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Decision Making Art – or Science

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DECISION MAKING ART—OR SCIENCE?

Actually, it's a little of each, but the use of mathematical models to simulate business situations makes possible for the first time almost scientific precision in many areas of decision making.

by Clark Sloat and
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Over the past few years, hundreds of business executives have, according to their natures, blood pressure and job security, either suffered through or exulted in playing the "management game." Basically, the management game pits several teams of executives against each other through the medium of a computer. Given certain basic assumptions; size of market, resources available, number of competitors, etc., each team makes certain operating decisions for its hypothetical company. These decisions are fed into the computer, digested and weighed against the operating decisions of the competing teams. The computer then determines just how much each company has improved or worsened its financial strength and feeds the results back to the teams so that they can make their plans for the succeeding quarter. The management game is a simulation of a competitive business situation just as military maneuvers are a simulation of a shooting war.

You, perhaps, are one of the increasingly large number of executives who have subjected themselves to the emotion-shattering experience called the management game. How would you describe it? After eliminating the unprintable expressions, phrases like the following would probably predominate:

- Playing the management game
- Practicing decision making
- Matching wits with your competitors
- Choosing business strategies

These expressions emphasize that the practice of management is an art based upon a combination of knowledge and experience and a feel for the way human beings act in typical business situations.

You may not believe this, but another group—admittedly a different kind of group—would probably describe this experience in quite a different manner—as, for example:

- Understanding the model
- Numerically evaluating alternative choices
- Computing the odds
- Gaming against a competitive model

Those individuals would be stressing the fact that scientific methods of analysis and evaluation can play a very important role in

$$U = C_5 + \frac{C_6 + C_7 M}{1 + C_8 m} + \max\left\{\frac{C_9}{1 + C_{10} v}, C_{11}\right\} + \frac{C_{12}}{M}$$

Formula Used In Management Game To Determine Unit Cost Of Production

making management more effective.

The extremists in one camp would claim that management is pure art; the extremists in the other, that it can be made virtually a science. The moderates, who in our opinion are right, would proclaim that the practice of business management (like the practice of medicine) is a combination of both art and science in which the two mix in varying proportions according to the circumstances of the case.

Perhaps, before proceeding much further, we should properly define one word which has already been used—"model," for the concept of "model" lies at the heart of the scientific approach to business management. A model is precisely what you might think it would be—a representation of reality. A model can assume a variety of forms. It can be physical. Bergdorf Goodman Co., for example, employs models in the limited sense of the word so as to provide madam with a somewhat idealistic representation of what the decision to buy a certain dress might do for her. A company which builds a pilot plant to see how a production process would work is also building a model.

Models need not be physical. As a matter of fact, there are far more models which are not physical than there are of the other type. A balance sheet is a model—a representation of a condition in monetary terms. H_2O is a model representing a molecular relationship of the two elements which form water. Another model is "length times width = area"—a model which is expressed in words. It is, of course, still a model when it is expressed as the kind of mathematical formula which we learned in grammar school:

$$(L \times W = A)$$

It is possible that some clever individual could build a physical representation of your business, although this would not be easy to do. It is much easier to prepare a model of a business or most parts of a business in nonphysical terms —in terms, actually, of mathematical formulas.

A management game (which is intended to represent a hypothetical business) is based on a formula or a series of formulas. This can be proven by the mere fact that the game can be run on a digital computer. We would be disclosing no secrets by citing a few of these formulas:

$$C_o + C_r - C_e = C_1$$

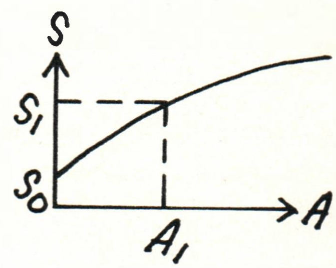
(Cash on hand at beginning of game plus cash received less cash expended equals cash on hand at end of period one.)

$$P = S - G - E$$

(Profit equals sales less cost of goods sold less expenses.)

You may bridle a bit about dignifying or confusing these well-known relationships in this manner. You should not. Formulas are the language of the mathematician and the scientist and they have every bit as much right to their language as you do to yours or, perhaps more appropriately, as your secretary does to her particular brand of shorthand.

Formulas, of course, can express ideas and relationships which are far more complicated than the simple, straightforward linear relationships I have just illustrated. It is a well-known physical fact, for example, that the octane rating of a gasoline can be raised by the addition of tetraethyl lead. But it is also true that the rate of improvement in the octane rating decreases with increasing lead concentration—that is, octane rating does not increase linearly with lead concentration. The same thing must be true about advertising. There must be some change, maybe several changes, in the rate at which advertising produces an increase in sales. One of our more picturesque figures of speech—"skimming off the cream"—indicates just how frequently this changing relationship does occur. The mathematician or the scientist would also have a shorthand way of expressing this more complicated idea. In the particular hypothetical case represented by the graph, it might be something like this:



$$S = \sqrt{S_0^2 + \frac{S_1^2 - S_0^2}{A_1} A}$$

(Advertising increases sales but at a decreasing rate.)

An article written by the developers of one management game provided the incidental intelligence that, at one stage in its development, the formula shown at the top of the facing page determined the unit cost of production.

Both are more complex ideas and formulas—but obviously nowhere near the limits of either. Stated another way, the mathematical formulas keep pace with the complexity of the idea.

We could go on and on and ultimately build up a model which compared at least roughly with the formulas on which the game is based. We could do this by the experience gained in observing what happened in this game and by drawing upon other experiences within and without the business world which we feel are comparable. If we could do the same thing for some part of a particular company or industry and/or the business world in general we would then have a mathematical representation of a real situation.

The limitations; the benefits

Then, all we would have to do would be to replace the letters in the formulas with some numbers and we could tell what would happen under any set of conditions. As you have undoubtedly discovered already, this would be an easy thing to do (1) if you could only figure out why the business acted the way it did in the past, and (2) if you could only feel pretty certain that the business or model would act the same way in the future.

There are several troubles: (1) the relationships both within and without the company are exceedingly complex; (2) the information about what actually happened is in large part inaccurate or incomplete; and (3) there is real uncertainty about the actions which will be taken by yourself and others in the future and the nature of the social, political, economic and physical environments at the time these actions are taken.

Yet, anyone who manages in anything other than a capricious manner must attempt to work out the best estimate he can as to what these facts and relationships were, are and will be. Otherwise he is guessing, hunching and hoping—"flying by the seat of his pants." What the moderate claims he can help management do is not to take over management but rather by the application of some of the techniques of the scientific method to help provide (1) a deeper insight into the nature of business relationships, (2) a better means of assigning values to many of these relationships, and (3) a better means of reducing or at least taking explicit cognizance of the uncertainty which surrounds many business plans and actions. The use of the words "deeper" and "better" was quite deliberate, for the moderate makes no claims that he has either the ultimate approach or the ultimate solution.

There are a number of techniques employed by the scientific approach —far more than can be covered in this paper in sufficient detail to provide any real knowledge of them. Let us, therefore, skim through a number of techniques. First, let us take a somewhat limited although definitely "real-life" problem and show how one mathematical technique called linear programing might be used. It is a very common problem—what is the best way to distribute a product from factories to dealers? If it is common, it is also complex.

The scientific approach would say that you must take into account at least the following:

1. The standard of service you desire to render your dealers and indirectly your ultimate customers
2. Production costs
3. Transportation costs
4. Inventory carrying costs
5. Data handling costs

To simplify matters, let us consider only the second and the third of these.

Let us use some figures, shown in Exhibit I, page 14.

The problem is to determine: (1) how much each plant should produce, and (2) which dealer should be supplied from which plant in order to minimize the sum of production cost and transportation cost.

This is a simple version of the way this problem would appear in most business situations because we have intentionally made it so. Nevertheless, the problem stated is not an easy one. If you attempt to solve it using merely business judgment you will encounter quite a few conflicts. When you try to take advantage of the best freight rates, you will find that you are not loading some of the plants sufficiently to take advantage of their lower cost of production. When you try to take advantage of the full capacity of the low-cost plants, you will find that freight costs are out of line. Further, even when you do the best job of allocating that you know how to do, you will have no specific idea how much better a solution is actually possible.

In any situation of this nature, where you are caught between the devil and the deep blue sea, mathematical methods become valuable in selecting the best, or optimum, course of action.

Let's take a look at how this problem can be solved. Exhibit II, facing page, shows the formula used.

As you can see, the development of this formula does not appear too formidable when it is broken down into its elements and the relationships of the various factors are explained in the words we normally use in our conversations. They are frightening, however, to the non-mathematician when merely presented as a body of symbols. However, through the use of these formulas and with the aid of a large-scale computer, it was possible to solve these rather intricate formulas in less than five minutes, of which fewer than five seconds were required for the actual computing. The answer to the problem is shown in Exhibit III, page 16.

You can do rather well with a pencil and paper with this extremely simple problem. How long, however, would it have taken you to arrive at the optimum answer and how would you have known when you had arrived there?

The optimum solution to this problem was secured through the use of one of the mathematical techniques known as "linear programing." This is a method used to produce the best solution to a problem where the relationships fall into a straight line—i.e., are linear—where total costs vary directly with volume, for example. In the foregoing problem, cost was assumed to vary directly with volume—it was a problem merely of selecting the best out of a number of courses of action. This relationship doesn't always hold true (in real life, it would almost surely not be true even in this case)—so linear programing doesn't solve all problems. In those cases, different types and other forms of mathematics are needed.

Of particular significance in this problem is the fact that the linear programing solution provides two additional optimum programs, i.e., three solutions were obtained, each of which yields a minimum cost schedule. This information could be very useful to management since a particular one of the three solutions might be preferable on some basis other than minimum cost. Perhaps some more or less intangible factors relating to the personalities of the plant managers, for example, might suggest the desirability of choosing one alternate best solution over the others.

An interesting and perhaps not self-evident fact is that one of the major benefits to be obtained from this approach is the determination of the best course of action to be followed when things go wrong—i.e., in a time of crisis. Some companies which have made investigations of what actually happened when a plant, part of a plant or something else became inoperable have concluded quite definitely that they make their big mistakes—and their expensive ones, too—when

EXHIBIT I

WAREHOUSE	MARKET (10# UNITS)	TRANSPORTATION COSTS FROM PLANTS 1	2	3	4	5
A	50M	$.250	$.375	$.375	$.500	$.175
B	250	.175	.250	.325	.450	.140
C	75	.100	.225	.275	.425	.175
D	25	.140	.220	.225	.425	.190
E	30	.195	.190	.150	.400	.220
F	40	.325	.210	.175	.235	.315
G	50	.350	.190	.150	.210	.325
H	200	.290	.190	.220	.125	.240
I	60	.295	.175	.190	.110	.250
J	40	.220	.090	.210	.150	.215
K	20	.450	.200	.175	.175	.340
L	150	.175	.350	.275	.325	.175
M	70	.200	.350	.300	.325	.200
N	10	.225	.375	.325	.350	.225
	1,070M					
PRODUCTIVE CAPACITY	1,300M	250M	300M	250M	300M	200M
UNIT PROD'N COST (10# UNITS)		$10.80	$10.75	$10.65	$10.80	$10.75

EXHIBIT II

Formal Mathematical Statement of Problem

Let

X_{ij} = no. of units of product manufactured in plant $i(i = 1,2 \ldots 5)$ and shipped to market $j(j = 1,2 \ldots 14)$

C_{ij} = unit cost of manufacturing product at plant i and shipping to market j

then

$C_{ij}X_{ij}$ = cost of manufacturing X_{ij} units of product at plant i and shipping this quantity to market j

so that the total manufacturing plus shipping cost to be minimized is given by

$$C = \sum_{i=1}^{5} \sum_{j=1}^{14} C_{ij}X_{ij}$$

Since the market requirements are limited and the plant capacities are likewise limited, it is necessary to include these restrictions in the solution. Thus, let

R_j = no. of units required by market $j(j = 1,2 \ldots 14)$

and

A_i = no. of units capable of being produced at plant $i \; (i = 1,2 \ldots 5)$ then the X_{ij} which minimize the above cost function must satisfy the following restrictions:

$$\sum_{i=1}^{5} X_{ij} = R_j \; (j = 1,2 \ldots 14)$$

$$\sum_{j=1}^{14} X_{ij} \leq A_i \; (i = 1,2 \ldots 5)$$

and finally since negative shipments are not meaningful here we must have that

$$X_{ij} \geq 0 \text{ for all i and j}$$

For the benefit of those who may have forgotten the meaning of some of the mathematical symbols used above:

Σ is a *summation* sign, the limits of the summation indicated by the numbers written above and below the sign. Thus $\sum_{i=1}^{5} X_i$ denotes the sum X_1, X_2, X_3, X_4, X_5, the *index* ranging from 1 to 5.

Finally, the symbol $\leq$ indicates that the left hand side is smaller than or equal to the right hand side; the symbol $\geq$ that the left hand side is greater than or equal to the right hand side.

the unexpected happens. The advantages of the combination of mathematical formulas and computer are that alternative methods can be ascertained rather quickly in an unemotional manner, with a high degree of assurance that the suggested solution is a good one in light of the new conditions.

If we had the space, we could discuss many additional interesting problems using these and other techniques. It would appear more productive, however, to explore a few ideas about probability and statistics since they are extremely important tools in decision making.

In the illustration of how products were to be allocated among factories, certain figures were used for expected sales, productive capacity, transportation costs, etc. For purposes of the illustration, they were considered to represent the future. Would they? We must confess, we are uncertain. To admit we are uncertain is a start but unfortunately it helps little, for we are certain or uncertain in very different ways and different degrees about these items.

Take the figures for productive capacity, for example. How likely is it that the productive capacity will be 1,300,000 units? You might say that, barring strikes and major catastrophes, you are fairly certain that this capacity can be reached, but there is a chance that it would not. If you were pressed long enough and hard enough you might end up with a statement like this:

ESTIMATED PRODUCTIVE CAPACITY	PROBABLE FREQUENCY OF OCCURRENCE
1,450,000 — 1,600,000	1%
1,350,000 — 1,450,000	3
1,250,000 — 1,350,000	90
1,150,000 — 1,250,000	3
1,050,000 — 1,150,000	2
Less than 1,050,000	1
	100%

Let us now look at sales. In most "real-life" situations, you would almost certainly not be willing to rate your ability to estimate total sales (let alone sales by individual areas) with anything like that degree of precision. Something like this might therefore result:

ESTIMATED ERROR	PROBABLE FREQUENCY OF OCCURRENCE
Over by + 30 to + 50%	5%
+ 10 to + 30%	10
— 10 to + 10%	50
— 30 to — 10%	25
— 50 to — 30%	10
	100%

These are probabilities related to our ideas of future events of a somewhat general type. Other probabilities can be developed which are more specific:

1. What is the probable traffic pattern over the George Washington Bridge throughout a day?
2. What is the probable number of customers desiring service in a bank during a Friday peak?
3. What is the probable number of mechanics' requests for tools at a tool crib during various periods of the day?
4. What is the chance that we will be out of stock if we carry a given minimum quantity of a particular item of inventory?
5. What is the probable number of buses which will be out of service on a given day because of mechanical breakdowns, etc.?

What is the significance of probability data? Just this: It helps the businessman to take specific cognizance of the degree to which uncertainty exists and thus to plot al-

EXHIBIT III

OPTIMUM (MINIMUM COST) SOLUTION

		Plants				
WAREHOUSE	**REQ'MENTS**	**1**	**2**	**3**	**4**	**5**
Alternative I:						
A	50,000					50,000
B	250,000	30,000	70,000			150,000
C	75,000	75,000				
D	25,000			25,000		
E	30,000			30,000		
F	40,000			40,000		
G	50,000			50,000		
H	200,000				200,000	
I	60,000				60,000	
J	40,000		40,000			
K	20,000			20,000		
L	150,000	145,000		5,000		
M	70,000			70,000		
N	10,000			10,000		
Plant capacities		250,000	300,000	250,000	300,000	200,000
Unused plant capacity		0	190,000	0	40,000	0
Alternative II:						
L		(70,000)		70,000		
M		70,000		(70,000)		
Alternative III:						
L		(10,000)		10,000		
N		10,000		(10,000)		

Total production cost = $11,503,000
Total transportation cost = 174,325
Total cost = $11,677,325

ternative strategies or a single strategy taking these facts into consideration.

A businessman in the illustration previously cited would be quite likely to consider that a capacity of 1,300,000 units would be available in the next period since this will be true 94 times out of 100 and because in 97 times out of 100 available capacity would equal or exceed 90 per cent of 1,300,000—and could presumably, therefore, be brought up to 100 per cent either by depleting inventories, working overtime, etc. He would therefore, in the absence of specific information to the contrary, be inclined to make his plans on the assumption that the capacity would be available.

Sales estimates are quite a different matter. In 35 per cent of the cases, sales would fall below expectations by from 10 to 50 per cent. Much less "certainty." This would probably lead the businessman to adopt a more cautious policy in producing and stocking items and also to incur the expense of constantly revising his forward sales estimates. More cautious, yes; but how much more cautious? It would depend on the potential loss from overstocking, the potential loss of sales resulting from understocking, the increased or marginal costs of producing additional quantities on an accelerated or emergency basis, etc.

Once again, within the limits of our ability to obtain data, all this can be expressed mathematically and thus an optimum strategy can be developed taking cognizance of the probability that a given set of conditions will occur a given number of times. Statistics thus can help to cope with the risks of uncertainty.

There is one additional fact about statistics which might be mentioned before we leave this unsophisticated and definitely incomplete discussion of them. Many forms of statistics are fairly cold-blooded; they search for normal and abnormal patterns of behavior and often attempt to ascribe them to causes without, you might say, getting excited about it. Statistics is full of words like "random," "stratification," "confidence level," "standard deviation," etc. The way you use statistics may be very warm-blooded indeed, but basically the process itself is not.

This last statement is in fairly sharp contrast with the next subject—game theory—which also involves mathematical statistics. It is a "theory" which states the quite obvious fact that in a situation in which two or more forces are competing for the same goal, the strategy employed by the opposing forces is itself of vital importance in selecting the best strategy to follow. This is just as true whether it be in a game of tennis or in war where each force directly opposes the other as it is when the opponents compete for some third party—such as the customer and his money. Game theory is at the base of the management game.

A good deal of the game theory you have applied has been intuitive. You have taken certain facts, and added certain hunches about what the others might do in the process of deciding how you will play. If you had this game stated as a formula and had the necessary computing capacity available, you could actually compute what your best play would be if your opponents took certain action (or actions within certain ranges). If you then also applied your estimate of the probability that your opponents would take certain actions, you could work out what would be the play which would most often be most profitable for you in accordance with your concept of the situation. You could likewise work out the probable consequences (both favorable and unfavorable) of taking another course of action. There would thus be available a valuable device to sharpen management planning and to reduce the impact of uncertainty on business plans.

The theory of games is, as yet, used relatively infrequently—primarily because the mathematics of such complex situations cannot be satisfactorily handled. Undoubtedly, however, this difficulty will be overcome sometime so that we may expect this theory to play an increasingly important role in business life.

The theory of games is only one of a number of theories or models which are being applied to practical business problems. Among the more well-known theories being put to work on practical problems we might mention:

1. Mathematical programing (which includes linear programing and transportation type models as special cases)
2. Queuing or waiting line analysis
3. Search theory (which is concerned with the development of a pattern of most profitable opportunities)
4. Automatic control theory, which includes the formal considerations related to the "feedback" principle
5. Information theory as it pertains to the gathering, processing and disseminating of data
6. Failure theory as applied to problems involving preventive maintenance policies

Of course, in addition to the above specific types of models, one utilizes directly some very basic mathematical disciplines, such as:

a. Matrices (useful for input-output analyses)
b. Probability and statistics (as we have noted earlier)
c. Higher algebra (including the theory of equations)
d. Differential and integral calculus
e. Concepts taken directly from geometry

and many more, limited only by the nature of the problem and the ingenuity of those responsible for its formulation and solution.

Areas of application

The problems which are now being solved by the mathematical techniques of OR (for this is what we have for the most part been discussing) are certainly not new problems. They have bedeviled the businessman for many years and he has rather successfully coped with them through the application of good judgment. He has produced sound, logical answers to these problems. However, with the assistance of these mathematical techniques, he can normally improve these answers. Generally, if the problem has been carefully studied and the best possible judgment answer supplied, that improvement is not great—often only 5 to 15 per cent, but at times it is less and at times substantially more. This additional improvement, however, can place a company in a far better competitive position and often means the difference between a moderately successful and a highly successful operation, for most of this 5 to 15 per cent is added straight to net profits (or at least to net profits before taxes).

At the present time we must admit frankly that we do not know all of the potential uses for these OR techniques. We do know a good many uses. Let me cite some—stressing once again that we are trying to find the best way to equate a number of interrelated factors.

Inventory control:

Variations in lead period
Variations in item demand rate
Marginal cost of carrying stock
Marginal cost of "ordering" or producing lots of various sizes
Penalty for being out of stock
Exposure to obsolescence
(Inventories can include such things as repair parts, production materials, salable items, airline hostesses, etc.)

Production scheduling and control:

Capacities of machines
Length of production cycle
Cost, etc., of carrying buffer stocks
Influence of lot size on production costs
Breakdown probabilities
Characteristics of demand for product
Cost of emergency production
(Scheduling and control apply not only to factories but also to such "nonfactory" activities as train movements, etc.)

Facility location—production allocation:

Standard of service
Production costs
Transportation costs
Inventory costs
Data handling costs
(The illustration previously discussed at some length is typical of these problems.)

Service facility (men—equipment):

Standard of service—cost of delay
Cost of facilities
(Service facilities include the men and equipment provided for such things as toll booths, teller cages, check-out counters, tool cribs, etc.)

Breakdown protection:

Probability—frequency of occurrence and duration
Standard of excellence
Cost of standby facilities
Cost of maintenance
(Applies to such diverse areas as buses broken down, employees absent, machine tools out of service, etc.)

Effort allocation:

As—Sales effort
As—Product mix
As—Quality control

This is obviously not intended to be a catalogue—only an indication of types of areas in which the techniques can be used.

Simulation, the use of models as an aid to more precise decision making, is so obvious an aid to management that its comparatively recent emergence in business would be surprising, except for one factor. Although the mathematics of decision making is relatively simple, the number of computations that must be made in even a fairly uncomplicated business situation is so intolerable that many of the most valuable techniques could never have been used without the development of electronic computers, which can make millions of simple computations in a second.

The second article in this series will outline the relationship between mathematical management—if we can use that phase—and high-speed data handling.