MODELING AN INVENTORY CONTROL SITUATION:
THE APPLICATION OF A PROTOCOL METHODOLOGY

Donald G. McGregor and James W. Kho
California State University, Sacramento

ABSTRACT

In simulating industrial systems, classical models assume the availability of probability distributions to describe stochastic processes. In the real world, such distributions, theoretical or empirical, are not always readily available. For inventory systems with stochastic demand, factors in the business environment such as consumer market, suppliers, buyer behavior, competition, and time constraints may change drastically over a period of time. The relationship of these factors and their relative impact in a given business situation is often represented by an intuitive approach to business decision-making.

A systematized rational model constructed around these factors is offered here to suggest that an effective computer inventory control model can be constructed using a system patterned after human decision-making processes. The protocol technique commonly used in building models simulating human decision behavior is employed. As an experimental problem, a simulation of a university textbook management system is undertaken. A significant phase of the experiment involves the simulation of the manager's decision-making process. The resultant model is validated by statistical tests, and has proven successful in this application.

INTRODUCTION

With the advent of computer technology, the use of digital simulation techniques has gained widespread acceptance as a powerful and versatile tool for the analysis of complex systems. Various simulation models (as in 1, 2, 3) have been developed and employed in the study of inventory systems. Implicit in classical models of inventory systems are the following assumptions:

1. Predictability of demand. If demand can be predicted with certainty (deterministic demand), an operating policy can be developed that will restrict the magnitude of stock-out to any desired level. If demand can be predicted only in a probabilistic sense (stochastic demand), the development of an appropriate operating policy is contingent on the availability of a density function that describes demand.

2. Known procurement lead time. As demand, lead time may be a constant or a random variable. Naturally, the analysis of inventory systems with probabilistic lead time involves greater complexity.

3. Computability of pertinent costs. Cost obviously is the most significant factor in determining an operating policy for a system. Carrying charges include lost return on investment, cost of storage, insurance, and inventory taxes. Other costs are ordering cost, lost sales, and cost of maintaining the operating policy once it has been established. The cost of lost goodwill is difficult to estimate, but lost goodwill can result in lost future demand.

4. Absence of other constraints. Models of both reorder point and periodic review inventory systems generally assume normal operating conditions. Often ignored, constraints on an inventory system do exist however and have significant effects. Prevalent restrictions include investment limits, storage facilities, quantity discounts, seasonal demand, and multiple item inventories.

The classical inventory models are certainly applicable to a wide range of cases. However, in the real world, one or more of the aforementioned assumptions are often invalid. Some prevalent examples are

* Seasonal and cyclic demand. For example, demand for snow skis is obviously different in December than it is in May. In addition to the seasonality factor, there is often a trend in the demand from year to year.

* Fickle consumer market. Consumers' tastes change drastically, sometimes over only a short period of time. Certain products, such as clothes and jewelry, are more susceptible than others.

* Technological advances. Improvements in technology may make certain products become obsolete. Recent developments in electronics and its impact on calculators present a case in point. Cost of goods may change drastically as a result.

* Uncertain supply sources. The recent oil embargo is a dramatic example. Abundance or shortage of food items is another.

* New competition. Under free enterprise, competition may increase or decrease based on marketing conditions. Its effect on demand is obvious.

Such changes in the business and industrial environment are in fact normal operating conditions in many markets. Where classical inventory models are inapplicable, these changes and their relative impact in a given business situation are often represented by an intuitive approach to business decision-making, that of the inventory manager. His decisions, often more accurate, are based on dynamic factors such as buyer behavior, competition, consumer market, supply, and advertising expenditures.

In this paper, it is suggested that an effective computer inventory control model can be constructed using a system patterned after human decision-making processes. The protocol technique commonly used in building model simulating human decision behavior is employed here.

PROTOCOL METHODOLOGY

The protocol technique (4, 5) is essentially a highly structured interview procedure in which a modeler attempts to obtain an organized and objectified description of an individual's decision behavior in a decision problem. Certain assumptions about the nature of human thought processes are implicit in the application of such a methodology:

1. Individuals are capable of organizing their thoughts and of applying structure to their decision behavior.

2. Complex human decision processes can be conceptualized as a network of simple decision branches.

3. An individual under a constant set of conditions will act consistently in making simple decisions.

The complexity of the actual implementation of the methodology may vary greatly between modeling situations dependent upon the extent to which the human decision maker modeled is capable of structuring the decision process and the extent to which the modeler has knowledge of the parameters involved in the decision problem. In any event, the following format or some variant of it is applied.

As a first phase, an initial interview is held with the decision maker to be modeled. This interview is generally for the purpose of identifying the decision problem as the decision maker views it and to establish an initial notion of the parameters involved and their interrelationships. The interview generally focuses on the following points:

1. Decision criteria. Included here are the outcomes desired from the decision process and the constituents of a "good" decision versus a "bad" decision.

2. Decision environment. Conditions under which the decision is to be made. Included here are the environmental conditions, business or otherwise, in which the decision maker operates. These generally set the parameters or factors to be considered in the decision process.

3. Relationships. Included here are the order of consideration of the parameters by the decision maker in the decision process, and the extent and nature of their interrelationships.

In fact, the protocol methodology in its entirety deals with these three facets of the decision problem. The application of the methodology attempts to progress from a simple description of each to a more complex and detailed account.

Following the initial interview phase, the decision maker is presented with a number of decision problems. These problems may be actual problems from the business situation or may be simulated real-world problems of a fictitious nature. Both types may be employed. Presentation is done in a highly structured interview setting. Typically, transcriptions of the interviewer/interviewee interactions are made.

Constraints are placed upon the decision maker in terms of type and amount of information permissible for each decision problem. Decision problems presented should permit consideration on the part of the decision maker of only such information as was obtained from the initial interview. This procedure has the effect of causing the decision maker to review carefully the decision process and to apply a degree of structure to the thought processes involved. As a result, his view of the decision process may be clarified and additional considerations previously unthought of may be perceived. For the modeler, this methodology causes the decision process to become revealed in an organized and structured manner somewhat under the modeler's control.

The particular design of both phases of the protocol methodology are determined by the decision process to be modeled and the needs of the modeler. The choice to apply such a methodology is determined by the lack of applicability of other previously discussed modeling techniques. Both the appropriateness of the choice of a protocol methodology and the design of a protocol methodology can best be seen through case study.

CASE STUDY

The case chosen for study here was that of an inventory manager for a university bookstore. This individual was responsible for the inventory control of all textbooks stocked by the bookstore. Prior to each semester, the inventory manager received estimates from each faculty member of the projected number of texts expected to be required for each textbook title used. The estimates were provided in advance of each semester to permit sufficient time for the ordering and shipping of stock from suppliers. At the end of each semester, unsold stock of titles to be used in the succeeding semester were retained as inventory. All other stock was returned to the suppliers subject to constraints in quantities returnable and credit allowable.

Past history had indicated that instructors' forecasts of consumer demand were generally unreliable and in excess of actual sales. In order to meet the constraints imposed by suppliers on allowable returns of overstock and to minimize shipping costs assumed in such returns by the enterprise, the inventory manager was required to modify instructors' estimates of demand. This tact was thought by the inventory manager to provide a more realistic estimate of the sales to be expected for a given textbook title. Ideally, such a modified estimate of demand would equal actual sales, with overstock resulting in the possibility of costly returns and understock necessitating reordering, resulting in possible loss of goodwill. Such was particularly the case when reorders could not be filled before semester termination.

This situation presents an interesting problem for simulation modeling. Though the decision-making task faced by the inventory manager in this case is seemingly adaptable to a classical modeling approach, few of the assumptions of such an approach could reasonably be met. Actual consumer demand was not generally predictable either deterministically or stochastically. Popularity of courses varied greatly contingent upon semester, course, and instructor. Typically, a large number of suppliers were dealt with; each with differing shipping times, returns policies, and billing policies. As a result, each textbook used in a given semester was considered individually by the inventory manager and an intuitive judgement made as to the number of texts to be ordered. Since a classical approach was deemed inappropriate in light of these considerations, a rational model of the decision behavior of the inventory manager in making modifications to instructors' estimates of buyer demand was constructed via a protocol methodology.

Application of the Methodology

An initial interview with the inventory manager established an overview of some basic parameters considered in the decision problem. A listing of the parameters was randomly ordered and each given a number. A second interview was held. During this interview the inventory manager was given a list of the parameters. The interviewer also had a list of the parameters along with the values of the parameters for a number of textbook titles drawn from inventory records.

The inventory manager was instructed to make modified estimates for each of the textbook situations. He was permitted to request the value for any parameter on the list one at a time. Information not on the list could be requested only if it was added to the list as a parameter. Note was made of the order in which the parameters were requested for each decision situation. Tape recording of the verbalizations by the inventory manager gave insight into the relationships between the parameters. Following the interview, the protocols were evaluated to determine the basic structure of the decision flow and to establish decision branches. Eleven parameters requested consistently in the protocols were given priority in consideration as choice points for the decision flow:

1. Volume of instructor's estimate.

2. History of previous usage.

3. Volume of instructor's estimate for previous semester.

4. Volume of modified estimate for previous semester.

5. Volume of reorders for previous semester.

6. Actual sales for previous semester.

7. Department in which book is to be used.

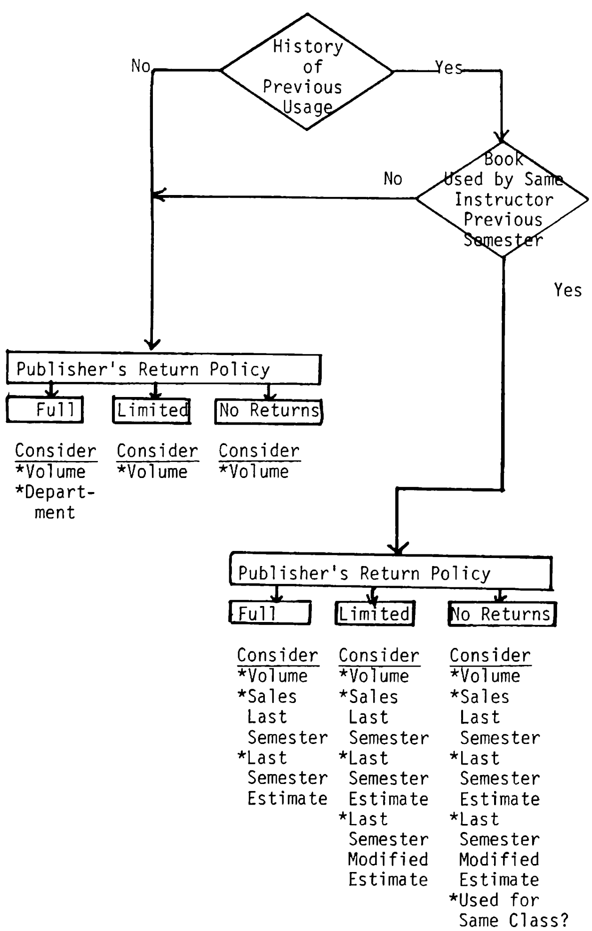
8. Book used in same class previous semester?

9. Book used by same instructor previous semester?

10. Publisher's return policy for overstock.

11. Constraints in reordering from publisher.

In order to establish a reliable basis for constructing a decision flow diagram, a number of estimate modification situations were prepared. These situations were constructed fictitiously in order to observe the relationship between parameters in a somewhat controlled situation. The protocol procedure described above was repeated with the fictitious data. During the interview, values of the parameters for each situation were varied by the interviewer to obtain modified estimates under as many possible combinations of conditions as was deemed realistic. This was done particularly to determine relationships between the magnitude of parameters and the resultant decision flow. Tape recordings of the interview were extremely helpful in objectively reconstructing the modification situations as presented to the inventory manager. Examination of the protocols resulted in the construction of a flow chart briefly depicted in Figure 1.



Flowchart of Case Study Model

Figure 1

The existence of a history of previous usage was considered by the inventory manager as being extremely important in the estimate modification process. In the absence of a previous history, the inventory manager was much less inclined to modify an instructor's estimate than otherwise. A second and equally important factor was the supplier's return policy on overstock. While the majority of suppliers permitted full return, a large number had a limited returns policy. Approximately 10% of the suppliers dealt with permitted no returns of overstock. The policy of this latter group represented the most serious financial constraints and necessitated exacting modifications of instructors' estimates. The three classes of suppliers' returns policies resulted in the consideration of additional factors as the severity of financial consequence resulting from overstock increased.

Model Validation

The validation of the decision flow model was done by comparing the output of the simulator with actual modified estimates made by the textbook manager. A sample of 117 situations was selected from inventory control records. The cases selected were from the most recently completed semester and were stratified on the basis of publishers' returns policy for overstock. Table 1 provides some statistics of the inventory control situation.

The sample was not obtained through random sampling but biased such that more difficult and complicated situations may be modeled. The difference in the percentage of publishers in the population and the percentage of publishers in the sample for each stratification given in Table 1 were then adjusted for by stratified sampling technique (6).

A chi-square test for goodness-of-fit was applied to modified estimates made by the model as compared to actual modified estimates made by the textbook manager. The resultant value of the test statistic (chi-square = 121.32, d.f. = 116, $p > .05$) indicated a reasonable fit of the simulated to the actual values of modified estimates according to the chi-square criterion. A similar result was obtained in the application of the two-sample Smirnov test for equality of distribution functions. Both validation criteria are seen as functionally powerful test for goodness-of-fit and as such may identify statistically significant deviations in model versus actual outcomes.

Table 1
Statistics of the Inventory Control Situation

Publishers' Returns Policy	% in Population	% in Sample	Number in Sample
Full returns	65%	43.58%	51
Limited returns	25%	41.88%	49
No returns	10%	14.54%	17
Total	100%	100%	117

Total number of titles used per semester-----2900 to 3500
% of new titles each semester----------------40%
Average number of books per title------------50
% of titles exceeding 100 books per title----less than 10%

A somewhat less sophisticated viewpoint toward validation in this situation was taken by examining the sum of deviations of the model versus actual modified estimates and the mean of those deviations as reported in Table 2. The textbook inventory control situation seen as a whole provides the textbook manager a latitude in the accuracy of modified estimates. The assumption being that errors in one direction will be offset by errors in the other such that on the average financial and goodwill constraints are met. As can be seen in Table 2, model modified estimates deviated from actual modified estimates by only 0.641 textbooks over the 117 cases simulated.

Table 2
Sum of Deviations and Mean of Deviations
Model vs. Individual

Publisher's Returns Policy	Sum of Deviations Model vs. Individual	Mean of Deviations Model vs. Individual
Full returns	202.00	3.960
Limited returns	-124.00	-2.530
No returns	-3.00	-0.176
Total	75.00	0.641

Model modified estimates were compared with actual sales in a chi-square test for goodness-of-fit as were actual modified estimates compared with actual sales. The resultant statistics strongly suggest very little difference in the ability of the textbook manager to predict actual sales over the model. It should be noted however that errors in estimating actual sales were strongly in the direction of overestimating rather than underestimation. In only 9 of the 117 cases did actual sales exceed the simulated estimate. It seems apparent that understocking of a particular title was seen by the manager as more consequential than was overstocking.

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