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EFFECTIVENESS ANALYSIS OF C^3 SYSTEMS*

by

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ABSTRACT

A methodology for analyzing and assessing the effectiveness of command, control and communications (C^3) systems is developed. The analysis is carried out by characterizing separately both the system and the mission in terms of attributes. These attributes are determined as functions of primitives that describe the system, the mission, and the context within which both operate. Then the system capabilities and the mission requirements are compared in a common attribute space. This comparison leads to the evaluation of partial measures of effectiveness which are then combined to yield a global measure. The methodology is illustrated through the assessment of the effectiveness of a communications network operating in a hostile environment.

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Abstract. A methodology for analyzing and assessing the effectiveness of command, control and communications (C^3) systems is developed. The analysis is carried out by characterizing separately both the system and the mission in terms of attributes. These attributes are determined as functions of primitives that describe the system, the mission, and the context within which both operate. Then the system capabilities and the mission requirements are compared in a common attribute space. This comparison leads to the evaluation of partial measures of effectiveness which are then combined to yield a global measure. The methodology is illustrated through the assessment of the effectiveness of a communications network operating in a hostile environment.

INTRODUCTION

System effectiveness is an elusive concept that encompasses technical, economic, and behavioral considerations. When the system to be evaluated is one which provides a service, such as a command, control and communications (C^3) system, then the needs of the organization that uses it must be taken into account. Furthermore, the worth of the service it provides may change in value as missions change, as technologies change and as the opponent's capabilities change. Thus, any methodology that is proposed for C^3 system effectiveness analysis must be sufficiently broad and flexible so that it can accommodate change and can evolve over time.

Such a methodology is proposed in this paper. The analytical aspects of the methodology address mainly the relationships between component characteristics, system structure, and operating procedures to system availability and performance. Availability is defined as a probabilistic quantity dependent on the random failure characteristics of system components (whether or not due to enemy action). System performance denotes the ability to achieve appropriate operational goals for a given availability state [Fink, 1980]. It is assumed that the cost associated with any system realization and operation can be computed: the total cost may reflect the costs for developing and implementing the system and the costs for operating and maintaining it. Finally, the assessment of worth is left for the final, and subjective stage of the methodology, since worth is a relative measure that involves value judgements [Dersin and Levis, 1981].

In analyzing the effectiveness of a C^3 system, it is essential that the diversity of users and types of services demanded be taken into account. Also, the tolerances associated with each system characteristic or attribute must be established so that the adequacy of the service provided by a given system realization can be evaluated.

The basic premise of the methodology is that a C^3 system provides a variety of services (or supports a variety of functions). The complementary premise is that each user imposes on a C^3 system a load which is generated from a need for service that the system may or may not be able to satisfy. Thus, on one side, there is the C^3 system with a range of capabilities for providing service, while on the other is the military organization with its diverse needs for service. Therefore, the first step of the methodology is based on the ability to model the system's capabilities and the organization's requirements in terms of commensurate attributes. This and the other steps in the methodology are described in the next section. In the third section, an illustrative example is presented.

SYSTEM EFFECTIVENESS ANALYSIS

The methodology outlined in this section is based on six concepts: *system, mission, context, primitives, attributes,* and *measures of effectiveness.* The first three describe the problem, while the last three define the key quantities in the analytical formulation of the problem.

The *system* consists of components, their interconnection and a set of operating procedures. A naval communications system, a computer network or a testbed are typical systems. The system can be centralized (e.g., a testbed facility) or decentralized (e.g., a computer network).

The *mission* consists of a set of objectives and tasks that the military organization is assigned to accomplish. The description of the mission must be as explicit and specific as possible so that it can be modeled analytically. For example, a mission specification such as "to defend the West Coast of the US" is too broad, while a more useful specification would be "to detect enemy submarines off the cost of California".

The *context* denotes the set of conditions and assumptions, i.e., the environment, within which the mission takes place and the system operates. For example, the context may include specification of the geographical area, the time of the year, and the prevailing set of international agreements.

Primitives are the variables and parameters that describe the system and the mission. For example, in the case of a communications network, primitives may include the number of links and nodes, the capacity of each link, and the probability of failure of each link. Primitives of a mission may be the designation of origin-destination pairs, the data flow rate between these points, and the duration of each transmission. Let the system primitives be denoted by the set $\{x_i\}$ and the mission primitives by the set $\{y_j\}$.

Attributes are quantities that describe system properties or mission requirements. System attributes for a communications system may include reliability, average delay, and survivability. Mission attributes are expressed as requirements for the same quantities as the system attributes, e.g., minimum reliability, maximum average delay, or minimum survivability. The system attributes are denoted by the set $\{A_s\}$ and the mission attributes by $\{A_m\}$.

Measures of Effectiveness are quantities that result from the comparison of the system and mission attributes. They reflect the extent to which the system is well matched to the mission.

These six concepts are the key components of the methodology for analyzing and assessing the effectiveness of C^3 systems.

The first step of the methodology consists of the selection of the set of system primitives. By definition, the elements of the set are mutually independent. In this sense, the primitives are the independent variables in the analytical formulation of the methodology.

The second step consists of defining attributes for the system that characterize the properties that are of interest in the analysis. The attributes are expressed as functions of the primitives. The values of the attributes could be obtained from the evaluation of a function, from a model, a computer simulation, or from empirical data. Each attribute depends, in general, on a subset of the primitives, i.e.,

$$A_s = f_s\ (x_i, \ldots, x_k) \tag{1}$$

Attributes may or may not be independent from each other. They are dependent, if they have primitives in common. A system realization results in the set of primitives taking specific values $\{\bar{x}_i\}$. Substitution of these values in the relationships (1) yields values for the attribute set $\{A_s\}$. Thus, any specific realization can be depicted by a point in the attribute space.

The third and fourth steps consist of carrying out a similar analysis for the mission: Selection of the primitives that describe the variables and parameters of the mission and definition of the mission requirements. Then models are selected that map the primitives y_j into the attributes:

$$A_m = f_m\ (y_j, \ldots, y_\ell) \tag{2}$$

Some of the mission attributes may be interrelated through dependence on common primitives. It is also possible to introduce directly some constraints between the attributes, e.g., a trade-off relationship between delay and accuracy. However, it is preferable that such trade-off relationships be derived through the functions or models that define attributes or requirements in terms of the mission primitives. Specification of values for the mission primitives results in a point or region in the mission attribute space.

The two spaces, the system attribute space $\mathcal{A}_s$ and the mission attribute space $\mathcal{A}_m$, although of the same dimension, may be defined in terms of different attributes, or attributes scaled differently. Therefore, the fifth step consists of transforming the system and mission attributes into a set of common, commensurate attributes that define a common attribute space $\mathcal{A}$. For example, one of the system attributes may be vulnerability, while the corresponding mission attribute may be survivability. Since they both reflect the same concept -- the effect of hostile actions -- one of them may be chosen as the common attribute, say, survivability, while the other one will then be mapped into the first one. Once the common set of attributes has been defined, the two sets $\{A_s\}$ and $\{A_m\}$ are transformed into commensurate sets that can be depicted in the common attribute space $\mathcal{A}$.

A possible additional operation in this step is the normalization of the various commensurate attributes so that their values are in the range [0,1]. If all the attributes are normalized in this manner, then the common attribute space is the unit hypercube. This is very useful in depicting graphically the loci of the sets $\{A_s\}$ and $\{A_m\}$ and in analyzing their interrelationships.

The sixth step is the key one in analyzing the effectiveness of a C^3 system in view of the mission that is to be carried out. It consists of procedures for comparing the system and mission attributes through the geometric properties of two loci in the attribute space. Consider first all the allowable values that the primitives of a specific realization of the system may take. If the primitives are allowed to vary over their admissible ranges, then the variations define a locus L_s in the attribute space. Similarly, a mission locus L_m can be constructed. Both loci are defined in the unit hypercube. The geometric relationship between the two loci can take one of three forms:

(a) The two loci do not have any points in common, i.e., the intersection of L_s with L_m is null:

$$L_s \cap L_m = \phi \tag{3}$$

In this case, the system attributes do not satisfy the mission's requirements and one would define the effectiveness to be zero, regardless of which specific measure is used.

(b) The two loci have points in common, but neither locus is included in the other:

$$L_s \cap L_m \neq \phi \tag{4}$$

and

$$L_s \cup L_m > L_s \tag{5}$$

In this case, a subset of the values that the system attributes may take satisfies the mission requirements. Many different measures can be used to describe the extent to which the system meets the requirements. Each of these measures may be considered as a measure of effectiveness which, if normalized, takes values in the open interval (0,1). For example, let V be a measure in the normalized attribute space. Then an effectiveness measure can be defined by

$$E = V(L_s \cap L_m)/V(L_s) \tag{6}$$

which emphasizes how well matched the system is to the mission.

(c) The mission locus is included in the system locus:

$$L_s \cap L_m = L_m \tag{7}$$

In this case, it follows from (7) that L_s is larger then L_m and, consequently, the ratio defined by (6) will be less than unity. This result can be interpreted in two ways. First, only certain system attributes values meet the requirements of the mission. This is consistent with the interpretation given in case (b). The second interpretation is that the use of this system for the given mission represents an inefficient use of resources since the system capabilities exceed the mission requirements. Inefficiency, in turn, implies lower effectiveness.

If the system locus is included in the mission locus, then the system's effectiveness is identically equal to unity.

The measure of effectiveness given by (6) is one of many partial measures that can be defined in the common attribute space. Let these partial measures be denoted by $\{E_r\}$. To combine these partial measures into a single global measure, utility theory may be used [Debreu, 1958; Phlips, 1974]. The k partial measures $E_1,\ldots,E_k$ are now considered to be the arguments of a utility function u. However, for the valid application of utility theory, the arguments of u must belong to the positive orthant of R^k, i.e., they should take values in $[0,+\infty)$. For this to happen, each E_r that takes values in [0,1) is mapped to an $\tilde{E}_r$ that takes values in $[0,+\infty)$. Many functions exist for transforming the bounded variables E_r to the unbounded ones; typical examples are

$$-\log(1-E)\ ;\ E/1-E\ ;\ \tanh^{-1}E$$

$$\tan(\pi E/2)\ ;\ E^{\alpha}/1-E^{\beta}$$

Each of these mappings tends to emphasize different segments of the range [0,1) and therefore weight in a different way the partial effectiveness measures E_r. Therefore, the subjective judgements of the system designers and the users can be incorporated directly into the methodology in three ways: (a) by choosing different partial measures, (b) by choosing the mapping function, and (c) by selecting a utility function. The global effectiveness measure is obtained, finally, from

$$\hat{E} = u\,(\tilde{E}_1,\tilde{E}_2,\ldots,\tilde{E}_k) \tag{8}$$

The seven steps of the methodology and their interrelationships are shown schematically in Figure 1. The diagram emphasizes that the system and the mission must be modeled and analyzed independently, but in a common context. The system capabilities should be determined independently of the mission and the mission requirements should be derived without considering the system to be assessed. Otherwise, the assessment is biased.

The methodology will be illustrated in the next section through application to a communications network operating in a hostile environment.

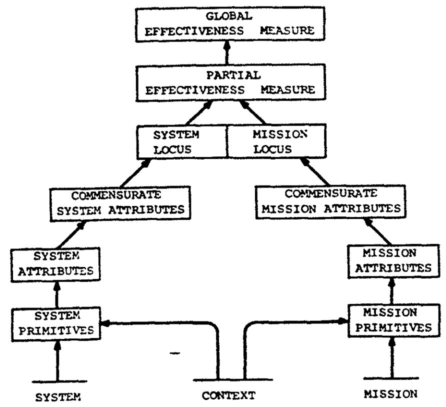

Figure 1. The Methodology for C^3 System Effectiveness Analysis

ASSESSMENT OF A C^3 NETWORK

Consider the communications network presented in Figure 2. It consists of seven nodes and thirteen links. The nodes represent information collection and transmission centers or decision centers or both. The network is assumed to be part of a C^3 system operating in a hostile environment. Specifically, it is assumed that the links are subject to jamming that disrupts communication between nodes. There are twenty-one possible origin-destination pairs in this network; only the pair (1,7) will be used because the subsystem it defines is equal to the whole network. Multiple pairs can be analyzed if each pair is considered as a subsystem.

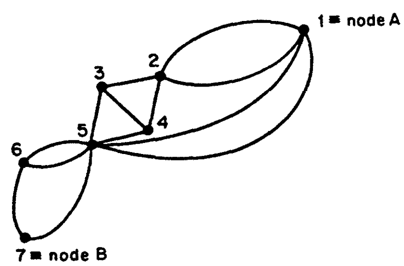

Figure 2. A Simple Communications Network.

The context for this network determines the environment in which the system will operate: geographical location, climatic conditions, enemy capabilities and resources. The context determines many of the primitives of both the system and the mission.

The mission is defined in terms of the objectives and tasks assigned to each node by the tactical plan. Let the aspect of the mission that is relevant to the pair (1,7), denoted by (A,B) from now on, be the collection of target information at node A and its transmission to node B where the weapon system is located.

Attributes

In one of the definitions of C^3 systems [AFM 1-1,1979] it is stated that "Command and control systems must provide the commander with communications networks that are reliable rapid, survivable and secure." The first three requirements motivated the definition of the attributes for this example: *reliability, time delay,* and *survivability.* A fourth one that characterizes the amount of information that can be transmitted between A and B is the *input flow.*

The attribute *Reliability* denotes the capability of the system to deliver a message from A to B when only the intrinsic, physical characteristics of the components (links) are taken into account. The relevant system primitive is the probability of failure, 1-p, of each link, where it is assumed that link failures are independent events. *Survivability* is defined as the ability of the network to continue functioning in the presence of jamming. The system survivability depends on the probability that the enemy attempts to jam a link (or links) and the probability that the link is jammed when attacked. Both reliability and survivability are special cases of availability. The distinction between reliability and survivability is that the former reflects the failure characteristic of components and the effect of the environment, while the latter models the effect on the network of the enemy's electronic warfare capability.

The attribute *Time Delay* introduces the notion of timeliness of the transmitted information and the rapidity with which it is transmitted. This attribute is critical because in many instances target acquisition by a weapon system depends on the speed with which tracking information is received from distant sensors. For this network, time delay between nodes A and B is defined as the sum of the delays in each link of a path from A to B. The time delay is related to the capacity of each link. Therefore, link capacity is a system primitive.

Input Flow is defined as the amount of data transmitted from A to B, The underlying assumption is that as more tracking data are collected and transmitted to the weapon system, the target acquisition is improved.

The input flow that can be transmitted depends on the link capacities and the network topology; it depends also on the time delay, i.e., there is an interrelationship between delay and flow.

Let the mission be the protection of platforms located at the network nodes by weapon systems located at node B, where the sensors are located in a platform denoted by node A. Therefore, the objective of the platform at A is to detect and identify enemy targets and communicate that information to the weapon systems. The objective of node B is to destroy at least m percent of the enemy targets while suffering no more than n percent losses. Therefore, mission primitives are the level of forces of the two opponents, the single shot kill probabilitites, the time interval between salvos, the radius of uncertainty in locating a target, and the relative velocity between the targets and the weapon systems. With these primitives, it is necessary to determine conditions on the attributes that will imply the success of the assigned mission. Now that the overall situation has been described, the seven steps of the methodology can be applied.

Step 1 and 2: System Attributes

Structural analysis models based on engineering reliability theory [Barlow and Proschan, 1975] and network theory [Ford and Fulkerson, 1962] can be used to model the reliability attribute and compute its value.

Let x_i be a binary variable indicating whether link i is functioning (x_i=1) or has failed (x_i=0). Similarly, the binary variable ϕ specifies the state of the communication between nodes A and B. If the state of the communication is determined completely by the state of the links, then

$$\phi = \phi(x_1,x_2,\ldots,x_{13}) \tag{9}$$

The function ϕ is called the structure function of the communication pair A,B. If p_i denotes the probability the link i is functioning, i.e.,

$$p_i = \text{prob } (x_i=1)$$

then the reliability index R is defined as the expected value of the structure function:

$$R = E\ [\phi(x_1,x_2,\ldots,x_{13})] \tag{10}$$

For simplicity, let all the link failure probabilities be equal. Then the reliability index for the pair A,B in the network defined in Figure 2 is given as follows:

$$R = h_{m_4}(p)\ [1-(1-h_{m_2}(p))(1-h_{m_1}(p)\ h_{m_3}(p))] \tag{11}$$

where

$$h_{m_1} = h_{m_2} = 1 - (1-p)^2$$

$$h_{m_3} = 2p^2 + 2p^3 - 5p^4 + 2p^5$$

$$h_{m_4} = 1 - (1-p^2(2-p)^2)\ (1-p).$$

The failure probabilities of the links are likely to vary with time. Since the p takes values in the interval [0,1], it follows that R, a continuous function defined on a closed set, takes minimum and maximum values. Furthermore, if p takes values in the subinterval [a,b] then R takes its minimum value R_{min} for p=a and its maximum R_{max} for p=b. Therefore, the reliability index R in eq. (11) is an increasing function of its argument p. If the bounds a and b are known, then the system reliability is bounded by

$$R_{min} \le R \le R_{max} \tag{12}$$

While survivability depends on totally different primitives, the analysis is identical with that for reliability, but with the probability p replaced by

$$1 - e_i q_i$$

where e_i is the probability that the enemy attacks link i and q_i is the probability that link i is jammed when attacked. If the probability of survival of a link takes values in the interval [a',b'], it follows that the survivability index is bounded as follows:

$$S_{min} \le S \le S_{max} \tag{13}$$

Queueing theory is used to model the time delay in the communications network. Specifically, the M/M/1 model [Schwartz, 1977] was used to determine the delay in transmitting packets from A to B. Let the capacity of each link in the network of Figure 2 be denoted by C_k, with k = 1,2,...,13. There are thirty different paths that can be chosen to transmit a packet from A to B and, therefore, thirty time delays, one for each path, can be computed. If path π_j is chosen, then the total delay along this path is [Bouthonnier, 1982]

$$T_{\pi_j} = \sum_{C_k \in \pi_j} \frac{1}{\mu C_k - F} \tag{14}$$

where $1/\mu$ is the mean number of bits per packet and F is the input flow from A to B. Clearly, there will be a minimum and maximum delay over the thirty paths. So, depending on the routing algorithm chosen, the delay T may be bounded as follows:

$$T_{min} \le T \le T_{max} \tag{15}$$

Now let all the link capacities be equal to C and let C vary between C_{min} and C_{max}. Then, for the network of Figure 2, the total delay from A to B satisfies [Bouthonnier, 1982]:

$$\frac{2}{\mu\ C_{max} - F} \leq T \leq \frac{6}{\mu\ C_{min} - F} \quad (16)$$

The last condition relates two of the attributes, *Time Delay* and *Input Flow*. In order to normalize these attributes so that they vary between 0 and 1, the following scaling factors are introduced:

$$T^* = \text{maximum duration of mission}$$

$$F^* = \mu\ C_{max} \quad (17)$$

Then the normalized attributes are

$$t = T/T^* \quad (18)$$

and

$$K = F/F^* \quad (19)$$

and relation (16) takes the form

$$\frac{2/T^*F^*}{1-k} \leq t \leq \frac{6/T^*F^*}{\frac{C_{min}}{C_{max}} - K} \quad (20)$$

Thus, inequalities (13), (14), and (20) define the system locus L_s in the four-dimensional unit hypercube.

Steps 3 and 4: Mission Attributes

Let x(t) denote the number of blue forces and y(t) the number of red forces. The desirable conditions for blue are that at the end of the mission (at time T^*),

$$x(T^*)/x(0) \geq n \quad (21)$$

$$y(T^*)/y(0) \leq m \quad (22)$$

where n and m are positive numbers in the interval [0,1). A model is needed that describes the engagement. For this example, the Lanchester combat model that describes the "salvo fire" engagement was chosen for its simplicity rather than its realistic depiction of naval engagements. War games or extensive simulations could be used to analyze the mission in some detail and obtain realistic estimates of the requirements.

In the "salvo fire" engagement model each blue (red) unit fires every t_x (resp. t_y) time units at random at red (blue) units. Let p_x(p_y) be the single shot probability of kill of a red (blue) unit by a blue (red) unit. If the single shot probabilities are small [Mangulis, 1980] then the Lanchester model reduces to

$$\dot{x} = -(p_y/t_y)\ y = -ay \quad (23)$$

$$\dot{y} = -(p_x/t_x)\ x = -bx \quad (24)$$

where the ratios of the kill probability to the interval between salvos denote the attrition rates a and b, respectively.

Solution of the differential equations (23), (24) leads to the "square-law" attrition process:

$$ay^2(t) - b\,x^2(t) = ay^2(0) - bx^2(0) \quad (25)$$

Substitution of conditions (21) and (22) in (25) yields a condition on the attrition rates:

$$\frac{b}{a} \geq \frac{1-m^2}{1-n^2}\ \frac{y^2(0)}{x^2(0)} \quad (26)$$

The attrition rate b was defined in (24) as p_x/t_x. Let r be the kill radius of blue's weapon system and let ρ denote the radius of uncertainty in locating red targets. Then

$$p_x = \pi r^2/\pi\rho^2 \quad (27)$$

The value of ρ depends not only on the surveillance systems, but also on the ability of the network to transmit surveillance data about a moving target accurately and quickly to node B. The radius of uncertainty is assumed to be given by the following function of S,R,F, and T:

$$\rho = \frac{2}{S+R}\ [10c(1-.9F) + vT] \quad (28)$$

where c is the radius of uncertainty due to the surveillance system alone and v is the relative speed to the red target.

Introduction of the normalized variables K and t, substitution of (27) and (28) in (26), and some algebraic manipulations yield the following requirement for the mission attributes:

$$S + R + c_1K - c_2t > c_3 \quad (29)$$

where c_1, c_2, and c_3 are coefficients dependent on a,m,n,c,T*,F*,x(0) and y(0).

The mission locus, L_m, is defined then as the portion of the four-dimensional unit hypercube bounded by the hyperplane (29).

Step 5: The System and Mission Loci

In the previous four steps, the inequalities defining the two loci were derived. Numerical values must be selected now so that the loci can be specified completely and the assessment of effectiveness carried out.

Let the probability of a link failing, 1-p, range from 0.607 to 0.630 and let the probability that a link will be jammed vary over the same range. Then, inequalities (12) and (13) become:

$$0.4 \leq R \leq 0.45 \quad (30)$$

$$0.4 \leq S \leq 0.45 \quad (31)$$

while (20) becomes

$$\frac{0.1}{1-k} \leq t \leq \frac{0.3}{0.7-k} \quad (32)$$

for T* F* =5 and C_{min}/C_{max} =0.7. Analysis of (32) shows that

$$0.1 \leq t \leq 1$$

and

$$0 \leq K \leq 0.9,$$

i.e., the normalized delay is at least 0.1 and the input flow cannot exceed 0.9. The locus L_s is depicted graphically in terms of three three-dimensional projections, Figs. 3, 4, and 5. In the third figure the unspecified axis is either S or R.

The mission locus, L_m, is defined by the inequality

$$S + R + K - t > 1$$

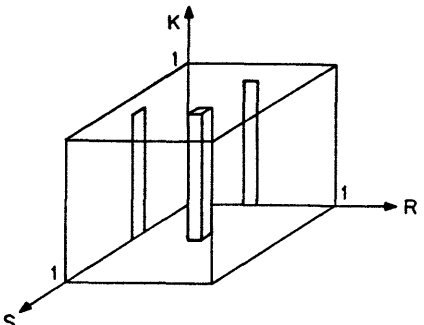

Fig. 3. Projection of L_s in (S,R,K) Space

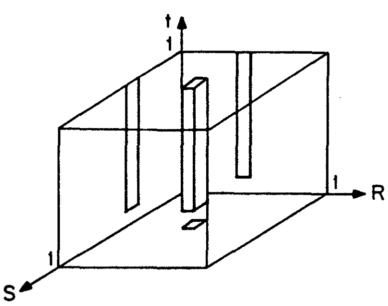

Fig. 4. Projection of L_s in (S,R,t) Space

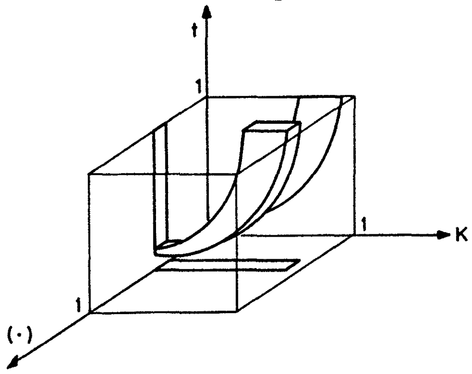

Fig. 5 Projection of L_s in (S,K,t) or (R,K,t) Space

where the coefficients c_1, c_2, and c_3 have been set equal to unity. The interrelationship between the system and the mission loci is shown in Figures 6, 7, and 8. Clearly, the two loci represent solids in four-dimensional space and, furthermore, the two solids intersect.

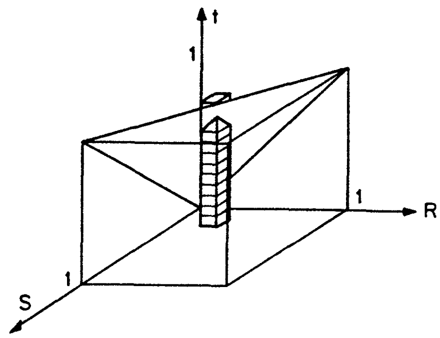

Fig. 6. Intersection of L_s and L_m in (S,R,t) Space

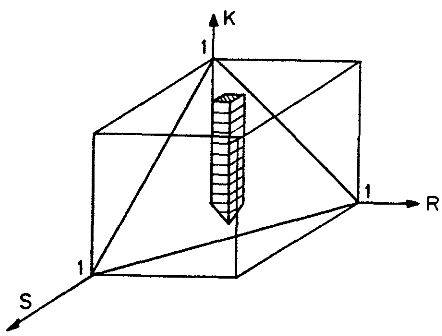

Fig. 7. Intersection of L_s and L_m in (S,R,K) Space

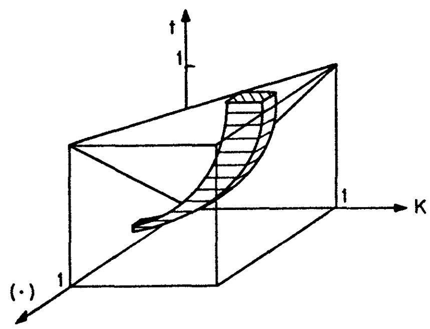

Fig. 8. Intersection of L_s and L_m in (S,K,t) or (R,K,t) Space

<u>Step 6</u>: Effectiveness Measures

Many different measures may be used to evaluate and compare the system and the mission locus. Let the first one considered be the volume:

$$V_1 = \iiiint dS\, dR\, dK\, dt$$

Then, the volume of the system locus can be computed analytically

$$V_1(L_s) = 0.131 \times 10^{-2}$$

The volume of the intersection of the system and mission loci can also be computed analytically

$$V_1(L_s \cap V_t) = 0.201 \times 10^{-3}$$

A class of measures based on volumetric comparisons is one defined by

$$V_2=\int\int\int\int w(S,R,K,t)\ dS\ dR\ dK\ dt$$

Let

$$w(S,R,K,t) = (S+R)\ \bar{K}$$

Then the system locus measure can be computed analytically

$$V_2(L_s) = 0.516 \times 10^{-3}$$

while the measure of the intersection is computed numerically

$$V_2(L_s \cap L_m) = 0.106 \times 10^{-3}$$

The partial measures of effectiveness are computed according to eq. (6):

$$E_1 = \frac{0.201 \times 10^{-3}}{0.131 \times 10^{-2}} = 0.15$$

$$E_2 = \frac{0.106 \times 10^{-3}}{0.516 \times 10^{-3}} = 0.205$$

Step 7: Systems Effectiveness

The two partial measures, E_1 and E_2, can be combined into a global measure of system effectiveness. First, however, the measures E_i should be mapped to the measures $\tilde{E}_i$ that range from zero to infinity. The function used is

$$\tilde{E} = \tan \frac{\pi}{2}\ E$$

Then

$$\tilde{E}_1 = 0.24 \quad ; \quad \tilde{E}_2 = 0.333$$

Finally, for the utility function

$$\hat{E} = A \cdot \tilde{E}_1^{\alpha_1} \cdot \tilde{E}_2^{\alpha_2}$$

with $A = 1$, $\alpha_1 = 0.5$, and $\alpha_2 = 0.5$, the global measure takes the value

$$\hat{E} = 0.283$$

Thus, all steps of the methodology were carried out and a measure of effectiveness for the specific communications network has been determined. If an alternative network is proposed, then the methodology can be applied to the second network and a measure of effectiveness obtained. Comparison between the two networks using the effectiveness measures (as well as the attributes) would be straightforward because both the attributes and the measures of effectiveness are commensurate.

CONCLUSIONS

A new approach for assessing the effectiveness of C^3 systems has been presented. The key idea is to relate, in a quantitative way, the capabilities of a C^3 system to the requirements of the mission(s) that the military unit or organization has been assigned to execute. Each step of the methodology (specification of system and mission primitives, definition of attributes, modeling the system and the mission, constructing the two loci) brings into sharper focus qualitative information on what the system is intended to do, where it is intended to be used, and how it is intended to be used. Posing and addressing these questions is essential for assessing C^3 systems which are complex, often large scale, service delivery systems.

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