Volume Title: The Quality and Economic Significance of Anticipations Data

Volume Author/Editor: Universities-National Bureau Committee for

Economic Research

Volume Publisher: Princeton University Press

Volume ISBN: 0-87014-301-8

Volume URL: http://www.nber.org/books/univ60-1

Publication Date: 1960

Chapter Title: Forecasting Requirements from the Business Standpoint

Chapter Author: Charles Holt

Chapter URL: http://www.nber.org/chapters/c6592

Chapter pages in book: (p. 9 - 28)

PART I

Forecasting Requirements from the Business Standpoint

CHARLES C. HOLT
GRADUATE SCHOOL OF INDUSTRIAL ADMINISTRATION,
CARNEGIE INSTITUTE OF TECHNOLOGY

At present, forecasting requirements as defined by current business practice consist largely of a few common-sense generalizations distilled from experience. However, the situation promises to change. Recent years have seen a significant innovation in the form of quantitative decision models. As applied to particular problems, these methods call for specific forecast information. Consequently as their use expands, forecast requirements will become more clearly defined.

In the present paper I shall try to foresee the nature of such future forecast requirements. The analysis will focus on the kinds of information the forecaster is asked to supply and will not deal directly with the methods used to obtain the information.

The Accelerating Use of Forecasts

Before World War I, forecasting by business firms was largely confined to a few firms which forecast their aggregate sales. Later efforts to improve the quality of the forecasts gradually led to the development of market research groups that concentrated on relevant industry considerations. However, the impact of general business conditions was generally ignored, a fact which led to serious errors in 1920-21. These costly experiences revealed the need for improved procedures, and some progressive companies began to establish specialized statistical and economic research groups to engage in general economic forecasting. By the end of the twenties forecasting was well established in the largest financial centers

NOTE: The research was undertaken for the project, Planning and Control of Industrial Operations, under contract with the Office of Naval Research. Reproduction of this paper in whole or in part is permitted for any purpose of the United States Government. The author gratefully acknowledges comments and criticisms of this paper by G. L. Bach, K. J. Cohen, Jacques Dreze, I. T. Ellis, Franco Modigliani, and Martin Shubik.

where interest centered largely on future security and commodity prices. The fact that the severe depression of the early thirties, and the recession of 1937-38, were "missed" by most forecasters provided a further impetus to the formation of full-time, professional forecasting departments.

A survey conducted in 1940 under the auspices of the Graduate School of Business of Stanford University[1] showed that out of a sample of thirty-one large corporations, eight had organized economics or statistical research departments engaged in forecasting external business conditions, while about fifteen prepared detailed sales forecasts for periods up to a year in advance. Even at this late date, however, roughly half of the companies surveyed did not engage in organized forecasting.

The extreme uncertainty which characterized the economic outlook after World War II greatly stimulated the forecasting efforts of corporations. In 1950 the Controllership Foundation surveyed a typical cross section of thirty-seven progressive corporations with activities in the forecasting area.[2] Of these, twenty-nine forecast general business conditions, twenty-six through organized staffs of their own, and three through outside research and advisory organizations. The growth in forecasting activity by business firms has continued to the present. Although many concerns still are extremely casual about their forecasting, it is unusual to encounter a fair-sized firm which makes no provision for it.

Now that forecasts are widely viewed as almost indispensable for business decisions, it is pertinent to ask why the widespread use of forecasting was so long delayed. Perhaps the primary reason was the lack of adequate data on the industry and national levels. It was not until the thirties that the data collection programs of the government began to assume their present form. Also in the early days business managers thought that the forecasts were unreliable and that they could guess as well as anyone—a contention often supported by the facts. The lack of agreement on forecasting methods and the wide diversity in results made agreement on forecasts difficult and hence they were of little use in coordinating departmental activities. Even good forecasts would have been of little use since few corporations engaged in organized planning. Actions tended to be taken in terms of current events rather than future developments. Where forecasts were employed, difficulties were encountered in determining their implications for action. The profusion of variables and the presence of uncertainty posed almost insoluble decision problems when only judgment could solve them.

As time passed some of these limitations diminished. When the more progressive business firms had demonstrated the usefulness of forecasts, competitive pressures stimulated the remaining companies to follow suit.

[1] P. E. Holden, L. S. Fish, and H. L. Smith, *Top Management and Control,* Stanford University Press, 1941.

[2] *Business Forecasting—A Survey of Business Practices and Methods,* Controllership Foundation, 1950.

Current Uses of Forecasts and Their Requirements

The uses of forecasts are now so varied that in many firms hardly a department is untouched by their influence. For example, forecasts are used in allocating sales effort and establishing sales quotas, in budgeting advertising expenditures, in planning that involves sources and applications of funds, in establishing prices that take into account both forecasted cost and forecasted sales volume, in establishing the need for the expansion of plant and equipment, in making purchase commitments for raw materials and components, in guiding product development and research into areas of potentially high profits, and in planning production, inventory, employment, and personnel training.

In addition, the adoption of an official company forecast is sometimes used as a planning procedure. A requirement that all plans be based on the same forecast gives some assurance that the plans will be consistent. Indeed it may be more important that all departments use the same forecast than that the forecast be accurate. Strictly speaking, coordination is required on a planning rather than on a forecast level, but the present form in which forecasts are prepared makes difficult the separation of the two. The "adoption" of a forecast may also serve a control function, but my paper will have little to say on this point.[3]

Despite the many contributions of forecasting to business planning, Solomon Ethe of the National Industrial Conference Board, as recently as 1956, pointed out that while many companies in industries faced with cyclical demands or with long lead-times of production face problems in the control of production, only a few have discovered how sales forecasts can help to solve them.[4]

Frank D. Newbury summarized the present-day thinking of many business managers when he said that they cannot escape forecasting while remaining responsible for a business enterprise—the question every executive faces is not *whether* he will forecast but rather *how* he will forecast. Any organized plan, he concludes, is better than no plan.[5]

Clearly the essential role of forecasts in decision-making is understood, but it is significant that this has not been followed up by a fundamental analysis of the functions of forecasts.

Ethe proposes the following criteria for choosing a forecasting system:[6]

1. Operating executives must understand how the forecasts are obtained

[3] Although the relations between forecasts, plans, and action decisions are becoming increasingly clear, the further problem of controlling an organization so that the actions are carried out has yet to be adequately treated. However, important fundamental research is under way.

[4] Solomon Ethe, "Forecasting in Industry," *Studies in Business Policy*, No. 77, National Industrial Conference Board, 1956, p. 70.

[5] Frank D. Newbury, *Business Forecasting*, McGraw-Hill, 1952, pp. 2–3.

[6] Ethe, p. 74.

and have confidence in the results. One of the chief objections to the more complicated mathematical methods is that an executive untrained in mathematics and statistics cannot understand how the forecasts are arrived at, and therefore tends to doubt, discredit, or ignore them.

2. Obviously the method chosen must result in fairly accurate forecasts—accurate both in the size of the average error and in the number of times "complete misses" take place.

3. The forecasts should be produced with a minimum of elapsed time and with adequate lead.

4. Sales forecasts should be provided in units and product groupings most readily useful to the company.

5. When selecting a forecasting method, a company should weigh the cost and the workload impact on its staff against possible benefits.

Newbury also recognizes the problem of obtaining the confidence of business managers but attributes the difficulty to the lack of forecast accuracy. He points out that engineering methods are often not understood but their results are accepted because their methods are known to "work."[7]

Herbert V. Prochnow presents the following specifications for successful forecasting:[8]

1. *Precisely correct* forecasts are "freakish accidents" and cannot be established as a measure or goal of satisfactory forecasting performance. Mistakes of the past should not lead to even greater future errors because of undue concern about "consistency" and "reputation." In a drive for "pinpoint" results there is serious danger that the basic direction of general business may be lost.

2. Although a forecaster with an above-average record typically is a skilled economic analyst who has a ready command of basic statistics and is aware of the numerous limitations of the data, he must not be afraid to make "estimates" and draw tentative conclusions from fragmentary information.

3. A forecaster needs a wide circle of personal contacts in business, government, universities, and private research organizations, as sources both of up-to-date information and of valuable interpretations.

4. Successful forecasting is a continuous process, involving the constant sifting of new information and statistics to find further support for the current forecast or sufficient reason to modify it. All too frequently business forecasting is done only once or twice a year and largely forgotten in the interim, with understandably poor results.

5. Successful forecasters make a special point not only to use outside

[7] Newbury, p. 21.

[8] Herbert V. Prochnow (ed.), *Determining the Business Outlook*, Harper, 1954, pp. 16-17.

contacts for information but also to check their forecasts with other informed individuals.

6. Successful business forecasting requires the ability to exercise an extraordinary amount of independent judgment, to project reasoned opinions—backed by experience—rather than hopes and desires, to maintain a broad point of view rather than merely that of an industry, company, union, occupation, or political party, and to weigh the different forces at work helping to shape the future course of business.

These specifications and injunctions, based on current forecasting practice, are not without value, but in many respects they are vague. Obviously our present knowledge of requirements for forecasts and forecast methods leaves much to be desired.

New Decision Methods and Their Impact

Since the second World War two developments have occurred which will have a tremendous impact on business decision-making in the future: (1) fundamental research on rational decision-making, and (2) the development of electronic computers. Both developments owe much to government-supported research. Thus far their application has been largely confined to the more progressive companies, but the results have been sufficiently encouraging to stimulate both further research and computer purchases. The time may not be too far distant when competitive pressures will speed the introduction of the new techniques on a broad scale.

OPERATIONS RESEARCH AND MANAGEMENT SCIENCE

Operations research dates back to the Battle of Britain when some scientists were called in as consultants to work on problems of military decisions. The successes of the scientific approach were so dramatic that similar teams were formed in the United States to consult with military organizations. After the war, the interests of the operations researchers shifted to business decisions. While they have not been conspicuous for doing fundamental research on decision methods, they have linked the theoretically oriented people and the practical managers in the business world. Other persons whose basic interests were similar but somewhat broader began to work on "management science." They endeavored to bring to bear on the problems of decision-making the knowledge available from the social and physical sciences and mathematics.

Most of this work could be called work on statistical decision theory, broadly interpreted.[9] The essence of the approach is to quantify a decision

[9] No effort will be made here to acknowledge the large number of contributors to the field.

problem by using the precise language of mathematics to describe the objectives to be sought, the relationships between the objectives, and the controlled and uncontrolled variables—the controlled variables being those influenced by the decision-maker. In its new form the decision problem becomes a mathematical problem amenable to solution by powerful mathematics and computers. This type of analysis has important implications for forecasting when it is extended to deal with (1) dynamic decision problems extending through time, and (2) uncertainty.

ELECTRONIC COMPUTERS

Much of the optimism associated with statistical decision analysis would not exist were it not for the availability of large-scale electronic digital computers. It is easy to transform a difficult problem involving many interacting variables and having repercussions that extend far into the future into a mathematical problem that has no known analytic solution. But even though general solutions may not be available, the powerful methods of numerical analysis may make solutions for particular cases quite feasible by means of electronic computers. And if numerical methods do not solve the problem, a quantitative simulation on an electronic computer may supply information on the key elements involved.

To date business firms have shown their greatest interest in the ability of electronic computers to solve routine data-handling chores. But as time goes by they increasingly will appreciate the computers' power to contribute to the solution of the really important decision problems involved in "running the business."

The beginning impact of these developments can currently be observed at some professional society meetings where a new kind of businessman can be heard discussing production problems in terms of marginal cost, machine capacity in terms of queuing theory, warehousing problems in terms of linear programming models, and decision optimality in terms of computer capacity. The next few decades will see a rapid acceleration in the application of the new methods to decision making.

IMPLICATIONS FOR FORECASTING

In any quantitative decision analysis with a time dimension, the future values of variables are explicitly stated—future values obtainable only by forecasts. *Without forecasts, the decision problem cannot be solved.*

When a quantitative analysis is made of a decision problem, it provides a basis for determining what information about the future is relevant. If the desired outcome (i.e. the decision criterion) is affected by the interrelationship between the current decision action and a future value of a variable, or if the current action influences any future actions which have such a relationship, then the future value of the variable is relevant.

Otherwise the future value of the variable is irrelevant and need not be forecast.[10]

The question of which variables are relevant and should be forecast depends entirely upon the particular decision problem being faced. It must be faced anew in each new decision analysis. The forecast requirements on the time span to be covered, information on forecast errors, and the costs of forecasting also are highly specific to a particular problem.

However, as a result of research on decision models appropriate to particular kinds of decision problems, we know something about the *kinds* of forecast requirements to be expected. Insofar as these analyses anticipate the decision-making of tomorrow, we can infer future forecast requirements.

More Exacting Forecast Requirements

Often the forecast requirements imposed by decision models are more exacting than those governing present practice. A general classification is presented below.

TIME PATTERNS

When the implications for action of a forecast are unclear, there is little point in trying to predict exact fluctuations. However, when they *are* clear, and when the action depends critically upon the time patterns of fluctuations, forecasts must be more refined.[11] For example, purchase and sales decisions by speculating warehouses may depend upon the exact time patterns of buying and selling prices forecasted.[12] The time pattern of price fluctuations is also important in analyses of security transactions subject to the capital gains tax.[13]

Current forecasting practice tends to cumulate variables over relatively long periods. For example, sales are often forecast on an annual or quarterly basis rather than monthly, weekly, or daily. The need for greater precision in forecasting the time pattern is found in several kinds of decision problems:

[10] For a rigorous development of the concept of irrelevance, see Franco Modigliani and Kalman J. Cohen, "The Role of Anticipations and Plans in the Economy of the Firm and Their Use in Economic Analysis and Forecasting," *Studies in Business Expectations and Planning*, Bureau of Economic and Business Research, University of Illinois, 1957, which they summarized in "The Significance and Uses of *Ex Ante* Data—A Summary View," *Proceedings of the Conference on Expectations, Uncertainty, and Business Behavior*, Mary Jean Bowman (ed.), Social Science Research Council, May 1958; see p. 3, Introduction to the volume.

[11] One implication of such a requirement is that we need to refine our analysis of seasonal patterns particularly in the direction of developing the theory of estimation.

[12] A. Charnes, W. W. Cooper, Jacques Dreze, and M. H. Miller, "Optimal Horizon and Decision Rules for the Warehousing Problem," forthcoming.

[13] R. F. Gemmill, "The Effect of the Capital Gains Tax on Asset Prices," *National Tax Journal*, June 1957, pp. 289-301.

1. Sometimes the future of certain variables will be found to be of conditional relevance depending upon the forecast future of other variables. For example, if a product can be sold in two markets, one of which is distinctly more profitable than the other, a forecast of sales in the profitable market will indicate whether or not the total output can be disposed of there. If the answer is positive, the sales potential of the second market is irrelevant. If it is negative, the variable is important and should be forecast. Such a situation would tend to require an accurate primary forecast.

2. How far ahead a forecast must reach may depend on the time pattern forecast. For example, if a short-term sales forecast indicates that plant capacity will be exceeded, a long-term sales forecast will be required to determine whether capacity should be expanded. Unless the short-term forecast indicates such a need, the long-term forecast is irrelevant to the current decision. Consequently, the short-term forecast must be relatively accurate. The same situation occurs when the forecast must be extended until a given action must be made. For example, a warehouser with an inventory on hand, in deciding whether to sell at existing prices or wait for higher prices, will need to forecast prices up to some alternate selling date. Frequently the length of time will depend on the values that the variables may assume in the future. Thus, it may be necessary to forecast only so far as to make sure that certain levels will not be exceeded. If such assurance is not forthcoming, the period must be extended and more detailed forecasting of the time pattern of fluctuations during the added period provided.

3. Some decision analyses indicate that the future values of some variables are relevant only up to definite fixed points in time. As time passes, the forecast period gradually contracts until a point is reached when it suddenly lengthens again. In such a situation a forecasting horizon of fixed length might not produce the needed information. Some business firms forecast their sales to the time when inventory will be at its minimum level and the danger of run-outs the greatest. That forecasting to such an inventory "crisis point" is best was clearly demonstrated in a number of production and inventory control decision analyses.[14]

NUMBER OF FORECASTS

Currently many decisions are made by clerks by common-sense methods, with no clear distinction between where the clerk's forecasting leaves off and his decisions begin. For example, in deciding how many of a particular product or part to order in any particular month, a clerk may check

[14] Franco Modigliani and Franz E. Hohn, "Production Planning Over Time and the Nature of the Expectation and Planning Horizon," *Econometrica*, January 1955, pp. 46-66. Also A. Charnes, W. W. Cooper, and B. Mellon, "A Model for Optimizing Production by Reference to Cost Surrogates," *Econometrica*, July 1955, pp. 307-323.

the storage bin to gauge how many units are on hand and then look at the sales record to see how many units were sold in recent months; on this basis he "forecasts" and also orders. The making of any one such decision would be of little consequence to a large firm, but the sum of all these judgmental decisions by clerks may virtually run the factory. Thus improvement in the quality of minor decisions and their coordination with more vital ones is a matter of great importance for business organizations. Quantitative decision analyses on this level will greatly increase the number of forecasts that are required. They will probably be supplied by relatively simple formulas, but they should also be consistent with the aggregate forecasts which are being used for decisions higher in the organization.

THE FORECAST OF RELATIONSHIPS

Not only will forecasts be required for particular variables, but the relationships between variables must also be forecasted. This is readily apparent in situations in which there is an interaction between the company's actions and the values that relevant variables will take in the future. For example, to price a product, a company must take into account the effect of price on sales volume. Here the forecaster is essentially asked to produce a demand curve.

The separation of the uncontrolled variables from the controlled considerably clarifies the job of the forecaster. Currently, when a sales department is asked for a forecast of dollar sales, it is being asked in part to anticipate the price and sales promotion decisions that higher management will make—presumably on the basis of the sales forecast. This lack of separation of the controllable from the uncontrollable partly explains the phenomenon of sales forecasts being officially "adopted" by a top level management committee of the operating departments. Such a "forecast" is part forecast, part plan and decision, and part a control commitment to put the decision into effect. To the extent that the forecaster can meet the exacting requirements of supplying forecasts of relations, it will be possible to separate forecasting of the uncontrolled variables from these other functions.

PROBABILITY DISTRIBUTIONS OF FORECAST ERRORS

Although forecasters are well aware that they do not and cannot make perfect forecasts, and although statisticians have emphasized errors of estimate, it is still a rare forecast that carries with it an estimate of its probable error. With the advent of decision models that include analyses of risk, some information on probable forecast errors is usually essential to weigh the risks and obtain an optimal decision. The exact information required will vary from problem to problem. For example, a decision model for scheduling heating oil production requires that the probability distributions of sales forecast errors be estimated.[15] If a buffer stock is carried as a hedge against forecast errors, an estimate is required of the upper tail of the sales forecast error distribution. Where the forecast horizon depends upon the delivery time, the relationship between the size of the forecast error and the forecast horizon may have to be estimated.

FORECAST PERFORMANCE AND COST

Some decision analyses become sufficiently refined to require estimation of the relationship between forecast errors and the resulting cost of worsened decisions. Also the costs of producing the forecasts by alternative methods are needed. By considering the costs of both the forecast errors and the forecasts themselves, a firm can select the best method of making forecasts for a particular decision. Only in the context of a complete decision analysis can this problem be treated adequately. Unfortunately the determination of the cost of forecast errors is an extremely subtle problem because there are usually several alternative ways of coping with the uncertainty associated with forecast errors.

Less Exacting Forecast Requirements

Most problems involving the time dimension call for a planned sequence of actions. However, only the first step can be translated into action. And plans for the future can be revised if new information develops in the interim. This fact has several important implications in relaxing forecast requirements.

IRRELEVANCE OF MOST OF THE FUTURE

Rigorous decision analyses show that much of the future is absolutely irrelevant to the decision at hand.[16] A decision analysis of great generality goes further to prove that most of the future is irrelevant in deciding a first move for any given level of optimality.[17] Decision analyses may show that the distant future is not irrelevant in that it *does* influence the present decision, but the size of the influence is relatively small. If the cost advantage of the forecast is less than the cost of producing the forecast, the forecast is termed practically irrelevant.[18] This further reduces the variables to be forecast.

[15] A. Charnes, W. W. Cooper, and G. H. Symonds, "Cost Horizons and Certainty Equivalents: An Approach to Stochastic Programming of Heating Oil," *Management Science*, April 1958, pp. 235-263.

[16] Modigliani and Cohen.

[17] A. Dvoretzky, J. Kiefer, and J. Wolfowitz, "The Inventory Problem," *Econometrica*, April 1952, July 1952, pp. 187-222 and pp. 450-466 and a simplified version of the results is presented by J. Laderman, S. B. Littauer, and Lionel Weiss under the same title in the *Journal of the American Statistical Association*, December 1953, pp. 717-732.

[18] Modigliani and Cohen.

In time we will learn the determinants of the forecast horizon, but at present little is known. Some variables may be conditionally irrelevant (either absolutely or practically) unless particular developments are foreseen in forecasting other variables.

REVISIONS

Another implication of the fact that decision analysis need indicate only the best first move is the probability that new information will become available by the time the second move is to be made, which will allow the future to be forecast more easily and cheaply. The question of how often to make forecast revisions can be studied by quantitative decision analysis, but provision also must be made for the cost of replanning on the basis of the revised forecast. There is no gain in getting new estimates unless they will be used.

MINIMIZING THE COST OF ERRORS

A decision analysis includes consideration of the penalties attached to forecast errors, presumably solving how best to prepare for a probable error and to recover from its effects once it has occurred. Precautionary devices, such as holding inventory as a buffer, may be so cheap that there is little need to strive for accuracy.

Furthermore, when a short-term forecast is in error, the decision-maker learns about it quickly and can take corrective steps. Statistical decision analyses and computers facilitate the replanning process. A fast response decreases the penalty associated with forecast errors and further relaxes the forecast requirements.[19] Note that replanning, in some cases, will be profitably done more frequently than reforecasting.

When the cost of forecast errors is weighed against the cost of improved accuracy, the decision may well favor a crude but cheap forecasting method. Several decision analyses that were applied to actual industrial operations tended to bear out this contention, which suggests that business firms should perhaps *first* concentrate on decision analyses rather than on improved forecasting.

STATISTICAL CONTROLS

The application of control procedures similar to those used in quality control may relax forecast requirements. Already, under some systems,

[19] The fast response to forecast errors finds its limiting case where the feedback of information is instantaneous (as is often found in servo mechanisms). Feedback and feed forward (i.e. forecasting) are alternatives in the sense that decision making can be improved by either. This point is developed by W. W. Cooper and H. A. Simon in *Short-Term Economic Forecasting*, Studies in Income and Wealth, Vol. 17, Princeton University Press for the National Bureau of Economic Research, 1955, pp. 352-359.

forecasts are allowed to stand without revision until errors of a certain magnitude occur. Further developments in this direction offer promise of decreasing the cost both of forecasting and of replanning.

Implications of a Production and Employment Decision Analysis

Some of the foregoing points may be clarified by describing a particular decision analysis. Take the problem of planning the aggregate levels of production and employment for a factory to minimize the total of payroll costs, overtime costs, hiring and layoff costs, costs of holding inventory, and the penalty of inventory run outs.[20] When the cost relationships can be approximated by a quadratic cost function, the costs can be minimized by using linear decision rules in setting production and employment. Decision rules calculated for a particular factory were:

$$(1) \qquad P_t = \left\{ \begin{array}{l} +0.463O_t \\ + \ .234O_{t+1} \\ + \ .111O_{t+2} \\ + \ .046O_{t+3} \\ + \ .013O_{t+4} \\ - \ .002O_{t+5} \\ - \ .008O_{t+6} \\ - \ .010O_{t+7} \\ - \ .009O_{t+8} \\ - \ .008O_{t+9} \\ - \ .007O_{t+10} \\ - \ .005O_{t+11} \end{array} \right\} +0.993W_{t-1}+153 = 0.464I_{t-1}$$

$$(2) \qquad W_t = 0.743W_{t-1}+2.09-0.010I_{t-1}+ \left\{ \begin{array}{l} +0.0101O_t \\ + \ .0088O_{t+1} \\ + \ .0071O_{t+2} \\ + \ .0054O_{t+3} \\ + \ .0042O_{t+4} \\ + \ .0031O_{t+5} \\ + \ .0023O_{t+6} \\ + \ .0016O_{t+7} \\ + \ .0012O_{t+8} \\ + \ .0009O_{t+9} \\ + \ .0006O_{t+10} \\ + \ .0005O_{t+11} \end{array} \right.$$

[20] For a complete analysis see Charles C. Holt, Franco Modigliani, and Herbert A. Simon, "A Linear Decision Rule for Production and Employment Scheduling," *Management Science*, October 1955, pp. 1-30; and Charles C. Holt, Franco Modigliani, and John F. Muth, "Derivation of a Linear Decision Rule for Production and Employment," *Management Science*, January 1956, pp. 159-177.

where P_t = units of product that should be produced during the forthcoming month, t

W_{t-1} = employees in the work force at the beginning of the month (end of previous month)

I_{t-1} = units of inventory minus units on back order at the beginning of the month

W_t = employees required for the current month, t (employees that should be hired is therefore $W_t - W_{t-1}$)

O_t = a forecast of units of product that will be ordered for shipment during the current month, t

O_{t+1} = the same for the next month, $t+1$, and so on.

The calculation of these rules from the cost estimates is roughly a five-minute job on an (intermediate) electronic computer. Decisions on production and employment can be calculated in a few minutes simply by inserting the initial conditions and forecasts into the rules. While the rules yield the first period decisions explicitly, there is an implicit tentative plan for future production and employment decisions obtainable if such information is needed for other decisions. I now turn to the forecast implications.

1. The implications for action of the forecasts of future sales (or orders) are clear. If the forecasts change, desirable production and employment will change correspondingly. The rules demonstrate that a decision cannot be made without a forecast of some kind.

2. In an absolute sense the *infinite* future is relevant for the decisions. However, the weights applied to the forecasts decline to very small values beyond the first twelve months, and for practical purposes are irrelevant. The length of the forecast horizon depends upon the particular cost relationships found in a factory to which this decision analysis is applied. The forecast weights decline much more rapidly for production than for employment. By the fourth month the weight for the former is down to 10 per cent of the weight for the first month. For employment this does not happen until the ninth month. Thus production will tend to respond to relatively short swings in forecast sales (the forecast time pattern is important here), while employment will reflect the weighted average of future sales over a fairly long time.

3. When a forecast error occurs the decision rules make compensatory adjustments in production and employment with a minimum of cost. The net effect of previous forecast errors is reflected in the initial conditions (i.e. the inventory and the number of employees on hand at the beginning of the current month, I_{t-1} and W_{t-1}. For example, if sales in the previous month were higher than anticipated, this would appear as a reduction in inventory, which will explicitly influence the production and employment decisions.

4. If uncertain sales are viewed as being drawn from a joint probability distribution, the forecasts that should be used are the expected values of the sales in the future periods. No other information about the probability distribution is relevant to the decisions.[21]

5. An explicit cost function allows the cost of forecast errors to be estimated.[22] The function used in this analysis related total cost for many time periods to linear, square, and cross-product cost components in the following variables: work force, production rate, inventory level, errors in forecasting orders, and actual orders. Eliminating from the cost expression the three controlled variables (work force, production rate, and inventory level) gives a function for minimum cost expressed as the sum of linear, square, and cross-product cost components in actual orders and forecast errors. By using an identity illustrated with the variables x and y,

$$E(xy) = (Ex)(Ey) + \rho_{xy}\sigma_x\sigma_y \tag{3}$$

where E = the mean or expected value operator

ρ_{xy} = their correlation coefficient

σ_x = the standard deviation of x

we can obtain a complicated expression for average cost per period of time in terms of means, standard deviations, and correlation coefficients of orders and forecast errors.

To understand the cost components, we might assume that there were no forecast errors and ask how much costs would be increased by fluctuations of orders about their mean. Then costs would rise by

$$\sum_{M=0}^{\infty} \alpha_M \rho(O_t, O_{t+M})\sigma_O^2 \tag{4}$$

where $\rho(O_t, O_{t+M})$ = the autocorrelation function of orders

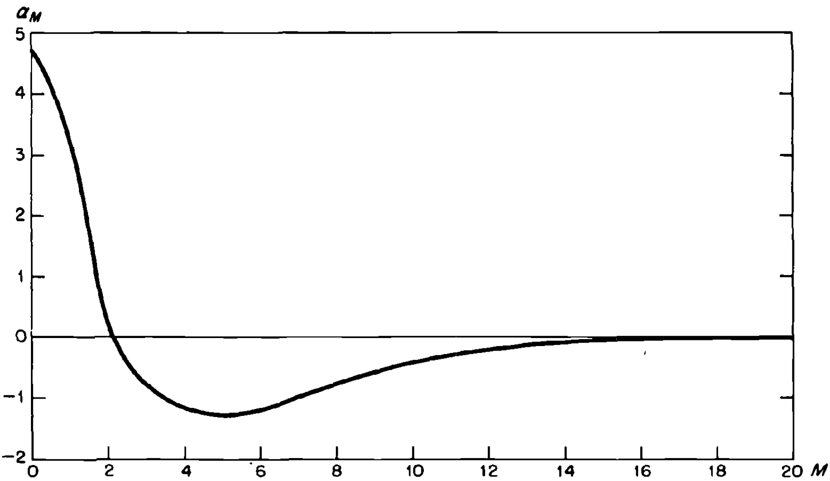
σ_O = the standard deviation of orders

α_M = a constant indicating the importance of the cost component.

The α_M's are dependent upon the cost structure of the factory. For the particular factory studied, the values shown in the accompanying diagram were obtained, indicating that a high correlation between sales of one- and two-period separations would increase costs; for three- through thirteen-period separations it would decrease costs.

[21] Herbert A. Simon, "Dynamic Programming under Uncertainty with a Quadratic Criterion Function," *Econometrica*, January 1956, pp. 74-81.

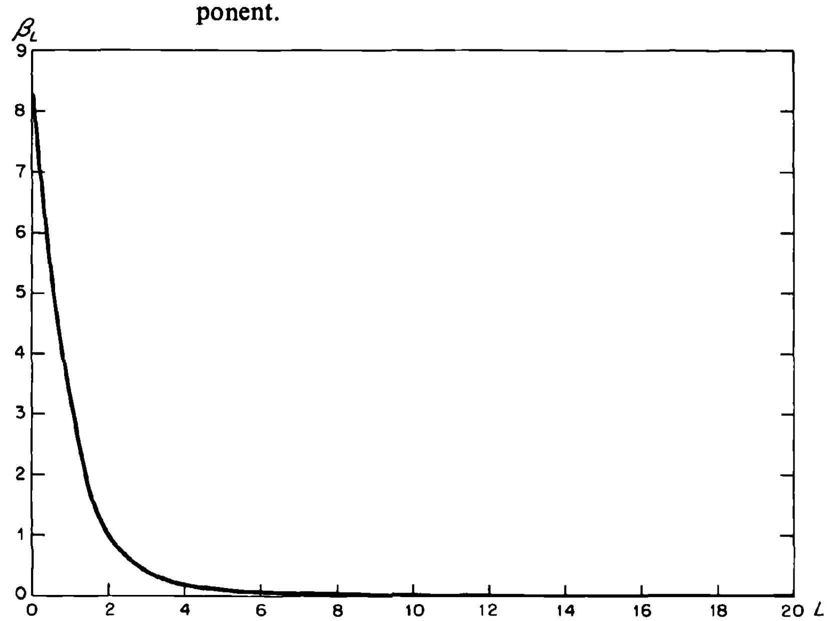
[22] For a more complete discussion of the cost of forecast errors see C. C. Holt, Franco Modigliani, J. F. Muth, H. A. Simon, *Planning Production, Inventories and Work Force*, Prentice-Hall, forthcoming, Chap. 9.



With the costs of these order fluctuations as a basis for comparison, we can determine how much costs would increase if sales did not fluctuate but random forecast errors were introduced. Costs would rise by

$$\sum_{L=0}^{\infty} \beta_L \sigma_\epsilon^2(L) \tag{5}$$

where $\sigma_\epsilon(L)$ = the standard deviation of forecast errors for a lead time L
β_L = a constant, indicating the importance of this cost component.



For the factory under consideration, the values shown in the second diagram were obtained. Note that the costs resulting from forecast errors decline rapidly as the lead-time is extended, emphasizing the relative importance of short-term forecasts. Although there are many other cost components associated with accurately forecast variations of sales and random forecast errors, here they are so small that they can be neglected.

Admittedly the above expressions for the costs of forecast errors are somewhat unwieldy. However, an explicit cost function and the optimal decision rules make possible an easy calculation on a computer to determine the costs that result from decisions based on different forecast methods. By weighing the different costs against the costs of obtaining the forecasts a choice can be made of the best forecasting method for the particular factory.

Conclusion

The approach to forecast requirements advocated here is subject to two different criticisms:

1. Many of the forecast requirements derived from quantitative decision analyses have long been known and even put to use. Thus it is unnecessary and unfortunate to use formalisms such as "statistical decision theory" that are foreign to the practical world of business.

2. While current forecasting and decision-making are largely an art, formal quantitative decision analyses are strictly scientific and the gap between the two is too great to be bridged, especially at the top management levels where unknowns and intangibles dominate the decision problems and judgment provides the solutions.

While there is merit to both points, it does not follow that formalized decision analyses should not or will not be used. Indeed, the fact that many of the conclusions arrived at through formal decision analyses are consistent with the conclusions reached by practicing managers on the basis of common-sense and experience is reassuring. Were this not so the applicability of the new methods would be in question. Formal decision analyses have a potential for carrying further than judgment.

Although the decision problems faced by top level management are the most difficult ones to subject to formal quantitative analysis, the fundamental *qualitative* knowledge obtained from the formal study of lower level decisions is of significant value in making the judgmental top level decisions, and some of the concepts may clarify the issues involved in top level decisions. For example, the notion of relevance may show what variables need to be forecast. Formal decision analyses will contribute to top level decision-making and the related forecast requirements long before they are suitable for direct application at that level.

It is likely that in the future a business executive will not insist on understanding the detailed methods of the forecaster any more than those of the engineer. He will have confidence in forecasts that work, and statistical decision analysis will be his best basis for judging a forecaster's performance.

For economists, the widespread use of explicit forecasts in formal quantified planning and decision analyses will greatly improve the reliability, consistency, and significance of their anticipation data. Finally, by the intensive study of the decision problems faced by businessmen, including the constraints arising from organizational structures and the costs of decision-making, economists should be better able to suggest and verify hypotheses on the relationships between anticipations data and business behavior.

COMMENT

IRA T. ELLIS, E. I. du Pont de Nemours and Company

Charles Holt reviews the scarcity of forecasting before 1940 and notes that even now there is a lack of adequate data at the industry and national levels. He outlines the current uses of forecasts by business firms and also describes what characteristics they should have. For example, the forecasting system should be able to produce timely results given in units and product groupings most readily usable by the company. And he provides a sample decision problem for planning an aggregate level of production and employment for a factory in order to minimize the total cost of production, including payroll costs, overtime costs, hiring and layoff costs, costs of holding inventory, and the cost of inventory depletion.

The paper is largely theoretical. It seems to be more concerned with the detailed planning or control of production than with the preparation of sales forecasts, for example. Yet economic advisers are more concerned with the general business outlook or "climate" within which businessmen must carry out their operations at some time in the future.

His discussion breaks new ground in the general field of decision-making and rationally planned production by top management in a particular company. The author properly notes that there are many other problems at this level besides the preparation or use of forecasts. Upper echelon decisions are not generally made on the basis of mathematical computations alone; much judgment is involved.

MARTIN SHUBIK, General Electric Company

In his paper, Charles Holt attempts to draw the implications which decision analyses hold for forecasting. He presents a highly readable historical discussion as background for his central theme, which is the interrelationship between forecasting, planning, and making action decisions. The incremental cost of information is investigated and its incremental worth in terms of improved decision-making is taken into account.

While Holt does an excellent job of stressing the modern decision theory point of view, there are several points to which more emphasis should have been given. One is sensitivity analysis. Holt discusses the concept of the relevant forecast horizon, the horizon obtained by introducing a concept of reasonable error. He also stresses the need to state the probable error when making a forecast. Both points are special instances of the general problem of sensitivity analysis encountered often in linear programming applications. When we find out whether our results will change much if there is a slight change in a parameter, we can judge the need for accuracy.

Another topic that is not adequately treated is the possibility of using machine methods for contingent forecasting. Holt stresses the importance of separating the controlled from the uncontrolled variables in a decision analysis. However, the latter variables may themselves be sorted according to whether they are, or are not, amenable to statistical treatment. One of the most promising features of the utilization of machines in anticipations work is that it will enable firms to evaluate the implications of a variety of contingencies. After examining the different outcomes, a plan can be selected which seems best under a broad range of eventualities. In this manner more effort on planning may be substituted for more effort on forecasting.

The modern approach to forecasting deals with the interactions between the information inputs and the business as a decision-making entity. As Holt points out, it is vital to compare continuously the costs of control of decision and information procedures with the costs of changing physical processes (such as the production cycle) and with the costs of improving forecasting. Forecasting and the decision processes are regarded as part of the variable costs of production rather than as elements of overhead.

In the section, "Implications of a Production and Employment Decision Analysis," the change in the nature of the content of the paper may be too great. Holt refers to an article in *Management Science* for the complete analysis of the example quoted. Nevertheless, the change of pace from a more or less nontechnical discussion to the specification of a twelve-time-period decision rule is so large that anyone who has not read the paper referred to is likely to feel somewhat disoriented.

Holt's paper, which bridges the gap between present work in the theory of decision-making and its applications to the problems of businessmen, helps to clarify one of the problems in present economic theory. Traditionally the theory of the firm has been based on the concept of a rational man operating in an environment about which he is fully informed. More recent models, however, have introduced an environment replete with uncertainties. One of the basic problems of economic man in the latter circumstances is to decide how much he is willing to pay for information whose worth he cannot evaluate in advance. Even if he knows what he wants, he still has this problem, and, as Simon and others point out, his goals may not be well defined.

Simon has suggested that the economists' concept of rational man should be replaced by his concept of "satisficing man."[1] I have not yet found a precise statement of the axioms of behavior for Simon's "satisficing" man, but the reading of Holt's paper has suggested one possible operational interpretation which reconciles these concepts and appears to correspond generally to current business practice. The businessman operates in an environment which can best be described as a multivariate system over which he has partial control and about which he has incomplete knowledge. His time is divided between (1) conforming to the system, and (2) improving that part of it which is under his control. The first behavior pattern corresponds to the operations of a "satisficing" man: he does not know precisely what he wants or precisely what his environment is or how he can manipulate it, but he has learned to stay alive in a "satisfactory" manner. As an economic man, however, he may perceive that a change in one or more of the parameters describing his environment would be advantageous. He then instigates a study aimed at changing his methods of production scheduling, forecasting, inventory control, or other procedures. This is a process of adaptive maximization and differs from the straightforward maximization process implicit in most of the theory of the firm, in that uncertainty about environment and goals, as well as the cost of information and decision-making, are explicitly regarded as part of the system.

[1] Herbert A. Simon, *Models of Man*, Wiley, 1957, pp. 204-205.