

and procedurally rational behavior. Among the limits to rationality are the fact that we can formulate, analyze, and interpret only a restricted amount of information; can devote only a limited amount of time to decision-making; and can become involved in many more activities than we can effectively consider and cope with simultaneously. We must therefore necessarily focus attention only on a portion of the major competing concerns. The direct effect of these is the presence of cognitive bias in information acquisition and processing and the use of cognitive heuristics for evaluation of alternatives.

Although in many cases these cognitive heuristics will be flawed, this is not necessarily so. One of the hoped-for results of the use of systems engineering approaches is the development of effective and efficient heuristics for enhanced judgment and choice through effective decision support systems.³⁰

There are many cognitive biases prevalent in most information-acquisition activities. The use of cognitive heuristics and decision rules is also prevalent and necessary to enable us to cope with the many demands on our time. One such heuristic is satisfying or searching for a solution that is "good enough." This may be quite appropriate if the stakes are small. In general, the quality of cognitive heuristics will be task-dependent, and often the use of heuristics for evaluation will be both reasonable and appropriate. Rational decision-making requires time, skill, wisdom, and other resources. It must, therefore, be reserved for the more important decisions. A goal of systems engineering is to enhance information acquisition, processing, and evaluation so that efficient and effective use of information is made in a process that is appropriate to the cognitive styles and time constraints of management.

26.5 SYSTEM DESIGN

This section discusses several topics relevant to the design and evaluation of systems. In order to develop our design methodology, we first discuss the purpose and objectives of systems engineering and systems design. Development of performance objectives for quality systems is important, since evaluation of the logical soundness and performance of a system can be determined by measuring achievement of these objectives with and without the system. A discussion of general objectives for quality system design is followed by a presentation of a five-phase design methodology for system design. The section continues with leadership and training requirements for use of the resulting system and the impact of these requirements upon design considerations. While it is doubtless true that not every design process should, could, or would precisely follow each component in the detailed phases outlined here, we feel that this approach to systems design is sufficiently robust and generic that it can be used as a normative model of the design process and as a guide to the structuring and implementation of appropriate systems evaluation practices.

26.5.1 The Purposes of Systems Design

Contemporary issues that may result in the need for systems design are invariably complex. They typically involve a number of competing concerns, contain much uncertainty, and require expertise from a number of disparate disciplines for resolution. Thus, it is not surprising that intuitive and affective judgments, often based on incomplete data, form the usual basis used for contemporary design and associated choice-making. At the other extreme of the cognitive inquiry scale are the highly analytical, theoretical, and experimental approaches of the mathematical, physical, and engineering sciences. When intuitive judgment is skill-based, it is generally effective and appropriate. One of the major challenges in system design engineering is to develop processes that are appropriate for a variety of process users, some of whom may approach the design issue from a skill-based perspective, some from a rule-based perspective, and some from a knowledge-based perspective.

A central purpose of systems engineering and management is to incorporate appropriate methods and metrics into a methodology for problem solving, or a systems engineering process or life cycle, such that, when it is associated with human judgment through systems management, it results in a high-quality systems design procedure. By high-quality design, we mean one that will, with high probability, produce a system that is effective and efficient.

A systems design procedure must be specifically related to the operational environment for which the final system is intended. Control group testing and evaluation may serve many useful purposes with respect to determination of many aspects of algorithmic and behavioral efficacy of a system. Ultimate effectiveness involves user acceptability of the resulting system, and evaluation of this process effectiveness will often involve testing and evaluation in the environment, or at least a closely simulated model of the environment, in which the system would be potentially deployed.

The potential benefits of systems engineering approaches to design can be interpreted as attributes or criteria for evaluation of the design approach itself. Achievement of many of these attributes may often not be experimentally measured except by inference, anecdotal, or testimonial and case study evidence taken in the operational environment for which the system is designed. Explicit evaluation of attribute achievement is a very important part of the overall systemic design process. This section describes the following:

1. A methodological framework for the design of systems, such as planning and decision support systems

2. An evaluation methodology that may be incorporated with or used independently of the design framework

A number of characteristics of effective systems efforts can be identified. These form the basis for determining the attributes of systems and systemic design procedures. Some of these attributes will be more important for a given environment than others. Effective design must typically include an operational evaluation component that will consider the strong interaction between the system and the situational issues that led to the systems design requirement. This operational evaluation is needed in order to determine whether a product system or a service consisting of humans and machines

1. Is logically sound
2. Is matched to the operational and organizational situation and environment extant
3. Supports a variety of cognitive skills, styles, and knowledge of the humans who must use the system
4. Assists users of the system to develop and use their own cognitive skills, styles, and knowledge
5. Is sufficiently flexible to allow use and adaptation by users with differing cognitive skills, styles, and knowledge
6. Encourages more effective solution of unstructured and unfamiliar issues, allowing the application of job-specific experiences in a way compatible with various acceptability constraints
7. Promotes effective long-term management

It is certainly possible that the product, or system, that results from a systems engineering effort may be used as a process or life cycle in some other application. Thus, what we have to say here refers both to the design of products and to the design of processes.

26.5.2 Operational Environments and Decision Situation Models

In order to develop robust scenarios of planning and design situations in various operational environments, and specific instruments for evaluation, we first identify a mathematical and situational taxonomy of

- Algorithmic constructs used in systemic design
- Performance objectives for quality design
- Operational environments for design

One of the initial goals in systems design engineering is to obtain the conceptual specifications for a product such that development of the system will be based on customer or client information, objectives, and existing situations and needs. An aid to the process of design should assist in or support the evaluation of alternatives relative to some criteria. It is generally necessary that design information be described in ways that lead to effective structuring of the design problem. Of equal importance is the need to be aware of the role of the affective in design tasks such as to support different cognitive styles and needs, which vary from formal knowledge-based to rule-based to skill-based behavior.³¹ We desire to design efficient and effective physical systems, problem-solving service systems, and interfaces between the two. This section is concerned with each of these.

Not all of the performance objectives for quality systems engineering will be, or need be, fully attained in all design instances, but it is generally true that the quality of a system or of a systems design process necessarily improves as more and more of these objectives are attained. Measures of quality of the resulting system, and therefore systems design process quality, may be obtained by assessing the degree of achievement of these performance criteria by the resulting system, generally in an operational environment. In this way, an evaluation of the effectiveness of a design decision support system may be conducted.

A taxonomy based on operational environments is necessary to describe particular situation models through which design decision support may be achieved. We are able to describe a large number of situations using elements or features of the three-component taxonomy described earlier. With these, we are able to evolve test instruments to establish quantitative and qualitative evaluations of a design support system within an operational environment. The structural and functional properties of such a system, or of the design process itself, must be described in order that a purposeful evaluation can be accomplished. This purposeful evaluation of a systemic process is obtained by embedding the process into specific operational planning, design, or decision situations. Thus, an evaluation effort also allows iteration and feedback to ultimately improve the overall systems design process. The evaluation methodology to be described is useful, therefore, as a part or phase of the design process. Also, it is useful, in and of itself, to evaluate and prioritize a set of systemic aids for planning, design, and decision support. It is also useful for evaluation of resulting system designs and operational

systems providing a methodological framework both for the design and evaluation of physical systems and for systems that assist in the planning and design of systems.

26.5.3 The Development of Aids for the Systems Design Process

This section describes five important phases in the development of systems and systemic aids for the design process. These phases serve as a guide not only for the sound design and development of systems and systemic aids for design decision support, but for their evaluation and ultimate operational deployment as well.

- Requirements specification
- Preliminary conceptual design
- Detailed design, testing, and implementation
- Evaluation
- Operational deployment

These five phases are applicable to design in general. Although the five phases will be described as if they are to be sequenced in a chronological fashion, sound design practice will generally necessitate iteration and feedback from a given phase to earlier phases.

Requirements Specification Phase

The requirements specification phase has as its goal the detailed definition of those needs, activities, and objectives to be fulfilled or achieved by the system or process that is to result from the system design effort. Furthermore, the effort in this phase should result in a description of preliminary conceptual design considerations appropriate for the next phase. This must be accomplished in order to translate operational deployment needs, activities, and objectives into requirements specifications if, for example, that is the phase of the systems engineering design effort under consideration.

Among the many objectives of the requirements specifications phase of systems engineering are the following:

1. To define the problem to be solved, or range of problems to be solved, or issue to be resolved or ameliorated; including identification of needs, constraints, alterables, and stakeholder groups associated with operational deployment of the system or the systemic process
2. To determine objectives for operational system or the operational aids for planning, design, and decision support
3. To obtain commitment for prototype design of a system or systemic process aid from user group and management
4. To search the literature and seek other expert opinions concerning the approach that is most appropriate for the particular situation extant
5. To determine the estimated frequency and extent of need for the system or the systemic process
6. To determine the possible need to modify the system or the systemic process to meet changed requirements
7. To determine the degree and type of accuracy expected from the system or systemic process
8. To estimate expected effectiveness improvement or benefits due to the use of the system or systemic process
9. To estimate the expected costs of using the system or systemic process, including design and development costs, operational costs, and maintenance costs
10. To determine typical planning horizons and periods to which the system or systemic process must be responsive
11. To determine the extent of tolerable operational environment alteration due to use of the system or systemic process
12. To determine what particular planning, design, or decision process appears best
13. To determine the most appropriate roles for the system or systemic process to perform within the context of the planning, design, or decision situation and operational environment under consideration
14. To estimate potential leadership requirements for use of the final system itself
15. To estimate user group training requirements
16. To estimate the qualifications required of the design team
17. To determine preliminary operational evaluation plans and criteria
18. To determine political acceptability and institutional constraints affecting use of an aided support process, and those of the system itself

19. To document analytical and behavioral specifications to be satisfied by the support process and the system itself
20. To determine the extent to which the user group can require changes during and after system development
21. To determine potential requirements for contractor availability after completion of development and operational tests for additional needs determined by the user group, perhaps as a result of the evaluation effort
22. To develop requirements specifications for prototype design of a support process and the operational system itself

As a result of this phase, to which the four issue requirements identification approaches of Section 26.4.1 are fully applicable, there should exist a clear definition of typical planning, design, and decision issues, or problems requiring support, and other requirements specifications, so that it is possible to make a decision whether to undertake preliminary conceptual design. If the result of this phase indicates that the user-group or client needs can potentially be satisfied in a cost-effective manner, by a systemic process aid, for example, then documentation should be prepared concerning detailed specifications for the next phase, preliminary conceptual design, and initial specifications for the last three phases of effort. A design team is then selected to implement the next phase of the system life cycle. This discussion emphasizes the inherently coupled nature of these phases of the system life cycle and illustrates why it is not reasonable to consider the phases as if they are uncoupled.

Preliminary Conceptual Design Phase

The preliminary conceptual design phase includes specification of the mathematical and behavioral content and associated algorithms for the system or process that should ultimately result from the effort, as well as the possible need for computer support to implement these. The primary goal of this phase is to develop conceptualization of a prototype system or process in response to the requirements specifications developed in the previous phase. Preliminary design according to the requirements specifications should be achieved. Objectives for preliminary conceptual design include the following:

1. To search the literature and seek other expert opinion concerning the particular approach to design and implementation that is likely to be most responsive to requirements specifications
2. To determine the specific analytic algorithms to be implemented by the system or process
3. To determine the specific behavioral situation and operational environment in which the system or process is to operate
4. To determine the specific leadership requirements for use of the system in the operational environment extant
5. To determine specific hardware- and software-implementation requirements, including type of computer programming language and input devices
6. To determine specific information-input requirements for the system or process
7. To determine the specific type of output and interpretation of the output to be obtained from the system or process that will result from the design procedure
8. To reevaluate objectives obtained in the previous phase, to provide documentation of minor changes, and to conduct an extensive re-examination of the effort if major changes are detected that could result in major modification and iteration through requirements specification or even termination of effort
9. To develop a preliminary conceptual design of a prototype aid that is responsive to the requirements specification

The expected product of this phase is a set of detailed design and testing specifications that, if followed, should result in a usable prototype system or process. User-group confidence that an ultimately useful product should result from detailed design should be above some threshold, or the entire design effort should be redone. Another product of this phase is a refined set of specifications for the evaluation and operational deployment phases.

If the result of this phase is successful, the detailed design, testing, and implementation phase is begun. This phase is based on the products of the preliminary conceptual design phase, which should result in a common understanding among all interested parties about the planning and decision support design effort concerning the following:

1. Who the user group or responsive stakeholder is
2. The structure of the operational environment in which plans, designs, and decisions are made
3. What constitutes a plan, a design, or a decision

4. How plans, designs, and decisions are made without the process or system and how they will be made with it
5. What implementation, political acceptability, and institutional constraints affect the use of the system or process
6. What specific analysis algorithms will be used in the system or process and how these algorithms will be interconnected to form the methodological construction of the system or process

Detailed Design, Testing, and Implementation Phase

In the third phase of design, a system or process that is presumably useful in the operational environment is produced. Among the objectives to be attained in this phase are the following:

1. To obtain and design appropriate physical facilities (physical hardware, computer hardware, output device, room, etc.)
2. To prepare computer software
3. To document computer software
4. To prepare a user's guide to the system and the process in which the system is embedded
5. To prepare a leader's guide for the system and the associated process
6. To conduct control group or operational (simulated operational) tests of the system and make minor changes in the aid as a result of the tests
7. To complete detailed design and associated testing of a prototype system based on the results of the previous phase
8. To implement the prototype system in the operational environment as a process

The products of this phase are detailed guides to use of the system as well as, of course, the prototype system itself. It is very important that the user's guide and the leader's guide address, at levels appropriate for the parties interested in the effort, the way in which the performance objectives identified in Section 26.5.3 are satisfied. The description of system usage and leadership topics should be addressed in terms of the analytic and behavioral constructs of the system and the resulting process, as well as in terms of operational environment situation concerns. These concerns include

1. Frequency of occurrence of need for the system or process
2. Time available from recognition of need for a plan, design, or decision to identification of an appropriate plan, design, or decision
3. Time available from determination of an appropriate plan, design, or decision to implementation of the plan, design, or decision
4. Value of time
5. Possible interactions with the plans, designs, or decisions of others
6. Information base characteristics
7. Organizational structure
8. Top management support for the resulting system or process

It is especially important that the portion of this phase that concerns implementation of the prototype system specifically address important questions concerning cognitive style and organizational differences among parties at interest and institutions associated with the design effort. Stakeholder understanding of environmental changes and side effects that will result from use of the system is critical for ultimate success. This need must be addressed. Evaluation specification and operational deployment specifications will be further refined as a result of this phase.

Evaluation Phase

Evaluation of the system in accordance with evaluation criteria, determined in the requirements specification phase and modified in the subsequent two design phases, is accomplished in the fourth phase of systems development. This evaluation should always be assisted to the extent possible by all parties at interest to the systems design effort and the resultant systemic process. The evaluation effort must be adapted to other phases of the design effort so that it becomes an integral functional part of the overall design process. As noted, evaluation may well be an effort distinct from design that is used to determine usefulness or appropriateness for specified purposes of one or more previously designed systems. Among the objectives of system or process evaluation are the following:

1. To identify a methodology for evaluation
2. To identify criteria on which the success of the system or process may be judged

3. To determine effectiveness of the system in terms of success criteria
4. To determine an appropriate balance between the operational environment evaluation and the control group evaluation
5. To determine performance-objective achievement of the system
6. To determine behavioral or human-factor effectiveness of the system
7. To determine the most useful strategy for employment of the existing system
8. To determine user-group acceptance of the system
9. To suggest refinements in existing systems for greater effectiveness of the process in which the new system has been embedded
10. To evaluate the effectiveness of the system or process

These objectives are obtained from a critical evaluation issue specification or evaluation need specification, which is the first or problem-definition step of the evaluation methodology. Generally, the critical issues for evaluation are minor adaptations of the elements that are present in the requirements specifications step of the design process outlined in the previous section. A set of specific evaluation test requirements and tests is evolved from these objectives and needs. These must be such that each objective measure and critical evaluation issue component can be determined from at least one evaluation test instrument.

If it is determined that the system and the resulting process support cannot meet user needs, the systems design process iterates to an earlier phase and development continues. An important by-product of evaluation is the determination of ultimate performance limitations and the establishment of a protocol and procedure for use of the system that results in maximum user-group satisfaction. A report is written concerning results of the evaluation process, especially those factors relating to user group satisfaction with the designed system. The evaluation process should result in suggestions for improvement in design and in better methodologies for future evaluations.

Section 26.5.6 will present additional details of the methodologies framework for evaluation. These have applicability to cases where evaluation is a separate and independent effort as well as cases where it is one of the phases of the design process.

Operational Deployment Phase

The last phase of design concerns operational deployment and final implementation. This must be accomplished in such a way that all user groups obtain adequate instructions in use of the system and complete operating and maintenance documentation and instructions. Specific objectives for the operational deployment phase of the system design effort are

1. To enhance operational deployment
2. To accomplish final design of the system
3. To provide for continuous monitoring of post-implementation effectiveness of the system and the process into which the system is embedded
4. To provide for redesign of the system as indicated by effectiveness monitoring
5. To provide proper training and leadership for successful continued operational use of the system
6. To identify barriers to successful implementation of the final design product
7. To provide for "maintenance" of the system

26.5.4 Leadership Requirements for Design

The actual use, as contrasted with potential usefulness, of a system is directly dependent on the value that the user group of stakeholders associates with use of the system and the resulting process in an operational environment. This in turn is dependent, in part, on how well the system satisfies performance objectives and on how well it is able to cope with one or more of the pathologies or pitfalls of planning, design, and/or decision-making under potentially stressful operational environment conditions.

Quality planning, design, and decision support are dependent on the ability to obtain relatively complete identification of pertinent factors that influence plans, designs, and decisions. The careful, comprehensive formulation of issues and associated requirements for issue resolution will lead to identification of pertinent critical factors for system design. These factors are ideally illuminated in a relatively easy to understand fashion that facilitates the interpretation necessary to evaluate and subsequently select plans, designs, and decisions for implementation. Success in this is, however, strongly dependent on adroitness in use of the system. It is generally not fully meaningful to talk only of an algorithm or even a complete system—which is, typically, a piece of hardware and software, but which may well be a carefully written set of protocols and procedures—as useful by itself. It is meaningful to talk of a particular systemic process as being useful. This process involves

the interaction of a methodology with systems management at the cognitive process or human judgment level. A systemic process depends on the system, the operational environment, and leadership associated with use of the system. A process involves design integration of a methodology with the behavioral concerns of human cognitive judgment in an operational environment.

Operational evaluation of a systemic process that involves human interaction, such as an integrated manufacturing complex, appears the only realistic way to extract truly meaningful information concerning process effectiveness of a given system design. This must necessarily include leadership and training requirements to use the system. There are necessary tradeoffs associated with leadership and training for using a system and these are addressed in operational evaluation.

26.5.5 System Evaluation

Previous subsections have described a framework for a general system design procedure. They have indicated the role of evaluation in this process. Successful evaluation, especially operational evaluation, is strongly dependent on explicit development of a plan for evaluation developed prior to, and perhaps modified and improved during the course of, an actual evaluation. This section will concern itself with development of a methodological framework for system evaluation, especially for operational evaluation of systemic processes for planning, design, and decision support.

Evaluation Methodology and Evaluation Criteria

Objectives for evaluation of a system concern the following:

1. Identification of a methodology for operational evaluation
2. Establishing criteria on which the success of the system may be judged
3. Determining the effectiveness of the support in terms of these criteria
4. Determining the most useful strategy for employment of an existing system and potential improvements such that effectiveness of the newly implemented system and the overall process might be improved

Figure 26.8 illustrates a partial intent structure or objectives tree, which contributes to system evaluation. The lowest-level objectives contribute to satisfaction of the 10 performance objectives for systems engineering and systems design outlined in Section 26.3. These lowest-level elements form pertinent criteria for the operational system evaluation. They concern the algorithmic effectiveness or performance objective achievement of the system, the behavioral or human factor effectiveness of the system in the operational environment, and the system efficacy. Each of these three elements become top level criteria or attributes and each should be evaluated to determine evaluation of the system itself.

Subcriteria that support the three lowest-level criteria of Fig. 26.8 may be identified. These are dependent on the requirements identified for the specific system that has been designed. Attainment of each of these criteria by the system may be measured by observation of the system within the operational environment and by test instruments and surveys of user groups involved with the operational system and process.

Algorithmic Effectiveness of Performance Objectives Achievement Evaluation

A number of performance objectives can be cited that, if achieved, should lead to a quality system. Achievement of these objectives is measured by logical soundness of the operational system and

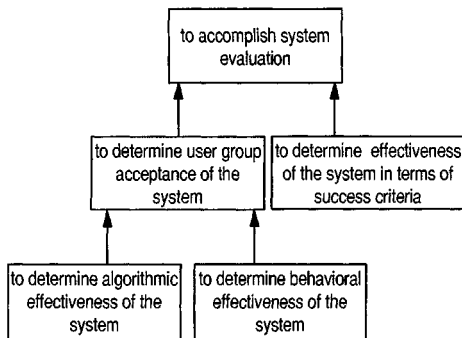


Fig. 26.8 Objectives tree for evaluation of decision support system.

process; improved system quality as a result of using the system; and improvements in the way an overall process functions, compared to the way it typically functions without the system or with an alternative system.

Behavioral or Human Factors Evaluation

A system may be well structured algorithmically in the sense of achieving a high degree of satisfaction of the performance objectives, yet the process incorporating the system may seriously violate behavioral and human factor sensibilities. This will typically result in misuse or underuse. There are many cases where technically innovative systems have failed to achieve broad scope objectives because of human factor failures. Strongly influencing the acceptability of system implementation in operational settings are such factors as organizational slack; natural human resistance to change; and the present sophistication, attitude, and past experience of the user group and its management with similar systems and processes. Behavioral or human factor evaluation criteria used to evaluate performance include political acceptability, institutional constraint satisfaction, implementability evaluation, human workload evaluation, management procedural change evaluation, and side-effect evaluation.

Efficacy Evaluation

Two of the three first-level evaluation criteria concern algorithmic effectiveness or performance-objective achievement and behavioral or human-factors effectiveness. It is necessary for a system to be effective in each of these for it to be potentially capable of truly aiding in terms of improving process quality and being acceptable for implementation in the operational environment for which it was designed. There are a number of criteria or attributes related to usefulness, service support, or efficacy to which a system must be responsive. Thus, evaluation of the efficacy of a system and the associated process is important in determining the service support value of the process. There are seven attributes of efficacy:

1. *Time requirements.* The time requirements to use a system form an important service-support criterion. If a system is potentially capable of excellent results, but the results can only be obtained after critical deadlines have passed, the overall process must be given a low rating with respect to a time-responsiveness criterion.
2. *Leadership and training.* Leadership and training requirements for use of a system are important design considerations. It is important that there be an evaluation component directed at assessing leadership and training needs and tradeoffs associated with the use of a system.
3. *Communication accomplishments.* Effective communication is important for two reasons. (1) Implementation action is often accomplished at a different hierarchical level, and therefore by a different set of actors, than the hierarchical level at which selection of alternative plans, designs, or decisions was made. Implementation-action agents often behave poorly when an action alternative is selected that they regard as threatening or arbitrary, either personally or professionally, on an individual or a group basis. Widened perspectives of a situation are made possible by effective communication. Enhanced understanding will often lead to commitment to successful action implementation as contrasted with unconscious or conscious efforts to subvert implementation action. (2) Recordkeeping and retrospective improvements to systems and processes are enhanced by the availability of well-documented constructions of planning and decision situations and communicable explanations of the rationale for the results of using the system.
4. *Educational accomplishments.* There may exist values to a system other than those directly associated with improvement in process quality. The participating group may, for example, learn a considerable amount about the issues for which a system was constructed. The possibility of enhanced ability and learning with respect to the issues for which the system was constructed should be evaluated.
5. *Documentation.* The value of the service support provided by a system will be dependent on the quality of the user's guide and its usefulness to potential users of the system.
6. *Reliability and maintainability.* To be operationally useful, a planning-and-decision-support system must be, and be perceived by potential users to be, reliable and maintainable.
7. *Convenience of access.* A system should be readily available and convenient to access, or usage will potentially suffer. While these last three service support measures are not of special significance with respect to justification of the need for a system, they may be important in determining operational usage and, therefore, operational effectiveness of a system and the associated process.

26.5.6 Evaluation Test Instruments

Several special evaluation test instruments to satisfy test requirements and measure achievement of the evaluation criteria will generally need to be developed. These include investigations of effective-

ness in terms of performance objective attainment; selection of appropriate scenarios that affect use of the system, use of the system subject to these scenarios by a test group, and completion of evaluation questionnaires; and questionnaires and interviews with operational users of the system.

Every effort must be made to ensure, to the extent possible, that evaluation test results will be credible and valid. Intentional redundancy should be provided to allow correlation of results obtained from the test instruments to ensure maximum supportability and reliability of the facts and opinions to be obtained from test procedures.

The evaluation team should take advantage of every opportunity to observe use of the system within the operational environment. Evaluation of personnel reactions to the aid should be based on observations, designed to be responsive to critical evaluation issues, and the response of operational environment personnel to test questionnaires. When any of a number of constraints make it difficult to obtain real-time operational environment observation, experiential and anecdotal information becomes of increased value. Also, retrospective evaluation of use of a system is definitely possible and desirable if sufficiently documented records of past usage of an aided process are available.

Many other effectiveness questions will likely arise as an evaluation proceeds. Questions specific to a given evaluation are determined after study of the particular situation and the system being evaluated. It is, however, important to have an initial set of questions to guide the evaluation investigation and a purpose of this subsection to provide a framework for accomplishing this.

One of the important concerns in evaluation is that of those parts of the efficacy evaluation that deal with various "abilities" of a system. These include producibility, reliability, maintainability, and marketability. Figure 26.9 presents a listing of attributes that may be used to "score" the performance of systems on relevant effectiveness criteria.

26.6 CONCLUSIONS

In this chapter, we have discussed salient aspects concerning the systems engineering of large and complex systems. We have been concerned especially with systems design engineering and associated information processing and analysis efforts. To this end, we suggested a process for the design and evaluation of systems and how we might go about fielding a design decision support system. There are a number of effectiveness attributes or aspects of effective systems. Design of an effective large-scale system necessarily involves integration of operational environment concerns involving human behavior and judgment with mechanistic and physical science concerns. An effective systemic design process should

1. Allow a thorough and carefully conducted requirements specification effort to determine and specify needs of stakeholders prior to conceptual design of a system process to accomplish the desired task
2. Be capable of dealing with both quantitative and qualitative criteria representing costs and effectiveness from their economic, social, environmental, and other perspectives

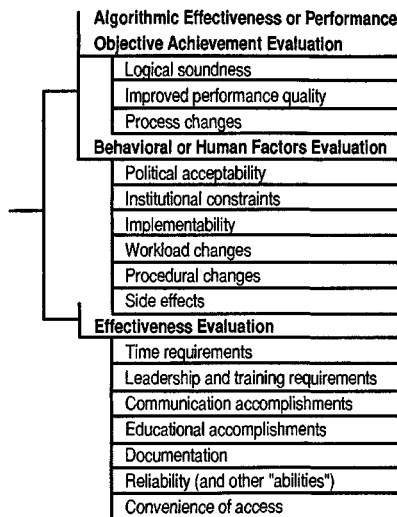


Fig. 26.9 Attribute tree and criteria for evaluation of decision support system for design and other end uses.

3. Be capable of minimizing opportunities for cognitive bias and provide debiasing procedures for those biases that occur
4. Allow separation of opinions and facts from values, and separation of ends from means, or values from alternative acts
5. Provide an objective communicable framework that allows identification, formulation, and display of the structure of the issue under consideration, as well as the rationale of the choice process
6. Allow for considerations of tradeoffs among conflicting and incommensurate criteria
7. Provide flexibility and monitoring support to allow design process evaluation rule selection with due consideration to the task structure and operational environment constraints on the decision-maker
8. Provide an open process to allow consideration of new criteria and alternatives as values change and broad-scope awareness of issues grows

There are a number of potential benefits of the systems approach that should follow high achievement of each of the criteria for effective systems design processes. An appropriate systems design process will

1. Provide structure to relatively unstructured issues
2. Facilitate conceptual formulation of issues
3. Provide cognitive cues to search and discovery
4. Encourage parsimonious collection, organization, and utilization of relevant data
5. Extend and debias information-processing abilities
6. Encourage vigilant cognitive style
7. Provide brokerage between parties at interest

There are many imperfections and limits to processes designed using the methodologies from what we know as systems engineering and systems analysis. Some of these have been documented in this chapter. Others are documented in the references provided here and in a recent handbook of systems engineering and management.³² But what are the alternatives to appropriate systemic processes for the resolution of issues associated with the design of complex large-scale systems; and are not the fundamental limitations to these alternatives even greater?

REFERENCES

1. A. P. Sage, *Systems Engineering*, Wiley, New York, 1992.
2. A. P. Sage, *Systems Management for Information Technology and Software Engineering*, Wiley, New York, 1995.
3. A. P. Sage, *Methodology for Large Scale Systems*, McGraw-Hill, New York, 1977.
4. J. E. Armstrong and A. P. Sage, *Introduction to Systems Engineering*, Wiley, New York, 1998 (in press).
5. A. D. Hall, *A Methodology for Systems Engineering*, Van Nostrand, New York, 1962.
6. A. D. Hall, "A Three Dimensional Morphology of Systems Engineering," *IEEE Transactions on System Science and Cybernetics* 5 (2), 156–160 (April 1969).
7. E. Reichtin, *Systems Architecting: Creating and Building Complex Systems*, Prentice-Hall, Englewood Cliffs, NJ, 1991.
8. E. Reichtin, "Foundations of Systems Architecting," *Systems Engineering: The Journal of the National Council on Systems Engineering* 1 (1), 35–42 (July/September 1994).
9. W. R. Beam, *Systems Engineering: Architecture and Design*, McGraw-Hill, New York, 1990.
10. D. N. Chorfas, *Systems Architecture and Systems Design*, McGraw-Hill, New York, 1989.
11. A. P. Sage and J. D. Palmer, *Software Systems Engineering*, Wiley, New York, 1990.
12. F. Harary, R. Z. Norman, and D. Cartwright, *Structural Models: An Introduction to the Theory of Directed Graphs*, Wiley, New York, 1965.
13. J. N. Warfield, *Societal Systems: Planning, Policy, and Complexity*, Wiley, New York, 1976.
14. D. V. Steward, *Systems Analysis and Management: Structure, Strategy, and Design*, Petrocelli, New York, 1981.
15. G. G. Lendaris, "Structural Modeling: A Tutorial Guide," *IEEE Transactions on Systems, Man, and Cybernetics SMC* 10, 807–840 (1980).
16. C. Eden, S. Jones, and D. Sims, *Messing About in Problems*, Pergamon Press, Oxford, 1983.
17. F. M. Roberts, *Discrete Mathematical Models*, Prentice-Hall, Englewood Cliffs, NJ, 1976.

18. A. M. Geoffrion, "An Introduction to Structured Modeling," *Management Science* **33**, 547–588 (1987).
19. A. M. Geoffrion, "The Formal Aspects of Structured Modeling," *Operations Research* **37**(1), 30–51 (January 1989).
20. A. M. Geoffrion, "Computer Based Modeling Environments," *European Journal of Operations Research* **41**(1), 33–43 (July 1989).
21. A. P. Sage (ed.), *Concise Encyclopedia of Information Processing in Systems and Organizations*, Pergamon Press, Oxford, 1990.
22. D. Kahneman, P. Slovic, and A. Tversky (eds.), *Judgment Under Uncertainty: Heuristics and Biases*, Cambridge University Press, New York, 1981.
23. L. J. Cohen, "On the Psychology of Prediction: Whose Is the Fallacy," *Cognition* **7**, 385–407 (1979).
24. L. J. Cohen, "Can Human Irrationality Be Experimentally Demonstrated?," *The Behavioral and Brain Sciences* **4**, 317–370 (1981).
25. D. von Winterfeldt and W. Edwards, *Decision Analysis and Behavioral Research*, Cambridge University Press, Cambridge, 1986.
26. L. Phillips, "Theoretical Perspectives on Heuristics and Biases in Probabilistic Thinking," in *Analyzing and Aiding Decision Problems*, P. C. Humphries, O. Svenson, and O. Vari (eds.), North Holland, Amsterdam, 1984.
27. R. T. Clemen, *Making Hard Decisions: An Introduction to Decision Analysis*, Duxbury Press, Belmont, CA, 1986.
28. R. L. Keeney, *Value Focused Thinking: A Path to Creative Decision Making*, Harvard University Press, Cambridge, MA, 1992.
29. C. W. Kirkwood, *Strategic Decision Making: Multiobjective Decision Analysis with Spreadsheets*, Duxbury Press, Belmont, CA, 1997.
30. A. P. Sage, *Decision Support Systems Engineering*, Wiley, New York, 1991.
31. J. Rasmussen, *Information Processing and Human–Machine Interaction*, North Holland, Amsterdam, 1986.
32. A. P. Sage and W. B. Rouse (eds.), *Handbook of Systems Engineering and Management*, Wiley, New York, 1997.