THE SPECIFICATION AND SELECTION OF MILITARY INFORMATION PROCESSING SYSTEMS

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Introduction

Military information processing systems often involve inordinate and unnecessary expenditures on the part of both industry and the military. On the one hand, industry frequently invests heavily in preparing what they consider to be realistic and competitive responses to REQUEST FOR PROPOSALS (RFPs) only to find that much of their time, effort, and funds have been wasted. Poorly specified performance and operational requirements in the RFP (resulting from virtually no requirements analysis), and the uncertain selection methods, frequently make the subsequent awards seem arbitrarily determined. On the other hand, following the contract award the military often expends much greater funds than initially programmed because of contract modifications resulting from greatly changed requirements—differences between the requirements as stated in the initial specifications and those that the system is ultimately expected to meet. In extreme cases the fabrication of the system may be nearly completed before the actual system requirements are determined.

Although many of the effects and a major part of the problem results from the near failure of industry and the scientific community to provide acceptable characterizing functions and performance measures for large or medium scale information processing systems, a major part of the problem stems from the failure of the military to perform or attempt a requirement analysis with available techniques, even though imperfect. Our immediate concern and the main orientation of our discussion is toward the latter aspects of this joint problem; accordingly, we place emphasis on the fact that in attempting to describe what is actually desired from (or goes into) the information processing system, the document called SPECIFICATIONS rarely, if ever, contains a sufficient enumeration of the particulars to define the requirements for the system.

The origins of many large scale military information processing systems often can be traced back, at least in part, to earlier systems initially mechanized by a variety of special purpose equipments, or "black boxes," which were generally designed to execute explicit functions with certain performance standards in a given operational environment. Because many systems of an earlier time period essentially were assembled without current techniques such as found in systems engineering, operations analysis, and cost-effectiveness studies, any interconnection of black boxes and people that could (usually) economically increase the capability of the military to perform its mission was generally acceptable. However, more recent analysis and synthesis techniques associated with the above-mentioned fields and others, notably that of computer design and programming, have brought about some (and offer even more) significant increases in the capability (and complexity) of military information processing systems. There has been at least one major consequence universally accepted in principle although not always practiced. This is the integrated systems design approach as opposed to a never ending series of ad hoc or quick fixes to modernize outmoded systems.

The improvements to be gained by the systems approach are, however, not without some special and difficult problems. A cardinal problem—the specification of the military information processing system—provides the central theme of this discussion. Even a general discussion of this important problem involves great difficulties since a complete characterization would suggest that there is some generally accepted and unambiguous usage of terms. Unfortunately, such is not the case. The authors have found, both in discussions with their colleagues and in examining some system specifications, that there are frequent occasions when operational requirements are almost inextricably intertwined with either performance or functional requirements, or both. Consequently, we attempt to clarify some commonly used and misused terminology to aid in providing an adequate characterization of the problem of specifying the system.

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The problem of selecting the system is clearly bound up with the problem of specifying the system. Cost-effectiveness analysis can provide a general methodology for optimal selection of some systems under certain constraints. However, such analysis is heavily dependent upon the knowledge and availability of performance measures and costs that can be quantified. The major obstacles to accruing this knowledge are noted and some methods of circumventing them (as an expedient only) will be discussed.

The Nature of the Specification Problem

The spectrum of military information processing systems very nearly covers the entire range of military systems. It includes command and control systems (both strategic and tactical), logistics systems, reconnaissance systems, intelligence systems, some types of weapon systems, and certain other types of systems. It is reasonable to hope that as the body of knowledge of the information sciences grows, some growth can be achieved in military science. In this regard it should be noted from past experience in other fields that the introduction of data processing and digital computer technology into a new field, causes a concentration of personnel, experience, and talent in the related information sciences which usually brings a greater formalism to that field. This results in a better understanding of many aspects of the field and usually helps produce significant improvements.

However, it may be unrealistic to expect relative parity in growth between the military and information sciences. Growth of knowledge in most scientific areas is largely the result of experiments and operational experience. The multifarious activities of industry, science, and business can be considered as complementary areas increasing the base of the information sciences. Military science has, unfortunately, the combat environment as its principal laboratory in which further factual knowledge is gathered, although large-scale computer simulations show good promise of providing a similar kind of knowledge in a much healthier environment. However, the relative increase of knowledge of one branch of science over another should not impose greater problems than those with which we are currently faced, if we can get over the hurdle of establishing a common basis for specifying the requirements for a military information processing system. We will not attempt to conjecture on the magnitude of the problem to be faced in the future if we postpone the effort to establish this basis for specifying systems that will be even more sophisticated than those that are currently required.

The nature of the difficulty can best be described as a peculiar combination of two extremes of problem definition. On the one hand, there is often an explicit description of the functions to be executed by a number of black boxes with certain performance standards. On the other hand, there is usually a vague, if any, description of the operational concept and requirements for the overall system. The best that can be expected from such a specification is optimized sub-system design because of the fairly well defined black box elements of the system. However, sub-optimization might not even result in satisfactory overall system performance. In spite of this possible consequence, proposals are still requested, submitted, and accepted on the basis of partial systems configurations of various black boxes even though both the military user and the industrial contractor are often painfully aware of the existing deficiencies of our current methods of specification.

Although there may be several other approaches to deriving system specifications that are of sufficient importance to be noted, we will briefly consider only two alternative approaches here, in addition to the approach we advocate, since a more comprehensive discussion of possibilities is beyond the scope or the intent of this paper. Furthermore, these two will provide sufficient contrast for the approach that we advocate. The first approach is the determination of system specifications as a result of a study contract awarded explicitly for that purpose. This has some merit since it generally involves a great deal of interaction between the military and industry in the performance of the study and its essential objective is the elimination of non-coherent specifications—the central theme of our discussion. Such an approach might be the most efficient current method to help achieve a realistic implementation goal, particularly if the study results should reveal blind development alleys which might have been undetected otherwise.

The second approach essentially amounts to determining the requirements of the system as the initial phase of an implementation contract. Although in many instances this phase of the contract is not so obviously stated, the necessity of such a phase is sometimes evident by virtue of the technically vague and often contextual descriptions of the tasks the system is required to perform to achieve its objectives. These instances are not actually characterized by imperfect specifications since they are not spelled out. For this type of contract the military designates a particular organization as a preferred prime systems contractor because of directly related experience, demonstrated capability, and past performance not readily available elsewhere.

It seems unlikely that procurement processes will be changed to the extent that all, or even many, of the future military information processing systems will be specified from requirements derived directly as a result of study contracts awarded for that purpose. Furthermore, it seems to us that such a course of action would be self-defeating in the long run, even though meritorious in some instances, since it does not lend itself to the most effective concentration of manpower and capabilities. A similar argument against the second approach (including a specification phase in an overall contract) can also be made.

The approach we advocate is for the military to specify their requirements. The military should always be in the best position to examine and continually analyze the requirements imposed on the system by the operational uses for which it is intended and the organizational and environmental structure within which it will be operated. The corollary is for industry to concentrate its manpower and capabilities in the area in which it is best qualified—systems, hardware, and software design. This is not to say that the military should not or does not have competent systems designers nor that industry should not or does not have competent military operations analysts. Such complementary capabilities are useful to help promote greater cooperation and understanding of each other's problems. However, it must be emphasized that as the user, the military is in the best position to know, or to be able to ascertain, the detailed requirements that the system must meet; likewise industry, as the designer and manufacturer, is in the best position to determine how to convert these requirements into hardware and software.

Operational, Performance, and Functional Requirements

The requirements that a system must meet can be divided into three major categories that we will call operational requirements, performance requirements, and functional requirements. If we accept the definition that performance embodies the notion that one or more functions are carried out to completion, without undue regard to quality or relative standards for individual functions, we can reduce the number of categories of requirements that a system must meet and only consider the performance requirements and operational requirements.

The performance requirements are those that determine what a system must be capable of doing—i.e., what characteristic tasks it should perform. For an information processing system, these can be stated broadly in terms of the information available to the system, the outputs that the system must generate from the available inputs, and the response time required and/or delay times permitted, but they should not be concerned with the internal machine functions to be executed; i.e., the information transfer functions. The operational requirements are those that determine the conditions, restrictions, and limitations which are imposed on the system or under which it must operate while meeting its performance requirements. They determine the operating methods and conditions such as mobility, ruggedness, environment (temperature, humidity, dust), shock, vibration, weight, size, electromagnetic interference, radiation resistance, vulnerability, survivability, maintainability, logistics support, and personnel training and qualifications. Cost, of course, is a subject now recognized as essentially related to system effectiveness or capability.

Performance and operational requirements can be considered separately although the operational requirements will usually have some effect on the ability of a particular hardware mechanization of a system to meet its performance requirements. Basically, a first cut at the (paper) system design should be based on the performance requirements keeping in mind insofar as possible the operational requirements. After this phase of the system design has been completed, the operational requirements should then be superimposed on the hypothetical system making compromises and modifying the design where necessary. In some cases, several iterations of a preliminary design relating performance requirements and operational requirements may be necessary.

Some further aspects of performance requirements will be discussed next, keeping in mind that the resulting preliminary system design will probably be modified by operational requirements.

Performance Requirements

The performance requirements of an information processing system can be and should be completely defined by listing the following factors:

- All of the available inputs.
- All of the required outputs.
- The response times and/or delay times permissible for the execution of functions in each case.

In listing the inputs and outputs it is not sufficient to identify them by function name only. Each input and output should be specified in as much detail as possible depending upon the knowledge of the system interface requirements. Whenever possible this information should be in terms of the number of characters, digits, or bits involved, the volume, the rate, the priority or significance, the accuracy and precision, and the frequency of occurrence of each item. Additionally a detailed breakdown of items into subitems down to the smallest unit of input/output information for the system should be stated. This is the kind of information that should be determined by the military from a detailed requirements analysis and then specified in the request for proposal as the requirements for the system. Note that none of the details of the internal information processing is included. It should be the bidders', and ultimately the contractor's, choice to determine the best way to generate the required outputs from the available inputs. In an information processing system, this is the core of the systems design problem and is one that frequently can be handled in a number of different ways.

As noted above, the system design problem is largely that of determining how to generate the required outputs in the given time frame from whatever input information is available. It is therefore necessary to relate the items of output information to the items of input information from which they are derived or, in engineering parlance, derive the transfer functions. A subsidiary, but nonetheless major, step of the design problem is to determine the number and types of equipment or black boxes required, how they are organized within the system, and what sub-set of functions each must perform. This information will help determine the input/output equipments required, the file storage capabilities required, the internal storage requirements, the functions that must be performed by the computers or data processors, the internal speeds required, the communications between equipments, the multiplexing and time sharing requirements, and most of the other functions that will help to identify each unit of equipment in the system and consequently specify its detailed characteristics and capabilities.

There are usually many alternative system configurations that might meet the performance requirements. The selection of the various combinations of these tasks and equipments should be left to the bidders with the military reviewers and evaluators determining which configurations satisfy the performance standards required. The final determination of system configuration would be the responsibility of the system contractor with the approval of the military user. Such procedures will encourage industry to exercise its initiative and capabilities without feeling that it is required to conform to some initially specified and perhaps arbitrary system organization. The military will reap the benefit of alternative system concepts from which they can select the one that best meets their requirements consistent with either a budget or capability criterion.

Operational Requirements

Once a first cut has been made at the system organization and configuration to meet the performance requirements, the operational requirements can be imposed on a conceptual system design to effect the modifications and compromises where necessary.

At this step some trade-offs between performance and operational capability might be required. For example, mobility may require a different modular breakdown of equipments or a different type of mass memory; environmental conditions may require a different type of internal memory or input/output unit; electro-magnetic interference and vulnerability may impose limitations on the transfer of data between physically separated units; maintainability and personnel training may require automatic trouble location techniques and a greater standardization of basic modules; and survivability may require dispersion of the system into physically separated modules with a capability for degraded performance following the loss of any unit. After the military has specified the operational requirements imposed by the uses to which the system is to be put and the conditions under which it must operate, industry should determine how to meet these operational requirements while maintaining the ability to meet the performance requirements.

In some cases it will be found at this stage of design that the state-of-the-art is such that both the performance and operational requirements cannot be met without making some sacrifices in one or the other, although (hopefully) some trade-off might be made between them. The question of whether or not to attempt advanced development (improve the state-of-the-art) should be clearly asked and unequivocally answered. If not, at this point the systems contractor should provide the military with a sensible set of performance measures, and perhaps a like set of operational effectiveness measures, so that the military customer could exercise his judgment in the selection of those trade-offs he deems desirable by the system design and configuration. In principle, the existence of a set of alternative system choices with appropriate and commensurable performance and operational effectiveness measures can provide both the military and industry with a powerful tool for system selection known as cost-effectiveness, which will be considered further in the following section.

The systems contractor should recommend trade-offs between performance or operational specifications that are primarily to permit an efficient mechanization of the system, and the military should be able to determine whether these trade-offs are acceptable or specify alternate ones where they are not acceptable. To a large extent, the successful design of a system (i.e., one which is capable of accomplishing the main purposes for which it was intended) is frequently a matter of making the proper compromises between the performance and operational requirements as embodied in the system design. Both the military and the systems contractor have a great stake in this and each can best contribute in his own area.

Cost-Effectiveness Analysis: A Method for System Selection

It was noted above that the method by which a system might be fairly and objectively selected would be a cost-effectiveness analysis. This kind of analysis assumes that knowledge of two major factors associated with the system are available or can be determined. These factors are:

- o The system performance and operational effectiveness measures.
- o The total system costs, which of necessity includes the operational and maintenance costs.

The basis of selection could be established by this method using one of two approaches depending upon the circumstances.*

The first approach assumes a fixed budget, hence the total system costs are constrained. The system is then selected by choosing the one which maximizes the system performance (or effectiveness) without exceeding the cost constraint. The second approach assumes some fixed level of operational effectiveness that must be achieved. For this method, the selection scheme is to choose the system that achieves the desired effectiveness with a minimum of system costs. Under certain circumstances, these criteria are essentially equivalent. This selection of one or the other approach is generally dependent upon the ease of analysis, the available information, and the intended use for the analytical results.

It is not our intention to present an exposition of the merits and methodology of cost-effectiveness analysis; this topic is treated admirably elsewhere. However, it is our intention to point out that this technique, which can be of immense value to both the military and industry, is not yet of particular use for the selection of military information processing systems, or, for that matter, for many other kinds of information processing systems. A major obstacle is the current lack of good methods for characterizing the functions and performance of information processing systems.

It is of extreme importance to emphasize the distinction between characterizing functions and establishing performance measures for information processing systems on the one hand, and of analyzing and specifying the requirements for the objectives and mission of the system on the other hand. It follows logically, from the observed results of some sciences as applied in other fields as well as from what we have said previously, that the former tasks (characterizing functions and establishing performance measures) are mainly the responsibility of industry and the scientific community and the latter tasks (analysis and specification of the requirements for the objectives and mission) are the responsibility of the military.

The lack of good performance measures and characterizing functions for data processing systems is not only an obstacle to the economic selection of information processing systems, but it is a significant impediment to an adequate dialogue between designers and users. The prolonged existence of semantic ambiguity in this field might offer some a slight advantage in brochuremanship, but it is a definite disservice to the joint endeavors of industry and the military as a whole.

Even though there is little in the way of an adequate language, and performance measures and characterizing functions to help establish criteria for system selection are virtually nonexistent, one should not conclude that the situation is completely hopeless. There are some reasonable steps that can be taken to insure that there is at least an awareness of some of the factors that might be taken into account in selecting a system. For example, if there is some critical time scale for design and fabrication of the system the military should make these facts known. The need for the system to evolve in accordance with some current or future specifications might be very important and could have significant effect on the design and consequently the costs. The number of total systems that are involved is an obvious factor of great importance, but the commonality

*The reader will find an excellent exposition of this topic in C. J. Hitch and R. N. McKean, "The Economics of Defense in the Nuclear Age," The RAND Corporation, R-346, March 1960, p. 175.

of the operational requirements for all units and the number and kind of specific differences for specific numbers of units is also of importance. These and other factors can have a significant impact on both the costs and efficiency of the system. Because of these considerations and others previously noted it is of the utmost importance that the military provide industry with their most accurate appraisals of the operation and performance requirements for the system.

Concluding Remarks

The military and industry jointly and separately have important jobs to perform in the specification and selection of military information processing systems. Each should attempt to accomplish those tasks for which it is best suited. The military, as the user and customer, should concentrate on the requirements analysis in order to determine both the detailed performance and operational requirements that the proposed system must meet. Specifications, partially in terms of equipment and their characteristics, and partially in terms of the operational environment, are an inadequate substitute for a requirements analysis. Conversely, industry should concentrate on designing a system to generate the required outputs from the available inputs within the given time constraints while meeting the operational requirements.

A proper and adequate requirements analysis performed by the military might also help eliminate industry's sometimes inadvertent attempts to reorganize the military or attempt to redirect their assigned mission in order to bring into consonance their view of the requirements and objectives of the systems design.