Network Analysis for Management Decisions

A Stochastic Approach

Sang M. Lee
Gerald L. Moeller
Lester A. Digman

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Sang M. Lee
University of Nebraska

Gerald L. Moeller
Management Consultant

Lester A. Digman
University of Nebraska

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I INTRODUCTION TO NETWORK ANALYSIS FOR MANAGEMENT

This book is about network analysis techniques for managers. More specifically, it is about stochastic networking techniques that can be used by practicing managers in making decisions, whether the setting be in the private or public sector. While the book is written for the manager and adopts his or her perspective, enough detail is included to permit the staff analyst or specialist to implement a stochastic technique and to provide the manager with a completed risk analysis as input to the decision that only the manager can make.

Within this framework part I provides a background for analysis. Chapter 1 contains a discussion of management's analytical functions. Chapter 2 deals with the management of new projects or ventures. Chapter 3 provides an overview of the major types of network models for management use. In part II an advanced stochastic networking technique—the Venture Evaluation and Review Technique (VERT)—is investigated in detail. Included is a discussion of the technique's general concepts, network construction and logic, input requirements, output reports, and computer mechanics.

Part III applies VERT-3—the most up-to-date version of the technique—to a representative sample of application areas to illustrate both the use of the technique and its value in a variety of real-world management and strategic decision situations. Part IV contains conclusions and discusses future directions for both VERT and stochastic network analysis in general.

1 ANALYTICAL FUNCTIONS OF MANAGEMENT

Numerous management science techniques that purport to aid managers exist. The vast majority are designed to assist in the process of analyzing a particular strategic or operational situation or a particular problem arising out of special projects or new ventures. Management science techniques are intended to provide a rational, scientific approach or solution for managers. But the real-world manager deals with risk; the manager must be able to account for, deal with, and accept the fact that nothing is absolutely certain. We live in a stochastic world.

Most analytical techniques are deterministic—that is, they do not specifically incorporate probabilistic events or occurrences in their solutions. Certain techniques, such as decision trees, help the manager visualize the array of choices and outcomes available and possible. However, such techniques greatly oversimplify the interrelationships involved. They also tend to give a point estimate, or specific value, for each alternative. Network techniques, on the other hand, allow for systematic planning and control but rarely incorporate chance events, partial successes, and a host of other real-world managerial problems. Simulation provides the manager with an array of likely outcomes, but largely on an ad hoc basis. In recent years, however, stochastic networking techniques have been developed that combine key advantages of previous techniques and thus provide the managers with

analyses more closely in tune with their needs. In fact, the stochastic methods are the only quantitative techniques that can accommodate "fuzzy" and uncertain future planning activities in a realistic manner.

In the past, managers were able to rely on judgment and intuition in areas where analytical techniques did not exist or in areas that the techniques were not able to treat. Problems, situations, and decisions are becoming progressively more complex and interrelated, however, and the manager needs progressively more help in dealing with these problems, situations, and decisions. It is not that judgment and intuition are no longer *necessary;* they are no longer *sufficient* for today's manager. More and more analytical input to decisions is required because of their increasing complexity and is possible because of recent advances in stochastic network analysis techniques.

FUNCTIONS OF THE MANAGER

Just as intuition and judgment are no longer sufficient (though still necessary) for effective management, neither are analytical techniques alone sufficient. Perhaps a brief glimpse at the manager's job will point out the complementary and dependent relationship between judgment and analytical techniques.

Traditionally, the manager's job has consisted of several universal functions—typically, planning, organizing, directing (or leading), and controlling. While generations of managers have been conditioned to think of their jobs in this way, few appear to relate to such generalized functions when describing their day-to-day tasks. With this dilemma in mind, Mintzberg (1975) has attempted to redefine the manager's job by observing actual tasks and activities that practicing managers perform and by classifying the activities into a more meaningful and descriptive framework. Mintzberg produced a series of managerial roles grouped into three categories:

1. *Interpersonal roles:* The manager acts as figurehead or leader and engages in liaison activities.
2. *Informational roles:* The manager acts as monitor, disseminator, and spokesperson.
3. *Decisional roles:* The manager acts as entrepreneur, disturbance handler, resource allocator, and negotiator.

While Mintzberg's framework undoubtedly adds to our understanding of what managers do, it is debatable whether individual managers can better relate on a day-to-day basis to his system of roles or to their traditional

functions. The point is, however, that the manager's job defies description according to a logical, step-by-step, scientific framework. Much as we have heard about the "rational managers," precise decision-making approaches, detailed formal planning, or cascading Management by Objectives (MBO) systems, most management jobs—particularly at higher levels of organizations—involve a good deal of trial and error. Political scientists irreverently describe the process of winding one's way through uncharted territory—as managers must do in strategic planning, in dealing with an unforeseen crisis, or in tackling a new problem—as "muddling" (Lindblom, 1959). This term refers to the conscious but nonscientific approach human beings employ in attempting to structure the unstructured. Recent studies have confirmed that effective managers "tend to arrive at their strategic goals through highly incremental 'muddling' processes rather than through the kinds of structured analytical processes so often prescribed in the literature and 'required' according to management dogma" (Quinn 1977, p. 21). The processes managers actually use are purposeful, politically astute, and effective, given the unstructured type of situation, problem, or decision at hand. Once the problem or decision has been defined, or structured, the analytical processes can be employed in a specific resolution or implementation.

Successful management involves three key elements: managing reality, managing time, and managing risks (Uyterhoeven et al. 1977). The manager must determine and deal with the *real* situation, not a simplified, deterministic model of the real world. The manager is under time constraints; some decisions must be "made by Tuesday" and cannot wait for the results of a study or a dynamic programming solution. In addition, the manager must think in terms of, and be able to deal with, risks—which ones and how many are worth taking and which are not.

In general, management's responsibility is to assure that an organization functions effectively and efficiently in a real-world setting. That is, the manager must see that the organization possesses four key elements, each of which is required for continued long-term success:

1. *Mission and strategies:* The organization should have a clear idea of why it exists (purpose or mission), what it is attempting to accomplish in the long run and in the short run (goals and objectives), how it plans to reach its goals (strategies), and how it chooses to conduct its affairs (policies and procedures).
2. *Plans:* The organization must have strategic, operational, and implementation plans in order to turn mission, objectives, and strategies into reality. Time, cost, and performance schedules are essential, as are specific work assignments.

3. *Structure and systems:* The organization must be structured in such a way as to facilitate effective planning, work accomplishment, and control. It must rely on timely information systems and organizational processes.
4. *Resource management:* The organization must have in place effective and efficient systems of supervision and management to assure and encourage a high level of return from the organization's human, financial, and physical resources.

Against this backdrop management science techniques must be designed and applied in order to be truly effective. The more congruent such analytical techniques are with the real world of the manager, the more widely and effectively they will be implemented.

Role of Management Science

Beer (1968) has defined science as systematic knowledge about the world —not the way we would like the world to be, but the way it actually exists. Management science, then, is systematic knowledge dealing with organized activities like the ones we have discussed. Management science is much broader than the mere application of quantitative techniques to largely operational problems of organizations. It goes to the very heart of the management process—the measurement and development of hypotheses and theories about the full range of organizational activity. Management science involves trying to understand the underlying systems and processes of the organization, including missions and strategies, plans, structures, and resource management. From this understanding will develop techniques to assist managers in their various roles and functions. Those techniques more in tune with the reality of the managers' needs will, of course, be more widely employed.

The Decision-Making Function

Decision making is a critical responsibility of managers. Encompassed by the decision-making functions are strategic decisions, operating decisions, planning decisions, control or corrective action decisions, and a host of others. While a relatively small number of people in any given organization have the final responsibility for officially making key decisions, a much larger number of people take part in the process by collecting data, analyzing the situation, working with information systems, evaluating alter-

natives, and developing recommendations. In fact, it is often difficult to ascertain just where a given decision is actually *made,* because it is shaped by the various people, groups, and organizational entities involved in decision-support processes.

Quantitative techniques have found their greatest application in the general area of decision making because of the usefulness of management science/operations research models in objectively analyzing decision situations. That is, quantitative techniques provide objective information to decisionmakers to assist in the choice function.

It is helpful to look at decisions from two perspectives, that of planning and that of control. Most of what we consider to be problem-solving activities are related to the control function—that is, when we engage in these activities, we are attempting to bring the organization's performance back "under control." The implication is that performance has deviated from what is desired, and the manager is trying to bring things back to where they should have been all along. The other side of the control coin involves the "breakthrough" concept of Juran (1964). This concept is more proactive: Once things are "under control," the goal is to achieve a higher level of performance through conscious efforts. Reaching this goal involves certain changes that may reduce control in the short run but that are designed to improve performance (quality, output, effectiveness, efficiency, cost, and so forth) when things are brought under control at the new, higher level of performance. This approach involves risk and short-term disruption, but it recognizes that performance improvement, not control, is the manager's ultimate goal. This type of planning decision requires that the manager be able realistically to assess and evaluate the risks of the attempted "breakthrough" strategy. This type of managerial action is also more positive in that the manager is proactively involved in "opportunity-finding" activities rather than in the more reactive "problem-solving" approach. To be optimally effective, the analytical techniques employed must be amenable to this type of managerial environment.

DECISIONS AMENABLE TO QUANTITATIVE ANALYSIS

It is natural for managers to use tools, quantitative or of other kinds, that are at their disposal. Where no such tools exist, or where tools do not fit the realities of the situation, managers must rely on less "scientific" approaches to do what they must as best they can. However, tools tend to be used (perhaps misused) just because they exist. In the words of one author, "If the only thing you have is a hammer, you tend to treat everything as

though it were a nail" (Maslow 1965, p. 111). Specialists in the technique areas tend to view problems and situations as opportunities to apply techniques rather than viewing techniques as means to solve problems. We tend to measure what is measurable and sometimes overlook what is not so measurable but is equally important. The tools available tend to affect the type of problems we attack and how we attack them; perhaps McLuhan (1964) was correct when he concluded that "the medium is the message."

Given the above caveats, let us not forget that this book deals with techniques to assist managers and analysts—techniques that come as close to the manager's actual decision-making and problem-solving processes as the current state of the art permits. Furthermore, let us not forget that all techniques, even advanced stochastic networking techniques, require that a given problem, decision, or situation be modeled. Not all situations can or should be modeled, regardless of the power of the technique. In order for modeling to be advisable (or even possible), several conditions must exist:

1. *Awareness:* The manager/analyst must be aware of the existence of a problem or opportunity situation and aware that quantitative techniques exist that could aid in the analysis of the specific situation.
2. *Time availability:* Sufficient lead-time must exist to permit implementation of the appropriate management science technique and must include times required for technique selection, problem formulation, model preparation or technique implementation, analysis of results, and implementation of results.
3. *Technique availability:* An appropriate technique must exist that is applicable to the problem or opportunity situation at hand.
4. *Resource availability:* The required human skills, computer time, money, and other resources must be available when needed.
5. *Data/information availability:* Most management science models/techniques require rather specific, quantitative data. The required information must exist in a form that will result in accurate, meaningful results. If such information does not exist (or if its accuracy is in doubt), it may not be advisable to perform the analysis since the results may be misleading. As the adage admonishes, "It is better to be roughly right than precisely wrong."

THE CONCEPT OF RISK ANALYSIS

The essence of managerial action involves dealing with risks. Risk is inherent in any activity because we live in a stochastic world; nothing is absolutely certain. The successful decisionmaker understands the existence of risk, is

able to ascertain the degree of risk, evaluates the desirable and undesirable potential outcomes and their ratios, limits assumed risks to tolerable levels given the situation and resources, and is able to make decisions in this context. In short, the successful decisionmaker possesses what we typically call *judgment*—that is, knowing when and when not to pursue certain courses of action.

Simply stated, risk analysis involves determining the unfavorable outcomes that can occur as the result of a decision or action and evaluating the likelihood that one or more of these undesirable events will occur. Thus, risk implies the occurrence of an unfavorable outcome, and risk analysis involves the assessment of its likelihood. The likelihood that our venture will fail is information that every manager/analyst needs in order to make decisions about a venture. If the information does not exist, it must be judged, guessed at, appraised by experts, or obtained by other means; it cannot be ignored.

However, many people are unable to deal effectively with less-than-certain situations involving risks. The optimist will tend to minimize the likelihood of unfavorable outcomes and assume that the positive results that are possible will, in fact, occur; the pessimist sees the situation from the opposite perspective. The effective manager, however, is a realist who knows that we are not certain that positive or negative results will occur and who is able to think in terms of their relative likelihoods. Such a manager attaches values ranging from highly favorable to highly unfavorable to the spectrum of outcomes. By examining the values of various possible outcomes,

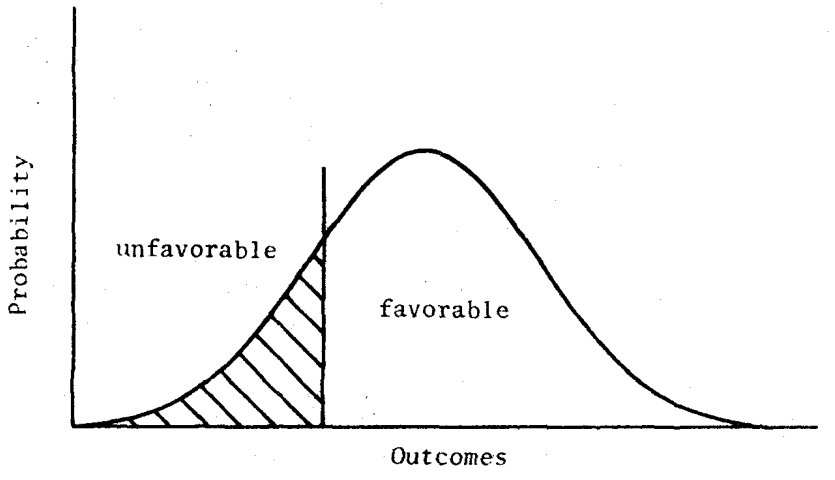

FIGURE 1.1. Risk Analysis Diagram

coupled with the likelihood of their occurrence, the manager can assess the expected return from a venture. The prudent manager will weigh the risk-to-reward ratio to assure that the favorable outcomes and their likelihood (return) clearly exceed the unfavorable and their likelihood (risk). Furthermore, the manager will assure that the organization can afford the worst possible case—that is, if the most unfavorable set of outcomes does occur (which is, after all, possible), the organization must be able to afford the amount of resources at risk.

Various techniques exist to aid the manager/analyst in assessing risks. Probability theory, network theory, decision theory, and reliability engineering techniques have proven successful to a degree. In recent years advances in the state of the art have permitted integration of the most desirable features of each of these approaches and have resulted in advanced stochastic networking techniques. The most advanced allow the manager/analyst realistically to model a wide range of possible occurrences and their likelihoods and to present final cost/profit, schedule, and performance outcomes (and their interactions) against risk in a format similar to that shown in figure 1.1. Thus, the manager/analyst is able systematically to deal with complex, interactive, probabilistic situations in an objective, rational way that greatly assists his or her judgmental ability.

ANALYSIS OF STRATEGIC DECISIONS

Traditionally, quantitative techniques have been applied to relatively specific, operational-type problems of organizations. Certain management science techniques have permitted a broadening of this focus to include finance, marketing, human resources, and other areas, but the scope of application has been relatively specific compared to the breadth of concerns facing managers. Even most stochastic techniques, while enabling managers and analysts to deal with and include more realism in their models, have been limited because of their inability to deal on a fully integrated basis with the range of parameters of concern to managers.

One area that has received little more than ad hoc, piece-by-piece assistance from management science techniques is strategic planning. Thus, it has remained largely judgmental and qualitative in nature—supported, of course, by ad hoc quantitative data and analyses. But this area of management, strategic planning and decision making, has the greatest impact on the success of the organization. In the final analysis strategic decisions, not efficiency of operations, determine organizational and competitive success. What good is it to produce Edsels efficiently? The direction and environ-

ment resulting from strategic decisions are clearly the overriding factors in determining success. Again, "It is better to be roughly right than precisely wrong."

Thus, techniques that could truly assist managers in evaluating new ventures would be of significantly more value to an organization than any other application. Ventures such as new products, marketing strategies, mergers and acquisitions, and alternative development projects are fertile ground for systematic analysis, provided that the analysis techniques are able to deal with the variables the manager must consider. The technique used must be able to incorporate the major threats and opportunities in the external environment—that is, it must account for economic, competitive/market, political/legal, technological, and social factors. It must also be able to incorporate the organization's internal strengths and weaknesses, including financial, physical, and human resources. The resulting analysis must provide interrelated information in the form of likely costs, time, and results (performance) and must incorporate contingencies for risks and discontinuities. The manager must be provided with a realistic picture of what can happen and how likely the outcomes will be, as well as be enabled to answer "what if" questions. Stochastic network techniques are now able to provide the manager with this critical and long-awaited capability.

CONCLUSIONS

We have observed that management science techniques have been limited in their usefulness to management by their inability to deal with the manager's critical concerns and needs on an integrated basis. What are needed are techniques to deal with chance-related events and to incorporate probabilistic data. Furthermore, the techniques must include key parameters and their interactions and portray the full range of outcomes and their relative likelihoods. This type of information, valuable to the manager in strategic and project as well as operational areas, would be a giant step in closing the long-existing gap between the manager and the management scientist.

2 PROJECT/VENTURE MANAGEMENT

Network techniques for management use were popularized by the development of the Critical Path Method (CPM) and the Program Evaluation and Review Technique (PERT) in the mid- to late fifties. These techniques were designed to facilitate the planning and control of large-scale construction and engineering development projects and were soon proven to be very effective aids in the management of complex, one-of-a-kind undertakings (see *Work Scheduling Techniques,* 1968). In the ensuing years, the techniques found ready application to a number of projects—for example, the *Polaris* and other weapon system development efforts, NASA's Apollo program and lunar excursion, and a host of more down-to-earth industrial and commercial undertakings.

Very frequently the PERT/CPM networking techniques were employed in a separate, ad hoc organization entity, a project office, set up to complete a one-time task. This office, headed by a project manager, relied on the networking technique as its key planning and control system. However, from a management point of view, the PERT/CPM approach had several inherent weaknesses that resulted in modifications incorporating probabilistic branching (PERT/CPM networks are deterministic) and variable (stochastic) events and activities. These stochastic network techniques, such as the Graphical Evaluation and Review Technique (GERT), led the way for