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Robert C. Weisselberg

Joseph G. Cowley

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Sometimes answers to the knottiest problems—or at least clues to the answers—lie in the simplest set of logical rules. Here are some approaches that can be used in common business situations—

STRATEGIES FOR DECISION MAKING

by Robert C. Weisselberg
EBS Management Consultants, Inc.

and Joseph G. Cowley
Research Institute of America

In a surprising number of cases, management problems fit into the group of recurring problem patterns whose identification has been the principal accomplishment of operations research. For each of these patterns operations researchers have devised a standard strategy. Some of these strategies require extensive use of mathematics; others need very little.

Three basic problem patterns are discussed in this article: search, flow-of-information, and replacement problems.

Most *search problems* call for finding the most efficient means of conducting a search, and the biggest job is establishing what the search problem is and what resources and methods should be used.

Flow-of-information problems generally require a large, comprehensive bank of data to support various management, planning, and engineering analyses. One example is constructing an input-output model, which is mostly a question of collecting and classifying raw data and estimating volumes for the future. Another example is the corporate model, which utilizes the total information system of the enterprise to answer "what if" questions. The corporate model (financial model, production model, or marketing model, as it is variously known) simulates the organization and predicts the effect upon finances, sales, or operations of adopting a particular strategy.

Replacement problems call for a balancing of costs of replacing materials, parts, machines, etc., by alternative approaches—essentially a cost comparison.

It is possible to illustrate the facets of the most common of these problems with a proverbial search that you are unlikely to experience as an executive . . .

If you lost a rare and valuable needle in a haystack, would you

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The parents whose toddler wanders away won't accept just any youngster found . . .

take the trouble to look for it? If the needle was worth $500 and your time $25 an hour, how long a time would you spend searching for it? And how would you go about it?

Perhaps finding a needle in a haystack is easier than most people think. When you dropped the needle, you must have been at one side of the stack. It isn't likely that you could have dropped the needle above your arm level. And the needle would probably come to rest within an inch or so of the surface. A cursory glance in the most obvious places could make an extensive search unnecessary—you might even look for the needle in the sun.

Segmenting the search area helps reduce search time. By setting aside each batch of hay that you examine, you avoid looking at the same hay repeatedly. Finally, some special technique or device might work magic. Sliding down the haystack would at least alert you sharply if you chanced to hit the needle. Recruiting a half-dozen small boys would extend your search capability. Best of all, a large magnet (always handy to have around) might pick up the lost needle in seconds.

While finding a needle in a haystack is hardly an executive problem, conducting a search is. Whether the prize is oil or customers or information or opportunities, the problem is much the same: how to know what you're looking for, how to organize the search, how to recognize the prize when you come upon it, and how to do all this with the least cost in time or money. Some typical search problems are:

The search for lost items (a missing airplane, the child lost in the woods, etc.).

The search for resources (drilling for oil, researching for new chemical compounds, etc.).

The search for opportunities (seeking new markets for existing products, new areas to research for possible new products, ways to cut costs, etc.).

The search for items previously stored or in hiding (information retrieval, search to identify fugitives from justice, etc.).

The search for errors or hazards (inspection and quality control, auditing for errors, etc.).

This list could easily be extended with additional search situations, some obvious and some not so obvious. Despite appearances to the contrary, most of these searches can be tackled with quantitative methods. Search theory, for example, has enabled the military to develop procedures to minimize time loss and maximize the chance of success in a search for missing airplanes. The essential characteristic of search problems is the *need or desire to find something*, and the objective of search theory is to maximize the chance that you'll find what you're looking for with a minimum expenditure of your resources (men, money, time, etc.).

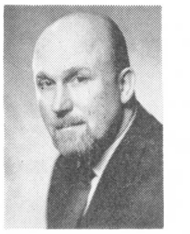
Of course, not all such problems are exactly alike. The overall strategy (allocating search effort most effectively) must be varied a bit to apply to differences in the object sought, to differing probabilities that the target can be found and recognized, and to the different ways in which an object can be concealed or stored.

In some cases, the object sought is not even known. The company seeking new customers, for example, may not know their identity and location in advance. It will then be necessary to define the criteria for a desired customer: how much buying power he must have, how good a credit risk he must be, how likely he must be to make repeat purchases, etc.

Another variant is target mobility. If the object sought is stationary, or nearly so, and on a single surface, the search can be fairly simple. The searcher sweeps the area in concentric circles or in parallel lanes. If the target is not limited to a surface (as a ship is) but can move in three dimensions (as an airplane can), the mathematics can become quite complex. If the target moves, the direction and speed will increase or decrease the chance of spotting the target at any given observation. Therefore, the probability that the object sought will be in a specific location may determine how the search should be structured: If a neighbor's bitch is in heat and your male dog gets loose, where do you look first?

Then there is recognition probability. Three naval aviators survived 34 harrowing days on a rubber raft in the Pacific during World War II. Ironically, a search plane passed within a half-mile of them the morning after they were

ROBERT C. WEISSELBERG is manager of management sciences at EBS Management Consultants, Inc., New York. He holds a BA degree from City University of New York and has done postgraduate studies at Georgetown, American, and New York Universities. Mr. Weisselberg was systems manager at Long Island Lighting Company and McGraw-Hill and administrative director for Management Assistance, Inc. During his career, Mr. Weisselberg also has been editor in management subjects for the Research Institute of America. JOSEPH G. COWLEY is managing editor for the Research Institute of America in New York. He received both his BA and his MA from Columbia University. Mr. Cowley's career includes selling, writing, and teaching on a college level. He is a member of Mensa and the American Marketing Association.



. . . as a replacement. And a missile malfunction, of course, demands finding the exact defect.

downed. Evidently the tiny raft, orange-yellow in color, was obscured by the reflection of the morning sun on the water as the search planes headed east, and they failed to see it.

Failure to observe a target, or to recognize it when it is seen, is an error many people cannot understand or tolerate. Yet it occurs. In auditing, the problem of recognition errors is difficult to overcome—more so than sampling errors. The sampling error can be avoided by proper statistical methods, such as use of an adequate sample, well dispersed. But physical and psychological factors may prevent an auditor from realizing that he has come upon the object of his search.

Also, assuming that you can locate the target and you do observe it as having the characteristics of the object sought, can you positively identify it? The hold-up victim may be able to point out the suspected robber from a police line-up—but will the identification hold up in court if, say, the suspect can produce an identical twin?

Some search problems demand only finding a reasonable object. The salesman who loses an order from Customer A but manages to bring in a new and better account, Customer B, may keep his sales manager happy. But other searches require finding one specific, *unique* object. The parents whose toddler wanders away at the beach, for example, won't accept just any youngster the lifeguards find. And a missile malfunction, of course, demands finding the *exact defect.*

A complex variant of the search problem is information storage and retrieval. Any library is a storage device from which a document may be retrieved; so is a file cabinet. Whatever form it takes, the information retrieval system consists of two main activities: *file,* and *find.* Simply stated, *A* places information *B* in storage location *C* to be found by *D* for future use. Until now, we have been concerned with the second half of the search problem, the *find* portion: How does the searcher, *D*, find the object or target, *B*, in the search area, *C*? We now wish to look at the first half, the *file* portion: How does the originator, *A*, store information, *B*, in a place, *C*, in such a way as to maximize the chance that it can be found at some future date by persons unknown and for purposes unknown to the originator?

But information is a difficult commodity to classify, store, and later find. It changes with the person handling it. Let's suppose that the originator is a scientist conducting a research experiment. His findings may be of interest to other scientists, now or in the future. So may his research technique. He is willing to report his findings, possibly because he hopes to help future mankind, possibly because he wants recognition, and possibly because publication will enhance his professional status. Whatever his reason, there may be a communication gap between the research as conducted and as described. A document indexer now reads the report and classifies it as he sees it, using his concept of the significant descriptive terms it contains (*U*, *V*), and also according to a term describing the technique used (*W*). Because the indexer's thinking is different from that of the scientist, these descriptors do not perfectly portray the information in the report, much less the complete research as conducted. However described, the document is stored according to its classification, to await future inquiry.

Some time elapses, years perhaps. The potential user of the information now appears, unaware of its existence. He is looking for any previous research about a subject he describes (in terms *U*, *X*, and *Y*) or about a technique (*Z*). Again, there may be a gap between his need for information and the terms he selects to define his need. Fortunately, the system provides a cross-index that relates two of the descriptors sought (*U* and *X*) with the document descriptors (*U* and *V*), and the paper is retrieved.

The terms used to store the document must be not only comparable to terms used to find it later, but sufficiently restrictive to prevent a great number of "false-drops" from cluttering up the search. One of the problems of information retrieval is achieving a balance in using descriptors between those that are broad enough to retrieve a maximum of information and those that narrow the search by eliminating information of marginal value.

Let's assume that you have a problem which you can now identify as "search" in nature. What is the best way to score a bull's-eye on your target?

The first step is to define the search situation:

What are you looking for? How would you recognize it if you found it? Are you looking for some unique item that you can identify or just any item in a class of targets that will meet your need?

What is the nature of the target? One or many objects sought? Moving or stationary? On a surface, or in three dimensions? A tangible item, or something abstract, like an idea? Does it matter *when* you find it—would its value change? Does it make a difference *where* you come across it?

What is the probability that the object sought will be in any given location? What is the probability that you would observe and recognize it?

What is the nature of the search? Are you trying to find the target—or to avoid it? Or do you have an object you want someone else to find? Are you concerned with the search only—or also with the method of storage or concealment that precedes the search?

What are the search resources? Some searches—such as where a life is in danger—may have a time limit, because the value of the object sought drops rapidly with time. Most searches are limited by economic factors: available effort, or equipment, or money. Is there some fixed limit to your search resources?

Determining search method

The second step is to formulate the search method that you will follow:

Is there some characteristic or feature that could localize the area of search? Can you look in some obvious place first?

Can you organize the search in stages? Is it possible to expend varying amounts of effort, in sequence?

Can you segment the search, breaking it down into manageable sections?

Can you utilize some special device or technique to get the job done more effectively?

The next step is to allocate search effort so as to find what you are seeking:

Is the search a simple matter, where you can use common sense to organize your resources?

Or is it a complex matter, of sufficient consequence to call for a mathematical approach? If so, you may need OR technicians to work out the optimum distribution of your search resources. In some cases, the probability of detecting the object sought is a negative exponential function of the search effort density. In other cases, where the effort has already been allocated, you may want to determine the marginal effort required to increase the detection possibility by a certain amount.

What equipment do you need to conduct the search, if any?

Finally, you should know when to terminate the search:

Have you found what you were seeking?

Or have you exhausted your resources without reaching your target? Will you extend the search, at extra cost, or will you call it quits?

Like search problems, information-flow problems can frequently be tackled without recourse to complex mathematical formulas. Yet questions of how data files are to be structured, what information is to be stored, and how that information should flow to the users are essential to scientific decision making. For unless the organization stores basic facts about its operations, it will not be able to conduct the many management, financial, and engineering analyses and the operations researches that are necessary if it is to compete in a rapidly changing world.

Most information needed to support decision making is of three types: routine tactical information (to support manufacturing and sales functions, to bill the customer, to pay employees, to process returns, etc.), routine strategic information (periodic financial statements, regular reports of performance and progress, etc.), and demand information (answers to unanticipated inquiries, special reports on out-of-the-ordinary situations, and special analyses of operations).

Typical information-flow problems facing the executive are how to know what his information needs really are, how extensive the information system must be to meet those needs, how far and how fast he can afford to go in developing the system he needs, and how to design it most effectively. Unfortunately, the people who can visualize the many ramifications of information problems are in short supply, and the temptation to tackle a small piece of the basic problem often leaves the executive with an inadequate tool to support his decision making needs.

One typical information-flow problem is organizing a materials management information system. This is more than just an inventory problem—it is often complex enough to warrant simulation on a computer of the present and future flow of materials throughout an organization, so that optimum quantities are ordered, stored, distributed, and used, so that future materials needs are projected from present usage and expected sales, and so that demand for money to pay vendors is accurately projected.

Three-part approach

Most problems about the use of information are corporate in scope; that is, they must be solved on an organization-wide basis. We shall therefore pass over the problems of how to tackle information flows of a minor nature. A suggested strategy for approaching major information problems contains three parts:

Definition of need: What information is needed to carry out the objectives of the organization, when is it needed, and in what form?

Determination of system: What system, equipment, and organization are required to provide the information needed?

Establishment of implementation plan: What priorities and schedules are required to develop the system, equipment, and organization needed?

Designing the system is essentially a matter of organizing the flow of information most effectively. That is, the design should *minimize* movement of data *into the system* (i.e., it should eliminate duplicate recording of source data). It should *minimize* the movement of data *within the system.* Finally, it should *maximize* the timely delivery of significant information *to the end user.*

The information system can be used as a model itself, to predict what would happen to sales, operations, or finances if a given course of action were adopted.

Such a model is usually called a corporate model, company model, or enterprise model. If it deals primarily with the monetary effects of various alternatives, it may be known as a financial model or economic model. If it is concerned with corporate operations, it may be called a production model, a marketing model, or an operations model. Whatever the name, the nature of the model is essentially the same. The activities of the corporation (or other enterprise) are expressed as mathematical relationships. The various mathematical relationships, along with input data at specified points, constitute a representation of the corporation. This model is used in two main ways: Either the input information is varied (to represent volume changes with time or other factors), or the mathematical relationships are manipulated (to reflect possible changes in the system). In this way, prospective changes can be analyzed through the use of the computer more easily and more economically than by changing the actual activities themselves.

Use of model

The corporate model, therefore, can serve such purposes as the following:

Determining the effect on finances if different levels of production or sales were assumed

Calculating how much capital would be needed, and when, to finance contemplated production

Predicting the effect of changing the prices for products or the rates for services

Determining the need for materials, fuels, etc. to support possible sales requirements or variations in the product mix

Testing the validity of proposed budgets

As a supporting tool for long-range planning.

Developing the corporate model requires knowing the information to be included in the data base, determining the relationships among components of the model, and establishing control points to tie in the information system with the model. Just how effectively a "what if" question may be answered by the model depends upon the level of detail provided in the data base. Thus, the sophistication and depth of the information system are constraints limiting the use of the corporate model.

The corporate model incorporates concepts underlying simulations of specialized business functions, but it is a macroscopic rather than a microscopic model. That is, at one time it looks at the entire enterprise as an integral system.

An extremely valuable economic tool is closely related to information-flow systems. It is input-output analysis, which constructs a model of the flow of goods and services rather than of information. The input-output model is a matrix showing the relationship between the materials and services used as input by the various segments of the economy and the corresponding materials and services produced as output by the same businesses and industries. The input-output model is used in the forecasting process to estimate the various changes in the economy and in pinpointing potential markets for various goods and services.

According to Milton L. Godfrey, formerly of EBS Management Consultants, Inc., input-output analysis can show the direct effect, and also many indirect effects, of various user purchases upon the different segments of the economy. When the consumer buys household furniture, the furniture industry feels the direct effects of this purchase; and in the input-output framework the transportation and warehousing sector, the wholesale and retail trade sector, and the finance and insurance sector would all be directly affected by their components of the purchaser's price. The following example, provided by EBS Management Consultants, Inc., in a brochure on the subject, concentrates on the furniture manufacturing sector itself.

The furniture sector must buy a variety of materials and services in order to produce the furniture. The sectors from which these purchases are made are considered to be affected *directly* by the sale of furniture. A host of *indirect* effects will also occur from the sale of a million dollars' worth of furniture.

Indirect sales effects

For example, there is the purchase of $5,150 of crude petroleum, the purchase of $56,060 of fabrics, the purchase of $1,130 of wood containers, and so on, continuing the list through all the sectors in the matrix. As a result of all these *indirect* transactions, the sectors will themselves make purchases, including possibly the purchase of furniture. Thus, because furniture is purchased by the final consumer, the furniture industry is directly affected; the furniture industry makes purchases from other industries; other industries, in turn, purchase some amount of furniture. Therefore, the total amount of furniture produced by the furniture industry is larger than the amount of furniture demanded by the final consumer, the difference being the demand for furniture that is indirectly generated. In this instance, the sale to the consumer of a million dollars' worth of furniture generates the direct purchase from the furniture industry of $551,000 worth. Then, indirectly, sales are generated for an additional $8,994 worth of furniture, a relatively small amount when compared to the amount of the direct sales.

In other types of products, the dollar value of indirect sales may be large when compared to the dollar value of direct sales. This becomes truer for industries several steps removed from the manufacture of the final product. For example, when a million dollars' worth of furniture is purchased by the final consumer, resulting in $551,000 in purchases at producer's price from the furniture industry, there are $3,875 in sales of refined petroleum products to the furni-

SALE OF PETROLEUM PRODUCTS

Furniture industry	$8,758.00
Other furniture and fixture industry	41.00
Transportation and warehousing	1,132.00
Retail and wholesale	5,480.00
Finance and insurance	10.00
	$15,421.00

ture industry. This figure is directly related to the actual making of the furniture itself. However, because of the activity generated among all the suppliers of materials and services to the furniture industry, an additional $4,883 worth of petroleum is required.

When, in addition to furniture industry activity, the activities in transportation, warehousing, etc. are considered, total sales of the petroleum refining industry caused by the sale of a million dollars' worth of furniture reach a total of $15,421, broken down as in the table on this page.

Thus, for the petroleum refining company, the input-output analysis provides a means for estimating the total demand for its products generated by consumer demand for various consumer goods, of which the demand for furniture is one example.

This demonstration of the computed effects of the sale of a million dollars' worth of furniture to the final consumer shows the new capability provided to analysts by input-output. A relationship between final demand and the sum of direct plus indirect sales of each industry is now available to users of the input-output model.

Thus, the use of input-output adds an entirely new dimension to the forecasting of sales of industrial products. The analyst for an industrial product manufacturer would develop a set of estimates for final consumption of those end products which have significant effects on his company's sales. Using the input-output tables, he would be able to compute the impact of final demand for products marketed by his company and its competitors. When used in addition to present methods for analyzing the trend of customer industries, this procedure usually results in substantial improvements in forecasts of sales of industrial goods.

When to replace equipment, people, financial support, or other resources and how to replace them are common management problems and often not too complex.

Perhaps the simplest is replacement of a single machine. The problem is usually one of timing; when do maintenance and repair costs become so great that replacement of the units is an economy? The decision means finding the optimum point in time to substitute renewed investment in equipment for increasing maintenance and repair expenses—a matter of comparing costs.

The comparison becomes complicated because it is necessary to determine the probability of repair with time. It is also complicated when the replacement equipment is more powerful or sophisticated, or of longer life, than the machine it replaces. However, there is seldom an exact replacement in kind; the neophyte replacing a retiring employee is of a younger generation, probably better educated, and with different social values and a different understanding of the job to be done.

Of course, the comparison may be further complicated by additional alternatives. You may consider, for example, the possibility of reducing maintenance to a bare minimum, using only enough to keep the equipment running and replacing it when it breaks down. Or you may replace certain wearing parts (e.g., the grinding heads on grinding machines), thereby prolonging the life of the total equipment with a minimum expenditure.

Where items deteriorate in value, a more complex problem is the method for replacing groups of them. Take a public utility that is required by law to test its meters every seven years. It has been established that it is easier and less costly to replace a meter and test it in the shop than to test it at its installed location. Meters, then, must be replaced every seven years, or earlier if they fail or if customers complain about meter readings. If a meter is to be replaced (because it is seven years old), what about the next-door meter which is six years and eleven months old? Should cost of travel be considered as a factor in establishing a group-replacement policy, by area? And, if so, how far down in age is it desirable to go in establishing the replacement group?

As with complex machines, the replacement of people requires a period of parallel operation. One does not lose a controller or a plant manager one day and bring in a replacement the next. On the other hand, what is a reasonable period for training a man to replace a key executive?

Most replacement problems, whether of a single item or a group of items and whether of equipment, people, or other resources, require one main strategy: how to minimize the sum of replacement and related costs.

If, for example, we want to establish a policy for replacing classes of equipment that fail at different ages, we seek a solution that minimizes the total of all costs: maintenance, replacement, travel and set-up, money invested, etc.

Replacement studies are primarily cost comparisons; but when more than one level of decision can be made (e.g., set up machine maintenance until complete breakdown; then consider replacing adjacent machines with like ages), other techniques can be applied.