EFFECTIVENESS ASSESSMENT OF THE METANET DEMONSTRATION[*]

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is placed on the design of the demonstration by assessing the effectiveness
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Alexander H. Levis
Laboratory for Information and Decision Systems
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

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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. While the methodology has been motivated by METANET, a network of heterogeneous networks, the approach is illustrated through a simple network that consists of heterogeneous components.

1. INTRODUCTION

METANET, a multi-year program sponsored by NAVELEX, 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. At the present time, a demonstration of some aspects of METANET is being planned for 1985. 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 [1].

The development of METANET poses a number of novel issues regarding the evaluation of measures of effectiveness (MOE's). The system has not been developed fully yet, so that evaluation of its performance in the field is not possible. Furthermore, since METANET is a research and development project, it is expected to produce data that can be used in assessing the effectiveness of an implemented prototype. Thus, one is led to the conclusion that one aspect of the effectiveness of METANET is how well it will demonstrate the capabilities of the technologies involved. The proposed demonstration has in turn a dual role: to demonstrate progress and accomplishments in developing the technology for METANET, and to demonstrate the potential of METANET itself.

In this paper, a methodology for the effectiveness analysis of such a system is outlined. It is based on the System Effectiveness Analysis methodology, [2], [3], but with some major modifications and enhancements to reflect the fact that a series of demonstrations of an incomplete, evolving system are planned. A new aspect of the methodology is the explicit consideration of the various entities involved in a demonstration: the system developers, the sponsoring agency, the system users, and the decisionmakers.

First the analytical framework is presented, and then its application to the effectiveness analysis of evolving systems such as METANET is described.

2. THE SYSTEM MODEL

Let m_j denote the j-th component of the system that is being developed:

$$S = \{m_1, m_2, \ldots, m_j, \ldots, m_J\} \qquad (1)$$

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

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

$$0 \leq \lambda_j(t) \leq 1 \qquad (2)$$

and if C_j denotes a threshold of operability for component j, then S(t) is the subset of S that is operational at time t:

$$S(t) = \{m_j(t) \mid \lambda_j(t) \geq C_j\} \qquad (3)$$

i.e., it consists of the elements m_j that have reached or exceeded their threshold of operability. 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).

Now, assume that at any time there is a collection of components that are operational. Out of these components, some 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 demonstrating the system's capabilities. These concepts can be stated formally as follows:

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

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

For example, if

$$S(t) = \{m_1, m_2\}$$

then

$$P(t) = \{\phi, \{m_1\}, \{m_2\}, \{m_1, m_2\}\}$$

where ϕ is the null element. If S(t) contains μ elements, then the number of subsets in P(t) is 2^μ,

which is a very large number of subsets. However, not all of them lead to useful configurations. Let $\tilde{P}(t)$ be the subset of $P(t)$ that merits consideration; the elements of $\tilde{P}(t)$ are candidate configurations for the demonstration. It is expected that few non-trivial configurations would be possible at any time.

Let us now apply this conceptual framework 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 new components m_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 how does one select the most effective one? To do that, the goals of the demonstration must be established.

3. THE DEMONSTRATION's GOALS

Four major sets of participants would be involved in a demonstration. Each one has his own goals and objectives for the demonstration itself. The first one consists of the contractors, the engineers and scientists who are developing the components, both hardware and software, and who are concerned with system integration. Denote this set of participants by I.

The second participant is the agency that is the program sponsor and manager. Denote this participant by A_g. 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 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). Denote this group by B.

Finally, there is the group of decisionmakers, who will observe the demonstration, and can make decisions about the program's continuation and eventual implementation. This group is denoted by C.

These groups share some, but not all the criteria for evaluating the demonstration. This will be explored in Section 5 where the utility function of each participant will be introduced. Prior to that discussion, however, the enhanced system effectiveness methodology will be described.

4. MEASURES OF SYSTEM EFFECTIVENESS

The objective is not to evaluate the performance of a system per se, but, rather, to measure the extent to which a system, given its performance, is effective in meeting the requirements of the mission it is designed to accomplish. Thus, system and mission ought to be viewed independently, but concurrently and in the same context.

The system's performance and the mission requirements are described in terms of a finite number of attributes x_i $(i=1,\ldots,n)$. For example, x_i can be a measure of reliability, a measure of survivability, or a time delay.

A utility function $u(x_1,\ldots,x_n)$ is introduced that translates into a real number the desirability, from the point of view of the mission, of each combination of attribute values:

$$V \subset R^n \xrightarrow{\quad u \quad} [0,1]$$

$$\underline{x} = (x_1,\ldots,x_n) \longrightarrow u(x_1,\ldots,x_n) = u(\underline{x}) \quad (5)$$

where V is the subset of R^n containing those combinations of attribute values which are physically meaningful. For example, a time delay is non-negative while the reliability index takes values between zero and one. In practice, it is often possible to take $V = [0,1]^n$ by appropriate mapping and scaling.

In a given context, a system is not expected to realize a specified combination of values of its attributes $\underline{x} = (x_1, x_2,\ldots,x_n)$ with probability one. Instead, a set of realizable values L_s exists; this set is called the system locus. Any value of $\underline{x}$ that belongs to L_s has a non-zero probability of being achieved by the system. To model this concept, a probability distribution f over V is introduced. The highest values of f occur at the values of $\underline{x}$ that are most likely to be reached by the system operating in the specified context, and f is identically equal to zero outside the system locus L_s.

Ideally, a system characterized by a probability distribution $f(\underline{x})$ is most effective with regard to a mission, described by the utility $u(\underline{x})$, if the points $\underline{x}$ for which $f(\underline{x})$ is high coincide with those points for which the utility is high. A measure of effectiveness that expresses this notion is given by the expected utility over V, i.e.,

$$E_f(u) = \int_V f(\underline{x})\, u(\underline{x})\, d\underline{x} \quad ; \quad d\underline{x} = dx_1 dx_2 \ldots dx_n \quad (6)$$

This measure takes values between zero and one. A graphical representation of the functions f and u for the case of two attributes (x_1,x_2) is shown in Fig. 1.

This concept is not restricted to completed systems; it can also be applied to measuring the effectiveness of evolving systems. Let π be an element of $\tilde{P}(t)$ (see Section 2), and let f_π be its probability distribution over the attributes $\underline{x}$. Then the measure of effectiveness of a demonstration using π, depends on f_π and u;

$$E_\pi(u) = \int_{\text{all attributes}} f_\pi(\underline{x})\, u(\underline{x})\, d\underline{x} \quad (7)$$

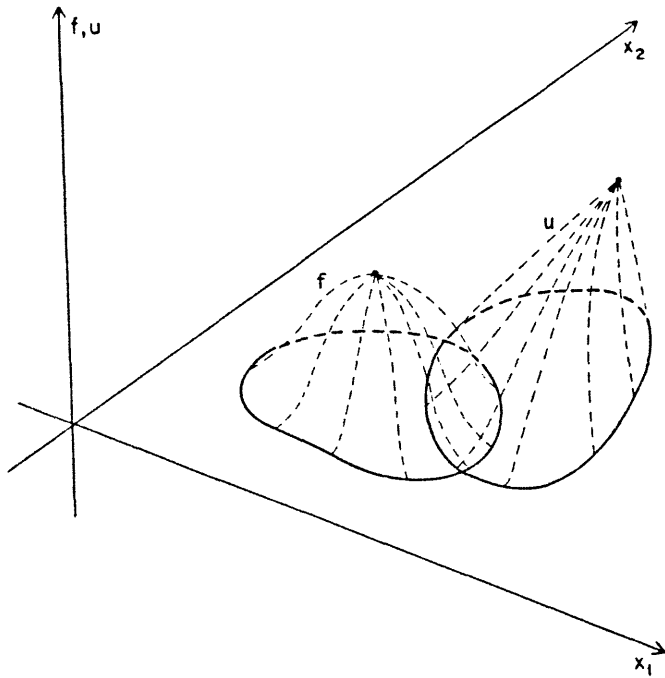Figure 1. The Functions $f(x_1,x_2)$ and $u(x_1,x_2)$

Expression (7) 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 goals:

$$\pi \longrightarrow E_\pi(u) \qquad (8)$$

The design objective is then to maximize the effectiveness of the demonstration by selecting the appropriate configuration π^*:

$$E_{\pi^*}(u) = E^* = \max_{\pi \, \epsilon \, \tilde{P}(t)} E_\pi(u) \qquad (9)$$

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^μ configurations. However, if the design of the alternative system configurations has been carried out properly, only several configurations need be evaluated. The steps of the procedure for selecting the optimal configuration for the demonstration 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 $\pi \, \epsilon \, \tilde{P}(t)$.

(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.

The steps of the methodology for selecting the optimal system configuration for the demonstration are summarized in Figure 2.
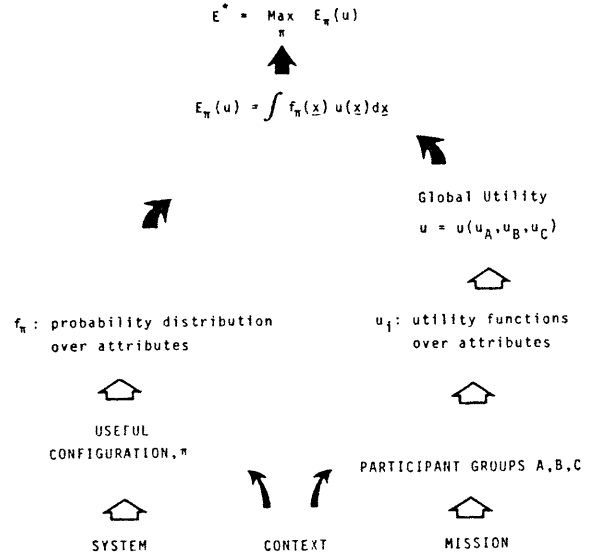

Figure 2. Methodology for Selecting the Optimal System Configuration

Up to this point, it has been assumed that the utility u is known. However, the utilities of the different participants are not the same. This aspect of the problem is discussed in the next section.

5. UTILITIES OF PARTICIPANTS

In Section 3 of this paper, three groups of participants that have a stake in the outcome of the demonstration were defined. These are groups A, B, and C. Each group expresses its satisfaction — or dissatisfaction — with the demonstration by focusing on a set of attributes that are relevant to this particular group. Let x_i (i=1,....,n) be the set of all relevant attributes (see Figure 3), i.e., each attribute x_i is relevant to at least one group. For example, x_1 might be relevant to A, but not to B or C.
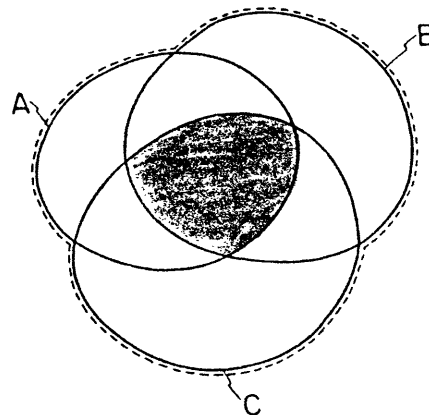

Figure 3. Sets of Atributes Relevant to Groups A, B, and C

The three groups do not necessarily have the same criteria for evaluating the demonstration. Let then

u_A, u_B, and u_C be the utility functions of groups A, B, and C respectively:

$$A: \quad \underline{x} \longrightarrow u_A(\underline{x}) \qquad (10)$$

$$B: \quad \underline{x} \longrightarrow u_B(\underline{x}) \qquad (11)$$

$$C: \quad \underline{x} \longrightarrow u_C(\underline{x}) \qquad (12)$$

If x_i is relevant to A, but not to B or C, then u_A varies with x_i, but not u_B or u_C. That is, if u_A, u_B, and u_C are differentiable,

$$\frac{\partial u_A}{\partial x_i} \neq 0 \; ; \quad \frac{\partial u_B}{\partial x_i} = 0 \; ; \quad \frac{\partial u_C}{\partial x_i} = 0 \qquad (13)$$

The shaded region in Figure 3, the intersection of the attribute sets that correspond to A, B, and C, contains the attributes that appear explicitly in all three utility functions in expressions (10) to (12). To complete the definitions, a global utility function $u(\underline{x})$ is defined by:

$$u(\underline{x}) = u(u_A(\underline{x}), u_B(\underline{x}), u_C(\underline{x})) \qquad (14)$$

The maximization problem of the previous section can be posed now more precisely:

$$\begin{array}{c} \text{maximize} \\ \pi \, \varepsilon \, \tilde{P}(t) \end{array} \quad E_\pi(u(u_A, u_B, u_C)) \qquad (15)$$

Attention is now focused on the global utility u, i.e., on how u can be related to the partial utilities u_A, u_B, and u_C.

5.1 Direct weighting

The global utility is an explicit function of the partial utilities. For example:

$$u = \frac{1}{3} u_A + \frac{1}{3} u_B + \frac{1}{3} u_C \qquad \text{(additive)} \qquad (16)$$

or

$$u = u_A^* \, u_B^* \, u_C \qquad \text{(multiplicative)} \qquad (17)$$

In both (16) and (17), the three participants' utilities are given equal weights regardless of the participants interaction or influence on decisions.

5.2 Indirect weighting: Organizational Interaction

In reality, the three groups of participants in a demonstration are not independent, nor do their actions affect the system in the same way. They interact before, during, and after the demonstration. Thus, it is important to sketch a model of the organizational interaction of the participants in the demonstration. A possible model of the interaction, motivated by METANET, is shown in Figure 4.
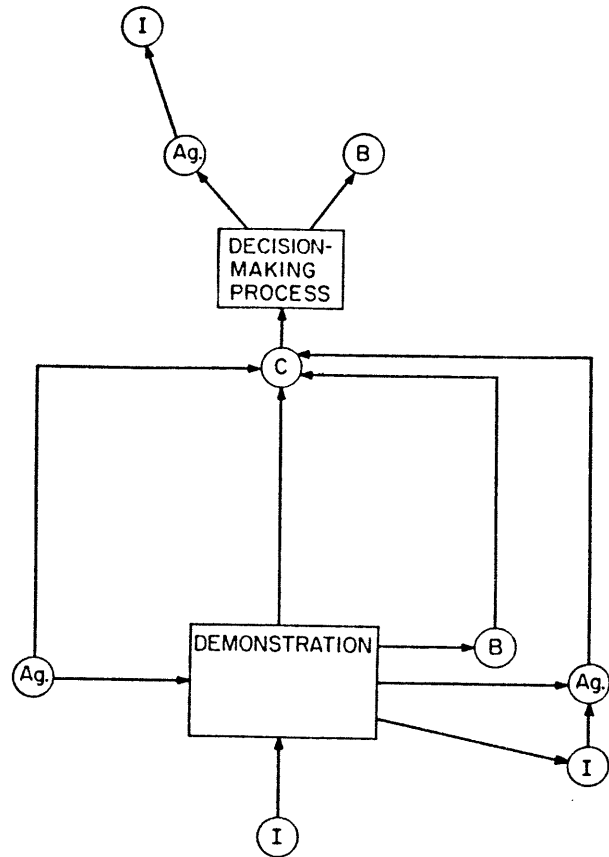

Figure 4. Organizational Interaction of Demonstration Participants

At the bottom of Figure 4, the contractors, denoted by I, provide the operational components of the system S, while the sponsor approves a scenario developed jointly by the contractors and the users. All four participants observe the demonstration. The contractors report their observations and recommendations to the sponsors (I → A_g; bottom right in Figure 4). 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 decisionmakers as a function of all the attributes, including, de facto, those explicitly relevant to C, and the utility functions of A and B:

$$u_C = u_C(\underline{x}, u_A(\underline{x}), u_B(\underline{x})) \qquad (18)$$

According to this model, the optimization problem (15) is hence equivalent to the following one:

$$\begin{array}{c} \text{maximize} \\ \pi \, \varepsilon \, \tilde{P}(t) \end{array} \quad E_\pi(u_C) \qquad (19)$$

where it has been assumed that

$$u(\underline{x}) = u_C(\underline{x}, u_A(\underline{x}), u_B(\underline{x})). \qquad (20)$$

6. EXAMPLE: DEMONSTRATION OF A COMMUNICATION NETWORK

The motivation for the development of the methodology comes from METANET, which is approaching the first major demonstration of its capabilities and of the underlying technological developments. Since application of the system effectiveness analysis to METANET is not yet possible, an illustrative example is presented that exhibits some of the generic characteristics or properties of a communications network consisting of heterogeneous nodes and links. Furthermore, it is assumed that this network is being developed and its first demonstration is to be held in the near future.

Suppose that a time t, nineteen components of the network are operational: seven nodes and twelve links. These constitute the set S(t) as previously defined. Many configurations can be obtained from these components (in this case, 2^{19}), but not all are useful for the demonstration. Let the objective be to establish communication between nodes 1 and 7, subject to the constraint that at least two non overlapping paths exist between these two nodes. Then, the number of useful configurations reduces to ten forming the set $\tilde{P}(t)$. These configurations are shown in Fig. 5. Note that configuration #9 is the one that includes all nodes and all links, while configuration #1 contains the fewest components among the 10 configurations.

6.1 Primitives

The system characteristics in a given context are described by a set of primitives [2], [3]. The first primitives that need to be defined are the probabilities of failure of the various system components.
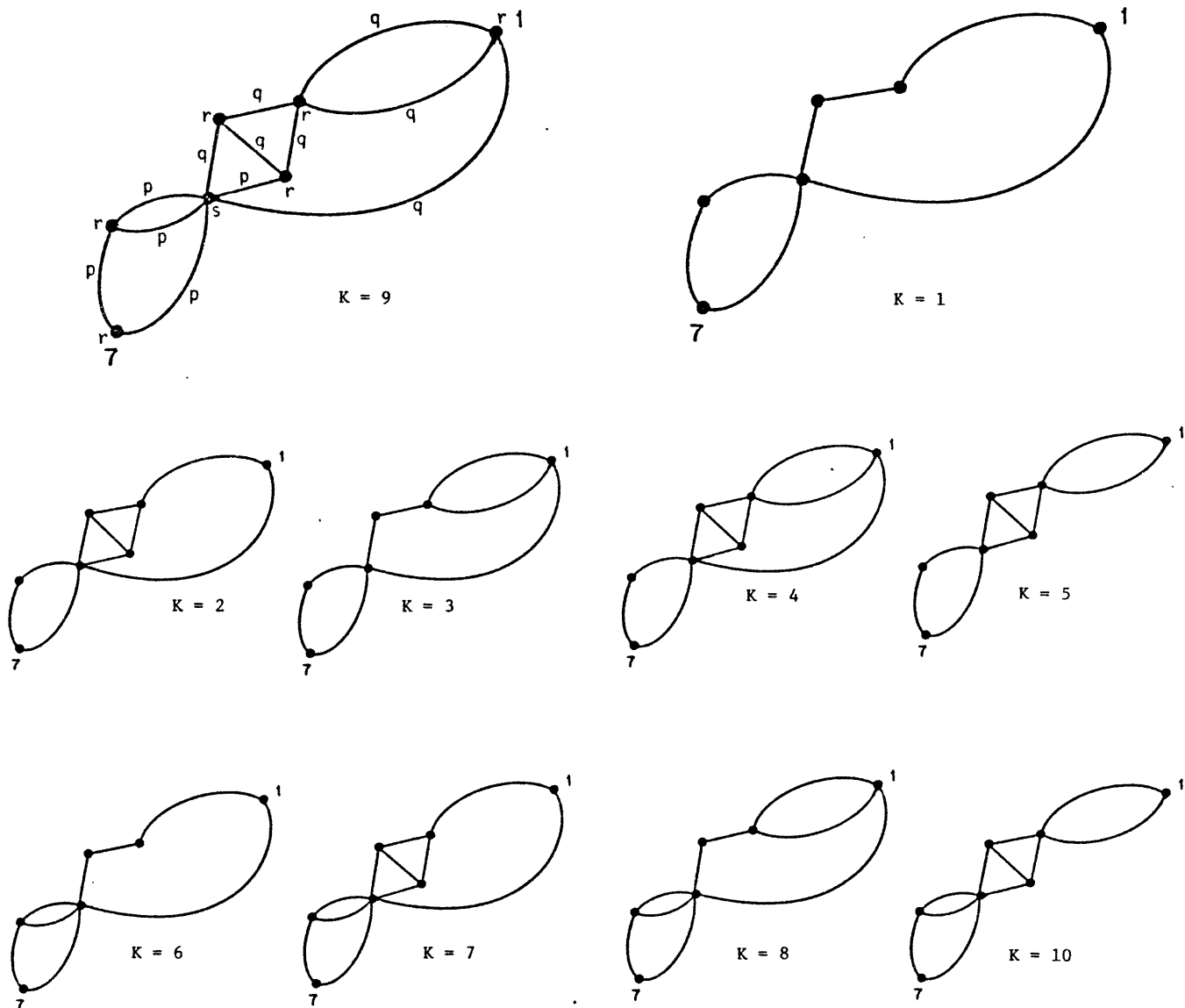

Figure 5. The Ten Useful System Configurations

These are:

1 − p = probability of failure of ground link (cable)

1 − q = probability of failure of satellite link

1 − r = probability of failure of node (platform)

1 − s = probability of failure of node (central)

The association of these failure probabilities with the corresponding system components is shown in Figure 5 (configuration #9).

6.2 Attributes

Six attributes are considered; all are defined so as to take values between 0 and 1. The attributes Reliability, Survivability, Input Flow, and Inverse Time Delay are continuous variables. The remaining two, Number and Cost of Components take discrete values.

6.2.1 Reliability and Survivability

Reliability denotes the capability of a network to deliver a message from node 7 to node 1 when only the physical properties of the components (links and nodes) are taken into account [2], [3]. In contrast, the attribute Survivability does not depend on the components' physical deterioration, but on the components' capabilities to resist enemy attacks.

6.2.2 Input Flow and Inverse Time Delay

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

$$T = \frac{1}{\mu C - \text{Flow}} \qquad (21)$$

It is more convenient to consider the inverse of time delay. The scaled attributes are then:

$$\text{Inverse Time Delay:} \quad \nu = \frac{2}{\mu C T} \qquad (22)$$

$$\text{Input Flow:} \quad F = \frac{\text{Flow}}{\mu C} \qquad (23)$$

6.2.3 Number and Cost of Components

Let N_o and L_o be the number of nodes and links in S(t). In this case, N_o is seven and L_o is twelve. Let N and L be the number of nodes and links in a specific configuration. If Cost denotes the ratio of the cost of one link to that of one node, the scaled attributes are:

$$\text{Number of components:} \quad x_s = \frac{N + L}{N_o + L_o} \qquad (24)$$

$$\text{Cost of components:} \quad x_6 = \frac{\text{Cost}*L + N}{\text{Cost}*L_o + N_o + 1} \qquad (25)$$

These six attributes form a vector $\underline{x}$,

$$\underline{x} = [R\ S\ F\ \nu\ x_s\ x_6]', \quad \text{where } \underline{x} \in [0,1]^6.$$

6.3 System Performance

Each useful configuration π constitutes a system in the System Effectiveness Analysis terminology. The performance of such a system in the context of the planned demonstration is characterized by a probability distribution $f_\pi(\underline{x})$ over the six attributes. The question becomes then the computation of $f_\pi(\underline{x})$, or of the system locus.

Let the configurations be numbered in sequence. The choice of a configuration K fixes the values of attributes x_s and x_6 ($x_s = x_s(K)$, $x_6 = x_6(K)$). The probability distribution f_π is a Dirac function in the plane (x_s, x_6) at the point $(x_s(K), x_6(K))$. Now, f_π remains to be defined over the four continuous attributes.

6.3.1 Reliability and Survivability

For each configuration K (K = 1 to 10), a Reliability/Survivability index is computed as a function of the four previously defined probabilities p,q,r, and s. Depending on whether the attribute Reliability or Survivability is computed, each of these probabilities is bound to vary in a different interval of [0,1]. For example, the probability of failure of a ground link, 1−p, is set equal to zero in computing S because ground links are assumed in this example not to be jammed. Hence, R and S vary in intervals, the limits of which are easily computed:

$$R_{min}(K) \leq R \leq R_{max}(K) \qquad (26)$$

$$S_{min}(K) \leq S \leq S_{max}(K) \qquad (27)$$

6.3.2 Input Flow and Inverse Time Delay

For each configuration K, T may vary between T_{min} and T_{max}, depending on the routing algorithm. Indeed,

$$\frac{L_{min}(K)}{\mu C - F} \leq T \leq \frac{L_{max}(K)}{\mu C - F} \qquad (28)$$

where $L_{min}(K)$ and $L_{max}(K)$ are, respectively, the minimum and maximum number of links contained in a path going from node 7 to node 1.

Using the scaled attributes, the inequalities (28) can be written as

$$\nu_{min}(K)\ (1 - F) \leq \nu \leq \nu_{max}(K)\ (1 - F) \qquad (29)$$

Conditions (26), (27), and (29), define the system locus $L_s(K)$ over the four continuous attributes. It is assumed that f_π is uniformly distributed over this locus.

6.4 Mission Requirements

All participants in the demonstration are not interested equally in all six attributes. Only the four continuous attributes are relevant to all groups. In addition, it is assumed that group A would like to see more components demonstrated. In contrast, Group C is concerned about the cost of the components. This distribution of the attributes is sketched in Figure 6. The utility function of each group is written next.
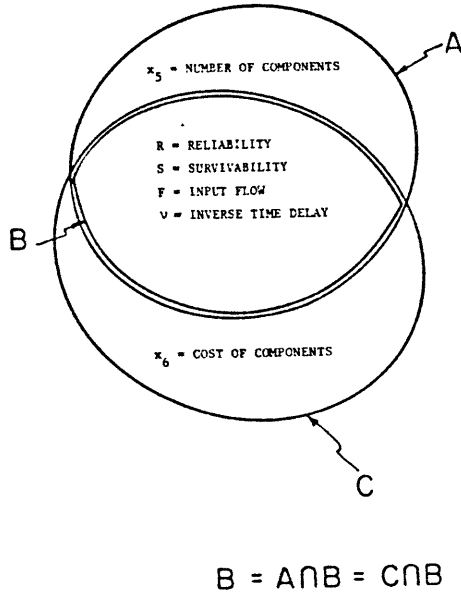

$$B = A \cap B = C \cap B$$

Figure 6. Distribution of Attributes in Utilities of Participant Groups

Let

$$v_j(\underline{y}) = 1 - \frac{(1-\underline{y})' \; Q_j \; (1-\underline{y})}{\underline{1}' \; Q_j \; \underline{1}} \qquad (30)$$

where

$$\underline{y} = (R \; S \; F \; \nu)', \qquad (31)$$

Q_j is a positive definite matrix with all its elements non-negative, and

$$j = A, B, \text{ or } C.$$

Then, it is assumed that

$$u_A(\underline{x}) = (x_s)^\alpha \; v_A(\underline{y}) \qquad 0 \leq \alpha \leq 1 \qquad (32)$$

$$u_B(\underline{x}) = v_B(\underline{y}) \qquad (33)$$

$$u_C(\underline{x}) = (1 - x_s)^\gamma \; v_C(\underline{y}) \qquad 0 \leq \gamma \leq 1 \qquad (34)$$

It should be noted that these functions exhibit decreasing marginal utility with respect to each of the four continuous attributes.

Finally, it is assumed that the global utility u is a weighted average of the partial utilities u_A, u_B, and u_C:

$$u = A*u_A + B*u_B + C*u_C \qquad (35)$$

where $A + B + C = 1$.

6.5 Results

Having computed the system locus (section 6.3) and assuming that the participants utilities are known (section 6.4), the measure of effectiveness of configuration K, namely,

$$E(K) = \int f_\pi(\underline{x}) \; u(\underline{x}) \; d\underline{x} \qquad (36)$$

can be computed. This measure is computed for each one of the ten candidate configurations. The optimal configuration is that configuration K^* for which the measure of effectiveness is maximum, i.e.,

$$E^* = E(K^*) = \max_{K=1,10} E(K) \qquad (37)$$

6.5.1 Reliability/Survivability Index

Let this index, defined in Section 6.3.1, be denoted by RS. It is a function of the four probabilities p,q,r, and s that describe the failure characteristics of the system components in the demonstration context. For a given system configuration and a given set of failure probabilities, the RS index can be computed (for details, see [2] or [3]). However, more insight is obtained, if the value of RS is plotted as a function of each one of the four primitives, while the other three are set equal to unity. This isolates the effect different types of components have on the system's reliability and survivability. The results of such an analysis are shown in Figure 7 for configuration #9 which contains the maximum number of components (see Figure 5). Four monotonically non-decreasing curves are shown; each one shows the Reliability/Survivability index RS as a function of one of the four probabilities: p, q for links and r,s for nodes. The results in Figure 7 confirm that node failures have a more pronounced effect than link failures, inasmuch as they reduce the RS index to a greater extent. Indeed, the values of the indices RS(p) and RS(q) are higher than the values of the underlying probabilities, i.e.,

$$RS(p) > p \quad ; \quad RS(q) > q$$

while the values of RS(r) and RS(s) are lower than or equal to the corresponding probabilities, i.e.,

$$RS(r) < r \quad ; \quad RS(s) = s.$$

6.5.2 Optimal Configuration

The determination of the optimal configuration depends on the values taken by the system and mission primitives. These primitives can be placed into three groups:

(a) Primitives whose values are dictated by the physical characteristics of the system or the context in which it operates (e.g., probabilities p, q, r, and s).
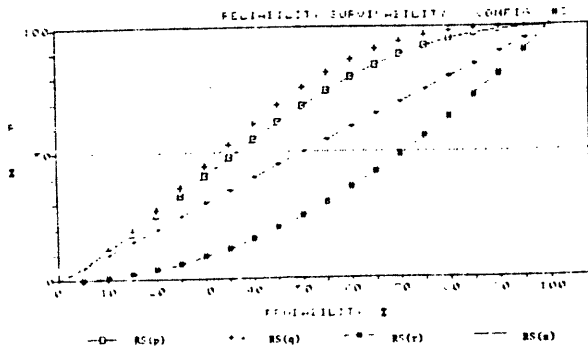
Figure 7. Reliability/Survivability Index
as a Function of its Primitives

(b) Primitives that reflect the utilities of the
participants in the demonstration. These include
the matrices Q_A, Q_B, and Q_C that appear in the
utility functions as well as the exponents α and
γ (see Eqs. (30), (32) and (34)).

(c) Primitives that depend on the analysts'
perception of the relative influence the various
participants have on the demonstration's outcome
and evaluation. The coefficients A, B, and C
used to construct the global utility function
belong to this group.

Parametric studies can be carried out for all
three categories of primitives. Since the effect of
the failure probabilities was already analyzed in
computing the RS index, the parametric studies were
focused on the exponents α and γ (when the Q matrices
are set equal to the identity matrix) and on the
coefficients A, B, and C.

Consider first the effect of the weighting
coefficients A, B, and C on the selection of the
optimal configuration. For simplicity, it was assumed
that B and C were equal. Then, since the sum of the
three coefficients must equal one,

$$B = C = (1-A)/2$$

The two other primitives, α and γ, were both set
at 0.5, while the Cost primitive, eq. (25), was set at
0.2. Then, coefficient A was varied from 0 to 1 in
increments of 0.05 and the procedure of determining
the optimal configuration was repeated. The results
are shown in Figure 8.

For very low values of A, the optimal
configuration is #1. This happens because at low
values of A, the preferences of group B and C are
amplified. Since the latter group is assumed to focus
on cost, the least costly configuration is considered
the most effective one for the demonstration. For
intermediate values of A, configurations #3 and #8
are, in turn, the optimal ones. For values of A that
are between 0.45 and 1.0, the optimal configuration is
#9 which is the one with the highest connectivity. In
this particular case, it is clear that for the given
primitives, configuration #9 is the most likely one to
maximize effectiveness, when there is so much
uncertainty about the relative weights on the
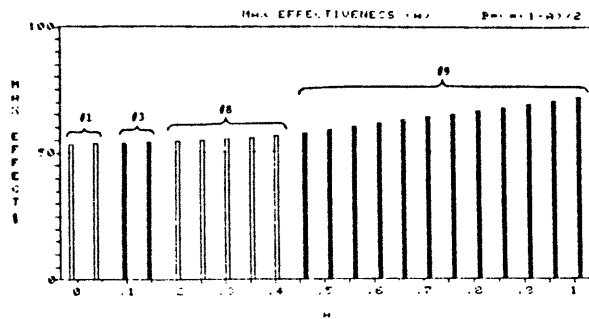utilities of the three participant groups.

Figure 8. Configuration that Maximizes Effectiveness
and Values of Maximum Effectiveness, as A
Varies from 0 to 1 ($\alpha=\gamma=0.5$; Cost = 0.2).

The next question that can be answered addresses
the robustness of the result. How sensitive is the
choice of configuration on the parameters of the
utility functions? This answer can be obtained easily
through a parametric study. The results of such a
study are shown in Figure 9, where, in addition to A,
the exponent γ in the cost term of utility u_C, eq.
(34), is allowed to vary. Throughout the study, α and
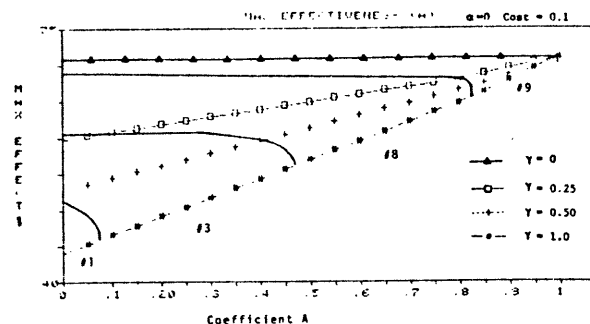Cost are fixed to 0 and 0.1, respectively.

Figure 9. The Effect of Weighting Cost in Utility
u_C on Maximum Effectiveness and the
Selection of Optimal Configuration, as A
Varies from 0 to 1.

For γ equal to unity, the value of maximum
effectiveness is low and the choice of optimal
configuration changes from low cost ones to higher
cost ones (from #1 to #3 to #8 to #9) as was also the
case in Figure 8. For γ equal to 0.5, the maximum
utility is higher for all values of A. However, the
lower cost configuration, #1, is not optimal any more
for any value of A. The sequence of optimal
configurations is #3, #8, and #9. For γ equal to
0.25, the optimal configuration is #8 for most values
of A; for very small values it is still #3 while

forhigh values it is #9. For γ equal to 0, configuration #9 is optimal for all values of A. From these results, it is possible to draw the boundaries that show the transition from one optimal configuration to another. This is done in Figure 9.

With such a representation that subsumes a whole sequence of results of the type shown in Figure 8, the designer can select with more confidence the configuration that will maximize the effectiveness of the demonstration, when there is uncertainty about the accuracy of the utilities and their relative weights. For example, if in early demonstrations the utility of groups B and C is not critical (low B and C), then configurations with large number of components will be selected. Furthermore, if cost of the system is not critical at the early stages but, rather, the feasibility of the mission is the key objective of the demonstration (γ very low), then configuration #9 will be the optimal one for all values of A.

7. CONCLUSION

A methodology for effectiveness analysis of an evolving system that will undergo a series of demonstrations has been presented. Part of the issue has been the design of the demonstration so that both the long term and short term missions are supported.

The approach requires the explicit specification of candidate technologies, the selection of candidate configurations, and the consideration of the utilities of the various groups involved in a demonstration. While the approach has been motivated by the development of METANET, the methodology is illustrated by a hypothetical network that includes heterogeneous components operating in a hostile environment. These first results are promising enough to warrant the further development of the methodology through application to a more realistic example.

8. REFERENCES

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