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SCHOOL OF INDUSTRIAL MANAGEMENT

A MODEL OF PRODUCTION DECISION BEHAVIOR

11-63

Peter D. Fox

Charles H. Kriebel

MASSACHUSETTS
INSTITUTE OF TECHNOLOGY
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I. INTRODUCTION

Decision making and delegation of the authority to make decisions are managerial functions which are basic to the operation of all organizations. Delegation is often effected by "programming" the decision sequence in the form of a decision rule.¹ Usually the rule does not completely determine behavior, since invariably some range of action is left to the discretion of the delegated decision maker. For top management the relative effectiveness of any such established rule will be a function of the complexity of the program, the specified objectives, and the interpretation of these objectives by the delegate in middle management. That is, the success with which the over-all objectives are accomplished will depend on the extent to which the program evokes the desired interpretation by the middle management group. In this regard, the problems accompanying suboptimization within the organization have been discussed extensively in the literature and need no further elaboration here.

In this study, a model is developed which describes some of the decision-making behavior of a manager at an intermediate level in a business organization. The frame of reference selected for the analysis is the production scheduling decision of a shoe box manufacturer. A (linear) decision rule is presented which corresponds to the existing scheduling decision, and a behavioral model provides a mechanism for predicting and understanding the

manager's behavior with reasonable accuracy. The model is not based on standard company costs, but on a particular type of aversion function which evolves from the manager's interpretation of the penalties and incentives set up by his superiors. Performance under the rule is discussed: first, by consideration of optimal behavior for a given loss schedule, and second by evaluating the manager's average behavior in the context of Edward H. Bowman's "New Theory".²

II. PRODUCTION MANAGEMENT ENVIRONMENT OF THE FIRM

The ABC Company is engaged in the manufacture of shoe boxes and shoe box covers. It is integrated backwards to its raw material supply, and the operations include paper and cardboard mills some two hundred miles away. The firm employs 250 people. The product line ranges over some 135 sizes for each set and includes 168 varieties of colors.

The firm's principal marketing areas include New England, New York and the East. While all production takes place at one plant, warehouses are maintained nationally. In servicing small-volume customers the firm employs an agency system of private and independent local representatives who act as intermediary distribution channels.

The demand for shoe boxes is relatively inelastic and is derived from the shoe industry. Since prices are "established" according to industry norms and quality is standard among firms, competition (in the industry) is based almost entirely on a firm's ability to provide steady, rapid service to customers. According to the Plant Manager, who is also the Production Vice-President, production scheduling is the salient factor relating to

the company's competitive position. A large proportion of sales orders come from nationwide customers who rely on many shoe box manufacturers to fulfill their needs. Consequently, a customer will place orders with the firm which provides the "best" service at the moment. As a result, there is a tendency among manufacturers to carry large in-process inventories in anticipation of demand. The size and selection of this inventory at the ABC Company is determined by an inventory control policy of the "s-S" variety, based on a synthesis of sales and treasury department estimates.

III. THE PRODUCTION PROCESS

The manufacture of shoe boxes at the ABC Company consists of three primary processing stages: (1) blanking, (2) printing and labeling, and (3) box forming or assembly. The two major raw material inputs to the manufacturing process are cardboard and paper (either colored, preprinted, or white). The width of the roll of cardboard determines the width of the shoe box size for a particular production run. The blanking sequence is accomplished as one continuous process, and consists of unrolling the cardboard in strips, sandwiching the cardboard between two strips of paper which represent the outside surface of the finished box, and stamping or cutting out the individual boxes.

After the blanking stage, the boxes are printed or labeled as required. In-process inventory is maintained in the form of plain boxes which are later printed or labeled when necessary. The finished orders are shipped from storage as "flat" sets (i.e., the boxes and covers are not shaped) to economize shipping space, and are assembled at their destination, either by the customer or by the manufacturer's agents at their location.

IV. PRODUCTION SCHEDULING DECISIONS

Production scheduling is one of the few decisions of consequence at ABC which takes place on a continuing basis. Although scheduling of the work force might generally be included as a part of this sequence, the Company maintains its direct labor at a constant short run level. When there is slack in the local labor market, new workers can be hired and trained within a week should the need arise. All hourly workers may be dismissed with twenty-four hours' notice; however, in the interests of a sound employee relations program, the firm seeks to stabilize the number of workers on the payroll. Thus, work force decisions are not, in fact, a consideration in the general production scheduling sequence.

Primary responsibility for production scheduling rests with the Production Control Manager. He reports directly to the Plant Manager, but typically consults the Manager only for major exceptions to the scheduling routine. The plant normally operates three 8-hour shifts per day, five days a week. Scheduling is performed for four shifts in advance, the three shifts of the following work day plus the first shift of the day after. Production capacity for the day shift is approximately 12,000 blanks per hour. Normal lead time on the production cycle is five days for an item which is not available from inventory stock, three days for items which require printing or labeling (and shipping) only, and one day for stock items that are already packaged and only require shipping. The estimated production time for an order which is given complete priority on all machines is one-half day, i.e., for an order which must be manufactured and is not carried in inventory. The delivery times promised to customers are of sufficient

length to protect the company from interdependent sequencing problems. The boundaries are flexible enough so that scheduling ceases to be an issue in the sense that it is of continuing concern to management. "Computationally difficult scheduling problems don't arise because those constraints that would create them are removed when they become active."³

The first processing stage, sandwiching and blanking, is the only phase of production which is actually scheduled by the Production Control Manager. The Printing and Labeling Department schedules its own incoming requirements, the second stage in the production cycle, and the third, or box forming stage is obviously not under the manufacturer's direct control. Average machine set-up time during the first stage of production is one-half hour; and set-up occurs whenever the size of the box (or cover) is changed over on the line. Consequently, orders for the same size box are scheduled together to reduce set-up time on individual runs. Normal procedure is to schedule (blinking) machines four shifts in advance, but to insert new incoming orders which require the same set-up into the normal schedule. That is, Production Control tries to schedule between 25,000 and 75,000 items of a given size at one time -- as a general rule of thumb.⁴ When new orders are received after schedules have been prepared, they may be inserted between already assigned orders in the existing schedules before these schedules are forwarded to the production floor. As the size of a particular run approaches an upper limit (75,000 items), there is a decrease in the likelihood of fitting in an additional order without substantially disrupting or delaying the previously scheduled items which follow the run.

Orders are received by Production Control from either of two sources: (1) a direct incoming sales order from a customer for an item not carried in inventory, or (2) from the Inventory Control group for stock items which have been depleted below their reorder point. The sum of these two inputs on any day constitutes the exact requirement to be scheduled by Production Control. Smoothing of the impact of sales fluctuations on production and inventory levels is predetermined for the scheduling decision by the selection of standard inventory items and the incoming orders from Inventory Control (as discussed earlier). Thus we may represent the Manager's programmed (linear) decision rule as:

$$P'(t) = \sum_i P'_i(t) = \sum_i \left[\tilde{O}_i(t) + K_i(t) \right] \quad [1]$$

where $P'(t)$ represents the normal scheduled run for all items on day t ;

$\tilde{O}_i(t)$ represents the actual incoming direct sales orders for item i (at the beginning of day t);

$K_i(t)$ represents the size of the Inventory Control production order for item i in day t .

$$K_i(t) = 0 \quad \text{for all items } i, \text{ such that } (I_i(t) - \tilde{O}_i(t)) > s_i \\ = \tilde{O}_i(t) - I_i(t) + S_i \quad \text{for } (I_i(t) - \tilde{O}_i(t)) \geq s_i$$

where $I_i(t)$ represents the amount of item i inventory in existence at the beginning of the day, and

s_i, S_i are the Sales-Treasury estimates of the lower and upper control levels for item $i, 0 \leq s_i \leq S_i$.

The most basic decision of the Production Control Manager is whether or not to insert an incoming order into the existing schedule. The existing order normally will either be inserted into this schedule, or scheduled for the following work day. We define the dependent variable Y as equal to zero for an order which could have been inserted but was not, and as equal to one for an order which has been inserted. Thus, for total production defined as:

$$P(t) = \sum_i P_i(t) \quad [2]$$

the actual scheduling decision rule for each item i is:

$$\begin{aligned} P_i(t) &= Y_i(t) \cdot P_i'(t) + (1 - Y_i(t-1)) \cdot P_i'(t-1) \\ &= Y_i(t)P_i'(t) - Y_i(t-1) P_i'(t-1) + P_i'(t-1). \end{aligned}$$

The Production Control Manager will select various values of Y_i (i.e., either 0 or 1) for each i during the period or day t, according to some priority reference and his loss schedule for the system.

1. Scheduling Priorities

The Manager's goals in scheduling are twofold: "to get customer orders out on time," and "to keep set-up costs low on the blanking machines." The scheduling priorities assigned by Production Control by and large depend on when the order was received; i.e., scheduling is typically on a "first come first served" basis. Occasionally, an order is advanced if the customer has requested "rush" service and Production Control feels that the request can be reasonably granted. All orders which are designated "rush" by the company are given top priority, if at all possible. Some priority preference

(although not formalized or explicit) is also made for regular or large volume customers, particularly if they are also customers of competitors.

Besides "rush" classifications, one other major consideration may enter into the scheduling priority system. At times the workload in the Printing Department reaches a low volume. When this occurs, Production Control gives preference to those orders which require immediate printing or labeling after the blanking operation. Orders which utilize pre-labeled paper or boxes which are to be held in in-process inventory will, in general, be assigned a lower priority under these circumstances. This latter category would include a substantial number of boxes which are processed with white paper and held in large quantities as in-process inventory.

From this discussion it appears that the elements of the priority system, which might influence the decision of whether or not an order is inserted, include:

- X_2 - the size of the scheduled run for the item, or the "group size".
- X_3 - the "size of the particular order under consideration".
- X_4 - the "repetitiveness with which the Manager expects to reschedule the item on a production run," based on historical performance.
- X_5 - the "preference (priority) 'label'".
- X_7 - the "size of the Printing and Labeling backlog".⁵

While undoubtedly there are several other elements which may enter into any specific decision, the Manager generally agreed that these factors represent the primary elements of influence.

It may be recalled that Production Control keeps track of each order as it passes through its various stages from the time of receipt to the time it is shipped. However, the information reported back to Production Control does not enter explicitly into the insertion decision process.

2. Model Specification

The first step in defining the model to be formulated involved specifying the values for the variables where these values were not self-evident. The dependent (discriminating) variable Y is set equal to 0 for a "no" and 1 for a "yes" decision. X_2 and X_3 are defined in terms of thousands of boxes or covers ordered. The variable X_4 assumes one of 5 integers for each observation; the code integers correspond to the following order cycles: 5 \equiv every day, 4 \equiv every two or three days, 3 \equiv once every week, 2 \equiv once every two weeks to one month, and 1 \equiv once a month or longer.

For simplicity and since some difficulty was encountered in distinguishing between more subtle classifications, a convention was adopted for the "priority" element, X_5 , such that it assumes only three values: 1 for a "delayed" shipment, or an order which would not be immediately shipped after manufacture had been completed; 2 for a "normal" priority order; and 3 for a "rush" priority.

On the basis of the above considerations, data were gathered for the independent variables X_2 , X_3 , X_4 , X_5 , and the corresponding decisions for Y during the course of a given day's scheduling operation. The Manager selected one day during the work week (Thursday) as "typical", and 25 observations were recorded for each of the state variables corresponding to the

Manager's decision. From observing the Manager's actual decisions and from subsequent conversations, it appeared reasonable to assume that the Manager related the factors linearly in effecting a particular decision. As a result a linear⁶ discriminant function was hypothesized for the decision of the form:

$$Y = \lambda_2 X_2 + \lambda_3 X_3 + \lambda_4 X_4 + \lambda_5 X_5 + \lambda_7 X_7 \quad [3]$$

the dependent variable Y serving as an index which differentiated the Manager's respective decisions as a linear combination of the specified priority system. In estimating the λ_i parameters of the discriminant function "least squares" criterion was employed, permitting the analysis to proceed as a simple multiple linear regression. For completeness several alternative forms of [3] were considered as prospective models, the most successful of which is presented below.⁷

Model I

As an initial approximation, the first model of the discriminant function considered included an intercept term. The analysis resulted in the equation:

$$Y = -0.0723 - 0.0086X_2 + 0.0058X_3 + 0.0553X_4 + 0.3465X_5 \quad [4]$$

(0.201) (0.0036) (0.0042) (0.0542) (0.0893)

The variables, X_2 and X_3 , are expressed in "thousands of units". Tests of the discriminant coefficients indicated that X_2 and X_5 are significant at the .05 level, X_3 and X_4 are inconclusive, and the constant term is not significant.

The inclusion of the intercept constant in [4] poses some intuitive problems in interpreting the Manager's actual decisions. Consequently, the next model omits this parameter, and corresponds to a hyperplane passing through the mutual origin of the independent elements.

Model II

The least squares estimation of [3] yielded the model:

$$Y = - 0.0091X_2 + 0.0061X_3 + 0.0496X_4 + 0.3265X_5 \quad [5]$$

(0.0032) (0.0040) (0.0508) (0.0671)

Equation [5] is selected for analysis, because it appears to have greater intuitive value as well as for its value to discriminate. The constant term in [4] is not significant in terms of its standard error, and is very small. Consequently, Model II is examined in the remaining discussion.

The primary test that was employed in determining the discriminating capability of this model was a comparison of Model II output and the actual decisions of the Manager. The procedure for these comparative tests was briefly as follows: for each decision to insert or not, made by the Manager, the corresponding values of the X_2, \dots, X_5 elements were substituted directly into the model and a value for Y was computed. For values of Y "near" zero the output decision was taken as "do not insert", and for Y values "near" one the converse was interpreted. For example, the Manager's decision rule might have been:

$$(Y \leq 0.4) \equiv \text{Do not insert}$$

$$(0.4 \leq Y \leq 0.7) \equiv \text{Undecided}$$

$$(0.7 \leq Y) \equiv \text{Insert}$$

The range of values below 0.4 and above 0.7 were surprisingly accurate with respect to the Manager's actual decision in nearly all instances: predicting the decision correctly in 20 out of 21 cases. More specifically, for the sample of 25 observations, 4 outcomes were in the undecided range and the decision rule in [5] correctly predicted 20 of the remaining 21 outcomes.

The Manager was asked to ascertain, as best he could, average cutoff (or indifference) values for each of the elements in the rule. For the elements X_3 and X_5 these values were approximately determined to be 3 and 2.5 respectively. The cutoff values for the X_2 and X_4 elements, however, were not as readily specified and only "narrow" ranges were given: $50 \leq X_2'' \leq 60$, and $3.0 \leq X_4'' \leq 3.5$ (where X_i'' represents the cutoff value of element i). Substituting in [5] for these X_i'' figures we find that the range of indecision under the rule would be from .4464 to .5654.

We may summarize this discussion by indicating that the approximation defined in Model II can predict a significant portion of the Manager's scheduling behavior with reasonable accuracy. For all computed values of [5] below 0.4 the Manager will not insert the new order into the existing schedule; for all computed values of [5] above 0.6, the Manager will insert. Using 0.4 to 0.6 as the range of indecision instead of 0.4 to 0.7 resulted in accurate prediction 20 out of 22 times. For cases where the computed value falls between the former limits the Manager will decide in accordance with his loss schedule and/or other considerations not explicitly incorporated in [5]. The remaining task is to prescribe criteria for Y values which fall within the nondeterministic range, i.e., $0.4 \leq Y \leq 0.6$.

3. Loss Schedules

As indicated, the Manager expressed an aversion for scheduling small size runs because of the set-up costs involved in changing over the production line. The general motivation is to distribute the fixed set-up charges over as large a particular run as is feasible (the general shape of this cost curve as a function of run size would correspond to a rectangular hyperbola).⁸ Below some lower limit, say L_1 , the Manager supposedly attaches certain "disutilities" to the penalties he incurs as a result of the change-over. For the insertion decision we can describe these "disutilities" by an aversion function which represents the Manager's loss schedule for not inserting.⁹ If for simplicity we assume this function to be linear, the schedule would have an X-intercept at L_1 , and have a negative monotone slope equivalent to the marginal increase in set-up costs (or "disutilities") per unit-X decrease (call this slope $A'_1(L_1)$, and the function $A_1(x)$). By analogy, when the size of a run approaches some upper limit, L_2 , we have seen that it becomes increasingly difficult for the Manager to insert an order into the run without incurring a penalty resulting from a loss in "flexibility". Again, we can describe the "disutilities" of the Manager by an aversion function which represents his loss schedule for inserting. This function, say $A_2(x)$, will have an X-intercept at L_2 , and increase (slope: $A'(L_2)$) positively from L_2 (assume monotonically). We can now define the general aversion function for the insertion decision as $A(x)$ where:

$$\begin{aligned} A(x) &= A_1(x) \text{ for } 0 \leq x \leq L_1 \\ &= 0 \quad \text{for } L_1 < x < L_2 \\ &= A_2(x) \text{ for } x \geq L_2 \end{aligned} \quad [6]$$

An example of one such aversion function with respect to a particular element of the Manager's priority system is indicated in Figure 1 for the element X_2 .

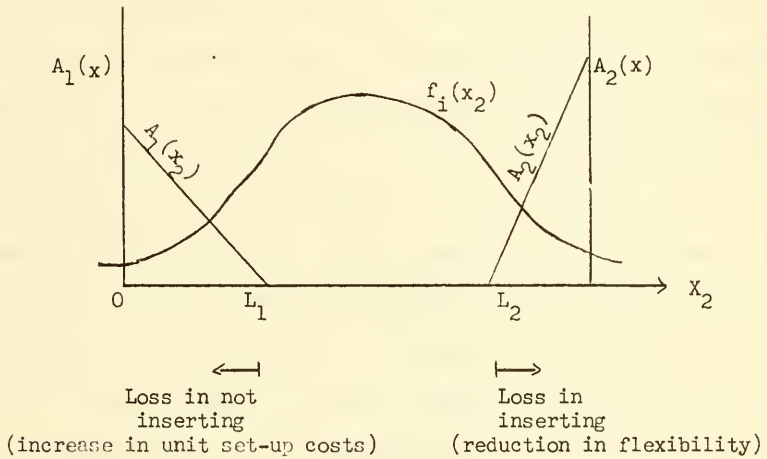


Figure 1

Example Risk Aversion Function for X_2

Although the general discussion leading to [6] has been in terms of the factor X_2 , the remarks generalize to include any X_i of the set X_2, \dots, X_5 . From conversation with the Manager it seems reasonable to assume that the respective $A_j^i(x_j)$ will differ for each X_i .

The criteria we propose to consider in the context of [5] are the respective "cut-off" values of the X_i 's which we call X_i^* . In the framework of optimal decision making we might proceed as follows: (1) Assume the X_i elements to be random variables with density (or mass) functions $f_i(x)$ respectively (see Figure 1). (2) The Manager can be assumed to be a

rational decision maker, and hence would select each X_i'' in the insertion decision model such that it would minimize his expected disutility, $E(D)$, where:

$$E(D) = \int_0^{L_1} A(L_1) dF_i(x) + \int_{L_2}^{\infty} A(L_2) dF_i(x) \quad [7]$$

(We note that the respective L_j values, as the $A_j(x_i)$, might also be a function of X_i , as indicated above.) (3) Having defined [7] for each day the Manager would (theoretically) compute $\partial E(D)/\partial X_i = 0$, and solve for X_i^* , the value which minimizes [7]. He would then set $X_i'' = X_i^*$, for each i in [5], which would yield an optimal Y for the day, Y^* .

Bowman's "New Theory" would propose that the Manager consider $X_i'' = \bar{X}_i \cong X_i^*$ for each i , where \bar{X}_i represents the Manager's mean behavior, on the basis of historical evidence. Straight forward comparisons of relative performance could then be made directly for \bar{X}_i vis-à-vis X_i^* , and the corresponding Y , by substituting directly into [7] for X_2, X_3, X_4, X_5 , given the individual aversion functions. For the variables X_3 and X_5 , approximations to these cut-off values were indicated previously to be 5 and 2.5 respectively.

V. CONCLUSIONS

In this paper, a model is developed which describes certain aspects of the decision-making behavior of a manager at an intermediate level in an industrial manufacturing firm. The production scheduling decision for which the Manager is responsible is critical to the company's profitable operation. The decision recurs daily and, by design of top management,

has been programmed as a decision rule. However, on closer examination, the Manager's behavior appears to correspond to a different decision rule than that programmed by the company and little of the information provided by the company enters into the Manager's rule to influence his behavior. The behavioral rule of the Manager evolves from the nonprogrammed area of the decision where he has relative freedom of action. The model is not based on standard company costs, but on a particular type of aversion function which relates to the Manager's interpretations of the penalties and incentives set up by his superiors. To the extent that his aversion function differs from the true money costs of the decision, his behavior suboptimizes company performance.

The model provides a mechanism for predicting the Manager's behavior with reasonable accuracy. The discriminant function presented is designed to describe the Manager's mean behavior, in the context of Bowman's "New Theory". The degree to which the company can elicit consistent behavior will determine the relative success of the programmed decision, i.e., the decision rule. Unfortunately as the analysis stands, real cost data are not made available, and thus, where variance in behavior does occur it is not possible to judge whether this variance is "good" or "bad" in terms of the desire by the Manager to optimize some objective criterion, e.g., costs or his aversion function.

In conclusion, the following observations seem appropriate:

1. Suboptimal performance under programmed decision rules may result from at least two forms of "inconsistent behavior":

- (a) behavior which results from discrepancies between the Manager's loss schedule and the company's cost schedule, and

(b) behavior which varies from the Manager's historical average.

2. The regression line developed may be divided into three parts, "yes", "no", and a range of indecision. The results outside the range of indecision are so nearly deterministic (or might be made so by a more complete formulation) that it may be considered unnecessary for the Manager to spend his time making what are, in effect, "trivial decisions". Since his time is limited he is then free to devote greater thought to the range of indecision. Within this range, he may want to see if a preliminary decision is in accord with the "New Theory" output and ascertain more closely whether the variance in question is "good" or "bad", i.e., whether actual behavior is closer to or further from the real optimum compared with the results which would have been obtained had he followed his mean historical behavior as defined by a mathematical model.

3. It would seem possible to define mean behavior which detracts from, rather than adds to, the goals the Manager (or the company) seeks to achieve. An example of this would be someone whose decisions vary with the days of the week because of the Manager's moods. In this instance, the model would describe a situation in which mean behavior itself should be changed.

4. Further research might devote attention to such areas as: relating changes in the derived aversion functions with changes in the penalty structure set up by the firm; introducing alternative characterizations of behavior; and extending the general considerations to paradigms beyond linear decision rules.

FOOTNOTES

1. "Programmed" decisions are those which are routine, repetitive, or procedural as contrasted with "nonprogrammed", novel, or ill-structured decisions. See H. A. Simon's The New Science of Management Decision, (Harper & Brothers, New York, 1960), and C. C. Holt, et al, Planning Production, Inventories, and Work Force, (Prentice-Hall, Inc., New Jersey, 1960).
2. E. H. Bowman, "A New Theory About Managerial Decision Making," paper given at the Conference of Factory Scheduling at Carnegie Institute of Technology's Graduate School of Industrial Administration, May 12, 1961, and published as "Consistency and Optimality in Managerial Decision Making," Management Science, January 1963. Also see E. H. Bowman, "Management Decision Making -- Some Research," Industrial Management Review, Vol. 3, Fall 1961.

Briefly, the "New Theory" presupposes (1) a "dish-shaped" (convex) criterion surface for the decision rule, (2) an awareness by management of this criterion function, and (3) "average performance" in reasonable proximity to "optimal performance" under the existing rule. Since the criterion function is assumed convex, the implication that "average behavior" may not exactly correspond to "optimal behavior" does not appreciably affect total performance in the vicinity of the extreme (optimum) point on the curve. However, actual behavior varies about the point of average behavior; the greater the variation, the higher the decision occurs on the cost curve. Thus, the "theory" hypothesizes, all but minor variations from the average add considerable cost increments and, therefore, markedly detract from total performance.

3. W. F. Pounds, "The Scheduling Environment," paper given at the Conference of Factory Scheduling at Carnegie Institute of Technology's Graduate School of Industrial Administration, May 12, 1961. The company management believes that the response from the customer as a result of improved or deteriorated service would be immediate.
4. The determination of these "limits" by the Production Control Manager is discussed in greater detail in the analysis which follows.

The Manager stated that there have been instances where the company has manufactured 250,000 boxes of a given size on one production run (over several shifts), but this is exceptional.

5. Unfortunately, for the two-month period during which the study was conducted, the size of the "printing and labeling backlog", (X₇), was not of sufficient magnitude (in either a positive or negative direction) to yield meaningful data. Consequently, the X₇ element was dropped from the analysis. The authors believe that over several months of operation the impact from this element would be manifest in the decisions.

6. This particularly seemed appropriate after some discussion with the Manager about the loss (and aversion) functions, and how he related these losses in evaluating the elements before deciding. The criterion of "goodness of fit" for the model also appeared to support this assumption, as well as some of the theoretical precedent in the recent research on the behavioral theory of the firm. One alternative consideration, although not formally tested by the authors, was to consider the ratio of X_3 to X_2 and linear relations for the remaining elements. A major factor in the authors' final determination was the intuitive appeal of the linear model in relation to the Manager's reference, versus a potential nonlinear model that may have provided a better fit for the data but a more remote affiliation to our perception of the decision environment.
7. For the following results standard econometric format is employed, e.g., the terms in parentheses appearing immediately below the regression coefficients in [5] and [6] are the respective standard error figures.

One of the alternative models considered involved combining the elements "group size" and "order size" into one "total" class. The rationale for this hypothesis was the premise that the Manager responds to these elements, X_2 and X_3 , only aggregatively, and he is not concerned with the relative magnitudes on an individual basis. A new variable was defined: $X_6 = X_2 + X_3$, and the model was analyzed both with and without a constant term, but these results were generally disappointing.

8. The company management was extremely secretive about actual cost figures. Apparently, policy directives from the parent corporation prohibit even partial disclosure of this information. As a result the discussion is phrased in terms of a hypothesized aversion (loss) function for the Manager. If we further assume that this function agrees with the actual costs involved (or synthesis of these costs), the discussion dealing with actual figures would be identical, i.e., for $A(d) \equiv C(d)$. For the function on the lower limit this assumption would appear to be highly justifiable, i.e., set-up costs \approx cost of not interpolating.
9. The considerations are in the same vein as the work by: E. Mansfield and H. Wein, "A Study of Decision-making within the Firm," Quarterly Journal of Economics, LXXII (1958), H. A. Simon, "A Behavioral Model of Rational Choice," Quarterly Journal of Economics, LXIX (1955). The existence conditions for aversion functions can be found in J. Marschak, "Rational Behavior, Uncertain Prospects, and Measurable Utility," Econometrica, XVIII (1950).

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