T_j that can be considered operational at time t_1 in the future.

(b) Consult with users to determine existing components and subsystems that could be made available for the demonstration at time t_2.

(c) Combine the results of (a) and (b) to determine set $S(t_2)$.

(d) Out of the elements in $S(t_2)$, design alternative system configurations, i.e., construct $\tilde{P}(t_2)$.

(e) Elements of $S(t_2)$ that have not been used in any of the candidate configurations in $\tilde{P}(t_2)$ should be dropped from further consideration for the demonstration at t_2.

The above procedure establishes the alternative system configurations for the demonstration. But to select the most effective one, the goals of the demonstration must be established.

2.3 The Mission

The demonstration of an evolving system has a dual goal. First, it should show the capabilities of the system that is being developed. It should also demonstrate progress and accomplishments in developing the system. This goal may be only partially shared by the various participants in the demonstrations. The first of the four major sets of participants consists of the contractors, the engineers and scientists who are developing the components, or are concerned with or system integration. The second participant is the agency that is the program sponsor and manager. The system contractors, I, and the agency, A_g, can be taken together to constitute a combined group, the developers (A). The third set of participants (B) consists of the system's users, the persons who are going to use it in carrying out their duties (ultimately as well as during the demonstration). Finally, there is the group of decisionmakers (C), who will observe the demonstration, and can make decisions about the program's continuation and eventual implementation.

All of them would like the demonstration to succeed. In addition to this common concern, group A would like to see more components demonstrated. Typically, each developer in group A would focus on "his" technologies and see to it that they are included in the demonstration. Conversely, group C would like to see more functions carried out during the demonstration. Typically, each decisionmaker in group C has a set of functions which he believes the demonstration should execute. The concept of function is used in contrast to that of end-product embodied by the components or technologies. In command and control, a function would be, for example, the interaction between commanders, or between a commander and a unit or organization. Let T and F denote the set of technologies and functions, respectively. Note that T is nothing but the set S(t) in developing the system model.

After having specified the context and developed the system and mission models, the attributes can now be introduced.

2.4 System Attributes

System attributes depend on variables (the system primitives) which describe the system's characteristics and on the context. In a given context, a system is not expected to realize a specific combination of values of its attributes $x_1, \ldots, x_n$ with probability one. Instead, a set of realizable combinations exists, each corresponding to a set of values taken by the system attributes. This set, L_S, is the locus of the system attributes. Any point $\underline{x}$ that belongs to L_S has a non-zero probability of being actually achieved by the system. To model this concept, a probability distribution f is introduced which is a complete description of the system's performance in the specified context. Therefore, for each useful configuration π, $\pi \in \tilde{P}(t)$, let f_π be the probability distribution of the system attributes $\underline{x}$.

In accordance with the dual role of the demonstration, the attributes that are relevant to assessing the effectiveness of evolving systems belong to one of two classes: Type 1 and Type 2.

Type 1 attributes are those with which the System Effectiveness Analysis would be concerned, if it were applied to a non-evolving or fully developed system. These attributes characterize the effectiveness of the ultimate system; they form a vector $\underline{y} = (y_1, \ldots, y_n)$. In the case of communication networks, reliability, input flow, and time delay are examples of Type 1 attributes.

In general, Type 1 system attributes are continuous random variables. Let L'_S denote the system locus in the Type 1 attribute space, i.e.,

$$L'_S(\pi) = \{\underline{y} \; ; \; g_\pi(\underline{y}) > 0\} \tag{5}$$

The second stated goal of the demonstration is to show progress and accomplishments in developing the system. The achievement of this goal is expressed in terms of Type 2 attributes, denoted by the vector $\underline{z}$. In this case, the attributes are two: z_A and z_C. Attribute z_A is a weighted fraction of the technologies used in the demonstration, while attribute z_C is a weighted fraction of the functions carried out:

$$z_A = \sum_{i=1}^{\#T} \omega_A(T_i)\, \tau(T_i) \;/\; \sum_{i=1}^{\#T} \omega_A(T_i) \tag{6}$$

and

$$z_C = \sum_{j=1}^{\#F} \omega_C(F_j)\, \phi(F_j) \;/\; \sum_{j=1}^{\#F} \omega_C(F_j) \tag{7}$$

where

T_i denotes technology i , $i=1,\ldots,\#T$

F_j denotes function j , $j=1,\ldots,\#F$

$$\tau(T_i) = \begin{cases} 1 & \text{if technology } i \text{ is included in the demonstration} \\ 0 & \text{otherwise} \end{cases}$$

$$\phi(F_j) = \begin{cases} 1 & \text{if function } j \text{ is carried out in the demonstration} \\ 0 & \text{otherwise} \end{cases}$$

$\omega_A(T_i)$ weighting of technology i by the developers (group A)

$\omega_C(F_j)$ weighting of function j by the decisionmakers (group C)

These two attributes z_A and z_C defined by Eqs. (6) and (7) take discrete values between zero and one. For each system configuration π, a specific subset of the technologies T is used and a specific subset of the functions F carried out. The values taken by z_A and z_C are hence known with certainty:

$$z_A = z_A(\pi) \quad ; \quad z_C = z_C(\pi) \tag{8}$$

The Type 1 and 2 attributes form a vector, $\underline{x} = (\underline{y}, \underline{z})$, which takes values in a subset of the (n+2) dimensional attribute space.

The distribution f_π is a Dirac function δ in the plane (z_A, z_C) at the point $(z_A(\pi), z_C(\pi))$. Distribution f_π can thus be written as follows:

$$f_\pi(\underline{x}) = g_\pi(\underline{y})\; h_\pi(\underline{z}) \tag{9}$$

where

$$h_\pi(\underline{z}) = \delta(\underline{z} - (z_A(\pi), z_C(\pi))) \tag{10}$$

The function $g_\pi(\underline{y})$, the component of $f_\pi(\underline{x})$ in the Type 1 attribute space, remains to be defined.

2.5 Mission Attributes

Mission attributes are used to describe the mission requirements in a specific context. Hence, they depend on variables which describe the mission characteristics (the mission primitives) and on the context. The set of combinations of attribute values that satisfy the requirements of the mission generates the locus of the mission L_M. Any point $\underline{x}$ that belongs to the mission locus satisfies, to some extent, the mission. However, all such points are not, in general, equally satisfactory. To model this concept, a utility function u is introduced that translates into a real number (between zero and one) the desirability, from the point of view of the mission, of each combination of attribute values. Since utility functions should be monotonically non-decreasing with respect to each of their arguments, the attributes should be defined in a way such that a higher value of any one attribute leads an to equal or higher utility, other things being equal.

Each group expresses its satisfaction -- or dissatisfaction — with the demonstration through some of the attributes. While all three groups are concerned about the values taken by the attributes $\underline{y}$, group A is, in addition, interested in the attribute z_A, and group C in the attribute z_C (see Figure 3). The partial utilities u_A, u_B, and u_C of groups A, B, and C respectively, can be written as:

$$u_A(\underline{x}) = v_A(\underline{y})\; w_A(z_A) \tag{11}$$

$$u_B(\underline{x}) = v_B(\underline{y}) \tag{12}$$

$$u_C(\underline{x}) = v_C(\underline{y})\; w_C(z_C) \tag{13}$$

The global utility is a function of the partial utilities introduced previously. For example,

$$u = a\, u_A + b\, u_B + c\, u_C \qquad \text{(additive)} \tag{14}$$

or

$$u = u_A^{\,a}\; u_B^{\,b}\; u_C^{\,c} \qquad \text{(multiplicative)} \tag{15}$$

where $a + b + c = 1$.

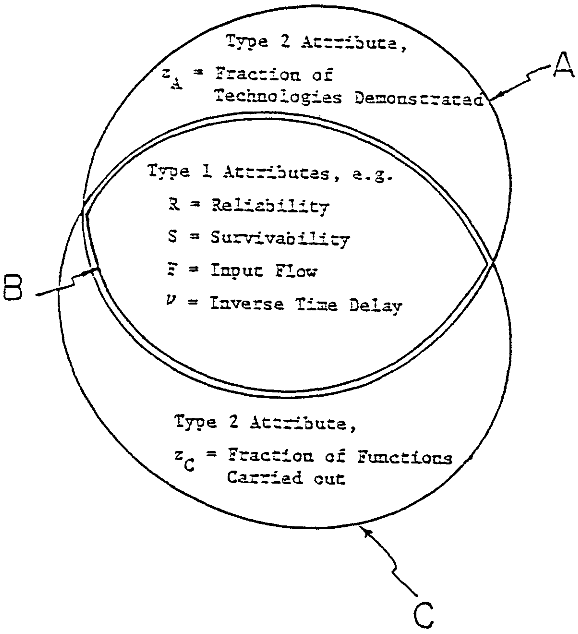

Figure 3. Partition of Attributes in Utilities of Participant Groups

Weights a, b, and c reflect the participants influence on decisions, regardless of their interaction. In reality, the three groups of participants in a demonstration are not independent. They interact before, during, and after the demonstration. Thus, it is important to sketch a model of the organizational interactions. One such model is shown in Figure 4.

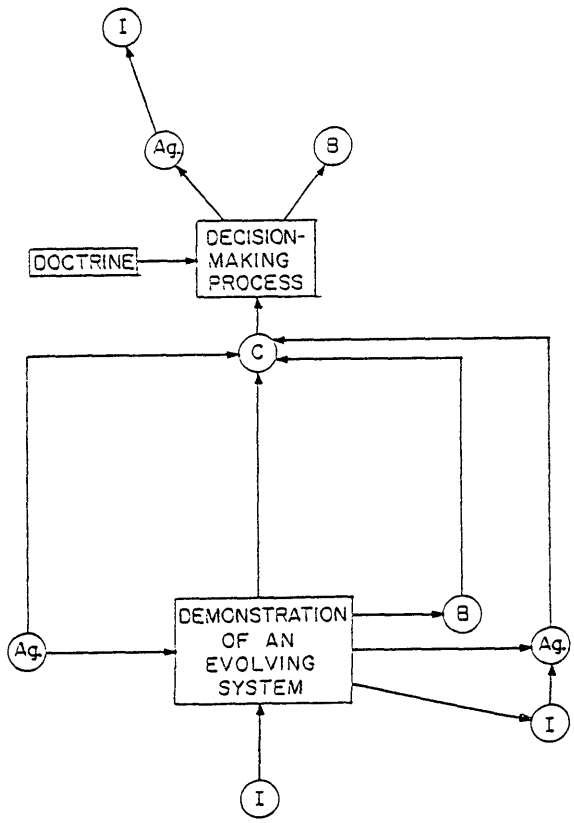

Figure 4. Organizational Interaction of Demonstration Participants

The contractors, denoted by I, provide the operational components of the system S, while the sponsor approves a scenario. All four participants observe the demonstration. The contractors report their observations and recommendations to the sponsors ($I \rightarrow A_g$). The users and the sponsor indicate their findings to the decisionmakers (group C). The sponsors, A_g, have already indicated to the decisionmakers the objectives of the demonstration. On the basis of their own observations and the inputs from the sponsoring agency and the users, the decisionmakers indicate their support for the program to the agency, and instruct the users to continue in assisting with the development and implementation of the system S.

Therefore, it is not inappropriate to express the utility of the demonstration as being that which is ultimately perceived by the decisionmakers. Indeed, the partial utilities u_A, u_B, and u_C result from the direct observation by the participants in groups A, B, and C, respectively, regardless of the interaction of those participants. After groups A and B report their observations to group C, the decisionmakers aggregate all three partial utilities in a global one. Hence, the global utility of the demonstration is an aggregation, by the decisionmakers, of the partial utilities of the developers, the system users, and the decisionmakers themselves.

$$u = u'_C(u_A, u_B, u_C) \qquad (16)$$

Function u'_C can be a direct weighting of u_A, u_B, and u_C, as in expressions (14) and (15). In this case, the implication of the model is that weights a, b, and c are fixed by the decisionmakers.

3. THE DESIGN OPTIMIZATION PROBLEM

A system is most effective with regard to a mission if, operating in a given context, it is most likely to achieve those combinations of attribute values that are highly desirable; that is, if the points $\underline{x}$ for which $f(\underline{x})$ is high coincide with those for which the utility u is high. An effectiveness measure that expresses this notion is given by the expected utility, i.e.,

$$E_\pi(u) = \int_{\underline{x}} f_\pi(\underline{x})\, u(\underline{x})\, d\underline{x} \qquad (17)$$

Expression (17) defines a functional which assigns a value to each useful configuration π; it is a measure of effectiveness of π with respect to the demonstration's goals. The design objective is then to maximize the effectiveness of the demonstration by selecting the appropriate configuration π:

$$E^*_\pi(u) = E^* = \max_{\pi \in \tilde{P}(t)} E_\pi(u) \qquad (18)$$

The determination of π^* cannot be done analytically; each configuration must be evaluated and the corresponding values of the effectiveness measure rank ordered. The procedure is impractical, if $\tilde{P}(t)$ includes all $2^{\#T}$ configurations. However, if the design of the alternative system configurations has been carried out properly, only a few configurations need to be evaluated. The steps of the procedure for selecting the optimal configuration for the demonstration, shown in Figure 5, can be summarized as follows:

(a) For a given mission utility function u, and for the configuration π defining the probability distribution f_π, evaluate $E_\pi(u)$.

(b) Repeat step (a) for each configuration $\pi \varepsilon \tilde{P}(t)$.

(c) Rank order the configurations π in $\tilde{P}(t)$ according to the values of $E_\pi(u)$.

(d) Select the configuration that maximizes expected utility.

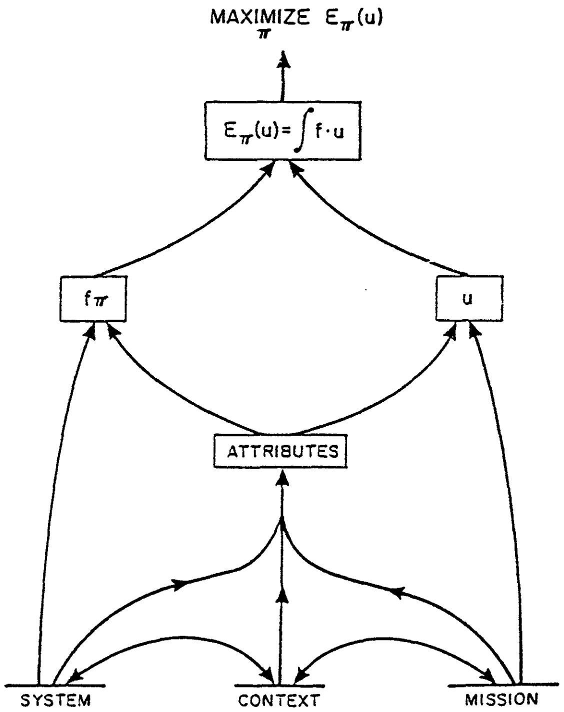

Figure 5. Methodology for Selecting the Optimal System Configuration

In order to implement this procedure, it is necessary to specify the functions v and w which define the partial utilities in Eqs. (11) to (13). These functions are given in the following form:

$$v_i(\underline{y}) = 1 - \frac{(1-Y)^t\, Q_i\, (1-Y)}{1^t\, Q_i\, 1} \qquad i = A,B,C \qquad (19)$$

$$w_A(z_A) = (z_A)^\alpha \quad ; \quad w_C(z_C) = (z_C)^\gamma \qquad (20)$$

where Q_i is a matrix with all elements non negative, and

$Y^t = (y_1\ y_2\ \ldots\ y_n)$ row vector of the Type 1 attributes

$1^t = (1\ 1\ \ldots\ 1)$

α and γ are real numbers between 0 and 1.

Specification of the partial utilities reduces to determining the three matrices, Q_A, Q_B, and Q_C, and the real numbers α and γ. This will be done in the context of an application - the effectiveness analysis of the METANET demonstration.

4. EFFECTIVENESS ANALYSIS OF THE METANET DEMONSTRATION

METANET can be described as a network of networks, where the objective is to demonstrate the feasibility of effective, reliable communication between a large heterogeneous set of nodes. Assume that a demonstration of some aspects of METANET is being planned. The plan is to freeze a set of components, select a set of nodes and links, and develop a scenario that will (a) demonstrate the capabilities and potential of METANET, and (b) indicate research and development needs (Mathis, 1983; Karam 1985).

4.1 The System Model

Fifteen components/technologies were frozen for use in the first demonstration of METANET; they constitute the set S(t) of operational components. These are:

Operational Technologies:

T_1 Tactical Situtation Assessment: performs part of the situation assessment function of C^2 and runs on operating system X.

T_2 Briefing Aid: allows a user to present briefings using computer graphics display hardware; runs on operating system X.

T_3 Weather Editor: allows a user to select a geographical area of the world and an environmental data field to be displayed; runs on operating system X.

T_4 Warfare Environment Simulator: provides a computer derived simulated naval war environment for both instructional and strategy testing purposes; runs on operating system X.

T_5 Local Area Network 1 (LAN1): generalized data communication network using data bus technology.

T_6 Multimedia Mail: to extend text mail, graphics, and vocoded voice; interactive interface with user connected to workstation, accessed from workstation (C^2WS).

T_7 Natural Language/Database: provides natural language access to Database (T_{10}), also includes the design and implementation of communication links among command and control workstations and Database; runs on workstation's computer.

T_8 Speech: to interface speech commands and queries to the Natural Language system, to synthesize responses from the query system into speech for the user; runs on workstation's computer.

T_9 METANET Gateway (GWY): to provide link between the workstations' local area network and other networks, including: LAN1, LAN2 (T_{12}), SANET (see T_{13}), and MILNET.

T_{10} Database: software system, allows a user to query multiple pre-existing, heterogeneous databases, using a single language and a simple integrated view of the available data.

T_{11} Data Management System (DMS): provides a graphical user interface to information, designed to be used directly by the decisionmaker; installed on board ship.

T_{12} Local Area Network 2 (LAN2): data communication network using ring technology.

T_{13} P-3C Radio Modifications: installation of a SANET (Satellite Network) node on a P-3 aircraft.

T_{14} SAT: enables linkage to SANET (see T_{13}).

T_{15} PLI: cryptographic device, enables linkage to MILNET.

Many system configurations can be obtained from these technologies, but not all are useful for the demonstration (Karam and Levis, 1984). The useful configurations are specified in conjunction with the possible scenarios in Section 4.4.

4.2 The Attributes

Six system attributes are considered relevant; they are defined so as to take values between 0 and 1. The traditional attributes are Reliability, Survivability, Input Flow, and Inverse Time Delay, and form the vector

$$\underline{y} = (y_1=R,\ y_2=S,\ y_3=F,\ y_4=\psi).$$

The novel attributes are the weighted fraction of components used and functions carried out; they form a vector

$$\underline{z} = (z_A,\ z_C).$$

Reliability denotes the capability of a network (see Section 4.4) to deliver a message from origin to destination when only the physical properties of the components are taken into account. In contrast, the attribute Survivability does not depend on the components' physical deterioration, but on the components' capabilities to resist enemy actions, e.g., jamming.

Let C be the capacity of any link in bits/sec. Assume the M/M/1 model of queueing theory and let $1/\mu$ be the mean packet size in bits/packet. If ϕ is the input flow on one link (packets/sec), then the mean time delay ξ for that link, which includes both queueing and transmission time, is:

$$\xi = \frac{1}{\mu C - \phi} \tag{21}$$

Instead of time delay it is more convenient to consider its inverse. The scaled attributes are then:

$$\text{Input Flow:} \qquad F = \frac{\phi}{\mu C} \tag{22}$$

$$\text{Inverse Time Delay:} \quad \psi = \frac{1}{\mu C \xi} \tag{23}$$

The Weighted Fraction of Technologies, z_A, and the Weighted Fraction of Functions, z_i, are given by expressions (6) and (7) where #T=15 and #F=4 (see Section 2.4).

4.3 The Mission Model

In this section, the participants in the demonstration of METANET are identified, and their expectations specified.

The Group of Developers (Group A): Six major developers can be identified (#A = 6): five system contractors and the sponsoring agency. Each developer contributed to the development of some or all the operational technologies (i.e., a subset of S(t)), and is particularly eager to see those demonstrated. This is expresed in terms of the technology by developer matrix, TA:

$$TA = \begin{bmatrix} 6/28 & 0 & 0 & 0 & 0 & 1/15 \\ 6/28 & 0 & 0 & 0 & 0 & 1/15 \\ 3/28 & 0 & 0 & 0 & 0 & 1/15 \\ 3/28 & 0 & 0 & 0 & 0 & 1/15 \\ 10/28 & 0 & 0 & 5/29 & 0 & 1/15 \\ 0 & 10/30 & 0 & 0 & 0 & 1/15 \\ 0 & 5/30 & 0 & 0 & 0 & 1/15 \\ 0 & 8/30 & 0 & 0 & 0 & 1/15 \\ 0 & 7/30 & 0 & 0 & 0 & 1/15 \\ 0 & 0 & 10/15 & 0 & 0 & 1/15 \\ 0 & 0 & 5/15 & 0 & 0 & 1/15 \\ 0 & 0 & 0 & 5/29 & 0 & 1/15 \\ 0 & 0 & 0 & 10/29 & 10/10 & 1/15 \\ 0 & 0 & 0 & 8/29 & 0 & 1/15 \\ 0 & 0 & 0 & 1/29 & 0 & 1/15 \end{bmatrix} \tag{24}$$

Element $(TA)_{ij}$ reflects the extent to which developer j would like to see technology i demonstrated. Matrix TA was estimated by asking each developer j (contractors or the agency) to fill in column j, by rating all the technologies on a 0 to 10 scale, for example. The input data are normalized for each developer so that

$$\sum_{i=1}^{\#T} (TA)_{ij} = 1 \qquad \forall\ j = 1,\ldots,\#A \tag{25}$$

The physical characteristic of the system's components and the context of the demonstrations dictate the following technology by attribute matrix, TY:

$$TY = \begin{bmatrix} 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 \end{bmatrix} \tag{26}$$

Element $(TY)_{ij}$ is equal to one if the developers believe that a good performance of technology i, when used, depends on the values taken by attribute j; it is equal to zero otherwise. Developer i is concerned with the performance of attribute j insofar as attribute j is directly affected by those technologies which developer i would like to see demonstrated, and that these technologies are actually demonstrated. These ideas can be expressed by formulating the developer by attribute matrix as follows:

Let the elements $(AY)_{ij}$ be defined by

$$(AY)_{ij} = \sum_{k=1}^{\#T} \tau(T_k)\ (TA)_{ki}(TY)_{kj} \tag{27}$$

where

$$\tau(T_k) = \begin{cases} 1 & \text{if technology k is included in the demonstration} \\ 0 & \text{otherwise} \end{cases}$$

Equation (27) can be written in matrix form

$$AY = (\underline{TA})^t\ (TY) \tag{28}$$

where

$$(\underline{TA})_{ki} = \tau(T_k)\ (TA)_{ki} \tag{29}$$

Thus, element $(AY)_{ij}$ denotes the degree to which developer i is concerned about the values taken by traditional attribute j. The developers' concern is contigent on the demonstration using "their" technologies. Finally, matrix Q_A in Eq. (19) can be determined by

$$Q_A = (AY)^t\ (AY) \tag{30}$$

Parameter α in Eq. (20) is not easy to assess. In practice a parametric study would be done where α is varied from 0 to 1. This completes the specification of the utility function for Group A.

The Group of System Users (Group B): The utility of group B is a function of the Type 1 attributes only

$$u_B(\underline{x}) = v_B(\underline{y}) = 1 - \frac{(1-Y)^t\ Q_B\ (1-Y)}{1^t\ Q_B\ 1} \tag{31}$$

The question then reduces to determining the weighting matrix Q_B. To do this, a matrix that relates system users to attributes needs to be introduced.

Let element $(BY)_{ij}$ denote the degree to which system user i is concerned with the values taken by attribute j. Matrix BY can be estimated by interviewing the system users individually. Each system user i is asked to fill in row i of matrix BY by rating all the Type 1 attributes on a scale of 0 to 10. The input data are then normalized for each system user, so that:

$$\sum_{j=1}^{\#Y} (BY)_{ij} = 1 \qquad \forall\ i = 1,\dots,\#B \tag{32}$$

Matrix Q_B is then equal to:

$$Q_B = (BY)^t\ (BY) \tag{33}$$

Since the system users in this case are those persons who will use the system during the demonstration, and only those, the system user by attribute matrix BY is then

$$(BY)_{ij} = 1/4 \qquad i=1,\dots,\#B\ ;\ j=1,\dots,4 \tag{34}$$

i.e., all the participants in group B are equally interested in each of the four Type 1 attributes.

The Group of Decisionmakers (Group C): The decisionmakers are concerned that the demonstration "perform well"; however, their concern is conditioned by which functions are carried out. The utility of group C is

$$u_C(\underline{x}) = (z_C)^\gamma\ (1 - \frac{(1-Y)^t Q_C\ (1-Y)}{1^t\ Q_C\ 1}) \tag{35}$$

Parameter γ is not easy to assess. In practice, a parametric study is done where γ is varied from 0 to 1. Matrix Q_C, however, can be written as

$$Q_C = (CY)^t\ (CY) \tag{36}$$

where CY is the "decisionmaker by attribute" matrix. Element $(CY)_{ij}$ denotes the degree to which decisionmaker i is concerned about the values taken by Type 1 attribute j insofar as the functions he would like to see carried out are actually carried out, and the performance of these is contingent on the values taken by attribute j. Hence, it is not unreasonable to formulate $(CY)_{ij}$ as follows:

$$(CY)_{ij} = \sum_{k=1}^{\#F} \phi(F_k)\ (FC)_{ki}(FY)_{kj} \tag{37}$$

where

$$\phi(F_k) = \begin{cases} 1 & \text{if function k is carried out in the demonstration} \\ 0 & \text{otherwise} \end{cases}$$

FC is called the "function by decisionmaker" matrix. Element $(FC)_{ij}$ expresses the extent to which decisionmaker j would like to see function i carried out. Matrix FC is determined by asking each decisionmaker j to fill in column j, by rating all the functions on a 0 to 10 scale. Then, the input are normalized for each decisionmaker, so that:

$$\sum_{i=1}^{\#F} (FC)_{ij} = 1 \qquad \forall\ j = 1,\ldots,\#C \tag{38}$$

Matrix FY is called the "function by attribute" matrix. Element $(FY)_{ij}$ is equal to one if the decisionmakers believe that a good performance of function i is dependent on the values taken by Type 1 attribute j. It is equal to zero otherwise.

Equation (37) can be rewritten in matrix form

$$CY = (\underline{FC})^t\ (FY) \tag{39}$$

where

$$(\underline{FC})_{ki} = \phi(F_k)\ (FC)_{ki} \tag{40}$$

In this case, there are four decisionmakers (#C=4), while four functions can be carried out by the demonstration of METANET (#F=4). Decisionmakers 1 to 3 are commanders in the Armed Forces; they are the real system users. Decisionmaker 4 represents a decisionmaking entity. Function 1 and 3 correspond to the interactions between commanders 1 and 2, and commanders 2 and 3, respectively. Function 2 (respectively, function 4) denotes the interaction between commander 2 (respectively, commander 3) and his staff.

The function by Decisionmaker matrix FC is:

$$FC = \begin{bmatrix} 1 & 1/3 & 0 & 1/4 \\ 0 & 1/3 & 0 & 1/4 \\ 0 & 1/3 & 1/2 & 1/4 \\ 0 & 0 & 1/2 & 1/4 \end{bmatrix} \tag{41}$$

The first three columns of the matrix result directly from the interaction scheme described previously. For example, consider commander 2: he interacts with commanders 1 and 3, and also with his staff. Thus, he is eager to see how METANET will carry out functions 1, 3, and 2; hence the second column of matrix FC. Decisionmaker 4 is equally interested in seeing all four functions carried out. Hence the fourth column of matrix FC.

The decisionmakers unanimously believe that any of the four functions should be carried out with maximum reliability, survivability, and input flow of data, and with minimum time delay. The function by attribute matrix FY is then:

$$(FY)_{ij} = 1 \qquad i = 1,\ldots,4\ ;\ j = 1,\ldots,4 \tag{42}$$

4.4 Scenario and Useful Configurations

Four facilities are available to house the METANET demonstration. An important set of hardware and software technologies can be made available at facilities 1 and 4. Facility 2 is the generator of weather data (DG), while facility 3 is a ship in the high seas. As it turns out, the use by the demonstration of facility 4 is a decision variable. Depending on whether three facilities (case a) or four facilities (case b) are used, the total network configuration will be slightly different (see Figures 6 and 7). It is assumed that facility 3, as well as the satellite (SANET) and P-3 nodes are in a hostile environment. Survivability is an issue for any technology using these nodes. (Hence the second column of matrix TY).

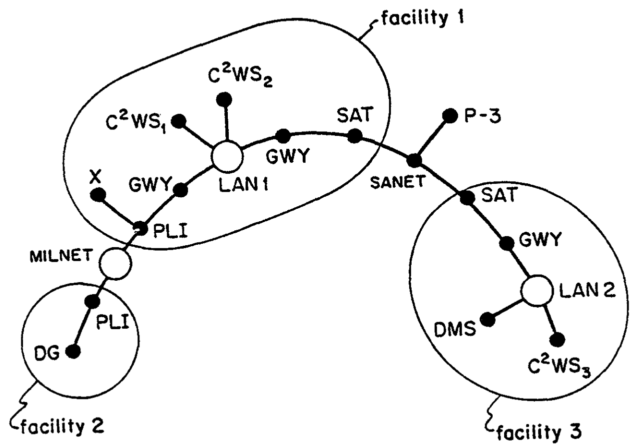

Figure 6. Total Network Configuration when Three Facilities are Used (Case a)

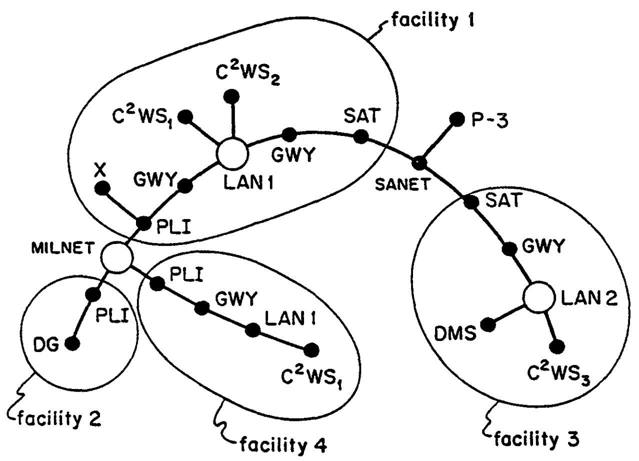

Figure 7. Total Network Configuration when Four Facilities are Used (Case b)

The scenario according to which the demonstration is run consists of several stages. An origin-destination pair, a session, is demonstrated at each stage; it performs one of the four functions described in Section 4.3. Seven sessions are identified. Session 1 is designed to carry out function 1. Sessions 2 and 3 execute function 2 each. Function 3 is carried out by session 4, while sessions 5, 6, and 7 carry out function 4.

All seven sessions do not have to be included in the demonstration: If s sessions are actually demonstrated ($1 \leq s \leq 7$), then the scenario consists of s stages. A useful system configuration corresponds to each such scenario; it includes the s origin-destination pairs. There are, $2^7-1 = 127$ (the null element ϕ is excluded) useful configurations in case a, and just as many in case b. Sessions 1 to 7 are drawn in Figure 8. Note that only session 1 has a different topology depending on whether three or four facilities are used.

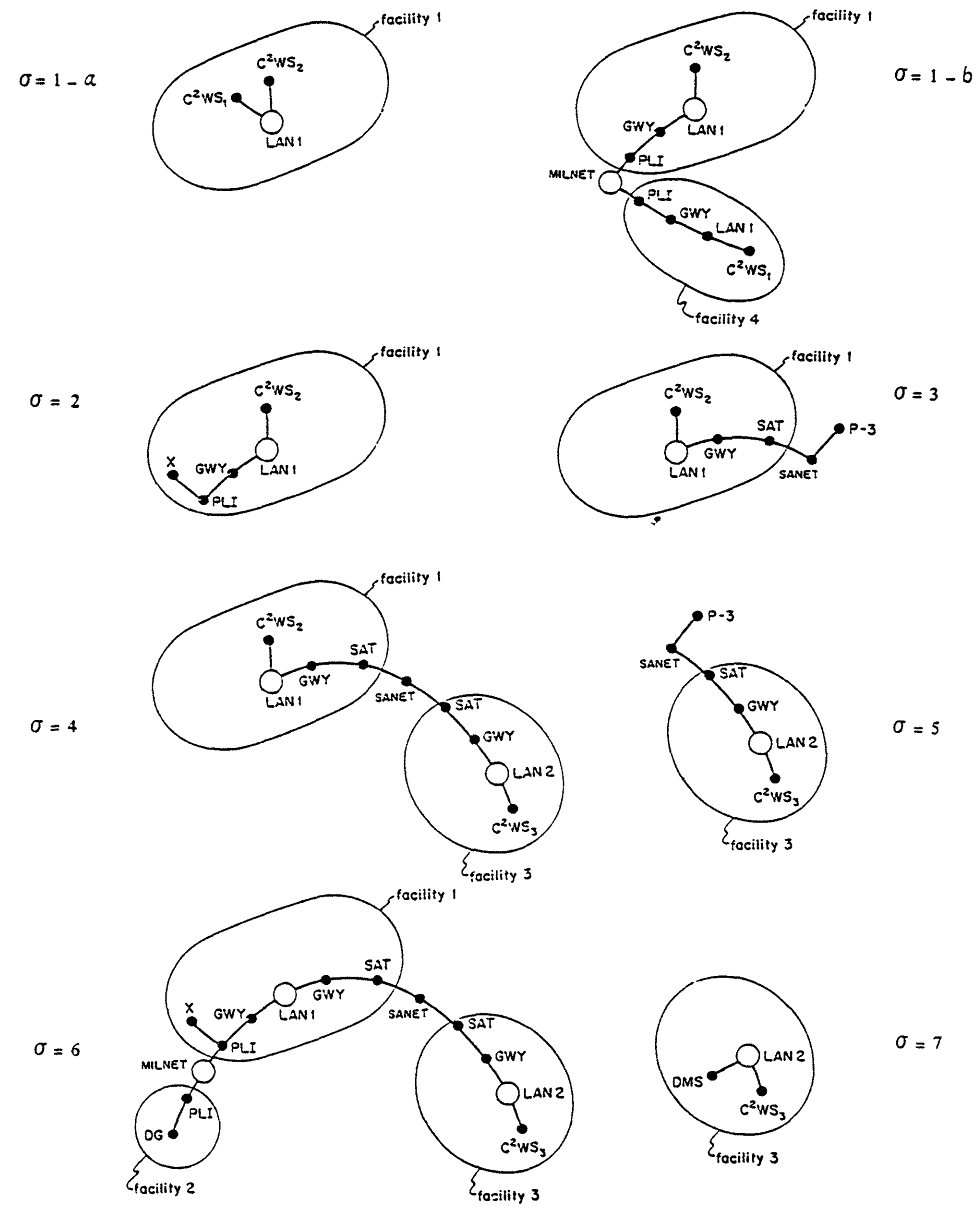

Figure 8. Topology of the Sessions

Each useful configuration π_K is characterized by the value taken by the binary variables $K(\sigma)$ for $\sigma = 1$ to 7, defined as follows:

$$K(\sigma) = \begin{cases} 1 & \text{if session } \sigma \text{ is included in configuration } \pi_K \\ 0 & \text{if it is not} \end{cases} \qquad (43)$$

For example, configuration $\pi_{(1100001)}$ is the one that includes sessions 1, 2, and 7.

The measure of effectiveness of a demonstration of METANET using π_K is:

$$E(K) = a(z_A(K))^{\alpha} \int g_{\pi_K}(\underline{y})\, v_A(\underline{y})\, d\underline{y} + b\int g_{\pi_K}(\underline{y})\, v_B(\underline{y})\, d\underline{y}$$

$$+ \; c(z_C(K))^{\gamma} \int g_{\pi_K}(\underline{y})\, v_C(\underline{y})\, d\underline{y} \qquad (44)$$

The probability distribution g is well defined when configuration π_K contains only one origin-destination pair. Let then

$$E_i(\sigma) = \int g_\sigma(\underline{y})\ v_i(\underline{y})\ d\underline{y} \qquad (45)$$

where i = A, B, or C and σ = 1,...,7. For each useful configuration π_K, let $\bar{E}_i(K)$ be the average of the $E_i(\sigma)$'s for all sessions σ included in configuration π_K, i.e.,

$$\bar{E}_i(k) = \sum_{\sigma=1}^{7} K(\sigma)\ E_i(\sigma)\ /\ \sum_{\sigma=1}^{7} K(\sigma) \qquad (46)$$

Expression (46) replaces the term $\int g_\pi(\underline{y}) v_i(\underline{y}) d\underline{y}$ when configuration π_K contains more than one session. The measure of effectiveness of a demonstration of METANET using π_K is then:

$$E(K) = a\ (z_A(K))^\alpha\ \bar{E}_A(K) + b\ \bar{E}_B(K) + c\ (z_C(K))^\gamma \bar{E}_C(K) \qquad (47)$$

The design optimization problem becomes:

Maximize E(k) over k=(k(1),...,k(7) for cases a and b.

In order to solve the design problem, it is necessary to specify a number of design parameters.

Weights $\omega_A(T_i)$ and $\omega_C(F_i)$ used in expressions for the Weighted Fractions of Technologies and Functions, Eqs. (7) and (8) are given are by:

$$\omega_A(T_i) = \sum_{k=1}^{6} (TA)_{ik} \qquad i = 1,...,15 \qquad (48)$$

$$\omega_C(F_j) = \sum_{k=1}^{4} (FC)_{jk} \qquad j = 1,...,4 \qquad (49)$$

On the other hand, a technology i is said to be included in a configuration π_K (i.e., $\tau(T_i)$=1) whenever it is used by at least one session in that configuration. Similarly, a function j is said to be carried out by the demonstration ($\phi(F_j)$=1) if it is executed by at least one session in configuration π_K.

Reliability and Survivability depend on the probability of failure of of the components. Each failure probability is allowed to vary in a different interval of [0,1], depending on whether Reliability or Survivability is computed. Hence, for each session σ

$$R_{min}(\sigma) \leq R \leq R_{max}(\sigma) \qquad (50)$$

$$S_{min}(\sigma) \leq S \leq S_{max}(\sigma) \qquad (51)$$

For each session σ, the time delay between origin and destination is

$$\xi = \frac{L(\sigma)}{\mu C - \phi} \qquad (52)$$

where L(σ) is the number of links in session σ between the origin and the destination. Using the scaled attributes Eq. (52) becomes

$$\nu = (1-F)/L(\sigma). \qquad (53)$$

Finally, the utility of the demonstration is assumed to be an additive average of the partial utilities, as given by Eq. (14). The Q matrices can be computed (for each session σ) by manipulating the data matrices given in this section. Parameters α and γ are set equal to 0.5, while coefficients a, b, and c in Eq. (14) are set equal to 1/3. Sensitivity analyses of the solution with respect to α, γ, a, b, and c were presented in Karam (1985) and Karam and Levis (1984).

4.5 Results

For each session σ, the quantities $E_A(\sigma)$, $E_B(\sigma)$, and $E_C(\sigma)$ were computed. The effectiveness of each configuration π_K was then computed according to Eq. (47). For each case (a or b), the configurations were then rank ordered. The results are given next.

Case a: Three Facilities

The best (first) ten configurations are listed in Table 1 in order of decreasing effectiveness. Each configuration π_K is identified by the values of the binary variables K(σ), σ= 1 to 7. For example, the configuration that ranks first includes all sessions but sessions 5 and 6, has a measure of effectiveness of 0.799, and a z_A and z_C equal to 0.98 and 1, respectively. Table 1 gives also the values of the system attributes z_A and z_C. Several remarks can be said about the results shown in this table.

Table 1. The First Ten Configurations (Case a)

Rank	Configuration π_K σ = 1 2 3 4 5 6 7	Effectiveness	z_A	z_C
1	1 1 1 1 0 0 1	0.799	0.98	1
2	1 1 0 1 1 0 1	0.793	0.98	1
3	1 1 1 1 1 0 1	0.787	0.98	1
4	1 0 1 1 0 0 1	0.785	0.83	1
5	1 1 1 1 0 1 1	0.782	1	1
6	1 1 0 1 1 1 1	0.778	1	1
7	1 1 0 1 0 0 1	0.777	0.75	1
8	1 1 1 0 0 0 1	0.777	0.98	0.73
9	1 1 1 1 1 1 1	0.775	1	1
10	1 0 1 0 0 0 1	0.771	0.83	0.73

First, the configuration including all sessions (K=(1 1 ... 1)) is not the optimal one, it ranks #9. The interpretation is the following: some sessions had better be ignored altogether in the first demonstration of METANET if they are not adequately developed, specially if they do not execute an additional function. It can be noted, with this respect, that the first seven configurations carry all four functions (z_C=1). However, configuration #8 has a z_C of 0.85: there is at least one function which is carried out by none of the sessions included in this configuration. Configuration #8 carries out fewer functions than configuration #9 (smaller z_C) and includes fewer technologies (smaller z_A); nevertheless, it is more effective for the first demonstration of METANET. In fact, all first four configurations have a z_A smaller than 1; i.e., none of them includes all fifteen technologies.

Case b: Four Facilities

The same type of results is obtained when four facilities are used, and hence the same conclusions can be drawn. Table 2 shows the first ten configurations, together with their effectiveness measure, and the values of system attributes z_A and z_C.

Table 2. The First Ten Configurations (Case b)

Rank	Configuration π_k σ = 1 2 3 4 5 6 7	Effectiveness	z_A	z_C
1	1 1 1 1 0 0 1	0.775	0.98	1
2	1 1 0 1 1 0 1	0.770	0.98	1
3	1 1 1 1 1 0 1	0.768	0.98	1
4	1 1 1 1 0 1 1	0.762	1	1
5	1 1 1 1 1 1 1	0.758	1	1
6	1 1 0 1 1 1 1	0.758	1	1
7	1 0 1 1 0 0 1	0.757	0.83	1
8	1 1 0 1 0 0 1	0.750	0.75	1
9	1 1 1 0 0 0 1	0.749	0.98	0.73
10	1 0 1 1 1 0 1	0.748	0.83	1

Note that the configuration including all sessions now ranks fifth, and that its effectiveness is reduced compared to case a. In fact, all configurations that include the first session ($\sigma = 1$) have their effectiveness reduced, if four facilities are used rather than three. When the mission primitives were given the following extreme values

$$a = 1 \quad , \quad b = c = 0$$

$$\alpha = 1 \quad , \quad \gamma = 1$$

this basic result remained unchanged: the top ranking configurations were still more effective when three facilities are used rather than four. The conclusion is then the following: given the values of the system primitives, the model predicts that, for the first demonstration of METANET, it will always be more effective to use three facilities, and sessions 1, 2, 3, 4, and 7 with the corresponding scenario.

It can be inferred from these results that showing an additional technology or carrying out an additional function at the time of the METANET demonstration may be at the expense of the overall effectiveness of such a demonstration. The model developed in this paper does not explicitly address the issue of optimally designing the series of demonstrations to come. It is expected, however, that the results obtained here will be more useful, if the next to the first demonstration were considered in the model.

5. CONCLUSIONS

A methodology for effectiveness analysis of an evolving system has been presented. It requires the explicit specification of candidate technologies and the consideration of the utilities of the various groups involved in developing the system. The context in which the methodology was formulated is that of a demonstration aimed at showing the progress achieved in developing the system as well as the capabilities of the latter. The methodology provides the decisionmaker with a powerful tool that can be applied systematically to quantifying the progress made in developing a system, the expectations of the various participant groups, and finally the global effectiveness of the system at each point in time.

6. REFERENCES

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