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USE OF SCENARIOS IN TECHNICAL EVALUATIONS

Scenarios play an important role in technical evaluations, yet they are not well understood. This article provides a definition of scenarios and a construct for their use in technical evaluations. Basic principles for scenario development are also discussed.

INTRODUCTION

We begin with a semantic problem. There are a number of misconceptions about the word "scenario," and many use the term, as defined here, without understanding it. We must approach the problem by clearly defining scenario and then explain the reasons for our selection of that definition.

Why are scenarios important? We address that question by showing the critical role that they play in technical evaluations. We also consider how to develop scenarios properly. Some scenarists approach scenario development haphazardly, relying on their intuition to cause the scenario to come out right, but we advocate a more rigorous and formal approach and then present some principles for scenario development.

WHAT IS A SCENARIO?

The term scenario originated in drama and is derived from *scena,* the Latin word for stage. The scenario provides additional information to the director and actors about the characters and scenes of a play so that the words of the play can be presented in the proper context.

During the 1960s, the term began to be used by the technical community, mainly for systems analysis, war gaming, and management gaming. It is now also used for other kinds of problems, e.g., in forecasting and in some aspects of artificial intelligence. In each of these technical areas, the term acquires slightly different meanings, which contributes to the current confusion.

Our interest is with scenario support of technical evaluations. For this application, the most appropriate definition for a scenario, given in Ref. 1, is that it is a statement of assumptions about the operating use environment of the particular system. In view of this definition, many people use scenarios in their work without realizing it. We will explain why the definition is a good one after making several observations about it.

First, "scenario" in the definition is focused on a particular system. A technical evaluation is concerned with a particular system. The system may be small, such as the guidance computer in a missile, or it may be both large and complex, such as an entire battle force consisting of scores of ships and aircraft spread over hundreds of square miles of ocean.

Second, the definition requires the scenario to be explicit. It is a statement, and only what is stated explicitly is part of the scenario. Incompleteness is a major problem in many scenarios, and analysts using an incomplete scenario in an evaluation may have to fill in missing items. Their additions may not be documented or they may not be compatible with other parts of the scenario.

Third, the scenario deals with the environment, including both natural and man-made aspects, in which a system operates. In a technical evaluation of a radar, for example, the scenario would define not only the propagation factors, such as atmospheric conditions, terrain masking, and clutter statistics, but also radar cross sections, trajectories, and numbers of targets. The environment should also be appropriate for the system. In evaluations of military systems, this implies that a responsive threat is part of the environment and is one that reacts to the capabilities of a new system. For example, the scenario for evaluating a new radar may include additional jamming by the enemy at the radar's frequency, additional in the sense that the jamming would not have been in the scenario were it not for the new radar.

Part of the scenario, often called its context, explains how the environment used in the scenario came to be, particularly with regard to the man-made aspects of it. For example, in a technical evaluation of a military system, the context of the scenario would include a discussion of the geopolitical background so that the rationale for the geographical situation, the hostile forces, and their tactics is clear. Adequate development of the context for the scenario is essential if the environment used in the technical evaluation is to be credible.

Fourth, the system is different from the scenario. A computer simulation used in a technical evaluation of a system contains several elements (Fig. 1): the model of the system, a description of how the system interacts with the environment, a definition of the environment (i.e., the scenario), and simulation controls, such as random number seeds, the number of iterations, etc. Unfortunately, some analysts (and even some scenarists) carelessly treat the system, or some of it, as part of the scenario. This should not occur with the definition presented above.

Finally, the scenario can contain a spectrum of conditions. It is a "statement of assumptions about the operating environment" for the system. The assumptions need not be a single condition; for example, the environment may include sea states that vary from 0 to 7 and target speeds may range from Mach 2 to 4, etc.

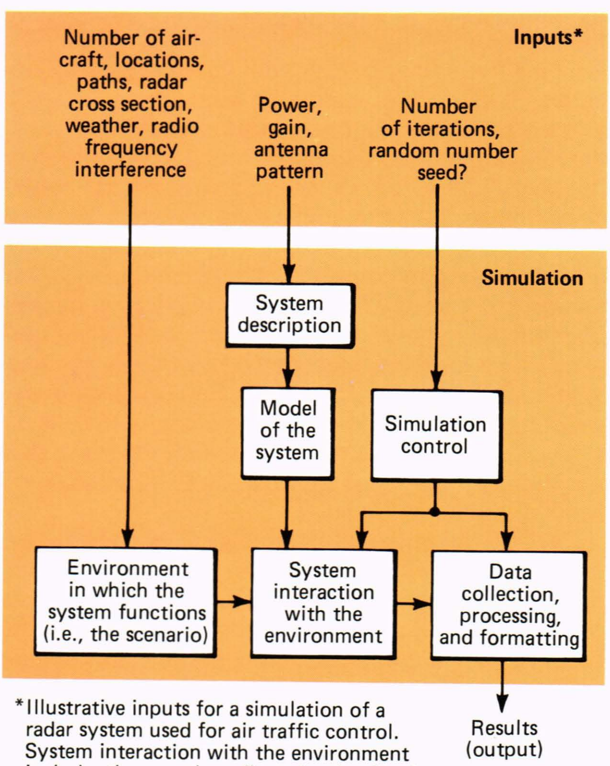
WHY THIS DEFINITION?

One can ask why the above definition for scenario is most appropriate for use with technical evaluations. The primary reason is that it helps to keep the elements of a technical evaluation distinct so that the impact of variations in each one can be readily understood.

As noted above, a technical evaluation involves three basic elements: a system, an environment (i.e., the scenario), and the interaction of the system with its environment. In a technical evaluation involving laboratory experiments, field tests, or operational data, the actual system (or at least parts of it) must be used in the technical evaluation, and interactions of the system with the environment can be observed.

In other kinds of technical evaluations, a model of the system may be used, in which case its interaction with the environment must be defined and described. For example, the radar range equation shown in the supplementary text insert defines the interaction between the system (i.e., the radar) and the environment (e.g., target radar cross section, clutter, jamming). Normally, the interactions between the system and its environment are based either on basic physical laws or patterns of human behavior (when the system model includes human decision processes).

By restricting the term to a statement of assumptions about the environment(s) in which the system operates, one is able to focus on the three distinctive elements of a technical evaluation mentioned above, thereby promoting clarity. For example, if a proposed new ra-



*Illustrative inputs for a simulation of a radar system used for air traffic control. System interaction with the environment includes the way the reflected radar signal strength decreases as the fourth power of the target range

Figure 1—Conceptual elements of a simulation of a complex system.

RADAR (SYSTEM) INTERACTION WITH THE ENVIRONMENT (SCENARIO)

Typical form of the radar range equation:*

$$R_{max} = \left[\frac{P_{av} \cdot G_t \cdot A_e \cdot \sigma \cdot n \cdot E_i(n) \cdot \exp(2 \cdot \alpha \cdot (R_{max}))}{(4\pi)^2 \cdot K \cdot T_0 \cdot F_n \cdot B_n \cdot \tau \cdot f_r \cdot (S/N)_1 \cdot L_s} \right]^{1/4}$$

System characteristics:

P_{av} = average transmitter power,
G_t = gain of the transmitting antenna,
A_e = effective aperture of the receiving antenna,
n = number of pulses received during the scan through beamwidth,
$E_i(n)$ = efficiency associated with the integration of n pulses,
F_n = receiver noise figure,
B_n = receiver noise bandwidth,
τ = pulse width,
f_r = pulse repetition frequency,
$(S/N)_1$ = signal-to-noise ratio for detection,
L_s = system losses.

Environment:

σ = radar cross section of the target,
α = attenuation coefficient of the propagation media; the equation as shown has constant attenuation over the total range from the radar to target,
K = Boltzmann's constant,
T_0 = standard temperature.

System-environment interaction:

Described by the above equation.

*M. I. Skolnick, *Introduction to Radar Systems*, McGraw-Hill, New York, p. 573 (1962).

dar is being evaluated, the change in detection range resulting from increasing the radar's power is understood as a consequence of a system change and is not misconstrued as occurring because of a change in the scenario. Careless use of the term for more than the environment can obscure the impact of factors and changes in a technical evaluation. Thus, this definition is preferred to scenario because it helps analysts and others involved in the scenario to appreciate more clearly what is happening and why.

Restriction of the scenario to the environment for the system being evaluated does not mean that the scenario is simple or trite. For example, a system modeling and simulation course in a technical management program requires students to develop a scenario for evaluating a remotely piloted vehicle (RPV). The student is asked to define whether his RPV is to be used in a military context or in a civilian context, such as the use of an RPV by law enforcement officials to detect smugglers or by government authorities to observe a disaster area. Table 1 lists some of the environmental factors that such scenarios might contain.

Table 1—Possible parameters for a remotely piloted vehicle (RPV) scenario.

Background: An RPV is evaluated using a computer simulation. Three possible situations exist: (a) military use of the RPV to observe enemy activities behind the front, (b) law enforcement use of the RPV to monitor traffic on a road network used by smugglers, and (c) use by civilian officials to observe activity in an area contaminated by an accidental release of toxic materials that would cause contagious illnesses.

Some possible scenario parameters for each situation are listed below.

Military	*Law Enforcement*	*Civil Disaster*
Terrain	Terrain	Terrain
Enemy bases	Vehicles • Kind • Speed • Roads used	Meteorological factors
Vehicles/objects • Size • Sensor signature • Kind • Movement	Meteorological factors	Population • Location • Reaction to disaster
Enemy sensor/weapons to detect/destroy/disrupt RPV • Kinds • Location • Policy on use		

HOW ARE SCENARIOS USED IN TECHNICAL EVALUATIONS?

Technical evaluations use a variety of analytical methods, including closed-form mathematical analyses, computer simulations, laboratory experiments, field tests, and even operational data from Fleet exercises.

There are many varieties of technical evaluations, several of which are conducted at APL. These can be grouped by function into the four basic categories described below. Table 2 shows how technical evaluations by different APL departments are distributed among the four categories.

1. *Evaluations that determine basic parameter values.* For example, a radar antenna installed on a ship will have an antenna pattern that may vary with azimuth. A technical evaluation to determine the variation of antenna gain with azimuth may involve calculations, computer simulations, and field tests and measurements.
2. *Evaluations that determine system performance.* What a system is and what a component of a system is depend on one's perspective, but, for this breakdown of technical evaluations, a system is normally at least a major equipment group such as a radar (for example, the radar whose antenna is used in the first category). A system performance evaluation may determine the detection range or tracking range of the radar.
3. *Evaluations that determine operational effectiveness.* This kind of evaluation looks at the mission that a system supports. For example, if the shipboard radar used as an example above were to be part of an antiair warfare system, the operational effectiveness evaluation would quantify the antiair warfare capabilities of the ship. This would depend on the detection and tracking capabilities of the radar, which, in turn, are affected by the

Table 2—Distribution of technical evaluations at APL.

Departments	*Category* 1 (*percentages*)	2	3	4
Aeronautics	10	60	20	10
Fleet Systems	10	50	25	15
Naval Warfare Analysis	5	35	35	25
Space	50	50	–	–
Strategic Systems	10	30	50	10
Submarine Technology	35	40	15	10
Unweighted mean	20	44	24	12

Note: The estimates were derived by the author from discussions with Department leaders. A similar estimate was developed for technical evaluations related to computing facilities needed at APL: 10% each for categories 1 and 2 and 40% each for categories 3 and 4.

antenna pattern. Such operational evaluations may be performed with computer simulations or be based on Fleet exercises or operational data.

4. *Evaluations that address concepts of employment, tactics, or strategy*. These consider how a system may be used and not just how it performs.

A technical evaluation is conducted for a purpose that is normally defined by a decision maker who is using the technical evaluation to help him make decisions about the design, employment, or capabilities of a system. The purpose of a technical evaluation is specified in a set of evaluation objectives that provide the focus for an analysis plan. Figure 2 shows how the elements relate to one another and to the scenario that is used with a technical evaluation involving a simulation. Figure 3 illustrates some of the hazards of the process that exist because judgment is required in deciding which aspects of the system to represent in the model and in deciding which conclusions to draw about the system based on testing or on a simulation exercise of the model. The expectations of the decision maker can also be a problem if conclusions about the system are at odds with them.

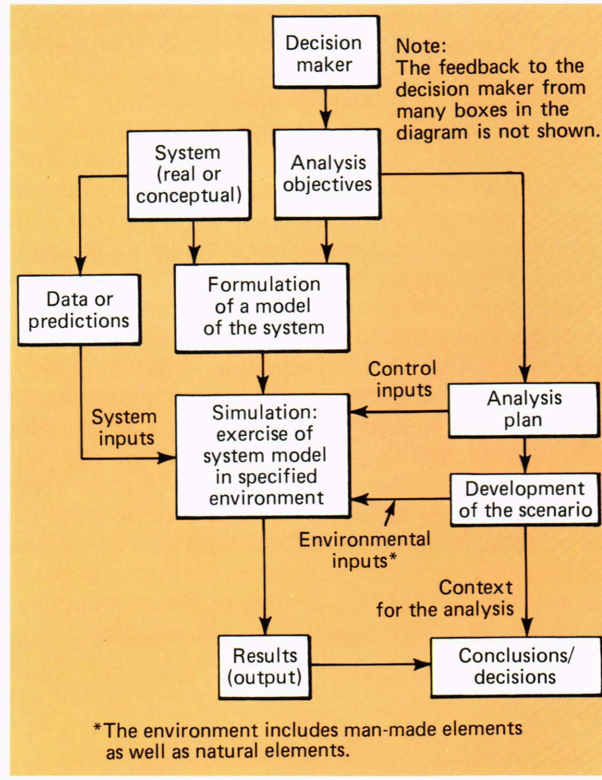


Figure 2—The analysis process in a technical evaluation using a simulation.

PRINCIPLES FOR SCENARIO DEVELOPMENT

Scenario development has been and continues to be an undisciplined art form.[2] There are no widely accepted standards for scenarios and no training programs for scenarists.[3] There exists no formal guidance about what to include and what to omit in scenarios and no standard format for presentation of scenario materials.[4] We have found fewer than a score of references on scenario development in the literature of the past two decades. It is hoped that this article and others based on the research described below will begin to ameliorate the lack of a discipline.

Unfortunately, there has been no consistent relationship between the quality of a scenario and the quality of the study—whether game, analysis, or evaluation—that uses the scenario[5] because good analysts can overcome deficiencies in a scenario, but even a good scenario cannot prevent analytic incompetence or misadventure. However, it is believed that good scenarios facilitate good studies by encouraging the use of good analysis procedures.

Before a scenario can be developed properly, the objectives of the technical evaluation need to be stated clearly and explicitly. At least three people are involved for most technical evaluations: the decision maker, the analysis leader, and the scenarist. Sometimes the same

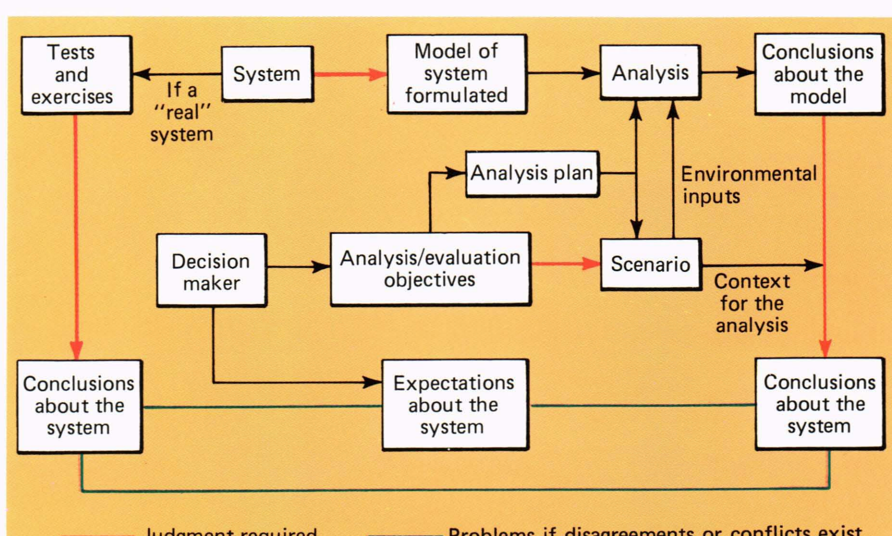


Figure 3—Potential problems with technical evaluations.

person will assume more than one role, e.g., the analysis leader can also be the scenarist. Sometimes a team of people will develop the scenario. This article uses "scenarist" for both individuals and groups who develop the scenario.

Among these three, not only will the objectives of the evaluation be decided (and perhaps documented), but the scope of the evaluation, the time and resources to be used in it, and the nature of its end product (e.g., report) will be determined. In most cases, these elements evolve. As Hoeber noted, "It should *never* be assumed that the initial problem, statement, or equation is correct."[6] Only after these matters have been settled can an adequate analysis plan be developed.

Such a plan for a technical evaluation addresses both the objectives of the evaluation and the methods to be employed in it. The analysis plan should specify, if possible, the analytic approaches and calculation procedures (e.g., a particular computer simulation) to be employed. Although scenario development should not begin until the analysis plan is complete, it may at times be desirable to make a preliminary version of a scenario when the analysis plan is still embryonic, in order to help focus the analysis plan. The scenario may not be focused on the problem if it begins before the analysis plan is focused.

The analysis plan is not the responsibility of the scenarist but of the analysis leader. However, the scenarist has a vested interest in the analysis plan because he cannot do his job correctly without a good analysis plan. For scenarists to help ensure that clear and comprehensive objectives are made explicit for the evaluation and that an adequate analysis plan is developed, they must have ready and continuing access to the decision makers and adequate stature to influence them as needed.

In developing a good scenario, the scenarist should plan the development process by

1. *Structuring the scenario into manageable subsets.* For example, one subset of the scenario might contain the inputs required for a particular calculation procedure planned for use in the evaluation. Or if a scenario has been developed for use in evaluating a Naval system in a multiwarfare situation, a subset of the scenario could be all the parameters related to a single warfare area.
2. *Planning for adequate documentation of the scenario.* This should include a record of decisions that were made about what to include and exclude, what values to assign various parameters, and what data sources and documents to use in describing the scenario.
3. *Planning for trial applications of the scenario.* No scenario is developed correctly the first time. It should follow the standard wisdom for system design: "Build a little, test a little."
4. *Planning for expert review.* A review of a scenario by those familiar with the system being evaluated, by those who have developed similar scenarios, and by those who know the calculation devices is essential for a scenario to have the balance and context that it needs. Such expert review should occur at several stages in scenario development: early, at critical decision junctions, and when the scenario is near completion. Such expert review will not occur unless the scenarist plans for it.

The basic characteristics of good scenarios—the ones that adequately support the objectives of the technical evaluation—are that it is complete, consistent, credible, and feasible, has adequate context, and clearly identifies its assumptions.

A complete scenario contains all environmental inputs (man-made as well as natural) for all calculation procedures to be used in the evaluation, identifies all the assumptions embedded in the calculation procedures, and describes the background for the situation as well as stating constraints and assumptions about the evolution of the situation. Otherwise, the scenario is incomplete.

The completeness of a scenario is determined by the objectives of the technical evaluation. For example, some of the parameters that might be needed to evaluate a military radar are indicated in Table 3 for several technical objectives. The parameters needed for one technical evaluation objective may not be required for another in order for a scenario to be complete.

Consistency in a scenario means that all the parameters in it are treated fairly unless there is a compelling reason (due to the objectives of the evaluation)

Table 3—Illustration of a radar evaluation.

Technical Evaluation Objectives	*Scenario Parameters*
Determine radar support of air defense weapon	• Target radar cross-section trajectory, kinematics • Jamming together radar signals
Determine logistics support requirements	• Temperature, vibration of radar locale (affects failure rate) • Level and number of maintenance personnel and repair philosophy (on-site, depot) • Geographical factors • Transportation facilities
Determine capability of the radar to function after a "hit" on the radar site by an enemy weapon	• Weapon characteristics such as a guidance system warhead size and type • Site layout and physical characteristics

to do otherwise. For example, if a radar that will not be used until the 1990s is being evaluated, the kinds of targets used for it in the scenario should also be characteristic of the 1990s.

Credibility for a scenario means that the conditions of the scenario are related to known and accepted conditions in such a way that most of those who are exposed to the scenario can accept it as reasonable. While no scenario should expect to find universal acceptance,[7] the scenarist should explain the relationship between the contents of his scenario and what is known and accepted. This forces him to be conscious of where his scenarios deviate from the known and to have good reasons for such deviations.

The feasibility of a scenario concerns the practical problem of developing and using it. Can the data and information required by the scenario be collected and the scenario written within the time and resources allocated? Are there any data items that cannot be obtained? Can the spectrum of conditions specified within the scenario (and the analysis plan that it supports) be analyzed within the resources available? The complete set of combinations for just 20 parameters with only two values each would take about two years of round-the-clock work if it took only 1 minute to consider each case. Obviously, the scenarist must exercise judgment in how he restricts the scenario so that it is possible to use it. Experience with similar scenarios helps one to know which elements of the scenario are most important.

The context of the scenario is what allows the decision maker, analysts, and others involved in the technical evaluation to approach the problems related to the system, whether issues of design or operations, from a somewhat common perspective.

> The utility of embedding complex problems in a clearly defined context has long been recognized by the research community. . . .A contextual framework helps one to exclude irrelevant materials and permits a concentration on the central problem under analysis . . . .One needs a context to avoid wasting time in reaching a common approach to the subject.[8]

Without such a common perspective, people involved in the technical evaluation will provide their own contexts for the problem, whether they are conscious of doing so or not. These individualized contexts color each person's perceptions and can lead to difficulties for the technical evaluation, not the least of which are communication problems among members of the evaluation team. Review of scenarios for similar systems and problems can help the scenarist to appreciate factors that should be part of the context for the scenario. Early review of the scenario context by a variety of experts can provide it with more scope and balance than it might otherwise have.

The scenarist has three goals for the context of his scenario: (a) to provide the focus for the analysis of the evaluation; (b) to help shape the perspective of the evaluation team so that they can communicate effectively among themselves, share the same approach to the system, and use the same assumptions about the environment and use of the system; and (c) to make the context of the scenario thwart some potential criticism of the evaluation by providing an acceptable (i.e., credible) context for the system.

Such contexts are not easily developed. They require creativity and discipline. "No great unexplained 'leaps' of logic" are allowed.[9] "A plausible and consistent set of conditions—carefully researched, without unexplained or radical alteration from the present environment—is the hallmark of a good scenario."[10] Such contexts are developed only after many cycles through the iterative process of scenario development.

It is important that all key assumptions of the scenario be stated explicitly. It helps to divide assumptions into four categories. First are those that determine the scope and objectives of the technical evaluation; these bound and shape the direction of the scenario. Second are the assumptions about what is immaterial for the technical evaluation. These are determined by the judgment of the scenarist (and analyst?), although he may use data and argument to support his position. Third are the assumptions that limit the scenario because of feasibility concerns. These are derived from priorities established by the decision maker or from the scenarist's judgment. Fourth are the assumptions required because of inadequacies in theory, data, or calculation procedures. Some of these have a practical basis: there are simply not enough time and resources to handle them. On the other hand, some are required because the subject (at least at present) is unknown.

In discussing how to avoid blunders in systems analyses, Quade quipped that "only smart, well-trained, and careful people should be used as systems analysts."[11] The same applies to scenarists.

Finally, it should be noted that there are many perils in the technical evaluation process that have not been discussed in this article, a few of which we illustrated earlier with Fig. 3. The model of the system may not appropriately represent it. The judgment exercised in drawing conclusions about system performance from limited testing or from conclusions about the model based on analysis and simulation may be faulty, and expectations of the decision maker may be unreasonable, etc.

CONCLUSION

Although this article gives only a brief statement of the principles involved, it indicates the general direction needed for scenario development. The principles are not very different from those of good analysis in general. However, their conscious application in scenario development has been less apparent than in other aspects of technical evaluation.

Many in the technical community need to think more clearly about scenarios, as defined here, and their use. Scenarists need to be more concerned about the praxis of their art and publish about it so that it can become more scientific. Only then will substantial improvement in scenario development result and be reflected in consistently better technical evaluations of systems.

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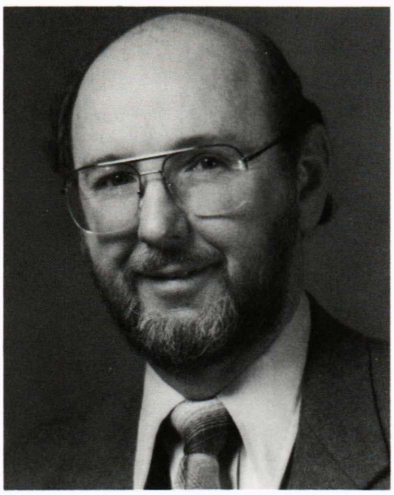

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