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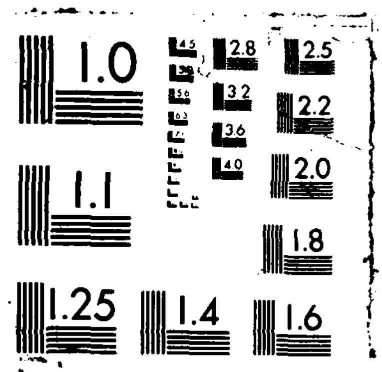
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A COMPARISON OF THE PERFORMANCE OF THREE INVENTORY CONTROL STRATEGIES IN THE COMMISSARY STORE ENVIRONMENT

THESIS

Michael B. Stark, B.S.
Captain, USAF

AFIT/GOR/ENS/87D-20

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The specific purpose of this study was to compare the performances of two alternative inventory control procedures selected from the literature with that of the strategy currently used by the Air Force Commissary Service in an attempt to answer the question: What is the most appropriate inventory control strategy to efficiently manage the inventory of *selected* items in the WPAFB commissary? Due to a number of analytical and practical constraints, simulation and simulation-related techniques were used to answer this question.

Extensive comparisons of the simulated performances of the three models were conducted at both the aggregate and individual item level with a sample of 90 items. Of the three procedures, the inventory control system proposed by Bytronic Technologies Corporation appeared to be the most promising at both the aggregate and individual item level.

Finally, striking a delicate balance between the two conflicting objectives of providing a given level of customer service, while at the same time seeking to maintain the lowest inventory levels possible, is easier when the relationships among inventory levels, customer service, and inventory performance are explicitly known. Therefore, graphs showing these actual trade-offs for the Bytronic system are presented. (Thesis).

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A COMPARISON OF THE PERFORMANCE OF THREE INVENTORY CONTROL STRATEGIES IN THE COMMISSARY STORE ENVIRONMENT

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Michael B. Stark, B.S.

Captain, USAF

December 1987

Preface

The specific purpose of this study was to compare the performances of two alternative inventory control procedures selected from the literature with that of the strategy currently used by the Air Force Commissary Service in an attempt to answer the question: What is the most appropriate inventory control strategy to efficiently manage the inventory of *selected* items in the WPAFB commissary?

Extensive comparisons of the simulated performances of these three models were conducted at both the aggregate and individual item level with a sample of 90 items. Of the three procedures, the inventory control system proposed by Bytronic Technologies Corporation appears to be the most promising. However, further exploration of the performance produced by the Bytronic procedure is clearly required before the conclusions of this study are adopted.

A common thread in any project of this magnitude is the assistance received from others; without their contributions, research of this nature could never be completed. This study is certainly no exception. In particular, I would like to extend my thanks to my faculty advisor, Major Joseph R. Litko, for his guidance and technical expertise which he shared so freely. I would also like to thank Lieutentant Colonel Stanley Polk of HQ AFCOMS for providing the basis of this study and his invaluable assistance regarding inventory control within the Commissary environment. Last, but certainly not least, I would like to thank my wife Cathy for her endless support and encouragement when the going got tough and my son Bryon whose seemingly endless energy was a constant source of inspiration.

Michael B. Stark

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Abstract

The specific purpose of this study was to compare the performances of two alternative inventory control procedures selected from the literature with that of the strategy currently used by the Air Force Commissary Service in an attempt to answer the question: What is the most appropriate inventory control strategy to efficiently manage the inventory of *selected* items in the WPAFB commissary? Due to a number of analytical and practical constraints, simulation and simulation-related techniques were used to answer this question.

In arriving at a satisfactory answer to the research question, a number of intermediate issues had to be addressed. The first of these issues was the selection of the two most promising alternative reorder strategies for comparison with the current reorder algorithm. Based upon an extensive review of the literature, a procedure recommended by Bytronic Technologies Corporation and a procedure presented in an article by Tijms and Groenevelt were the two systems chosen.

Once the two alternative strategies had been selected, the next issue addressed was the development of performance measures with which to accurately assess the performances of the three inventory control systems. Interviews with AFCOMS personnel revealed that of the many potential measures available, not-in-stock rates and inventory-to-sales ratios were the most relevant for Commissary Service operations. In addition, a number of other inventory "profile" measures were tracked,

analyzed, and reported throughout the study to supplement the comparison.

The last issue addressed concerned the appropriate probability distribution to assume for the randomness of daily demand and to incorporate into the simulation models. Since the results of the simulations were clearly a function of the distribution used, the accurate resolution of this issue was crucial. An extensive review of the professional literature and analysis of the sample data found that an assumption of normally distributed demand was reasonable.

Once each of these issues had been resolved, extensive comparisons of the simulated performances of the three models were conducted at both the aggregate and individual item level with a sample of 90 items. Of the three procedures, the inventory control system proposed by Bytronic Technologies Corporation appeared to be the most promising at both the aggregate and individual item level.

Detailed study of the Bytronic system revealed that its performance could be improved even more so with further refinement of the multi-item classification scheme used to categorize the 90 items within the sample.

Finally, striking a delicate balance between the two conflicting objectives of providing a given level of customer service, while at the same time seeking to maintain the lowest inventory levels possible, is easier when the relationships among inventory levels, customer service, and inventory performance are explicitly known. Therefore, graphs showing these actual trade-offs for the Bytronic system are presented.

A COMPARISON OF THE PERFORMANCE OF THREE INVENTORY CONTROL STRATEGIES IN THE COMMISSARY STORE ENVIRONMENT

I. Introduction

General Background of the Study

Tasked with the administration and operation of 139 retail stores around the world, the mission of the Air Force Commissary Service (AFCOMS) is truly global in nature (1:115). With annual sales in excess of $2.2 billion dollars in 1986 alone, the volume of business conducted by the Commissary Service clearly indicates the need for sound management principles and practices (1:115). This need is further exacerbated by the fact that the Commissary Service has become the target of increasing congressional scrutiny as lawmakers attempt to trim government spending.

Although at first glance a typical commissary store may simply look like a military version of its civilian counterpart, the resemblance is actually quite superficial. Beyond the fact that both sell grocery and subsistence items, the contrasts are rather striking. Perhaps the most important distinction between the two is the mission, or primary objective, for which each exists. Virtually all civilian grocery retailers exist for one ultimate reason--profit maximization. The Commissary

Service, on the other hand, exists as a form of non-pay compensation for military members and their dependents. According to a recent *Air Force Magazine* article:

> Patrons repeatedly save an average of twenty-five percent by shopping in the commissary since all Air Force commissaries sell goods at cost plus a five percent surcharge required by law to pay for equipment, supplies, and other expenses. [1:115]

Commissary Service operations are also somewhat unique since all personnel and labor costs are financed by the federal government through appropriated funds while inventories are purchased by means of a revolving stock fund.

In spite of these marked differences between the Commissary Service and civilian grocery retailers, the Commissary Service must strive to conduct its business operations in the most economical and efficient manner possible in view of the close scrutiny to which it is commonly subjected. Keeping an adequate, yet not excessive, stock of goods on hand for future sale is a critical component of such operations since inventories represent one of the major investments made by an organization (28:ix). In addition, inventories have a direct impact on the fraction of customer demand that can be met immediately with stock on hand and thus are closely related to the level of customer service a particular commissary store can provide its customers. More specifically, if inventory levels tend to be consistently inadequate, shortages occur as demand for the item exceeds its supply. On the other hand, if a store manager attempts to preclude such shortages by carrying excessive inventories, a number of off-setting, adverse side effects will result. Although it then becomes easier to provide better customer service, holding and storage costs will rise. Losses due to spoilage, pilferage, and mishandling will also increase. These latter costs must be weighed against any advantages gained by stocking a larger inventory. Obviously neither one of these two extremes of inventory management is acceptable if AFCOMS is to operate in an efficient manner.

Recent interviews with AFCOMS personnel reveal that current inventory management practices vary widely from store to store and meet with varying degrees of success. For instance, during a recent interview, the Wright-Patterson Air Force Base (WPAFB) commissary store officer cited the following, reoccurring problems with current inventory practices: 1). 100 to 200 not-in-stock items on any given shopping day, 2) an inventory-to-sales ratio closer to 1:1 than the stated objective of .5:1, and finally, 3) daily handling and spoilage losses of approximately $500 to as much as $1000 (19). Although these problems take on an added degree of significance since the Wright-Patterson Air Force Base commissary is the fifth largest store within AFCOMS, with monthly gross sales typically in excess of $3.5 million dollars, these inventory control problems are not unique to the Wright-Patterson Air Force Base store. As a result, AFCOMS is actively seeking to improve its "inventory policy" ; that is to say, when and by how much should a store replenish its inventory? (23).

Research Question

The current reorder algorithm, or formula, used throughout AFCOMS is more the result of years of trial-and-error experimentation rather than the result of any detailed, scientific analysis. Furthermore, a comprehensive review of the professional literature regarding inventory control reveals that a number of alternative reorder strategies hold significant promise of improving inventory management practices within AFCOMS. In view of these facts, the specific purpose of this particular investigation is to compare the performances of two alternative inventory control procedures selected from the literature with that of the current method in an attempt to answer the question: What is the most appropriate inventory control strategy to efficiently manage and control the inventory of *selected* items in the WPAFB commissary?

Scope and Limitations of the Research

As a result of the sheer number of items which comprise the inventory of the WPAFB store (approximately 10,000), this study will necessarily be restricted to a much smaller subset or sample of items. In addition, although a number of alternative reorder strategies presented in the literature offer a significant degree of promise with regard to improving inventory control within the commissary environment, only two of these are presented in this study as a result of the necessity of achieving some degree of practical scope. Moreover, due to the rather substantial gap that currently exists within inventory control as a field of science between theory and practice, it is unrealistic to expect any proposed reorder strategy to provide an absolute optimization; on the contrary, what is hoped for is a significant improvement over current practices. Finally, although extrapolation of the results of this study to products beyond those contained in the sample may seem warranted if one or both of the proposed alternative reorder strategies proves to be highly successful, no attempt will be made to do so within this study.

Specific Objectives of the Research

To attack a problem of this magnitude, a logical and coherent approach is essential. Therefore, the problem will be addressed in five distinct phases as outlined below:

1. **Propose two alternative reorder strategies which possess significant promise of improving inventory control practices.** The particular inventory model, or reorder strategy, selected for a certain application is clearly a direct function of the operating environment in which it will be implemented. The literature seems to imply that commissary store operations might benefit significantly by implementing an alternative reorder strategy for a number of reasons. Such a strategy might yield a variety of benefits. Consequently, the specific aim of this particular sub-objective is to determine what are the two most promising reorder strategies to select for in depth study. This sub-objective is accomplished in the literature review.

2. **Develop, verify, and validate a simulation model for each of these two alternatives as well as one for the current reorder system.** Due to a number of considerations regarding

analytical feasibility and experimental design, simulation and simulation-related techniques are used in this study to assess the performance of each of the reorder algorithms. Clearly, if the results of this study are to gain a sufficient degree of acceptance and credibility, the models that produce these results must be subjected to extensive verification and validation.

3. **Develop performance measures with which to compare the performance of the three reorder strategies using the selected sample and statistical inference.** In order to accurately assess the performances of the various reorder strategies (the current and the proposed models), criteria by which to judge the relevant merits of each must be developed. Although easily quantifiable measures such as not-in-stock rates and inventory-to-sales ratios readily come to mind, other more subjective factors such as ease of use and intuitive appeal must also be considered.

4. **Select a sample and identify the probability distribution that most accurately reflects the randomness of daily demand.** Clearly, the composition of the sample used to compare the performances of the three alternative models will influence the assumptions on which this study rests as well as the applicability of the results it produces. In addition, the sample used will also have an impact on the experimental design (that is, run length and number of replications) necessary to attain a specified level of statistical precision. By taking these various considerations into account, the specific aim of this sub-objective is to determine the most appropriate probability distribution with which to represent the randomness of daily demand.

5. **Design and conduct an experiment to compare the performances of the three alternative inventory control strategies.** The primary goal of this sub-objective is to assess and summarize the performance of each strategy and to answer the question: What is the most appropriate reorder strategy to efficiently manage the inventory of *selected* items in the WPAFB commissary? Since the particular items which compose the sample of this study are chosen such that they are typically available at commissary stores worldwide, the results of this study are not necessarily restricted to the operations of the WPAFB store. In addition, interviews with HQ AFCOMS personnel reveal that there is nothing peculiar to WPAFB commissary store which might preclude or seriously limit the generalization of the results of this study to other similar commissary operations.

Overview of Remaining Chapters

Chapter 2 provides an extensive discussion of the professional literature relevant to inventory control management within the Air Force Commissary Service. More specifically, the unique environment in which the Commissary Service operates, the four categories of costs that are typically relevant to inventory management, the issue of selecting an appropriate alternative reorder strategy, the simulation of inventory systems, and finally, the issue of categorizing a multi-item inventory are the five topics that are addressed.

Chapter 3 gives a detailed presentation of the three inventory control simulation models actually used in this study. Following an overview of the basic structure and the assumptions of each model, the procedure used for the verification and validation of the three models is presented in detail.

Chapter 4 presents the methodology used in comparing the performances of the three alternate inventory control systems and a look at the data collection and data preparation procedures to support the models. Next, a number of statistical considerations for the analysis of simulation results are addressed. Finally, the experimental design used to support the research objectives is presented.

Chapter 5 presents the analysis of the results of the study at an aggregate level. Once the model demonstrating the best performance has been identified, this model is subjected to further study at both the aggregate and individual item level.

Chapter 6 provides a summary of the limitations of this research and a number of practical implications of the results. Recommendations for refinement, adaptation, and future use of the models are also presented. Finally, a number of conclusions regarding the utility of the study to the Air Force Commissary Service are stated.

II. Discussion of the Literature and Specific Implications

Scope and Organization of the Review

As a popular field of applied science, inventory management encompasses a very broad subject area. In contrast, this particular literature review is limited to examining only those aspects of inventory management relevant to inventory control procedures within the Air Force Commissary Service.

With regard to organization, the specific format of this review is topical in nature. More specifically, the first part of the discussion of the literature addresses the unique environment in which the Commissary Service operates and the impact of this environment on the selection of an appropriate inventory control procedure for implementation. This portion of the discussion seeks to cast the world of inventory management within AFCOMS in its proper setting in order to set the stage for this study. The next portion of the review addresses the unique nature of the AFCOMS in light of the four categories of costs that are typically relevant to inventory management. Next, the issue of selecting an appropriate alternative reorder strategy is addressed. In fact, the two alternative inventory control procedures actually selected for comparison with the current method are presented in detail at this point in the review. Following the presentation of the two proposed alternatives, the simulation of inventory systems is addressed. Finally, since one of the alternative reorder strategies selected for comparison advocates the use of an inventory partitioning scheme, the issue of categorizing a multi-item inventory is also discussed.

Characteristics of the Commissary Store Operating Environment Pertinent to Model Selection

The particular inventory control procedure, or reorder strategy, selected for a certain application is a direct function of the operating environment in which it is implemented. In general, based upon a classification scheme used by Silver, inventory control procedures can be classified according to the following aspects of the environment in which they are implemented: 1) deterministic versus stochastic demand, 2) continuous versus periodic review cycle, 3) backorders versus lost sales, 4) single versus multiple items, 5) single versus multiple periods, 6) stationary versus significantly time-varying parameters, 7) nature of the supply process, 8) procurement cost structure, 9) shelf-life considerations, and 10) single versus multiple stocking points (27:632). Each of these ten factors is addressed in further detail below. In addition, a number of considerations peculiar to food retailers are also discussed.

Deterministic versus Stochastic Demand. Deterministic demand exists when there is relatively little or no uncertainty concerning the level of consumer demand for a specific inventory item. For instance, if *exactly* 22 boxes of Kellogg's Rice Krispies™ cereal in the 13 ounce size sold every ten days at the Wright-Patterson Air Force Base commissary store, the demand for this particular product is said to be "deterministic." Although deterministic demand may be a reasonable approximation of reality for certain items within certain inventory systems, such a simplified situation does not exist for the demand for items stocked by the Commissary Service. According to Millar

Demand [for supermarket items] is random, fluctuations are immediate and trends can be short-lived. A frosty morning in Spring or Autumn boosts the sale of sausages that day; a health scare kills the sale of canned salmon overnight. [20:109]

Unfortunately, although stochastic, or probabilistic, demand provides a much more accurate portrayal of the random consumer demand with which the commissary manager must contend, stochastic demand is much more difficult to deal with analytically than is its deterministic counterpart. According to Silver and Peterson, "the introduction of uncertainty in the demand pattern significantly complicates the inventory situation from a conceptual standpoint" as well (28:251).

Continuous versus Periodic Review. Continuous, or order point recognition, review refers to the practice of ordering a replenishment quantity as soon as stock comes down to a predetermined level; that is, the stock level is always known (20:109). Conversely, periodic, or cyclical, review refers to the practice of determining stock status only at certain, discrete time intervals and ordering enough replenishment stock to meet expected demand until the next order arrives; that is, between reviews there may be "considerable uncertainty" regarding the stock status. According to Silver and Peterson, "the main advantage of continuous review is that, to provide the same level of customer service, it requires less safety stock (hence, lower carrying costs) than does periodic review" (28:255). Although Millar feels that the order point recognition review approach is the more "theoretically correct" in view of this rather significant advantage, he states that the continuous review policy possesses a number of rather serious drawbacks that preclude its use in the supermarket setting (20:109). He notes that even though a computer can be used to "watch" the inventory levels of several thousand items, "immediate ordering on recognition would be impossible" since such a reorder policy would cause "chaotic ordering on a central depot or supplier and consequent chaotic deliveries" (20:109). Furthermore, in spite of the fact that with continuous review, stock status is *supposedly* always known and thus the inventory system can signal when a replenishment order is warranted, Bytronic Technologies Corporation* asserts:

> The commissary environment does not quite match the requirements for such a [continuous review] system to work correctly. The scanning system [at the checkout register] provides the means to have a perpetual (continuous) inventory count, but orders are only placed when the vendor representatives call. This periodic stock replenishment violates the requirements of a continuous review system. [7:79]

Consequently, a periodic review system is more appropriate for the commissary operating environment since "orders are placed during the

* Bytronic Technologies Corporation conducted a research study to investigate a wide range of management and technical issues (including inventory control systems and a suggested reorder algorithm) related to the Automated Commissary Operations System. The Air Force Commissary Service commissioned the study to ensure that stores are receiving the maximum possible benefits of data automation.

natural periodic visits by the vendors' representatives" (7:79). In addition, from a more practical standpoint, another advantage of the periodic review approach is that all items supplied by the same vendor can be given a common review interval and thus it allows a reasonable prediction of the level of "workload" required by the reorder, the restocking, and the receiving staffs (20:110).

Backorders versus Lost Sales. Another issue an inventory control system must address is what happens to a customer's order when he or she seeks to purchase an item that is temporarily out of stock. Silver and Peterson define the two possible extremes as follows:

> 1. Complete backordering. Any demand, when out of stock, is backordered and filled as soon as an adequate sized replenishment arrives.
>
> 2. Complete lost sales. Any demand when [an item is] out of stock is lost; the customer goes elsewhere to satisfy his or her need. This situation is common at the retail-consumer link. For example, a person is unlikely to backorder a demand for a loaf of bread. [28:253]

Although commercial food retailers frequently issue "rain checks" for out-of-stock specials and in effect "backorder" a specific item, the Commissary Service does not typically promote advertised specials per se and thus does not backorder any unsatisfied demand. As a result, "an 'out-of-stock' is a lost sale, not a delayed one" (20:109). Admittedly, it is possible that a customer may delay (that is, "backorder") his or her demand for an item if that particular item is temporarily out of stock. However, this contingency is not incorporated into this study.

Single versus Multiple Items. Although a substantial portion of the professional literature is restricted to inventory control procedures that assume a "single item in isolation from all other items," such simplified procedures are not an entirely accurate portrayal of actual operations within the Commissary Service since it is tasked with the management of inventories that are frequently composed of over 7,000 individual items and is faced with a variety of complicating factors and constraints such as varying demand patterns, varying review periods, budget limitations and numerous vendor restrictions, just to name a few (27:628).

Silver points out a number of item interdependencies that can exist within the multiple item context:

1. Overall constraint on budget or space used by a group of items
2. Coordinated control to save on replenishment costs
3. Substitutable items--when a particular item is not in stock, the customer may be willing to accept a substitute product
4. Complimentary demand--certain products tend to be demanded together; in fact, the customer may not accept one without the other. [27:632]

Explicit considerations of these item interdependencies can drastically increase the complexity of a study, however, and render the analysis intractable. Consequently, these factors are excluded from explicit consideration in this study.

Single versus Multiple Periods. A single period situation exists when there is a "relatively short selling season" and stock overages left over from one period cannot be saved in order to satisfy demand during the next selling season (27:632). Newspapers and Christmas trees are two good examples of products that fit this situation. Although the Commissary Service undoubtedly carries a limited number of these seasonal or single period type items, the vast majority of its inventories consist of multiple period type items. As a result, this study considers only the multiple period case.

Stationary versus Significantly Time-Varying Parameters (Nonstationarity). Nonstationarity in this context refers to the situation in which demand patterns--more specifically, average demand rates--vary appreciably with time. Obviously, such a dynamic demand rate will have an impact on the determination of control parameters such as the stock control level and the reorder point (28:350). For the Commissary Service however, although random fluctuations in daily demand for a given product are rather common, historical sales data reveal that the total quantity of a given product sold from one month to the next does not vary *appreciably* for most individual items. As a result, a model selected for implementation by the commissary would not have to be overly concerned with nonstationarity. As a caveat to this rather general statement, however, it is recognized that some items do demonstrate rather marked variations in demand rate and thus might be more accurately controlled by an inventory model that took this nonstationarity into account. Although an *exact* analysis of such a situation (probabilistic and time-varying demand) is much too complicated for most real-world applications, there are a number of heuristic approaches that yield relatively good performance. In spite of this fact, items with nonstationary demand parameters are not addressed in this study.

Nature of the Supply Process. Although most of the items ordered by the Commissary Service are received after a known and constant leadtime, intervening influences such as a strike or bad weather can occasionally delay a scheduled replenishment. Such occurrences tend to be more the exception rather than the rule, however, and thus assuming a fixed and known leadtime is generally reasonable.

Procurement Cost Structure. In some cases the so-called "fixed price" cost of an order may actually be "semi-variable" if, due to a *quantity discount perhaps, the unit cost of an item* is a function of the size of the replenishment. (27:633). Special promotions or rebates by a vendor can have a similar impact on the procurement cost structure of a given item. In general, however, and for the purposes of this study, the fixed cost component of ordering costs is assumed to be static.

Shelf-Life Considerations. Another factor complicating inventory control within the commissary environment is that many stocked items have a short shelf-life. According to Silver, limited shelf-life is usually due to one of two factors, namely obsolescence or deterioration of stock (27:633). "Obsolescence" occurs when an item can only be sold for a small fraction of its original price due to the appearance of a new and improved product on the market (27:633). On the other hand, "deterioration" or "perishability" refers to the case when, due to a degradation of the stock itself, a product is no longer fit for sale

(27:633). Although stock rotation can minimize the adverse impact of obsolescence and deterioration, a certain amount of "stock wastage" is unavoidable (20:109). Incidentally, most of the professional literature makes no allowance for the short shelf-life of many items.

Single versus Multiple Stocking Points. Most supermarket chains use centralized warehouses to stock several of their retail stores and thus make use of multi-stage inventory systems. As a result, relatively low inventories are kept at any given retail store since replenishment by a centralized warehouse is typically possible within a relatively short period of time; in many cases, replenishment is available within less than 24 hours. In contrast, although most commissary stores are serviced by literally hundreds of vendors and food distributors, inventories for a particular store are held only in its own adjoining warehouse and no where else. As a result, commissary store operations are more appropriately classified as "single echelon."

Other Considerations Peculiar to Food Retailers. In addition to the foregoing considerations, the inventory control system of the commissary is further complicated by a number of other factors. For instance, as Millar points out, the dollar value of total sales are high, but the average unit sale is low:

> An average neighborhood supermarket of, say 1,000 square metres will have sales of £50,000 weekly, with an average unit price of about 50 pence, i.e., 100,000 items. The offtake of these items will be compressed into the second half of the week, with perhaps 50-60% taken from Thursday late opening to close of business on Saturday. The handling problems are prodigious. [20:109]

Another complicating factor is that many "goods received (and, therefore, order quantities) are [only available] in fixed multiples of the unit of sale, usually a case or 'outer' quantity" (20:109). Finally, the common problems and conflicting trade-offs associated with any inventory control system apply "like an umbrella" over these particular "trade features" (20:109).

Costs Relevant to Inventory Control

According to Silver, there are usually four categories of cost that are relevant to inventory management decision making:

1. Replenishment [Order] Costs. These are the costs incurred each time a replenishment action is taken. It is convenient to express the costs as the sum of two parts: (i) a fixed component, often called the setup cost, independent of the size of the replenishment; and (ii) a component that depends on the size of the replenishment, in particular including the cost of the [item] itself.

2. Carrying [Holding] Costs. Having material in stock incurs a number of costs including: (i) the cost of borrowing the capital tied up or foregoing its use in some other investment, (ii) warehouse operation costs, (iii) insurance, (iv) taxes, and (v) potential spoilage or obsolescence.

3. Costs of Insufficient Supply in the Short Run [Shortage Costs]. When inventory levels are insufficient to routinely satisfy customer demand, costs are incurred, whether or not they are explicitly measured. Unsatisfied demand leads to immediate costs of backordering and/ or lost profit on sales. In addition, such poor service can have a longer range cost impact through loss of [customer] goodwill.

4. System Control Costs. This crucial category of costs has largely been ignored in the inventory theory literature. It includes the costs of acquiring the data necessary for the adopted decision rules, the computational costs, and other costs of implementation. [27:630]

Due to its significantly different primary objective and its nonprofit nature, however, the Commissary Service must view these four categories of costs in a somewhat different light than its profit-oriented civilian counterpart. For instance, with respect to ordering costs, Bytronic Technologies contends that these costs are "insignificant" to the commissary since orders are written by the vendors themselves during their periodic visits. Although such orders have to be processed by a succession of people within the administrative staff of the commissary, there is no explicit, tangible cost associated with placing an order.

With respect to carrying costs, the size of the revolving stock fund used to finance inventories has historically proven to be of such a size that the "cost of capital"--as used in the traditional sense--has not proven to be a binding constraint on commissary store operations. Although, as the custodian of the stock fund, AFCOMS must demonstrate fiscal responsibility and prudent use of the fund, no explicit "cost of capital" per se is incurred by a store when it uses a portion of the fund to purchase inventory. Moreover, although warehouse operation costs and the costs associated with potential obsolescence and deterioration represent additional carrying costs, these costs are strictly secondary in nature when compared to the primary objective of meeting a prescribed level of customer service.

The third category of costs, shortage costs, are typically the most difficult to measure. The situation within the commissary is certainly no exception. It is clear that by specifying a policy with respect to customer service level, a definite shortage cost is tacitly implied (11:105). Although in most applications, explicit values for shortage costs for unsatisfied demand are difficult to determine, Fogarty and Aucamp demonstrate a procedure that can be used to compute the implied backorder cost of a specified policy concerning backorders (11). However, since HQ AFCOMS specifies a given level of customer service that each store must strive to achieve, the determination of the shortage costs implied by such a policy (beyond academic interest, perhaps) are not particularly relevant to the study at hand.

Finally, with respect to the last category, system control costs, AFCOMS has already made a rather substantial investment in a database management system known as the Automated Commissary Operations System (ACOS). As a result, the majority of the system control costs required by a particular inventory control system and the computational costs associated with it have already been determined and thus represent sunk costs.

The different perspective of AFCOMS with respect to many of these categories of costs makes the task of pursuing an effective and efficient inventory control strategy more difficult since the success of any such control system has traditionally been measured in terms of its ability to minimize total cost. The nonprofit nature of the Commissary Service handicaps this effort even further. In fact, according to Anthony in his text, *Management Control in Nonprofit Organizations*:

> The absence of a single, satisfactory overall measure of performance that is comparable to the profit measure is the most serious factor inhibiting the development of effective management control systems in nonprofit organizations. [2:35]

Alternate Model Selection

An inescapable fact of inventory management in general is that most real-life inventory control decisions are functions of numerous parameters or factors and are thus rather complex in nature. For instance, in view of the foregoing discussion of the factors and costs that characterize the commissary store environment, the *theoretically ideal* model for implementation would appear to be one which can cope with *all* of the following:

1. Probabilistic demand that is occasionally rather erratic
2. Periodic review
3. Occasional "backlogs"; that is, deferred customer demand
4. Multiple items with item interdependencies
5. Single as well as multiple periods for *some* items
6. Time-varying demand process parameters for *some* items
7. A procurement cost structure that is a function of the size of the replenishment order

8. Shelf-life considerations such as obsolescence and deterioration of stock

9. "Peculiarities" of the food retail business

Clearly, a model that could take *all* of these considerations into account clearly exceeds the capabilities of any known inventory control procedure. Moreover, as Byrkett regrettably points out, although the professional literature "abounds" with inventory procedures "developed for almost every conceivable set of circumstances, when it comes time to develop an inventory system for a particular application, none of the literature models seem to fit exactly" (6:1). The commissary store environment is certainly no exception to Byrkett's observation. When confronted with this situation, Byrkett states that the analyst can pursue one or both of the following courses of action:

1. Modify an existing model to fit the given situation, and/or

2. Assume that even though not all of the assumptions in the existing model are satisfied, it will do an adequate job of controlling the inventory. [6:1]

A third option is to lower the demands or expectations placed on the model. In other words, instead of vainly searching for an inventory control procedure that can take *all* factors and possible contingencies into account, the analyst can settle for a model that does a reasonably good job of incorporating only the most salient factors. Admittedly, the task of incorporating only the most important factors, while simultaneously trying to preserve the simplicity of the inventory control procedure, is not an easy one. Obviously, such a procedure will ignore a number of other relevant factors that are not considered. In spite of this fact, such a sacrifice is usually essential if the search for a feasible reorder strategy is to proceed and be successful. Selection of a model that is not overly sensitive to minor changes in the assumptions on which it is founded is also an important consideration.

In keeping with the philosophy of the third option, the search for an effective inventory control strategy for implementation by the Commissary Service can be guided by a list of somewhat more realistic expectations than those specified by the nine requirements above. A more reasonable set of requirements that still retains the essential elements of the commissary environment is the following:

1. Probabilistic demand
2. Periodic review
3. Lost Sales
4. Single items with no item interdependencies
5. Multiple periods for all items
6. Relatively stationary demand process parameters
7. A supply process in which leadtime is relatively fixed

Although the impact of a number of other considerations such as item interdependencies and quantity discounts are now ignored, the search for an alternative inventory control strategy is now more realistic and directed. Moreover, the list of revised requirements stated above is helpful in narrowing the field of potential systems in view of the vast number of control systems that are available for inventory management.

Possible Inventory Control Systems for Stochastic Demand. As Silver and Peterson point out, the fundamental objective of any inventory control system is to provide answers to the following three questions:

1. How often should the inventory status be determined?

2. When should a replenishment order be placed?

3. How large should this replenishment order be? [28:256]

Of the many different types of inventory control systems used in an environment characterized by probabilistic demand, Silver and Peterson define the four most common systems as follows:

1. Order-Point, Order-Quantity (s,Q) System. This system involves continuous review (that is, R [review period]=0). A fixed quantity Q is ordered whenever the inventory position [stock on hand minus backorders plus stock on order] drops to the reorder point s or lower. This system is often called the two bin system.

2. Order-Point, Order-Up-to-Level (s,S) System. This system again involves continuous review and a replenishment is made whenever the inventory position drops to the reorder point s or lower. However, in contrast to the (s,Q) system, here a variable replenishment is used, enough being ordered to raise the inventory position to the order-up-to-level S. The (s,S) system is frequently referred to as the min-max system because the inventory position, except for a possible momentary drop below the reorder point, is always between a minimum value of s and a maximum value of S.

3. Periodic-Review, Order-Up-to-Level (R,S) System. This system, also known as a replenishment cycle system, is in common use, particularly in companies not utilizing computer control. The control procedure is that every R units of time (that is, at each review instant) enough [stock] is ordered to raise the inventory position to the level S.

4. [Periodic Order-Point, Order-Up-to-Level] (R,s,S) System. This is a combination of (s,S) and (R,S) systems. The idea is that every R units of time we check the inventory position. If it is at or below the reorder point s, we order enough to raise it to S. If the position is above s, nothing is done until at least the next review instant. The (s,S) system is the special case where R=0, and the (R,S) is the special case where s=S-1. [28:256-258]

Naddor provides a comprehensive comparison of the optimal solutions of the first three inventory control systems (that is, the (s,Q), the (s,S), and the (R,S)) for the case of a single item (21). The objective function that he uses to assess the performance of each is the minimization of the total expected cost per unit of time denoted by C and defined as follows:

$$C = C_1 + C_2 + C_3 = (c_1 * I_1) + (c_2 * I_2) + (c_3 * I_3) \qquad (2.1)$$

where C_1, C_2, and C_3 represent the cost of carrying inventory, the cost of incurring backordered shortages, and the cost of replenishing inventories, respectively, and c_1, c_2, and c_3 are the corresponding unit costs defined as follows:

c_1 = unit cost of carrying inventory (in dollars per unit in inventory per unit time)

c_2 = unit cost of incurring backordered shortages in dollars per unit short per unit time)

c_3 = unit cost of replenishing inventories (in dollars per replenishment, independent of the amount)

and finally, I_1, I_2, and I_3 represent average inventory carried, average shortage, and average number of replenishments per unit time, respectively.

By using a number of alternative situations with different demand patterns, leadtimes, review periods, and costs structures, Naddor tests the performance of each of the three inventory control systems and presents the following conclusions:

1. The minimum cost for the (R,S) policy is equal to or greater than that for the (s,Q) policy which, in turn, is equal to or larger than that for the (s,S) policy.

2. The minimum cost for the (s,S) policy is about 10% less than that for the (R,S) policy.

3. The optimal scheduling period in an (R,S) policy is about the same as that in a corresponding deterministic system.

4. The optimal order levels S_0 in the (R,S) and (s,S) policies are about the same.

5. The optimal reorder points s_0 in the (s,Q) and (s,S) policies are about the same

6. The optimal lot size Q_0 in an (s,Q) system is about the same as that in a corresponding deterministic system. [21:1238]

Naddor makes frequent use of these observations in deriving heuristic decisions rules for each of the inventory control systems. These rules allow the analysis of inventory systems on the basis of their "average demand, standard deviation of demand, probability of no demand, leadtime, carrying cost, replenishment cost, and an availability index" (21:1234). Compared with the performance of the optimal decision rules which typically require substantially more computational effort, the heuristics provide exceptionally good results. Although not explicitly stated by Naddor, his heuristic decision rules assume deterministic leadtime, backlogging of excess demand, and an explicit specification of ordering and carrying costs.

The performance of the (R,s,S) control procedure has also been tested in a number of studies. For example, a 1960 study by Scarf demonstrated that under rather general assumptions regarding demand patterns and relevant cost factors, the (R,s,S) control procedure produces a lower total cost (that is, ordering, holding, and shortage costs) than does any other type of system (25). Another study conducted by Eilon and Elmaleh arrived at the same conclusion (10).

The report prepared by Bytronic Technologies Corporation and sponsored by AFCOMS addressed the very issue of the most appropriate inventory control system. In this report, Bytronic Technologies states that an (R,s,S) system is the best choice for the commissary situation (7:79). In this context, R represents the time between vendor reviews of the inventory position. At such time, if the inventory position is at or below the reorder point s an amount sufficient to raise the inventory position up to the stock control level S is ordered. Conversely, if the the inventory position is above s, no action is taken during this review cycle. As defined by Bytronic Technologies, the stock control level is "an inventory level to cover demand during the time between vendor representative visits and delivery leadtime, plus some safety stock" (7:79). Silver and Peterson point out that the (R,s,S) system can be viewed as the "periodic version" of the well-known "Order-Point, Order-up-to-Level" or "s,S" system (28:258).

The rather impressive performance of the (R,s,S) control procedure is rather costly, however, in terms of the computational effort required to yield *optimal* values of R, s , and S. As a result, a number of so-called heuristic procedures have been developed for numerous applications. More specifically, for the case of an (R,s,S) system with deterministic leadtime, backlogging of excess demand, and explicit shortage costs, computational methods which yield approximately optimal values control rules are discussed in Wagner (31).

Although Fogarty and Aucamp demonstrate a procedure that can be used to compute the implied backorder cost of a specified policy concerning backorders, in most applications, explicit values for shortage costs for unsatisfied demand are difficult to determine (11). Consequently, Schneider has devised a heuristic procedure for approximating the reorder point of an (R,s,S) system that incorporates the more widely used practice of specifying a service level requirement (such as the fraction of demand satisfied directly from the shelf) when the order quantity is predetermined (26). Tijms and Groenevelt extend the applicability of his results and, more importantly, present approximations that can be routinely used in practice. Although their results assume complete backlogging of excess demand, their analysis requires only "slight modifications" to handle an inventory system in which excess demand is assumed to be lost (29:179). The periodic version of the Tijms and Groenevelt procedure assumes that the order quantity, (S-s), is predetermined. In addition, the control system is based on the inventory position defined as "the stock on hand... plus stock on order" (29:176). As a typical (R,s,S) system, if the inventory position is at or below the reorder point s, an amount sufficient to raise the inventory position up to the stock control level S is ordered. If the inventory position is above s, no action is taken during this review cycle. The leadtime of each replenishment order is assumed to be a nonnegative discrete-valued random variable with given mean $\mu(L)$ and standard deviation sd(L).

Assumptions of the Tijms and Groenevelt Model. The assumptions upon which the Tijms and Groenevelt procedure rests include:

1. The probability that replenishment orders cross in time or arrive simultaneously is negligible.

2. (S-s) is sufficiently large compared with the average demand μ_R in the review time (say, $S-s \geq 1.5\mu_R$).

3. The stock on hand just after the arrival of a replenishment order is positive except for a negligible probability. [29:177]

Silver and Peterson cite a number of other more subtle assumptions implicit in the Tijms and Groenevelt heuristic:

1. Although demand is probabilistic, the average demand rate changes very little with time.

2. Unit shortage costs (explicit or implicit) are so high that a practical operating procedure will always result in the average level of backorders being negligibly small when compared with the average level of the on-hand stock.

3. Forecast errors have a normal distribution with no bias (that is, the average error is zero) and a *known* standard deviation for forecasts over a period of duration R+L. In fact, we only have an estimate.

4. The value of R is assumed to be predetermined. In most situations, the effects of the two decision variables, R and S, are not independent, that is, the best value of R depends on the S value, and vice versa. However, it is quite reasonable for practical purposes to assume that R has been predetermined without knowledge of the S value.

5. The costs of the control system do not depend on the specific value of S used.

6. The case of normally distributed demand is appropriate to use as long as $CV_{(R+L)} \leq 0.5$ where $CV_{(R+L)} = SD(R+L)/X(R+L)$ is the coefficient of variation of demand over R+L. When CV exceeds 0.5 a gamma distribution provides better results. [28:292-3]

After considerable mathematical manipulation, Tijms and Groenevelt (29:178) show that the reorder point achieving the required service level

P_2 in the most efficient manner can be approximated by selecting s to satisfy the following equation:

$$SD(R+L)^2 * J_u\{[s-X(R+L)]/SD(R+L)\} - SD(L)^2 * J_u\{[s-X(L)]/SD(L)\} \quad (2.2)$$
$$= 2 * (1-P_2) * X(R) * ((S-s) + \{[SD(R)^2 + X(R)^2]/2 * X(R)\})$$

where

S-s is assumed predetermined (for example by EOQ)

$X(t)$ = expected demand in a period of duration t

$SD(t)$ = standard deviation of errors of forecasts of total demand over a period of duration t

$J_u(k) = \int_k^{\infty} (u_0 - k)^2 f_u(u_0)du_0$ is a special function of the unit normal distribution

According to Hadley and Whitin (14):

$$J_u(k) = \{(1 + k^2) * [p_{u\geq}(k)]\} - [k * f_u(k)] \quad (2.3)$$

As a result, Equation 2.2 requires a trial-and-error type solution. Fortunately, however, if s is replaced by the quantity $[X(R+L)+k*SD(R+L)]$, and the service level P_2 is close to 1, and the demand pattern is relatively smooth, then Equation 2.2 stated above for determining the reorder point s can be simplified to selecting k so as to satisfy (28:354):

$$J_u(k) = \frac{2 * [(1-P_2)/P_2] * X(R) * \{(S-s) + \{[SD(R)^2 + X(R)^2]/2 * X(R)\}\}}{SD(R+L)^2} \qquad (2.4)$$

Consequently, if a table of $J_u(k)$ versus k values is available, determining the reorder point and the stock control level is easily accomplished using the following two equations:

$$\text{Reorder Point} = X(R+L) + [k * SD(R+L)] \qquad (2.5)$$

and

$$\text{Stock Control Level} = \text{Reorder Point} + (S-s) \qquad (2.6)$$

Since the second term on the left of Equation 2.2 has been removed, the reorder point produced by Equation 2.4 is obviously larger, and consequently, the service level that it produces is also somewhat higher than that produced by the original formula. Finally, to cope with the case of lost sales (as is the case assumed for the commissary environment) and to ensure that the fraction of demand to be met from stock on hand is still at least P_2, Tijms and Groenevelt point out that the reorder point s can be approximated by substituting $(1-P_2)/P_2$ for $(1-P_2)$ in Equation 2.4 above (29:179). Clearly, for P_2 close to 1, the backlogging and lost-sales cases will not differ greatly.

Bytronic Technologies Corporation Model. An alternative inventory control procedure has been proposed by Bytronic Technologies Corporation. This much less sophisticated approach envisions partitioning the inventory of the commissary according to a modified ABC classification scheme. (Partitioning of multi-item inventories is discussed later in this literature review).

According to the Bytronic Technologies Corporation procedure, the stock control level of each item can be computed as follows (7:80):

$$\text{Stock Control Level} = [DMD * (RVW + L)] + B \qquad (2.7)$$

where

DMD = historical average daily demand

RVW = number of days between vendor reviews

L = number of days leadtime

B = buffering to cover uncertainty

Subsequently, the necessary replenishment up to the stock control level is accomplished by ordering the following replenishment quantity (7:80):

$$\text{Order Quantity} = \text{Stock Control Level} - \text{Inventory Position} \qquad (2.8)$$

As the report points out, the Bytronic procedure is similar to the current approach used by AFCOMS which computes the stock control level as follows (7:81):

$$\text{Stock Control Level} = \{(RVW + L + SDAYS) * [DMD + (TRND - 1)]\} \quad (2.9)$$

where RVW, L, and DMD are as defined above while SDAYS is the safety leadtime (in days) and TRND is the demand trend. The order quantity for the current system is calculated by substituting this value for stock control level into a formula identical to Equation 2.8 above. Due to the inclusion of a demand trend, however, the inventory control procedure currently used by the Commissary Service is technically classified as a "pro-active" system. As defined in the Bytronic Technologies report, "pro-active procedures are based on forecasting the demand for the upcoming period" (7:78). Since even the most sophisticated forecast is subject to a certain degree of error, Bytronic Technologies states that a "reactive" procedure is more appropriate for the Commissary environment:

> Since no forecast will be consistently accurate, practitioners prefer reactive systems when they have a choice. Reactive systems, as the name implies, react to recent events to restore inventories to an appropriate level. The restoration algorithm is based on the time between review, vendor delivery time, and some buffer stock to absorb demand and delivery variance. These systems employ a naive forecast; the demand to be experienced in the near future is assumed to be [approximately] equal to the demand of the recent past. [7:79]

Another difference between the model proposed by Bytronic Technologies and the Current model is the use of a safety leadtime instead of a safety stock in the later model. As Silver and Peterson point out, the use of equal time supplies for a broad group of items in an inventory population as a safety stock is "seriously in error because it fails to take account of the differences and uncertainty of forecasts from item to item" (28:263).

The buffering quantity B in Equation 2.7 above is referred to as the safety stock. Its purpose is to cover uncertainty due to either demand or delivery time variability. According to the Bytronic procedure, the appropriate safety stock for a particular item is a function of either its inherent demand or delivery time variability or perhaps some combination of the two. In turn, as discussed later in this review, the classification of an item is also a function of these two sources of variability. As a result, the procedure for determining the safety stock for an item is dependent on its classification.

A great deal of the professional literature relating to the determination of safety stocks in a stochastic demand environment assumes that the randomness of demand for a particular product is normally distributed about its mean demand. As a result, safety stock is typically specified as a multiple of "the number of standard deviations away from the mean demand during the review period RVW and the leadtime L" (7:84). Although some experts recommend a safety stock level equal to three standard deviations of demand variation over the time between reviews and leadtime, Brown states that a factor of three is too high since customers are willing to accept a lower level of in-stock items, and since such a model establishes an unnecessarily high cycle stock level (5). As a compromise, the Bytronic Technologies report recommends using a factor of 2.25 times the standard deviation initially and adjusting the factor as required (7:84). Before this factor can be used to calculate the required safety stock, however, the standard deviation must be "adjusted for the period the system is exposed to uncertainty (that is, review period plus leadtime) as follows (7:84):

$$SD(R+L) = SD(DAY) * (RVW + L)^{1/2} \qquad (2.10)$$

More specifically, if demand uncertainty has caused the item to be classified as a Type A, then the Bytronic Technologies report recommends that the safety stock be computed using the following formula:

$$B_{A1} = 2.25 * SD(DAY) * (RVW + L)^{1/2} \qquad (2.11)$$

Although standard deviation is the variability measure typically used to establish the required safety stock, Bytronic Technologies recommends using the mean absolute deviation (MAD) about an expected value instead, due to its simplicity and ease of calculation (7:81). MAD is computed as follows:

$$MAD = (1/n) * [\Sigma_{i=1}^{n} (DMD_i - DMD)] \qquad (2.12)$$

where i is an index of daily movements, n is the number of samples, and

DMD = average daily movement

DMD_i = daily movement for day i

Instead of continuously recalculating the MAD everyday, however, Bytronic Technologies proposes using some "linear combination" of the most recent day's MAD and a historical measure of the MAD of a product in a recursive relationship as follows:

$$MAD_{NEW} = [w * (DMD_i - DMD)] + [(1 - w) * MAD_{OLD}] \qquad (2.13)$$

where DMD and DMD_i are as defined above and w represents a smoothing weight ($0 \leq w \leq 1$). Since this calculation is recursive in nature, an initial value of MAD must be specified in advance (7:83). Returning to the original equation for determining the safety stock, Equation 2.11, and substituting the approximation (1.25 * MAD) for SD(DAY) yields (7:85):

$$B_{A1} = 2.25 * (1.25 * MAD) * (RVW + L)^{1/2} \qquad (2.14)$$

or

$$B_{A1} = 2.8 * MAD * (RVW + L)^{1/2} \qquad (2.15)$$

In contrast to the current reorder algorithm, this approach produces a "dynamic safety stock level" and allows the system to "adjust the stock buffer as item movement variability changes over time" (7:85).

For items that have been classified as Type A as a result of relatively high vendor leadtime variability, the Bytronic Technologies report recommends determining the required safety stock by using the following formula:

$$B_{A2} = DMD * (L_W - L) \qquad (2.16)$$

where DMD and L are as previously defined and L_W is the reasonable worst case leadtime. The objective of this calculation is to provide a safety stock equal to "the worst performance of the vendor except for extreme outliers" (7:85).

In contrast to Type A items, by definition, Type B items require no sophisticated safety stock calculations. As a result, a simple 20% buffer is recommended by Bytronic Technologies as a reasonable starting point. Type B buffer stock can thus be computed as follows:

$$B_B = (0.2) * DMD * (RVW + L) \qquad (2.17)$$

Likewise, Type C items can be treated in a similar fashion but with an even smaller initial buffering factor such as 10%:

$$B_C = (0.1) * DMD * (RVW + L) \qquad (2.18)$$

Simulation of Inventory Systems

When developing a mathematical model as an aid to inventory control decision making, it is obviously desirable to use modeling that leads to analytic decision rules; that is, rules that are implementable through the use of formulas, tables, and graphs (28:71). Unfortunately, an inescapable fact of inventory management in general is that most real-life inventory control decisions are functions of numerous parameters or factors and are thus rather complex in nature. Consequently, as Silver and Peterson point out:

> When there are dynamic or sequential effects with uncertainty present (for example, forecast errors), it may not be possible to analytically derive (through deductive mathematical reasoning) which of two or more alternative courses of action is best to use in a particular decision situation. In such a case, one can turn to simulation, which still involves a model of the system. However, now, instead of using deductive mathematical reasoning, one instead, through the model, simulates through time the behavior of the real system under each alternative of interest [28:71].

As a result, inventory control problems are a very common area of application for simulation methodology. In fact, according to Banks and Malave', with the exception of waiting line , or queue-type analysis, inventory control problems are the most frequent application for simulation methodology (4:283). Simulation techniques are frequently employed when an analytic solution is either impossible or extremely complex. Some inventory systems are simply too complex to have an analytic solution. In other cases, even when a solution does exist, the analysis often becomes intractable. Banks and Malave' note that an analytic solution to a problem may not be feasible because of one or more of the following reasons:

1. Leadtime and demand are stochastic. Although approximate models are available for the case of stochastic leadtime and demand, some difficulties can be encountered when applying these models to real world inventory systems. The analytic models cannot handle cases where the demand does not follow a stationary distribution or where orders can cross.

2. Extremely complex problem. Sometimes a problem may be so complicated that it could be solved only by simulation. When the number of levels or items in an inventory system is large and dependency exists between levels and/or items, an analytic solution may be impossible.

3. A specific problem. An analytic solution may not be available when the problem under study is so specific that it does not fit the structure of any general analytic model. [4:283-284]

Furthermore, Clark notes that simulation can be very useful in studying the behavior of an inventory control system whose analytic solution is very complex because "complexities not included in the decision model can be inserted into the simulation in order to provide a qualitative evaluation of the use of the decision model in an actual system" (8:284).

Two other common uses of simulation methodology are the comparison of the performances of several different inventory control strategies and the evaluation of alternative inventory control parameter settings within a given model. When used in this manner, a rather significant advantage of simulation methodology in analyzing inventory control systems is that it allows the performance of a proposed system to be studied in detail in a totally non-obtrusive manner prior to actually being implemented. As a result, current operations remain intact until the new alternative has been thoroughly tested and evaluated in a "realistic" operating environment. Furthermore, "optimal" system parameter settings can be estimated in advance so a lot of time is not spent trying to determine these once the new strategy has been implemented. Finally, since the performance of a given inventory control strategy is typically a function of several parameters, simulation provides a degree of sensitivity analysis that is indeed impressive when contrasted with either the computational burden of trying to do so analytically or the obvious limitations associated with attempting to do so with an actual inventory system.

As a matter of practical necessity, and in view of the preceding discussion, the use of simulation methodology to address inventory control within the Commissary Service seems well justified. Before presenting the simulation models actually developed for use in this study, the use of simulation in predicting the performance of an inventory control system is presented. In addition, a number of practical considerations that must be taken into account when using simulation in this manner are also presented.

<u>Use of Simulation in Predicting System Performance</u>. In view of the widespread use of simulation in predicting system performance, MacCormick investigates the statistical accuracy of forecasts made by using simulation methodology. More specifically, MacCormick examines the bias and variance of these forecasts and seeks to determine how the

forecasts vary with different system settings such as "the length of the demand history used for policy revision and forecasting, and with environmental specifications, such as the underlying demand process, costs, and replenishment leadtime" (18:605).

As the focus of his study, MacCormick selects the *approximately* optimal (that is, minimum expected total cost) statistical (s,S) class of decision rules in a multi-period environment. In addition, he uses a normal distribution as a simplifying assumption and "estimates of demand mean and variance computed from recent history" (18:605). As with most inventory control procedures, there exists a trade-off between holding and shortage costs within the (s,S) system. This trade-off is influenced by the relative values specified for each of these costs. However, as MacCormick notes, the values used for each are typically based on rather arbitrary and subjective judgements. As a result, the analyst, before implementing an inventory control system, frequently "wishes to predict the system's performance for one or more specifications of the parameter settings employed in the computational process" (18:606). MacCormick states that for an (s,S)-type control system, "the various approximations that are used in the computations make it highly questionable to use probability formulas to provide reliable estimates of the system's performance" (18:606). Consequently, the analyst must resort to simulation. In doing so, he typically makes use of the limited amount of historical data, from which he estimates the demand mean and variance. These estimates are then used in the (s,S) computations to predict, by simulation, how the selected rules will perform in the future (18:606). Based on these forecasts, the analyst may decide to adjust the holding or shortage cost parameters. MacCormick notes that the trade-off process using simulation is typically carried out with aggregates for one or more groups of items (18:606). In addition, he states two sets of rather important questions that arise from the use of simulation is such a manner:

1. How good are the statistical predictions of the system's future operating characteristics? Are the forecasts biased? What is their variability?

2. How does the accuracy of retrospective simulation forecasts depend on the amount of historical demand information available? On the system's parameter specifications? On the demand environment? [18:606]

In order to answer these questions, MacCormick assumes that the analyst has n periods of demand history available, and further, that the analyst believes that the next n periods of demand will be drawn from the same underlying demand distribution. Next, the analyst estimates values for the demand mean and variance from the past n periods and calculates the (s,S) rule for the next n periods based on an approximation procedure presented by Veinott and Wagner (18). Finally, to forecast performance over the next n periods by retrospective simulation, the analyst operates the system with the calculated (s,S) rule and the previous n demands. MacCormick uses the forecasting method just described for all 648 design points of the full factorial design depicted in Table 1 below.

Table 1. Full Factorial Design for MacCormick Experiment

FACTOR	LEVELS	NUMBER OF LEVELS
Demand distribution Mean=μ Variance=sd^2	Negative binomial ($sd^2/\mu=9$) Negative binomial ($sd^2/\mu=3$) Poisson ($sd^2/\mu=1$)	3
Mean demand (μ)	2, 4, 8, 16	4
Unit holding cost (C_{in})	1	1
Unit backlog penalty cost (C_{out})	4, 9, 99	3
Replenishment setup cost (C_{fix})	32, 64	2
Replenishment leadtime (L)	0, 2, 4	3
Demand history length (n)	13, 26, 52	3

For each of the 648 cases, MacCormick replicates the retrospective forecasts 200 times to derive the comparisons between actual and predicted values for the following operating characteristics:

1. Expected total costs

2. Expected period-end inventory

3. Expected backlog frequency

4. Expected backlog

5. Replenishment frequency

By implementing this experimental design, MacCormick arrives at the following observations:

> 1. For each of the operating characteristics, the actual expected value is systematically underestimated by a retrospective simulation forecast... [Although] the bias is negligible for inventory quantity and replenishment frequency, even for n as small as 6 periods... the bias is severe for the backlog quantity and frequency, even for n as large as 52 periods.
>
> 2. For each characteristic, the bias becomes smaller with increases in the demand history length.
>
> 3. The dispersion [in forecast error] is so great that little reliance can be given to a single forecast made from the demand history for one item. [18:609, 612, 614]

In view of the foregoing, MacCormick recommends that the analyst be "generous" in selecting the number of items to be used for the system's design test (18:615). Similarly, "the analyst is advised to use as long a demand history length as is available and sufficiently representative of the future demand environment" (18:615).

<u>Practical Aspects of Inventory Simulation</u>. Simulation methodology is widely used in practice since *comprehensive* analytical solutions are only available for the most trivial applications. As a result, a solution for a more realistic situation must usually be obtained through the use of simulation. However, "this leaves the simulation itself as the judge of its own merits, which is a vicious circle" (9:56). Fortunately, Diegel presents a number of observations based on sample theory that can be used to circumvent this apparent deadlock.

<u>Simulation Run Length</u>. A rather common question with which analysts must grapple is: What is the appropriate run length to produce results that seem reasonable? Although, in general, a longer run length is associated with more reliable results, this approach can become "so expensive that simulation becomes impractical" (9:53). Fortunately, as Diegel points out, "excessive run lengths are not normally required because a well-designed simulation will produce reliable results from surprisingly short runs" because of the following two reasons:

> Reliability depends on run length measured in critical events or decision units, not time units. The critical question is: How many lots were actually ordered during this simulation? It is not: How many time units were covered by this run?
>
> The number of critical events needed for stochastic convergence (smooth results), conforms to small sample theory. Short runs are as reliable as small samples... for many situations a number like 25 is a sizable number absolutely speaking. [9:53]

Although an analytic solution usually assumes continuous data and thus "smooth areas under the curve," simulation on a digital computer must obviously require that the data be represented and summed in a discrete fashion (9:58). Diegel mentions two complications that arise as a result of this fact:

> 1. The first point to note is that ending inventories are assumed away by analytic solutions for this kind of problem, but they are a distinct and practically unavoidable possibility in a simulated solution.
>
> 2. Similarly, an analytic approach tends to ignore initial conditions... [but] a simulation cannot usually get underway without some provision of stock on hand at the beginning of the run, certainly not if leadtimes are uncertain. [9:61]

By having to explicitly take account of these peripheral conditions, the simulated solution will typically lie above the theoretical solution (9:60). However, Diegel states that the absolute size of the effect of the peripheral conditions tends to be "essentially constant" (9:60). Consequently, "where peripheral effects are measurable, and where a simulation is intended to approximate an analytic, long-run solution," Diegel states that it is better to run one long simulation than to average the results from several short ones for the following reason:

> The results of all the short runs are likely to be significantly distorted by the effect of peripheral conditions, hence averaging them will not help. However, a long run will reduce peripheral effects to insignificance. [9:60]

Diegel warns that a larger number of random parameters will require a longer run to produce the same degree of statistical convergence

(9:69). In addition, he notes that a similar relationship exists between the degree of variation in any one random factor and the run length required; this is true because "the standard error of the mean is strictly proportional to the standard deviation of the individual measurements" (9:70).

Finally, in an effort to ensure that the run time of the one longer run remains feasible, Diegel recommends choosing a unit time length that is as "coarse as is at all consistent with the discrete nature of the data within the context of the simulation's accounting procedure" (9:68). In general, Diegel states that the "largest feasible time unit must be consistent with the smallest change in the decision variables, so that no more than one decision can take place within one time unit" (9:68).

Required Sample Size. In essence, a simulation is a sample. Consequently, determining the appropriate run length is equivalent to determining the necessary sample size required to estimate an inventory system characteristic with a given degree of precision and confidence. Geisler addresses this very issue:

> A typical simulation model may contain several random variables whose probability distributions are specified and which interact with each other in complex ways... Since these simulation models deal with random variables, they are amenable to statistical analysis; and it is also clear that since certain parameters and probability distributions are to be estimated, the question of the confidence and precision of such estimates must be faced... Thus, the issue of the sizes of samples that must be drawn from simulation models affects the feasibility of using simulation in routine research. [12:261-262]

To conduct his study, Geisler uses the (s,S) inventory control system with the zero procurement leadtime case, plus three nonzero cases in which leadtime equals two, five, and ten time units. The demand ∂ is assumed to be exponentially distributed, so that:

$$f(\partial) = \Omega * e^{-\Omega\partial} \quad (2.19)$$

The mean number of shortages per period and the mean number of overages per period are the two parameters for which he seeks to determine the required sample size. Geisler defines these two variables as follows:

> If x_n represents the stock level at the start of the n-th time period, then the number of shortages in the n-th time period, represented by y_n, is defined as follows:
>
> $$y_n = \{-x_n \text{ if } x_n<0\} \text{ or } y_n=\{0 \text{ if } x\geq 0\} \quad (2.20)$$
>
> Similarly, v_n, the number of overages in the n-th period, is defined as follows:
>
> $$v_n = \{-x_n \text{ if } x_n>0\} \text{ or } v_n=\{0 \text{ if } x\leq 0\} \quad (2.21)$$

Geisler is specifically interested in calculating the sample sizes required to ensure that "the sample estimates of the mean shortages and overages (per time period) differ in absolute value from the corresponding true values no more than K_1 and K_2, respectively, with 95% confidence" (12:262). As a result, if **y** is the sample estimate of the mean shortages per time period and Y is the true value, Geisler seeks to determine the minimum value of n_y, the sample size, such that:

$$Pr\{|\mathbf{y}-Y|>K_1\} \leq 0.05 \qquad (2.22)$$

Likewise, if **v** is the sample estimate of the mean overages per time period, and V is the true value, Geisler seeks to determine the minimum value of n_v, the sample size, such that:

$$Pr\{|\mathbf{v}-V|>K_2\} \leq 0.05 \qquad (2.23)$$

In other words, Geisler seeks to calculate "the minimum sample sizes for estimating Y and V such that there will be a 95 percent confidence that **y** and **v** will differ from their corresponding true values by no more than the true value in absolute amount" (12:263). As Geisler points out: "This is the same as requiring the sample values to differ no more than approximately 100 percent from the corresponding true values, with 95 percent confidence" (12:263).

Calculations for estimating y_n and v_n for the four procurement leadtime variations of the (s,S) system were performed using 80 different inventory policies with each model, as defined by selected stock control levels S and reorder points s (12:261). More specifically, Ω was fixed at .01 while Δ was defined as the quantity s-S and was set at values of 1, 10 ,100, 200, 300, 400, 500,1000, 5000, and 10000. Finally, s took on the values 1, 10, 100, 200, 300, 400, 500, and 1000.

From this rather extensive experimental design, Geisler arrived at the following conclusion regarding required sample size:

> Over the range of conditions examined, the sample sizes required to estimate shortages per period and overages per period tend not to be excessive; that is sample sizes of less than 100 are usually required to obtain the level of precision specified (a sample estimate within approximately 100 percent of the true value) at a 95 percent confidence interval. [12:261]

As a result of this finding, Geisler concludes that simulation methodology is indeed a "feasible technique for estimating certain parameters with reasonable precision and confidence" (12:270).

In a follow-on study, Geisler actually tests the methods that are used in the original study to compute the necessary sample size required to estimate an inventory system characteristic with a given degree of precision and confidence. In this follow-on study, the methods are tested by "applying them to particular inventory cases, and determining how well the actual precision and confidence obtained in the estimates agreed with expectation" (13:709). In general, Geisler found that the actual precision and confidence obtained for each of the four different inventory policies (that is, the (s,S) system with zero, two, five, and ten period leadtimes) agreed closely with his expectations. With respect to the shortage calculations, the results ranged from 94.3 to 97.6 percent (13:712). Results for the overage calculations, on the other hand, ranged from 95.6 to 99.9 percent (13:712). Based on these findings, Geisler concludes that the statistical estimation procedure presented in his original article for computing sample sizes of the (s,S)-type inventory control system is valid and provides accurate estimates of mean shortages and mean overages.

Classification of Multi-Item Inventories

Organizations that maintain large amounts of inventory often place their stock keeping units into a number of different "functional" categories based on some relevant similarities for inventory management purposes (7:78). Stock keeping unit refers to the specific unit of stock to be controlled that is "completely specified" as to function, style, size, and color (28:11). For instance, the same brand of strawberry jam in two different sizes would constitute two separate stock keeping units.

In the commissary setting, different stock keeping units are distinguished by unique universal product codes or "UPCs". Silver and Peterson point out that the inventory management systems of many organizations can be greatly improved by simply "adopting decision rules that do not treat all SKUs [stock keeping units] or all categories of aggregate inventory investment equivalently" (28:67). In general, some possible factors by which to categorize or partition an inventory include item demand variability, item unit cost, and item storage requirements. Holt proposes that multi-item inventories can also be subdivided on the basis of common reorder times as might be the case for a line of products supplied by a single distributor (16:60)

One common scheme that is frequently used to partition a large, multi-item inventory into three distinct categories is called an ABC analysis. According to Bytronic Technologies Corporation, even though Type A items typically represent only 20% of the total stock keeping units, they account for approximately 50% of the total annual dollar movement of the population of items under consideration (7:78). As a result, Type A items merit sophisticated control and managerial attention. In a commercial organization, it is this high carrying cost that makes Type A items the target of special treatment (7:78). In contrast, for the Commissary Service, Bytronic Technologies states that a particular item should be labelled a "Type A" item on slightly different grounds:

> For the commissary environment a troublesome item is one which has a highly variable demand from order cycle to order cycle or a high variability in its leadtime from the vendor. It is this variability--the uncertainty as to whether or not the item will incur a stockout before the next delivery--that labels it a Type A item. [7:78]

At the other end of the spectrum, Type C items typically make up 50% of the total stock keeping units, but are "benign and require only simple order control procedures," while the remaining 30% of the total stock keeping units--Type B items--fall somewhere in between these two extremes (7:78). When a computer-based inventory control system is available (as in the case of most commissary stores), some authorities recommend that the Type B category of items be expanded to encompass as much as 50% of the total stock keeping units (28:68).

One major objective of the ABC classification is to enhance and streamline inventory control by more accurately aligning the level of control sophistication and managerial attention a product receives with the particular demand and leadtime characteristics of that item. In view of the vast array of items stocked by a typical commissary store, this more discriminating approach offered by an ABC analysis seems to possess a significant degree of intuitive appeal.

According to Rivers, an ABC classification scheme can also be useful for determining appropriate safety stock policies for various items (24:6). Silver and Peterson define safety stock as "the average level of the net stock just before a replenishment arrives" (28:253). In his article "Effective Safety Stock Planning," Krupp states that "the purpose of safety stock is to maintain a reserve (buffer) inventory to support demand variances in *excess* of forecasted levels" (17:40). As more concisely stated by Rivers, safety stocks are primarily used for one purpose: "As a hedge against stockouts" (24:6).

As van der Veen points out, safety stocks have a direct impact on the fraction of demand that can be delivered from stock and thus are closely associated with the level of customer service a specific retailer can provide to its customers (30:367). More specifically, if demand is sufficiently random and if safety stocks tend to be consistently inadequate, shortages will occur whenever actual demand for the item exceeds its "available stock" (15:625). On the other hand, if a store manager attempts to preclude such shortages by carrying excessive safety stocks, a number of off-setting, adverse side effects will result. Although it then becomes easier to provide better customer service, holding and storage costs will rise (15:624). In addition, losses due to spoilage, pilferage, and mishandling will also increase. These latter costs must be weighed against any advantages gained by stocking a larger inventory. Clearly, neither one of these two extremes of inventory management is acceptable if AFCOMS is to operate in an effective and efficient manner.

III. Inventory Simulation Models

Simulation Model Development

The stated objective of this study is to compare the performances of three inventory control systems; namely, the system currently used by AFCOMS, the reorder strategy advocated by Bytronic Technologies Corporation, and finally, the Tijms and Groenevelt procedure selected from the professional literature. Due to a number of practical and analytical considerations already addressed in the literature review, simulation methodology is used in this investigation to assess the performance of each of these three reorder strategies.

The simulation models used in this study are isomorphic in nature and thus loosely represent a one-to-one correspondence of the actual systems which they seek to represent. Although such modeling tends to be less efficient than some more sophisticated approaches which are more abstract in nature, isomorphic modeling is typically more easily understood and thus often gains a greater degree of user acceptance and confidence than a less transparent simulation. In addition, due to the limited size of the sample of interest, the penalty paid for this ease of understanding is not exorbitant. Although a separate simulation model is constructed for each of the three systems, the assumed operating environments and basic structures of the models are actually quite similar. As a result, assumptions regarding these common operating environments are presented first. Next, structural features common to all of the models are addressed. Finally, any unique characteristics or input requirements of each model are presented.

Model Assumptions. The demand patterns of all 90 items in the sample are assumed to be stationary. In other words, although the actual daily demand for a particular product on any given day is stochastic, the average daily demand and the standard deviation of daily demand for the product do not vary appreciably over time. In addition, all 90 items of the sample are assumed to be supplied by the same vendor and thus share a common review period and replenishment leadtime; however, review period and leadtime can be altered between simulation runs. Finally, the unit price of each item is assumed to be independent of replenishment size and is held constant throughout the entire study.

Basic Model Structure. A block diagram of the basic model structure is presented in Figure 1. All three of the models are based on variations of this basic structure. The reorder control systems they implement belong to the periodic-review, order-point, order-up-to-level, or simply (R,s,S), class of inventory control systems. The common time unit used in all of the simulations is one day. In an attempt to increase the precision of the experiment, the same sample of items is used to assess the performance of each of the models. Obviously, however, the manner in which inventory control parameters are determined varies significantly from system to system. The actual computer code for each of the three models is presented in Appendices A, B, and C. Although the documentation within the code itself is believed to be sufficient to understand the mechanics of each simulation, some general comments regarding the overall operation of the model seem to be in order.

Model Inputs and Initialization. Although the specific model inputs depend on the particular model being tested, all three of the models

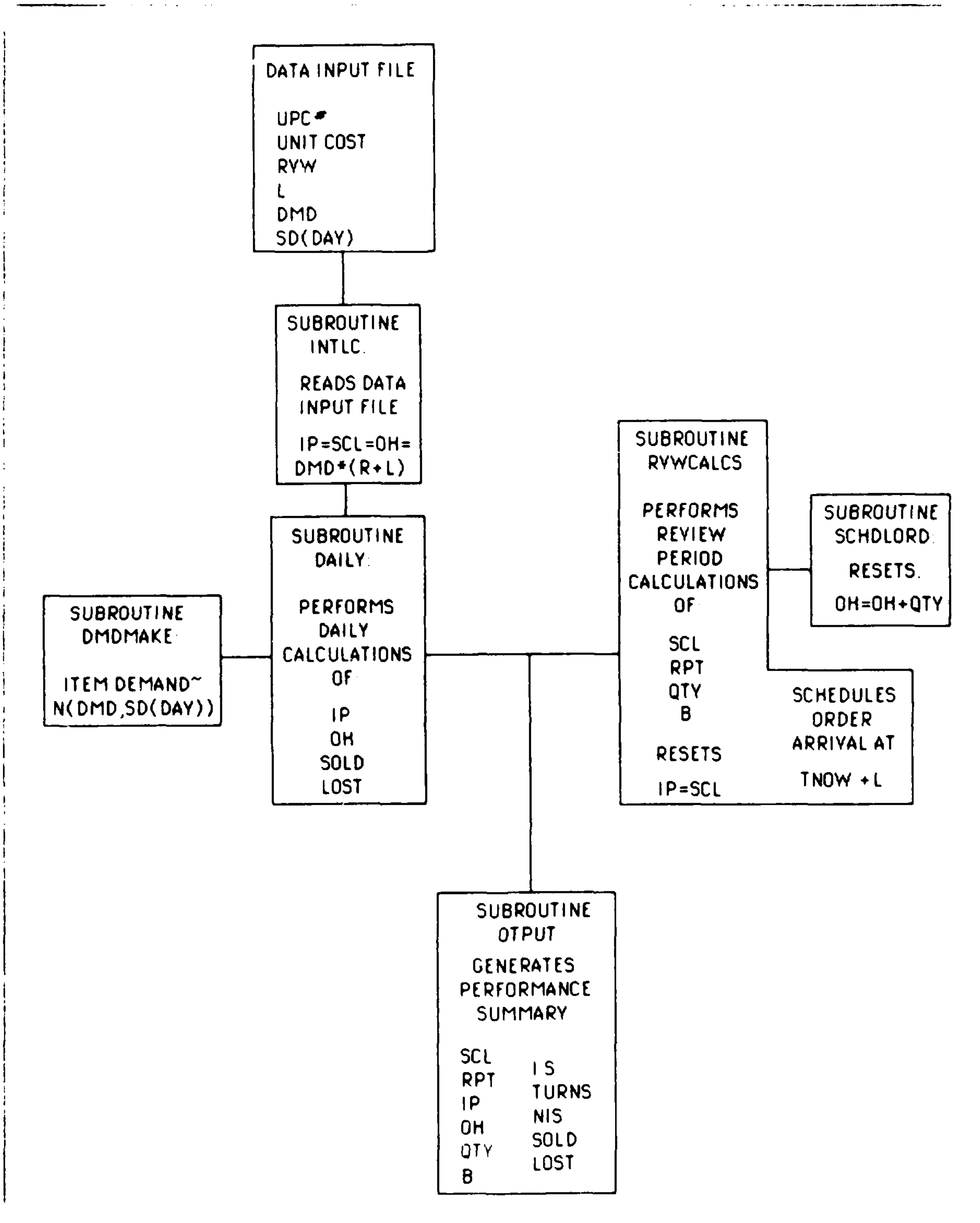


Figure 1. Basic Model Structure

share a number of input requirements in common; namely, item UPC number, unit cost of the item, review period, mean daily demand, standard deviation of daily demand, and leadtime. Any special input requirements of a certain model are cited below during the discussion of that particular model.

At the beginning of each simulation run, the SLAM II processor calls subroutine INTLC in order to read these relevant characteristics of all 90 items in the sample from a data input file. Subroutine INTLC also sets the initial conditions of the simulation. Since a simulation cannot get underway without some initial provision of stock at the beginning of a run, initial values (denoted by a zero subscript) of inventory position, stock control level, and on hand inventory are set as follows:

$$\text{Inventory Position}_0 = \text{Stock Control Level}_0 = \text{On Hand Inventory}_0$$
$$= \text{Average Daily Demand} * (\text{Review Period} + \text{Leadtime}) \qquad (3.1)$$

(As will be pointed out in Chapter IV--Methodology, the statistical registers are cleared after 360 days of simulated store operation in an effort to reduce the bias induced by these initial starting conditions.)

Daily Transactions. Following initialization, subroutine DAILY performs the daily sales transactions associated with inventory control. As long as an item is in stock (that is, on hand inventory is positive), customer demand is satisfied and inventory position and on hand inventory are reduced accordingly while cumulative number sold is incremented. However, once on hand inventory goes to zero, customer demand is assumed to be lost until the next replenishment arrives since no backordering of demand is possible. Consequently, any customer demand during an item stockout represents a lost sale, not a delayed one, and thus cumulative lost sales are incremented for each such occurrence.

The daily demand pattern for each of the 90 items is generated according to the procedure specified in the DMDMAKE subroutine. Subroutine DMDMAKE assumes that the randomness of daily demand for each UPC fits a Normal distribution with a mean and variance as specified for each UPC during model initialization. The Bytronic report cites theoretical and empirical evidence that supports this assumption (7:84). From a more practical standpoint, daily demand for all UPCs is restricted to the positive real numbers since negative demand is undefined.

Review Period Calculations. The heart of each of the three inventory simulation models is contained within the subroutine RVWCALCS. The status of an item is reviewed whenever "time" is equal to an integral multiple of the review period of the item. For instance, a product with a review period of 7 days is subjected to review whenever time equals 7, 14, 28, 35, 42, and so on until the end of the simulation period. If a review of the item is necessary, stock control level and the reorder point are calculated according to the characteristics of the item being reviewed as well as the decision rules of the particular inventory control system in use . Next, subroutine RVWCALCS determines if a replenishment is required during this particular review period by checking if the inventory position is below the reorder point. If so, an order is called for, and subroutine RVWCALCS calculates the order quantity necessary to raise the inventory position up to the stock control level of that UPC. When a replenishment order is actually placed, this subroutine resets the inventory position of that item equal to its stock control level. The scheduling of a replenishment order arrival is accomplished by subroutine SCHDLORD which places an order arrival on the event calendar at TNOW (the current simulated time) plus the leadtime of that product. Finally, RVWCALCS increments on hand inventory by the size of the order once the replenishment arrives.

Model Output. In order to accurately assess the performance of the three control systems, criteria by which to judge the relevant merits of each must be developed. As the final step in the simulation, the SLAM II processor calls the subroutine OTPUT. Subroutine OTPUT is used to generate the average values of the following performance measures on both an individual item and aggregate (that is, averaged across all 90 items) level:

1. Average Inventory Position (IP). The average inventory position of a system is the average value of the following relation:

   $$IP = (\text{Stock On Hand}) + (\text{Stock On Order}) - (\text{Backorders}) \qquad (3.2)$$

   For the commissary environment, since no backorders are allowed, inventory position can never become negative.

2. Average On Hand Inventory (OH). The average on hand inventory of a system is the average value of the amount of stock that is physically present either on the shelf or in the warehouse. Consequently, on hand inventory can never be negative.

3. Average Reorder Quantity (QTY). The average reorder quantity is the average size of the replenishment quantity that is ordered at each review period R.

4. Average Buffer Stock (B). The average buffer stock is the average level of the on hand inventory just before a replenishment arrives. As the name implies, buffer, or safety stock, provides a hedge against stockouts caused by unusually large demand during either the review period or the leadtime.

5. Inventory-to-Sales Ratio (I:S). The inventory-to-sales ratio is the proportion of the dollar value of the average inventory position during a period to the dollar value of the number of units sold within that same period:

$$I{:}S = \frac{\text{(Unit Cost)} * \text{(Average Inventory Position)}}{\text{(Unit Cost)} * \text{(Number of Units Sold)}} \qquad (3.3)$$

Since the unit cost of the item appears in both the numerator and the denominator, it can be deleted without altering the expression. The inventory-to-sales ratio is now a dimensionless quantity.

6. Stock Turns (TURNS). The number of stock turns is the inverse of the inventory-to-sales; it is similar in use to the payback period in investment analysis.

7. Not-in-Stock Ratio (NIS). The not-in-stock ratio is the proportion of the number of lost sales (number of units of unsatisfied demand) to total demand (both satisfied and unsatisfied) during the same period.

The cumulative number of items sold (SOLD) and lost sales (LOST) are also reported on an individual item and aggregated average basis. In addition, the UPC (UPC#), unit cost (UNIT COST), review period (RVW), leadtime (L), average daily demand DMD), standard deviation of daily demand (SD(DAY)), stock control level (SCL), and reorder point (RPT) of each item in the sample are given in the Performance Summary Report of all three models.

Unique Aspects of Each Model. In spite of these numerous structural similarities, each of the approaches to inventory management within the Commissary Service obviously employs different decision rules to control inventory*. These unique decision rules for each model are contained in the subroutine RVWCALCS and either one or two auxiliary subroutines which support its operation. For all three models, subroutine RVWCALCS is called during the review cycle for a particular UPC and is only executed if the inventory position of that product has dropped below its reorder point.

Current Model. A block diagram of the "Current" model is given in Figure 2. As can be seen in this figure, this particular model has a subroutine labelled TREND in addition to the standard components of the basic model. Due to the inclusion of this subroutine which calculates a demand trend factor for each item, the inventory control procedure currently used by the Commissary Service is technically classified as a "pro-active" system. As defined in the Bytronic Technologies report, "pro-active procedures are based on forecasting the demand for the upcoming period" (7:78). Subroutine TREND is executed every 30 days. It calculates the value of the trend factor to be used by the subroutine RVWCALCS during the next 30 day period when determining the stock

*Although the derivations or theoretical foundations of the decision rules of the two proposed inventory control systems were presented in the literature review of this study, these rules are also briefly presented here to support the discussion and for ease of reference

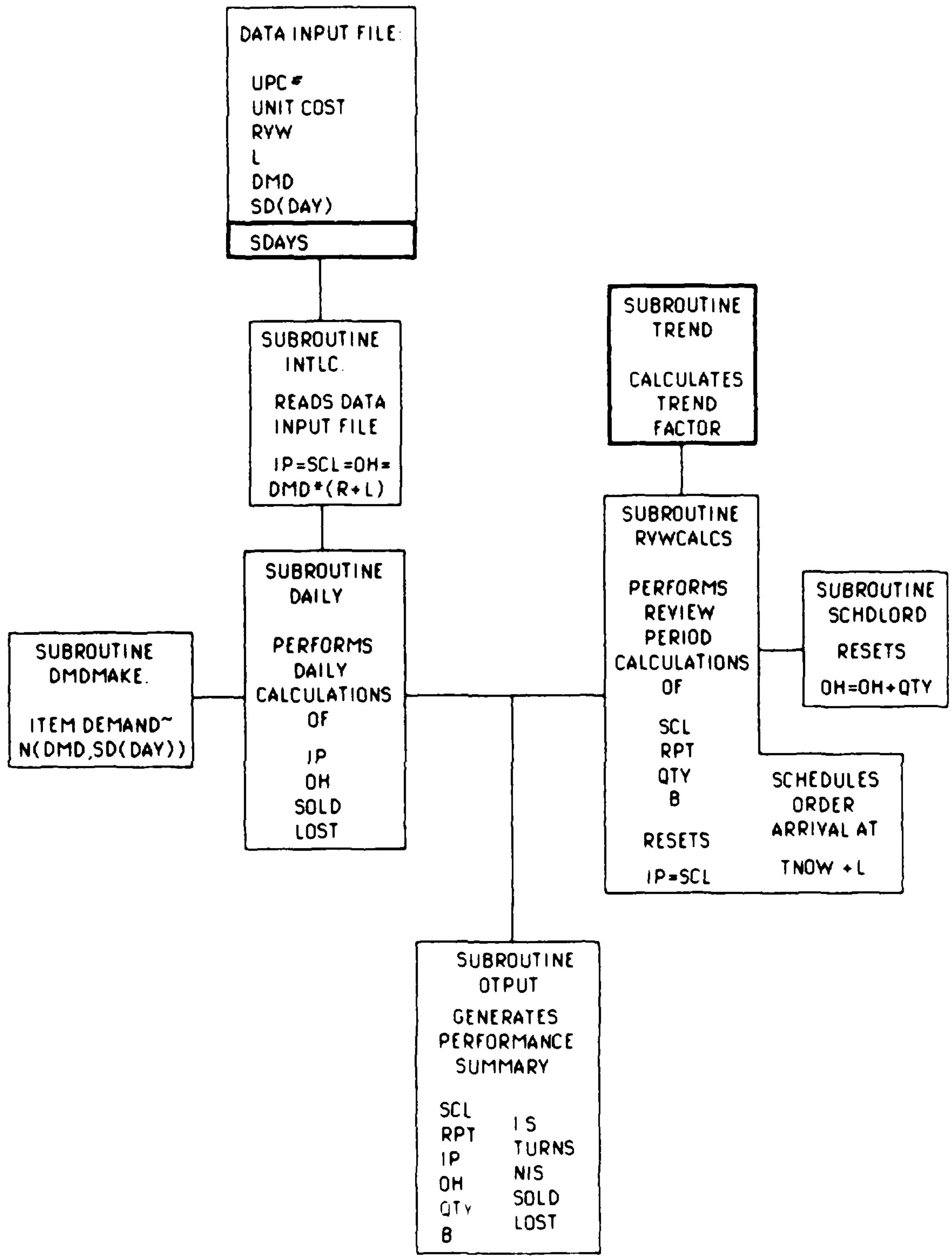


Figure 2. Current Model Structure

control level and the suggested replenishment quantity. A separate trend factor is calculated for each UPC. Each trend factor is computed using the following procedure:

1. Once at least twelve months of monthly demand history for each UPC has been recorded, Total Yearly Demand for a given UPC is determined by simply summing Monthly Demand over the twelve previous months:

$$\text{Total Yearly Demand} = \sum_{m=1}^{12} \text{Monthly Demand}(m) \qquad (3.4)$$

   In the event that fewer than 12 months of demand history are available for a particular UPC, monthly demand is estimated for any missing month(s) by multiplying the average daily demand for that item by 30 days.

2. Trend Total is now set equal to Total Yearly Demand.

3. Next, the Trend Average for a given UPC is calculated by dividing the Trend Total (Total Yearly Demand) by 12:

$$\text{Trend Average} = \text{Trend Total}/12 \qquad (3.5)$$

4. Trend Percent for any given month is calculated by dividing the monthly demand for that month by the Trend Average of that UPC.

$$\text{Trend Percent}(m) = \text{Monthly Demand}(m)/\text{Trend Average} \qquad (3.6)$$

5. Percent Total is calculated using a weighted sum of the Trend Percents of the four most recent months. As an example, the percent total for UPC 00287 for the month of July would be computed as follows:

$$\begin{aligned}\text{Percent Total}_{00287}(\text{July}) = {} & 4 * (\text{Trend Percent for June}) + \\ & 3 * (\text{Trend Percent for May}) + \\ & 2 * (\text{Trend Percent for April}) + \\ & 1 * (\text{Trend Percent for March})\end{aligned} \qquad (3.7)$$

6. Finally, the actual Trend for any given month is computed by dividing the percent total for that month by 10.

$$\text{Trend}(m) = \text{Percent Total}(m)/10 \qquad (3.8)$$

After subroutine TREND determines the appropriate trend value, subroutine RVWCALCS computes the stock control level as follows (7:81):

$$\text{Stock Control Level} = (\text{Review Period} + \text{Leadtime} + \text{Safety Days}) * [\text{Average Daily Demand} + (\text{Trend} - 1)] \qquad (3.9)$$

where the number of safety days for each UPC is identified as a model input parameter. The reorder point of a product for the current system is simply equal to its stock control level minus one which virtually guarantees a reorder during each review. Whenever the current inventory position is found to be less than the reorder point during the review of an item, subroutine RVWCALCS computes the suggested order quantity as follows:

$$\text{Order Quantity} = (\text{Review Period} + \text{Leadtime} + \text{Safety Days}) * [\text{Average Daily Demand} + (\text{Trend} - 1)] - \text{Stock Available} \qquad (3.10)$$

Since stock available is defined as inventory on-hand plus on-order, it is equivalent to inventory position and thus the order quantity can also be determined using the following equivalent formula:

$$\text{Order Quantity} = \text{Stock Control Level} - \text{Inventory Position} \qquad (3.11)$$

As with the other two inventory control procedures, subroutine RVWCALCS resets the inventory position equal to the value of the stock control level specified once the replenishment order is placed. Finally, on hand inventory is incremented by the size of the replenishment once the order actually arrives.

Bytronic Technologies Model. A block diagram of the Bytronic model is given in Figure 3. In contrast to the current procedure, the Bytronic Technologies model is strictly reactive in nature and does not incorporate any sort of forecast or trend calculation. In addition, unlike the current system, the subroutine RVWCALCS for this approach produces a dynamic safety stock level. As pointed out in the Bytronic Technologies report, "such dynamic behavior will allow the system to adjust the stock buffer as item movement variability changes over time" (7:85). Furthermore, since this procedure makes use of an ABC partitioning scheme, the actual required safety stock is also a function of the classification of the item which in turn is based on its variability of demand and/or its variability in leadtime from the vendor. More specifically, if demand uncertainty has caused the item to be classified as a Type A, then subroutine RVWCALCS computes the safety stock using the following formula:

$$B_{A1} = 2.25 * \text{Standard Deviation of Daily Demand} * (\text{Review Period} + \text{Leadtime})^{1/2} \qquad (3.12)$$

On the other hand, for items that have been classified as Type A as a result of relatively high vendor leadtime variability, subroutine

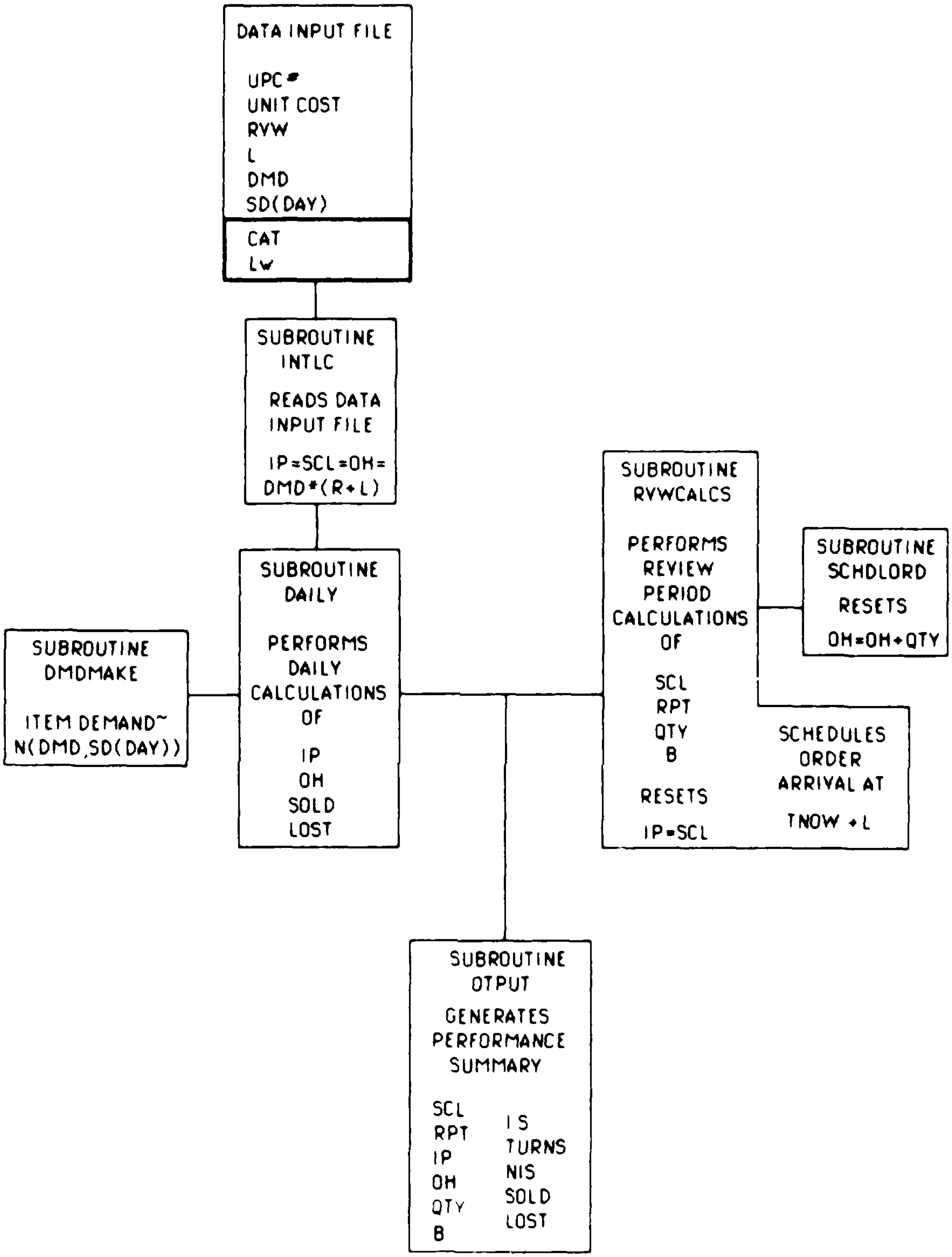


Figure 3 Bytronic Model Structure

RVWCALCS computes the required safety stock as follows:

$$B_{A2} = \text{Average Daily Demand} * \text{(Reasonable Worst Leadtime - Leadtime)} \quad (3.13)$$

The objective of this calculation is to provide a safety stock equal to "the worst performance of the vendor except for extreme outliers" (7:85).

In contrast to Type A items, Type B items, by definition, require no sophisticated safety stock calculations. As a result, a simple 20% buffer is recommended by Bytronic Technologies as a reasonable starting point. Type B buffer stock is thus computed by subroutine RVWCALCS as follows:

$$B_B = (0.20) * \text{Average Daily Demand} * \text{(Review Period + Leadtime)} \quad (3.14)$$

Likewise, Type C items can be treated in a similar fashion but with a smaller initial buffering factor such as 10%:

$$B_C = (0.10) * \text{Average Daily Demand} * \text{(Review Period + Leadtime)} \quad (3.15)$$

The classification of a particular item is identified as a model input parameter during model initialization. For items classified as Type A due to relatively high variability in vendor leadtime, the "reasonable worst case leadtime L_W is also identified during model initialization

Once the appropriate buffer has been determined, the stock control level is calculated using the following formula:

Stock Control Level = (3.16)

[Average Daily Demand * (Review Period + Leadtime)] + Buffer

Like the current system, the reorder point of a product for the Bytronic system is simply equal to its stock control level minus one. Whenever the current inventory position is found to be less than the reorder point during the review of an item, subroutine RVWCALCS computes the suggested order quantity as follows:

Order Quantity = (3.17)

{[Average Daily Demand * (Review Period + Leadtime)] + Buffer}

- Inventory Position

or simply,

Order Quantity = Stock Control Level - Inventory Position (3.18)

As with the other two inventory control procedures, subroutine RVWCALCS resets the inventory position to the value of the stock control level specified once the replenishment order is placed. Finally, on hand inventory is incremented by the size of the replenishment once the order actually arrives.

Tijms and Groenevelt Procedure. As can be seen in Figure 4, the Tijms and Groenevelt model incorporates the use of a forecasting subroutine. The first task of subroutine RVWCALCS for the Tijms and Groenevelt procedure is call the subroutine FCASTR. Subroutine FCASTR estimates the following parameters:

X(R): expected demand during the review period

X(R+L): expected demand during the review period plus the leadtime

SD(R): standard deviation of errors of forecasts of total demand over the review period

SD(R+L): standard deviation of errors of forecasts of total demand over the review period plus the leadtime

Once these four values have been estimated by the subroutine FCASTR, the decision rules of the Tijms and Groenevelt procedure call for selecting k so as to satisfy the following equation:

$$J_u(K) = \frac{2 * [(1-P_2)/P_2] * X(R) * \{(S-s) + \{[SD(R)^2 + X(R)^2]/2 * X(R)\}\}}{SD(R+L)^2} \quad (3.19)$$

where X(R), X(R+L), SD(R), SD(R+L) are as defined above, the quantity (S-s) is assumed predetermined (for example by EOQ), $J_u(k)$ is a special function of the unit normal distribution, and finally, P_2 is the specified fraction of demand to be satisfied routinely from the "shelf" (that is, neither lost nor backordered). Since subroutine KFIND contains a table of $J_u(k)$ versus k values, finding the appropriate solution to this equation

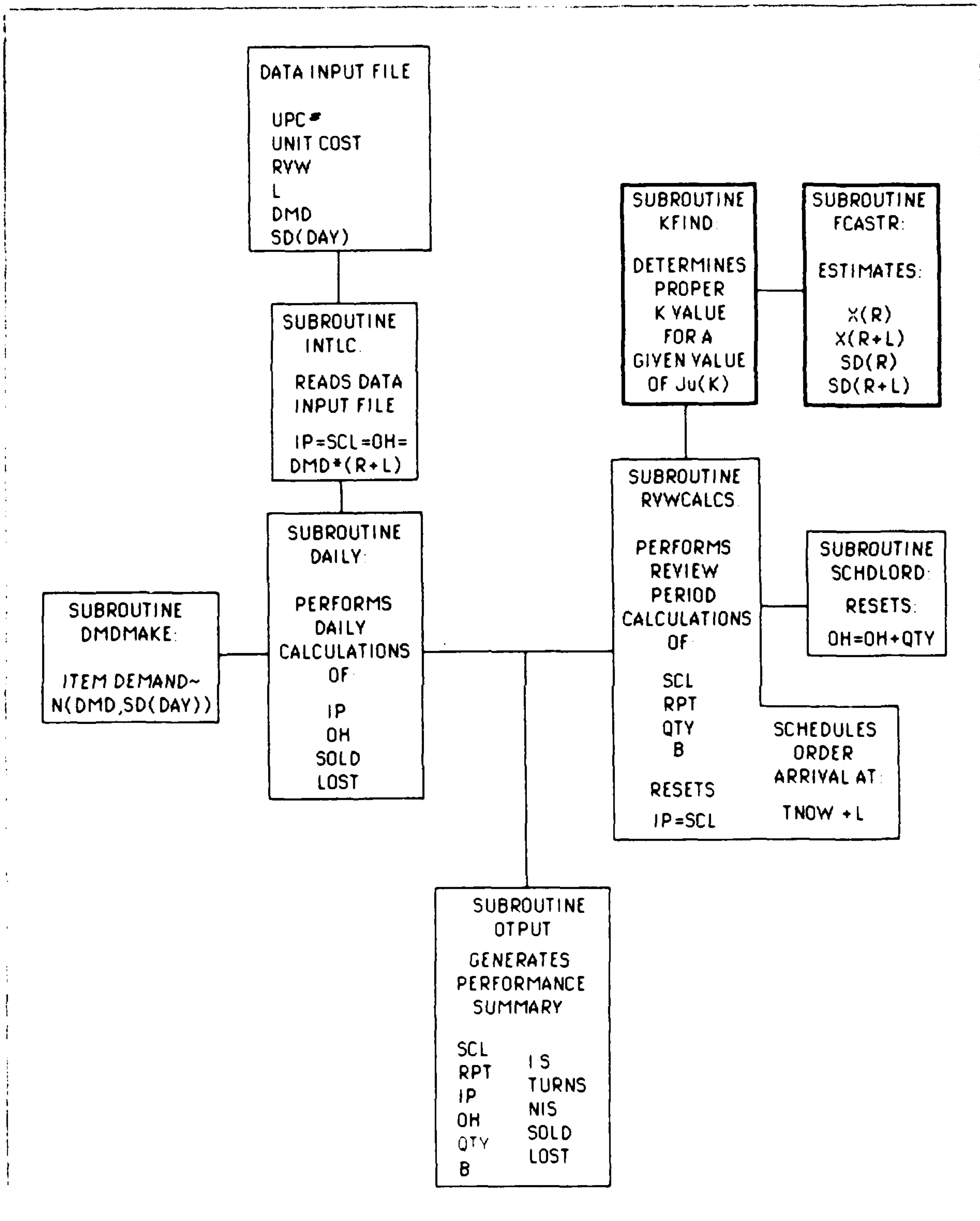


Figure 4. Tijms and Groenevelt Model Structure

poses no problem. In addition, determining the reorder point and the stock control level is easily accomplished by subroutine RVWCALCS using the following two equations:

$$\text{Reorder Point} = X(R+L) + [k * SD(R+L)] \qquad (3.20)$$

and

$$\text{Stock Control Level} = \text{Reorder Point} + (S-s) \qquad (3.21)$$

Finally, whenever the current inventory position is found to be less than the reorder point during the review of an item, subroutine RVWCALCS computes the suggested order quantity as follows:

$$\text{Order Quantity} = [\text{Reorder Point} + (S-S)] - \text{Inventory Position} \qquad (3.22)$$

or simply,

$$\text{Order Quantity} = \text{Stock Control Level} - \text{Inventory Position} \qquad (3.23)$$

As with the other two inventory control procedures, subroutine RVWCALCS resets the inventory position to the value of the stock control level specified once the replenishment order is placed. Finally, on hand inventory is incremented by the size of the replenishment once the order actually arrives.

Verification of the Inventory Simulation Models

Simulation model verification is establishing that the simulation code performs as intended in order to enhance the credibility of the model. Banks and Carson provide a more formal definition:

> Verification refers to the comparison of the conceptual model to the computer code that implements that conception. It asks the question: Are the input parameters and logical structure of the model correctly represented in the code?

Although verification may be considered one of the most important aspects of a simulation study, Banks and Malave' point out that very little has been written about the subject as it applies to inventory control systems in general since the verification process tends to be so model-dependent.

The process of verification is usually done by manually checking calculations. Consequently, although all three of the inventory control models presented in this study assume that item demand is stochastic, products with deterministic demand are typically used for the purposes of model verification. Making the computer code as self-documenting as possible and having the computer code checked by someone other than the original programmer are two additional aspects of the verification process incorporated into this study.

As previously mentioned, subroutine OTPUT is called at the end of each simulation run and is used for end-of-run processing and printing a summary of the simulated performance of each inventory control system. Since the Performance Summary Report is the means by which the performance of a system is evaluated, a logical approach to model verification is to manually check the accuracy of each field of this report. The Performance Summary Reports of all three models contain many of the same fields of output information. In fact, the manner in which the following fields are calculated is entirely independent of the inventory control system being simulated:

1. UPC#: universal product code

2. UNIT COST: (self-explanatory)

3. RVW: review period (days)

4. L: replenishment leadtime

5. DMD: average daily demand

6. SD(DAY): standard deviation of daily demand

7. SD(R+L): standard deviation of daily demand adjusted for the period during which the system is exposed to uncertainty; in this case, this period of uncertainty is equal to the review period plus the leadtime

8. IP: average inventory position

9. OH: average on hand inventory

10. QTY: average replenishment quantity size

11. B: buffer size

12. I:S: average inventory-to-sales ratio (over 30 day period)

13. TURNS: average number of stock turns (over 30 day period)

14. NIS: not-in-stock ratio

15. SOLD: cumulative number of satisfied demands

16. LOST: cumulative number of lost sales

Consequently, only the verification of these sixteen values for the model currently used by AFCOMS is presented here; calculations demonstrating the accuracy of these fields for both the Bytronic and the Tijms and Groenevelt procedures are identical and are deferred to Appendices E and F, respectively. The determination of the remaining fields of the Performance Summary Report for each model is, however, a function of the particular inventory control system being evaluated and, consequently, must be verified individually.

In addition to being reported at the individual item level, the aggregated average values of stock control level, reorder point, as well as fields 8 through 16 above are also presented on the summary report of each model. Similar to the 16 fields defined above, the calculation of all of these fields is entirely independent of the model under evaluation. Moreover, since all of these fields represent simple mathematical averages of their respective quantities, their calculation and verification are tedious, but trivial, and thus are not presented here.

Current model. A Performance Summary Report produced by the simulation model incorporating the reorder algorithm currently used by the Commissary Service is shown in Figure 5 for two items. The first item, UPC .00001, possesses deterministic demand (that is, its standard deviation of daily demand, SD(DAY), equals zero) and thus is used for the verification of the majority of output fields produced by the current

PERFORMANCE SUMMARY REPORT FOR CURRENT INV CONTROL SYSTEM

UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	TRND	S-DAYS			
0.00001	1.99	7.	5.	10.00	0.00	0.00	1.00	5.			
	------- AVERAGE VALUE AS OF DAY 60.00000 --------										
	SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
	170.	169.	124.	73.	76.	50.	0.46	2.2	0.097	542.	-58.
UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	TRND	S-DAYS			
0.00002	1.99	7.	5.	10.00	1.00	3.46	1.00	5.			
	------- AVERAGE VALUE AS OF DAY 60.00000 --------										
	SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
	170.	169.	124.	73.	76.	50.	0.46	2.2	0.097	539.	-58

Figure 5. Partial Performance Summary Report for Current Model

algorithm. The second item, UPC .00002 is only used for the verification of the SD(R+L) field of the current model since it has a standard deviation of daily demand other than zero.

For both items, the accuracy of the first six fields of this report--UPC* (UPC number), UNIT COST, RVW (review period in days), L (leadtime in days), DMD (average daily demand), and SD(DAY) (standard deviation of daily demand)--is easily confirmed since these values are taken directly from the data input file. However, the next field, SD(R+L), does require some mathematical manipulation. SD(R+L) represents the standard deviation of daily demand adjusted for the period during which the system is exposed to uncertainty; in this case, this period of uncertainty is equal to the review period plus the leadtime. The reported value of 3.46 for the SD(R+L) of the second product is easily verified by making the appropriate substitutions into the following formula:

$$SD(R+L) = SD(DAY) * (RVW + L)^{1/2} \tag{3.24}$$

$$SD(R+L)_{.00002} = 1.00 * (7 + 5)^{1/2} = 3.46 \tag{3.25}$$

The next field, TRND (trend factor), is generated according to the procedure specified in subroutine TREND. For the case of stationary demand data (that is, a fixed mean and variance of demand for each product over time) the correct value of the trend factor is 1.00. Since UPC numbers .00001 and .00002 assume such stationary demand patterns, the accuracy of their reported TRND fields (that is, 1.00 for both items) is readily verified.

The final field in the first row of the summary report, SDAYS (safety days) is also taken directly from the data input file without any mathematical manipulation and thus its verification poses no difficulty.

With respect to the first field of information of the second row of the output summary, SCL (stock control level), the reported value of 170 can be confirmed by making the appropriate substitutions into the following formula:

$$SCL = (RVW + L + SDAYS) * \{DMD * (TRND - 1)\} \tag{3.26}$$

$$SCL_{.00001} = (7 + 5 + 5) * \{10.0 + (1.00 - 1)\} = 170 \tag{3.27}$$

The reorder point of a product for the current system is simply equal to its stock control level minus one. Consequently, the next field in the second row of the output report, RPT (reorder point) for the first item is correctly reported to be 169. The same is true for UPC .00002:

$$RPT_{.00002} = 170 - 1 = 169 \qquad (3.28)$$

The next three fields, IP (inventory position), OH (on hand inventory), and QTY (replenishment quantity) represent averages of their respective quantities and thus can only be verified by manually tracking the values of these quantities on a daily basis over a finite period. The fields SOLD (cumulative number sold) and LOST (cumulative number of lost sales) can also be verified using this procedure. In turn, the accuracy of the NIS (not-in-stock), I:S (inventory to sales ratio), and TURNS (stock turns) fields can be established once the accuracy of the foregoing fields have been confirmed.

The "trace report" of IP, OH, and QTY--tracked on a daily basis for a simulation period of 60 days--is presented in Appendix D and confirms the accuracy of the values reported for each of these three quantities as well as the accuracy of the SOLD and LOST fields.* Subsequently, the field NIS can be easily checked since it is simply the number of lost sales divided by total demand during the same period:

$$NIS = \frac{LOST}{\text{Total Demand}} = \frac{LOST}{LOST + SOLD} \qquad (3.29)$$

$$NIS_{.00001} = \frac{58}{58 + 542} = .097 \qquad (3.30)$$

Next, the accuracy of the I:S (inventory-to-sales ratio) and TURNS (stock turns) fields can be manually checked:

$$I{:}S = \frac{IP}{30 * (SOLD/\text{Simulation Duration})} \tag{3.31}$$

$$I{:}S_{.00001} = \frac{124}{30 * (542/60)} = .46 \tag{3.32}$$

while

$$TURNS = 1/(I{:}S) \tag{3.33}$$

$$TURNS_{.00001} = 1/(.46) = 2.2 \tag{3.34}$$

Finally, for the current model, the field B (safety stock, or buffer) is simply equal to the number of safety days multiplied by the average daily demand. As a result, the stated value of 50 for the buffer of UPC .00001

* In order to demonstrate the accounting accuracy of the LOST (lost sales) field, the model was initialized with artificially low values of inventory position and on hand inventory so that a "lost sale" condition would occur.

is easily confirmed as follows:

$$B = (SDAYS) * (DMD) \tag{3.35}$$

$$B_{.00001} = (5) * (10.00) = 50.0 \tag{3.36}$$

Bytronic Model. A Performance Summary Report produced by the simulation model incorporating the reorder algorithm proposed by Bytronic Technologies is shown in Figure 6 for four items. Only the first of the four items has a nonzero standard deviation of daily demand; the remaining three items possess deterministic demand with a standard deviation of daily demand equal to zero. However, the CAT (category) field of each item is unique in order to ensure that the model is

```
PERFORMANCE SUMMARY REPORT FOR BYTRONIC INV CONTROL SYSTEM
------------------------------------------------------------------------------
UPC#      UNIT COST   AVW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00000     1.99       7.   5.  10.    1.00      3.46      0.    0.
          -------   AVERAGE VALUE AS OF DAY   60.00000   --------
          SCL    RPT     IP    OH    QTY    B   I:S  TURNS   NIS      SOLD  LOST
          128.   127.    85.   37.   72.    8.  0.31  3.2   0.091     554.  -54.

UPC#      UNIT COST   AVW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00001     1.99       7.   5.  10.    0.00      0.00      1.    15.
          -------   AVERAGE VALUE AS OF DAY   60.00000   --------
          SCL    RPT     IP    OH    QTY    B   I:S  TURNS   NIS      SOLD  LOST
          220.   219.   169.  114.   83.  100.  0.62  1.6   0.097     542.  -58.

UPC#      UNIT COST   AVW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00002     1.99       7.   5.  10.    0.00      0.00      2.    0.
          -------   AVERAGE VALUE AS OF DAY   60.00000   --------
          SCL    RPT     IP    OH    QTY    B   I:S  TURNS   NIS      SOLD  LOST
          144.   143.   100.   52.   73.   24.  0.37  2.7   0.097     542.  -58.

UPC#      UNIT COST   AVW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00003     1.99       7.   5.  10.    0.00      0.00      3.    0.
          -------   AVERAGE VALUE AS OF DAY   60.00000   --------
          SCL    RPT     IP    OH    QTY    B   I:S  TURNS   NIS      SOLD  LOST
          132.   131.    90.   42.   72.   12.  0.33  3.0   0.097     542.  -58.
```

Figure 6. Partial Performance Summary Report for Bytronic Model

functioning properly for all categories of items. The four possible categories are coded as follows:

1. CAT 0: Type A_1--items which possess relatively high variability of daily demand.

2. CAT 1: Type A_2--items which possess relatively high variability of vendor leadtime

3. CAT 2: Type B--items which require a 20% buffer

4. CAT 3: Type C--items which require a 10% buffer

A value for the field L_W (reasonable worst leadtime) is specified for UPC .00001 (Type A_2 or CAT 1) item since this value is required to determine the appropriate safety stock for this category of item. Since the values of both the CAT and the L_W fields are taken directly from the data input file without any manipulation, their accuracy is self-evident.

With respect to field B (buffer, or safety stock), the reported values for each of the four items must be confirmed independently since different formulae are used for the calculation of each buffer. The first UPC is a Type A_1 (CAT 0) item with a safety stock computed as follows:

$$B_{A1} = 2.25 * SD(DAY) * (RVW + L)^{1/2} \qquad (3.37)$$

$$B_{.00000} = 2.25 * 1.00 * (7 + 5)^{1/2} = 8 \qquad (3.38)$$

The next item, UPC .00001, is a Type A_2 (CAT 1) item and thus has a safety stock computed as follows:

$$B_{A2} = DMD * (L_W - L) \qquad (3.39)$$

$$B_{.00001} = 10.00 * (15 - 5) = 100 \qquad (3.40)$$

The value of 24 reported for field B of the third item is readily confirmed since the safety stock for a Type B (CAT 2) product is determined as follows:

$$B_B = (0.20) * (DMD) * (RVW + L) \qquad (3.41)$$

$$B_{.00002} = (0.20) * (10.00) * (7 + 5) = 24 \qquad (3.42)$$

Finally, the last item is a Type C (CAT 3). As a result, its buffer stock is computed as follows:

$$B_C = (0.10) * (DMD) * (RVW + L) \qquad (3.43)$$

$$B_{.00003} = (0.10) * (10.00) * (7 + 5) = 12 \qquad (3.44)$$

Once the accuracy of the buffer for a particular item has been established, the SCL (stock control level) reported for that item can be verified by making the appropriate substitutions into the following formula specified by the Bytronic procedure:

$$SCL = [DMD * (RVW + L)] + B \qquad (3.45)$$

$$SCL_{.00001} = [10.00 * (7 + 5)] + 100 = 220 \qquad (3.46)$$

Similar to the current system, the reorder point of a product for the Bytronic system is simply equal to its stock control level minus one. Consequently, the next field in the second row of the output report, RPT (reorder point) for UPC .00001 is correctly reported to be 219 (that is, 220 - 1). The same is true for items .00000, .00002, and .00003:

$$RPT_{.00000} = 128 - 1 = 127 \qquad (3.47)$$

$$RPT_{.00002} = 144 - 1 = 143 \qquad (3.48)$$

$$RPT_{.00003} = 132 - 1 = 131 \qquad (3.49)$$

Tijms and Groenevelt Model. A Performance Summary Report produced by the simulation model incorporating the reorder algorithm proposed by Tijms and Groenevelt is shown in Figure 7 for two items. The first of the two items possess deterministic demand with a standard deviation of daily demand equal to zero, while the second has a nonzero standard deviation of daily demand.

PERFORMANCE SUMMARY REPORT FOR TIJMS INV CONTROL SYSTEM											
UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R)	SD(R+L)	JUK	K	S-s	
0.00001	1.99	7.	15.	10.00	0.00	0.00	0.00	*****	0.00	105.	
	------- AVERAGE VALUE AS OF DAY 60.00000 --------										
	SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
	325.	220.	249.	107.	198.	0.	1.13	0.9	0.263	442.	-158.
UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R)	SD(R+L)	JUK	K	S-s	
0.00002	1.99	7.	15.	10.00	7.00	18.52	32.83	0.378	0.18	105.	
	------- AVERAGE VALUE AS OF DAY 60.00000 --------										
	SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
	331.	226.	257.	104	175	6.	1.08	1.0	0 181	475.	-109.

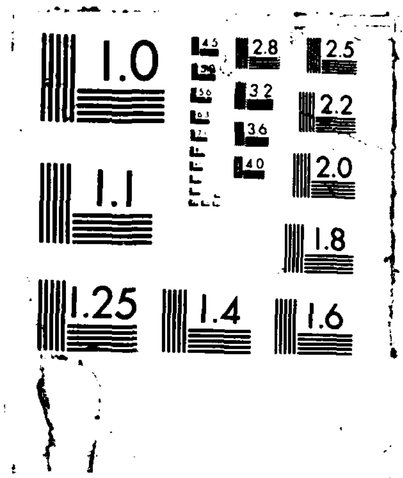
Figure 7. Partial Performance Summary Report
for Tijms and Groenevelt Model*

In addition to the SD(DAY) and SD(R+L) fields present on the Performance Summary Reports of the other two models, the Tijms and Groenevelt report contains an additional field related to standard deviation of daily demand; specifically, the field SD(R) which represents the standard deviation of daily demand adjusted for the review period of the item. The reported value of 18.52 for the SD(R) field of the second product is easily verified by making the appropriate substitutions into

*Although products with deterministic demand cannot normally be used in the Tijms and Groenevelt model since such products would cause division by zero during the determination of $J_u(k)$, the code has been temporarily modified to allow such products to be used for verification purposes.

AD-A189 461 A COMPARISON OF THE PERFORMANCE OF THREE INVENTORY CONTROL STRATEGIES IN T..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. M B STARK 2/3

UNCLASSIFIED DEC 87 AFIT/GOR/ENS/87D-20 F/G 5/1 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

the following formula:

$$SD(R) = SD(DAY) * (RVW)^{1/2} \tag{3.50}$$

$$SD(R)_{.00002} = (7.00) * (7)^{1/2} = 18.52 \tag{3.51}$$

The last three fields of the first row of the summary report, JUK ($J_u(k)$), k, and S-s, are required for the determination of the RPT (reorder point) and SCL (stock control level) fields. $J_u(k)$ is defined, and thus confirmed by using the following function:

$$J_u(k) = \frac{2 * [(1-P_2)/P_2] * X(R) * ((S\text{-}s) + \{[SD(R)^2 + X(R)^2]/2 * X(R)\})}{SD(R+L)^2} \tag{3.52}$$

Setting P_2 equal to .98 and making the appropriate substitutions for the remaining variables of UPC .00002 yields:

$$J_u(k)_{.00002} = .378 \tag{3.53}$$

In turn, the field K is the solution of the following equation for a given value of $J_u(k)$ as determined by Equation 3.52 above:

$$J_u(k) = \{(1 + k^2) * [p_{u\geq}(k)]\} - [k * f_u(k)] \tag{3.54}$$

As a result, Equation 3.52 usually requires a trial-and-error type solution. However, since subroutine KFIND contains a table of $J_u(k)$ versus k values, finding the appropriate solution to this equation poses no problem. A table of $J_u(k)$ versus k values is given in Appendix G in order to confirm the accuracy of the value .18 reported for the field k on the summary report for the Tijms and Groenevelt inventory control system for the second product. Finally, the field (S-s) is assumed to be predetermined (for example by EOQ). For purposes of this study, this field is set equal one and a half times the average demand during the review period in order to meet one of the fundamental assumptions of this procedure. The value stated for the field S-s of the second product is easily confirmed using the following equation:

$$(S-s) = 1.5 * (DMD) * (RVW) \quad (3.55)$$

$$(S-s)_{.00002} = 1.5 * (10.00) * (7) = 105 \quad (3.56)$$

In addition, confirming the accuracy of the values stated for the RPT (reorder point) and SCL (stock control level) fields is easily accomplished by using the following two equations and making the appropriate substitutions:

$$RPT = X(R+L) + [k * SD(R+L)] \quad (3.57)$$

$$RPT_{.00002} = 220 + [(.18) * (32.82)] = 226 \quad (3.58)$$

and

$$SCL = RPT + (S-s) \tag{3.59}$$

$$SCL_{.00002} = 226 + 105 = 331 \tag{3.60}$$

Finally, for the Tijms and Groenevelt procedure, the field B (safety stock, or buffer) is simply equal to the value of k multiplied by the field SD(R+L). As a result, the stated value of 6 for the buffer of UPC .00002 is easily confirmed as follows:

$$B = (k) * SD(R+L) \tag{3.61}$$

$$B_{.00002} = (.18) * (32.83) = 6 \tag{3.62}$$

<u>Validation of the Inventory Simulation Models</u>

Validation is the process of ensuring that a model is an accurate portrayal of the real system it is intended to simulate. Naylor and Finger have developed a three-step model validation procedure that has been widely implemented:

1. Build a model that has high face validity.
2. Validate the model assumptions.
3. Compare the model input-output transformations to corresponding input-output transformations of the real system [22:92-101].

Face Validity. Conceptual models typically involve a rather significant degree of abstraction and/or simplification of the actual system under evaluation; fortunately, all three of the models presented in this study tend to be very isomorphic in nature and inherently possess a rather high degree of "face validity". Consequently, instead of representing some sort of mystical "black box," in essence, each of the models is nothing more than a sophisticated accounting procedure whose functioning is tedious but routine. As a result, once the computational accuracy of the model has been established through model verification, the only component of the model that remains subject to some degree of skepticism is the distribution of demand assumed for each product within the sample. However, both the Bytronic Technologies report and the Tijms and Groenevelt article recommend assuming Normally distributed demand subject to the condition that the coefficients of variation of all items are less than 0.5.

The consistency of the results produced by each model can be checked as an additional phase of the validation process. For instance, average inventory position and average inventory on hand are positively correlated with the review period and the leadtime of a particular UPC and thus, these quantities should become increasingly large as review period and leadtime are lengthened. (Consistency checks of this nature are performed throughout the entire output analysis process performed in Chapter V--Results and Findings.)

Validation of Model Assumptions. Although a number of simplifying assumptions are made during the model development stage, the demand data used in this study is actual daily demand data collected from the

Wright-Patterson commissary store. As a result, the effects of most of the considerations that were not explicitly incorporated into the model structures are reflected in this data.

Validating Input-Output Transformations. As Banks and Carson note:

> The ultimate test of a model, and in fact the only objective test of the model as a whole, is the model's ability to predict the future behavior of the real system when the model input data match the real inputs and when a policy implemented in the model is implemented at some point in the [real] system. [3:386]

Instead of validating the input-output transformations of the model by predicting the future, Banks and Carson note the modeler may use historical data produced by the actual system being simulated (3:387). In effect, "accurate prediction of the past" can be substituted for accurate "prediction of the future" for the purpose of model validation. Unfortunately, however, within the practical constraints of this study, neither of these two courses of action is feasible. More specifically, with respect to the former approach--predicting future performance of the system, the time and effort required to actually implement the decisions recommended by the inventory control models of this study system simply exceed the scope of this research. The second approach to model validation--accurately predicting the past--is not possible either. Although one of the models supposedly incorporates the reorder algorithm currently used by the Commissary Service, interviews with personnel of the WPAFB store reveal that inventory control recommendations provided by ACOS are routinely overridden. As a result of these rather marked deviations from the suggested policies of the "current reorder algorithm" and the fact that neither the Bytronic nor the Tijms and Groenevelt procedures have ever been actually implemented by the Air Force Commissary Service, historical data is simply not available for any of the three models.

IV. Methodology

General Approach

The unique nature of AFCOMS with regard to the four categories of cost (replenishment, holding, shortage, and system control) that are typically relevant to inventory management was discussed earlier in the review of the literature. In view of this discussion, the general approach taken in this study to compare the performances of the three alternative inventory control systems was also somewhat unique. Rather than imposing an artificial cost structure on inventory control within the Commissary Service, the method of comparing the models was to see which yields the best performance subject to keeping not-in-stock ratio (NIS) at some prescribed level.

The stated objective of AFCOMS is to minimize inventory-to-sales ratio (I:S) subject to limiting NIS to a value of .02 or less. Although a store manager is granted some leeway with respect to I:S, the latter requirement is assumed to be fixed according to HQ AFCOMS policy. Consequently, although inventory-to-sales ratios were treated as a response variable and were thus allowed to vary, any proposed system which resulted in a NIS ratio in excess of the stated objective of .02 or less was judged to be unacceptable. Although I:S and NIS were the two output measures of primary interest, a number of other performance measures were tracked, analyzed, and reported in order to supplement the comparison and to provide a more complete "profile" of the respective inventories produced by each system.

Data Collection

In order to accomplish the objectives of this study, data was collected to support the simulation models. More specifically, daily item movement had to be tracked in order to determine average daily demand and standard deviation of daily demand for each product within the sample. In addition, this level of data was required to determine if a suitable predictive model could be fitted to the pattern of daily demand with which to estimate X_R, X_{R+L}, SD_R, SD_{R+L} for the Tijms and Groenevelt procedure. The day of the week and the occurrence of paydays were believed to be the two effects which have the greatest impact on item demand.

As a result of the sheer number of items which comprise the inventory "population" of the WPAFB store (approximately 10,000), data was collected for a much smaller sample of items. Although ACOS digests, manages, and summarizes an impressive amount of data and thus represents a rather substantial asset for decision-making within the commissary store environment, the micro-level of data required for this study tended to exceed the resolution capability of ACOS. For instance, sales data is typically aggregated over a month or over several individual UPCs rather than recorded on either a daily or individual item basis. Consequently, the data required for this investigation was not readily available in any *convenient* form within ACOS. Interviews with computer support personnel at HQ AFCOMS revealed that the only feasible method to track individual item movement, was to print an ACOS report known as the "Vendor File Listing" for each day of the period under study.

A Vendor File Listing is available for every vendor or distributor that services a commissary. Currently, there are over 600 vendors that actively supply the WPAFB store. Of these 600, however, the top ten vendors account for a rather substantial percentage of the 10,000 items stocked by the commissary in somewhat of a Pareto-type distribution.

Although the Vendor File Listing contains a great deal of extraneous information from the viewpoint of this research, it did contain one essential field--MOVEMENT--by which daily demand could be assessed. Ideally, obtaining a Vendor File Listing for several different suppliers was desirable from the standpoint of making the sample of items to be analyzed as representative as possible of the population from which it was drawn. However, due to a number of practical operating considerations with which the WPAFB store must contend (primarily, the limited amount of printer time that could be spared for research purposes and secondly, manpower constraints), the data collection plan had to be tempered somewhat. As a compromise, the commissary manager agreed to print a complete Vendor File Listing for the single largest vendor, Proctor and Gamble Corporation, for approximately 30 days of actual store operation.

In view of the large number (roughly 200) and diverse nature of items supplied by Proctor and Gamble, this appeared to be a satisfactory sampling plan from which an adequate sample could be extracted. In addition, 30 days of data for each UPC was felt to be an adequate length of time in which to capture both the day-of-the-week and payday phenomena in order to build a predictive model for the Tijms and Groenevelt procedure. Finally, to ensure that a reasonable sample size for detailed analysis would be obtained, 105 items were tracked on a daily basis initially to allow for any item attrition (due to excessive stockouts, discontinued items, et cetera) that might occur during the course of the data collection period.

Input Data Preparation. Due to the store being closed on Mondays, occasional computer difficulties, and the occurrence of a national holiday, the data collection period had to be extended from 30 days to 47 days of store operation. Doing so resulted in the collection of 32 days of usable data. In addition, of the 105 items originally tracked, 15 UPCs had to be dropped from further consideration since these items were inadvertently deleted from the Proctor and Gamble Vendor File Listing midway through the data collection period; this action resulted in a sample size of 90 items. Appendix H gives a description of the items included in the sample.

Once the data collection was completed, three sets of daily demand data were constructed according to the input requirements of each of the three models. The first two sets of data, constructed for use in the Current and Bytronic inventory simulation models, were very similar with one exception. For both sets of data, the average daily demand and the standard deviation of daily demand for each product were calculated. However, although no further processing was necessary for preparing the data set for use in the Current model, the items had to be categorized according to the procedure specified in the Bytronic Technologies report before being used as input in the Bytronic model.

The Bytronic procedure calls for ranking the items according to their inherent variability of demand. (Although this classification scheme also includes a category of items based on high variability of vendor leadtime, this category of items was not used since the other two inventory control systems used in this study assume that leadtime is deterministic.) Accordingly, the coefficient of variation (CV) for each item was computed using the following formula:

$$CV_{(R+L)} = [SD(D) * (R + L)^{1/2}]/[DMD * (R + L)] \quad (4.1)$$

where the numerator represents the standard deviation of daily demand corrected for the period during which the system is exposed to uncertainty (that is, the review period plus the leadtime), while the denominator represents the average demand during the review period and the leadtime. Next, the 90 UPCs were ranked in ascending order by their coefficients of variation (See Table 2 below).

Although the Bytronic report suggests a 20%-30%-50% partitioning of an inventory into categories A, B, and C respectively, in general, the overall values of the coefficients of variation of the 90 sample products were lower than originally anticipated. In fact, the highest CV observed was only .163. Consequently, the 20%-30%-50% classification scheme tended to provide excessive safety stocks. Some limited experimentation revealed that a 0%-50%-50% partitioning scheme provided NIS rates comparable to those generated by the Current and Tijms and Groenevelt models. As a result, the last 45 items listed in Table 2 were classified as Type B while the first 45 were assigned a Type C category. Incidentally, the surprisingly low CV values for all 90

Table 2. Ranking of Sample Items by Coefficient of Variation

RANK	UPC	DMD	SD(DAY)	CV	RANK	UPC	DMD	SD(DAY)	CV
1	0.00354	9.39	2.49	0.052	46	0.00408	34.47	13.94	0.079
2	0.00901	17.32	5.03	0.057	47	0.00415	19.19	7.70	0.079
3	0.60712	66.09	20.31	0.060	48	0.00988	15.87	6.42	0.079
4	0.91290	20.72	6.36	0.060	49	0.40060	15.32	6.20	0.079
5	0.00391	40.32	12.70	0.062	50	0.60511	48.56	19.60	0.079
6	0.00426	9.55	3.00	0.062	51	0.62712	40.90	16.71	0.080
7	0.00946	21.93	7.16	0.064	52	0.00824	15.91	6.58	0.081
8	0.00394	13.92	4.61	0.065	53	0.00405	22.31	9.34	0.082
9	0.91240	27.62	9.15	0.065	54	0.00427	12.07	5.02	0.082
10	0.00309	25.06	8.39	0.066	55	0.36030	22.56	9.40	0.082
11	0.00321	23.50	7.88	0.066	56	0.00718	16.41	6.99	0.084
12	0.35510	35.90	12.15	0.066	57	0.42027	15.13	6.49	0.084
13	0.91250	14.32	4.83	0.066	58	0.42110	22.00	9.46	0.084
14	0.00287	16.25	5.52	0.067	59	0.62792	44.00	18.93	0.084
15	0.00404	17.81	6.17	0.068	60	0.65881	22.68	9.87	0.085
16	0.44425	11.06	3.86	0.068	61	0.00407	28.27	12.48	0.087
17	0.60571	24.29	8.43	0.068	62	0.66151	16.03	7.08	0.087
18	0.40010	41.59	14.56	0.069	63	0.67312	28.69	13.09	0.089
19	0.44014	37.69	13.30	0.069	64	0.61612	42.19	19.30	0.090
20	0.00345	19.78	7.21	0.071	65	0.62312	32.97	15.32	0.091
21	0.00501	32.59	11.73	0.071	66	0.62172	65.66	30.78	0.092
22	0.35000	18.44	6.64	0.071	67	0.00775	29.59	14.01	0.093
23	0.44018	20.34	7.37	0.071	68	0.00844	13.33	6.34	0.093
24	0.60641	86.56	31.20	0.071	69	0.00580	68.09	32.78	0.094
25	0.97330	16.19	5.83	0.071	70	0.61222	84.79	41.18	0.095
26	0.00622	10.50	3.85	0.072	71	0.61652	33.54	16.33	0.095
27	0.00735	8.52	3.18	0.073	72	0.00863	23.60	11.54	0.096
28	0.00823	37.41	13.98	0.073	73	0.00942	10.72	5.28	0.097
29	0.44212	13.71	5.10	0.073	74	0.00712	26.30	13.12	0.098
30	0.44511	21.22	7.89	0.073	75	0.90240	13.04	6.62	0.100
31	0.00883	32.16	12.12	0.074	76	0.48534	22.81	11.88	0.102
32	0.35500	35.96	13.53	0.074	77	0.00864	20.00	10.80	0.106
33	0.66251	16.70	6.26	0.074	78	0.00523	123.61	67.60	0.107
34	0.00555	35.03	13.44	0.075	79	0.00618	25.13	14.34	0.112
35	0.62372	45.81	17.47	0.075	80	0.00413	23.17	13.36	0.113
36	0.91740	12.35	4.72	0.075	81	0.00884	12.36	7.48	0.119
37	0.00439	14.71	5.75	0.077	82	0.00805	31.00	19.02	0.120
38	0.00482	16.23	6.37	0.077	83	0.41040	29.10	18.20	0.123
39	0.00411	11.03	4.38	0.078	84	0.40020	15.42	9.73	0.124
40	0.00412	34.84	13.79	0.078	85	0.62351	75.44	48.31	0.126
41	0.00717	63.88	25.36	0.078	86	0.63031	58.00	39.15	0.132
42	0.36020	30.28	12.08	0.078	87	0.41000	16.58	11.30	0.134
43	0.44180	10.56	4.22	0.078	88	0.63011	58.23	42.24	0.142
44	0.62112	48.86	19.39	0.078	89	0.41100	18.33	13.87	0.148
45	0.00312	14.81	5.95	0.079	90	0.00592	50.83	42.21	0.163

sample items reaffirmed the validity of using the assumption of normally distributed demand since the professional literature recommends doing so as long as $CV_{(R+L)} \leq .5$ (28:353).

Building the second set of data was somewhat more involved. Similar to the first set, the average daily demand for each product was calculated for each UPC. Next, however, instead of merely calculating the standard deviation of daily demand for each, a general linear model was fitted for each item using daily demand as the response variable and using coded values of the day of the week and the occurrence of paydays as regressor variables. The mean square error of each resulting model was now used in place of the standard deviation of daily demand since the Tijms and Groenevelt procedure incorporates the use of a forecast in an effort to account for some of the variability of daily consumer demand. Although at the aggregate level a model could be built that achieved reasonably good fit with a relatively high coefficient of determination ($R^2 = .85$), at the individual item level, the explanatory power of the resulting models was substantially lower with a mean of .447, a low of .166, and a high value of .780. Even though the majority of the R^2 values were not particularly high, the Tijms and Groenevelt procedure attempts to provide superior performance by capturing some of the variability of item demand by using a forecast. Plots of the residuals versus the fitted values did not reveal anything troublesome to preclude the use of the root MSE as an estimate of SD(DAY) for each UPC in the Tijms and Groenevelt model.

Statistical Considerations for Analysis of Simulation Results

A simulation model was constructed for each of the three inventory control systems under consideration in order to provide results that simulate the outputs of the real systems. Once these simulation models had been sufficiently verified for computational accuracy and subjected to at least the initial stages of validation, these three models were used to estimate certain characteristics of each system in order to assess the performance of each.

As Welch points out, simulation models usually have a "random input that consists of a set of sequences of random variables whose distributions are specified" (32:268). In turn, the output resulting from a simulation model is also typically a "set of sequences of random variables" that represent various performance measures of the system under study. In the case of this study, the input random variables are the daily demand for each of the 90 items in the sample, while average inventory position and average inventory on hand are examples of two performance measures represented by sequences of output random variables.

Independent Replications. As a result of the random nature of the output measures, statistical techniques were used to estimate certain characteristics of their distributions. The performance measures of interest in this study are steady-state characteristics; that is, their associated distributions converge to what are known as "limiting" or "steady-state" distributions. The procedure used in this study was the use of independent replications--the simplest procedure for estimating characteristics of steady-state distributions. The general strategy of this procedure was to first estimate the duration of the transient period and then to estimate the mean and variance of the steady-state distribution of interest.

Estimation of the Transient Phase. In many simulations, the models must be "warmed-up" in order to arrive at a steady-state condition. During the warm-up phase, some distributions pass through a transient phase during which the random sequences are a function of the initial conditions of the model prior to actually converging to their limiting distributions.

In order to accurately estimate the steady-state characteristics of a simulation, it is usually desirable to discard the observations of the sequence produced during the transient or warm-up phase since their distributions do not accurately reflect the steady-state distribution (32:289). Although there is generally no a priori method to estimate the duration of the transient phase, one simple procedure is to plot the variable(s) of interest against current time in the simulation at specified intervals across a range of time sufficient to observe the convergence of the measure of interest.

For the purposes of this study, I:S was the most relevant performance measure to be plotted against time in order to estimate the duration of the transient phase. At the aggregate level, this measure represented an average over the 90 items contained in the sample; therefore, neither "smoothing" nor "averaging" across replications was used during the pilot runs that were made to determine the extent of the transient phase. Furthermore, since this procedure represented only a *rough* approximation of the extent of the transient phase, this technique appeared to be adequate. Plots of I:S versus time for the Current, Bytronic, and Tijms models are given in Figure 8 below. Although the Tijms and Groenevelt procedure took nearly a year to warm up, the other two models achieved steady-state more quickly. However, in order to ease the comparison of the three, a time of 360 days was chosen as the end of the transient phase for all three models. Accordingly, all statistical registers of the simulations were cleared at this time to minimize the biasing effect of the initial conditions.

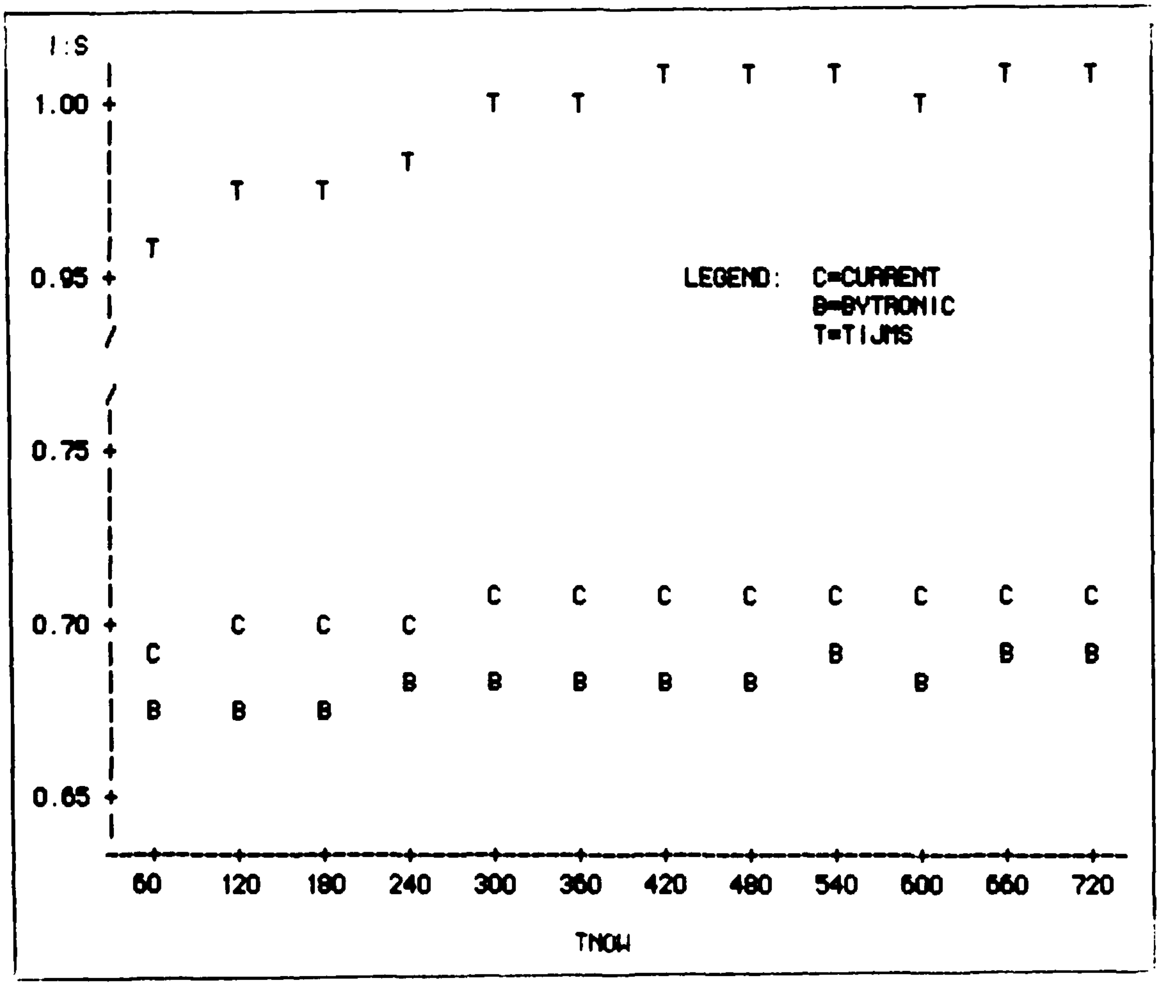


Figure 8. Plot of I:S versus time for Current, Bytronic, and Tijms Models

Estimation of the Steady-State Parameters. In essence, a simulation run is simply an experiment or realization of an output sequence (that is, the simulated performance) of the system under a certain set of prescribed conditions. As a result, to perform the estimation of the parameters of the output distribution, first, a specific combination of model settings is used to generate "a particular realization of the set of input sequences" (32:269). Each unique set of model settings is equivalent to what is typically referred to as a "treatment" in the field of design of experiments, while the individual settings altered during the course of the study are analogous to independent variables or "factors." Next, repeated simulations are run with this realization as input in order to generate repeated realizations of the set of output sequences and achieve a specified level of statistical precision (32:269). Finally, a confidence interval for each of the performance measures can be calculated using standard statistical techniques.

Achieving Desired Accuracy. As Welch points out, there is no *a priori* method to determine "what quantity of data (that is, what number of sequences of data of what length) produces what confidence interval width" (32:321). However, a pilot experiment is often useful in approximating this relationship:

> [The] pilot experiment provides a rough estimate of the magnitude of the quantity of interest and a rough estimate of the relationship between the confidence interval width and the quantity of data processed. With these estimates a main experiment that will yield confidence intervals of approximately the desired width can be planned. [32:321]

From a purely practical standpoint, a change in inventory-to-sales ratio of 0.05 or more was believed to be significant. Consequently, a pilot experiment was conducted to determine the quantity of data (that is, the required run length and number of replications) necessary to detect a change in I:S of this magnitude. In view of the general desirability of fewer, longer runs as opposed to several, shorter runs, the number of replications of each of the three models was set equal to five. Review period and leadtime were set at values of 14 and 12 days, respectively, while run length was set equal to two years (once the model had achieved steady-state). The pilot experiment revealed that 0.002 was a good estimate of the standard deviation of I:S.

For the purposes of this study, "D_F" was used to denote the minimum detectable difference between two mean values of I:S produced by any two levels of a given factor F. Assuming an alpha level of .01, D_{System} was calculated to be .0027. As a result, the ability to detect a change in I:S of .05 or more (due to a change in the inventory control system used) was virtually guaranteed using estimates of I:S produced by five replications and a run length of two years. Similar calculations to determine D_F values for the review period and leadtime factors produced D_{Review} = .0027 and $D_{Leadtime}$ = .0018. Consequently, as with the inventory control system factor, the ability to detect a change in I:S of .05 or more produced by either of these factors was virtually guaranteed using estimates of I:S resulting from five replications and a run length of two years. The calculation of these factors are given in Appendix I.

Experimental Design

The experimental design specifies the necessary combination of parameter settings (that is, treatment levels) to test the hypothesis of interest; namely, whether or not there are significant differences among the inventory-to-sales ratios produced by the inventory control procedures, the review periods, and the leadtimes. For a simulation-type study such as this one, the experimental design also states the necessary run length and number of replications to calculate confidence intervals for the performance measures of interest with a specified level of accuracy; namely a change in I:S of $\pm$ .05.

A three-factor factorial design was used in this study to assess and compare the simulated performance of each of the three inventory control systems. The three factors used, as well as the allowable levels of each, were defined as follows:

1. Inventory control system: 3 levels--the system currently used by AFCOMS (Current), the reorder strategy advocated by Bytronic Technologies Corporation (Bytronic), and finally, the Tijms and Groenevelt procedure (Tijms).

2. Review Period: 3 levels--7, 14, and 21 day review cycles

3. Leadtime: 2 levels--8 and 12 day replenishment leadtimes

The treatment combinations used are shown in Figure 9 below. Based upon the statistical accuracy considerations cited above, five replications, each two years in duration, were conducted at each of these 18 design points for a total of 90 observations.

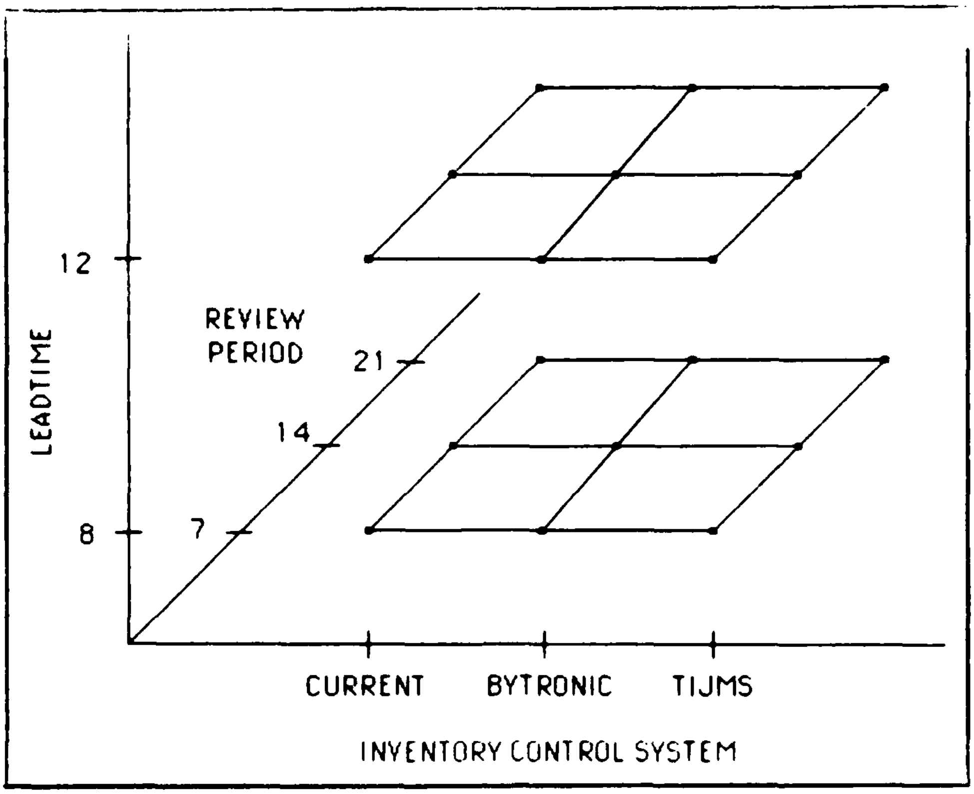


Figure 9. Treatment Combinations for Three-Factor Factorial Design

V. Results and Findings

Statistical Analysis of the Simulation Results

A full three-factor factorial design with the treatment combinations as specified previously in Figure 9 was used to measure the effect of the inventory control system, the review period, and leadtime on the inventory-to-sales ratio at the aggregate level. All possible two and three-factor interactions were also incorporated into the model. Five replications of this design were conducted. The analysis of variance is given in Table 3 below.

Table 3. Analysis of Variance Table

DEPENDENT VARIABLE: INVENTORY-TO-SALES RATIO

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	17	5.54073761	0.32592574	83685.81
ERROR	72	0.00028041	0.00000389	PR > F
CORRECTED TOTAL	89	5.54101802		0.0

R-SQUARE	C.V.	ROOT MSE	ISR MEAN
0.999949	0.2472	0.00197348	0.79830341

SOURCE	DF	TYPE I SS	F VALUE	PR > F
SYS	2	2.02331286	99999.99	0.0
RVW	2	2.47662537	99999.99	0.0
L	1	0.43925668	99999.99	0.0
SYS*RVW	4	0.59961287	38489.67	0.0
SYS*L	2	0.00192281	246.85	0.0001
RVW*L	2	0.00000061	0.08	0.9242
SYS*RVW*L	4	0.00000639	0.41	0.8006

The effect of the three factors clearly exceeded the 5% critical level. In addition, there were two highly significant two-factor interactions; the first was between the control system factor and review period, while the second was between the control system and the leadtime.

Based upon estimates of the model parameters, the fitted model can be written as follows:

$$y_t = 1.420 + (-0.524)IND_{t1} + (-0.519)IND_{t2} + (-0.685)IND_{t3}$$
$$+ (-0.346)IND_{t4} + (-0.133)IND_{t5} + (0.453)IND_{t6} + (0.229)IND_{t7}$$
$$+ (0.385)IND_{t8} + (0.195)IND_{t9} + (0.020)IND_{t10} + error_t \qquad (5.1)$$

where the effect of a particular treatment is proportional to its parameter estimate and the IND_{ti} are defined as follows:

IND_{t1} = 1 if SYSTEM = Current; 0 otherwise
IND_{t2} = 1 if SYSTEM = Bytronic; 0 otherwise
IND_{t3} = 1 if REVIEW = 7 days; 0 otherwise
IND_{t4} = 1 if REVIEW = 14 days; 0 otherwise
IND_{t5} = 1 if LEADTIME = 8 days; 0 otherwise
IND_{t6} = 1 if SYSTEM = 1 and REVIEW = 7 days; 0 otherwise
IND_{t7} = 1 if SYSTEM = 1 and REVIEW = 14 days; 0 otherwise
IND_{t8} = 1 if SYSTEM = 2 and REVIEW = 7 days; 0 otherwise
IND_{t9} = 1 if SYSTEM = 2 and REVIEW = 14 days; 0 otherwise
IND_{t10} = 1 if SYSTEM = 2 and LEADTIME = 8 days; 0 otherwise

Figures 10 and 11 below give a graphical representation of the effect of the first two factors (inventory control system and review period) on the inventory-to-sales ratio with the third factor (leadtime) fixed at its two allowable values of eight and twelve days, respectively.

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IND_{t6} = 1 if SYSTEM = 1 and REVIEW = 7 days; 0 otherwise
IND_{t7} = 1 if SYSTEM = 1 and REVIEW = 14 days; 0 otherwise
IND_{t8} = 1 if SYSTEM = 2 and REVIEW = 7 days; 0 otherwise
IND_{t9} = 1 if SYSTEM = 2 and REVIEW = 14 days; 0 otherwise
IND_{t10} = 1 if SYSTEM = 2 and LEADTIME = 8 days; 0 otherwise

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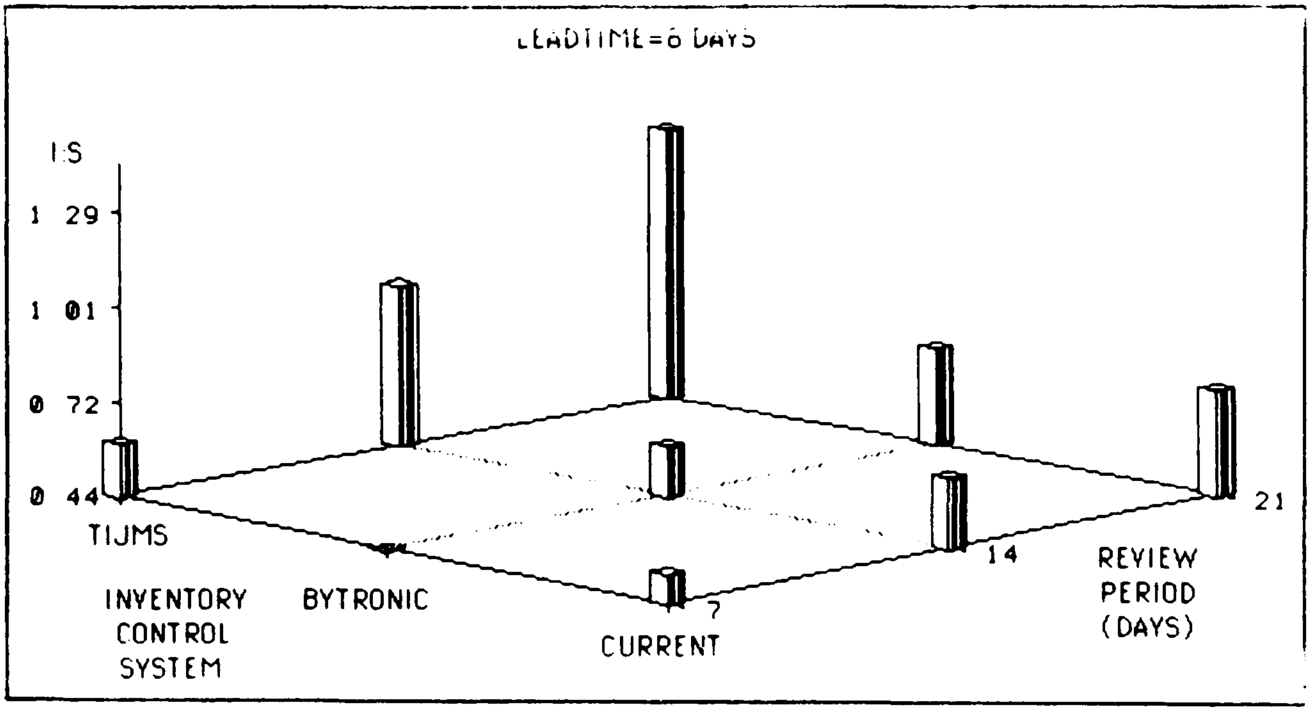


Figure 10. 3-D Plot of I:S vs System and Review Period for Leadtime=8

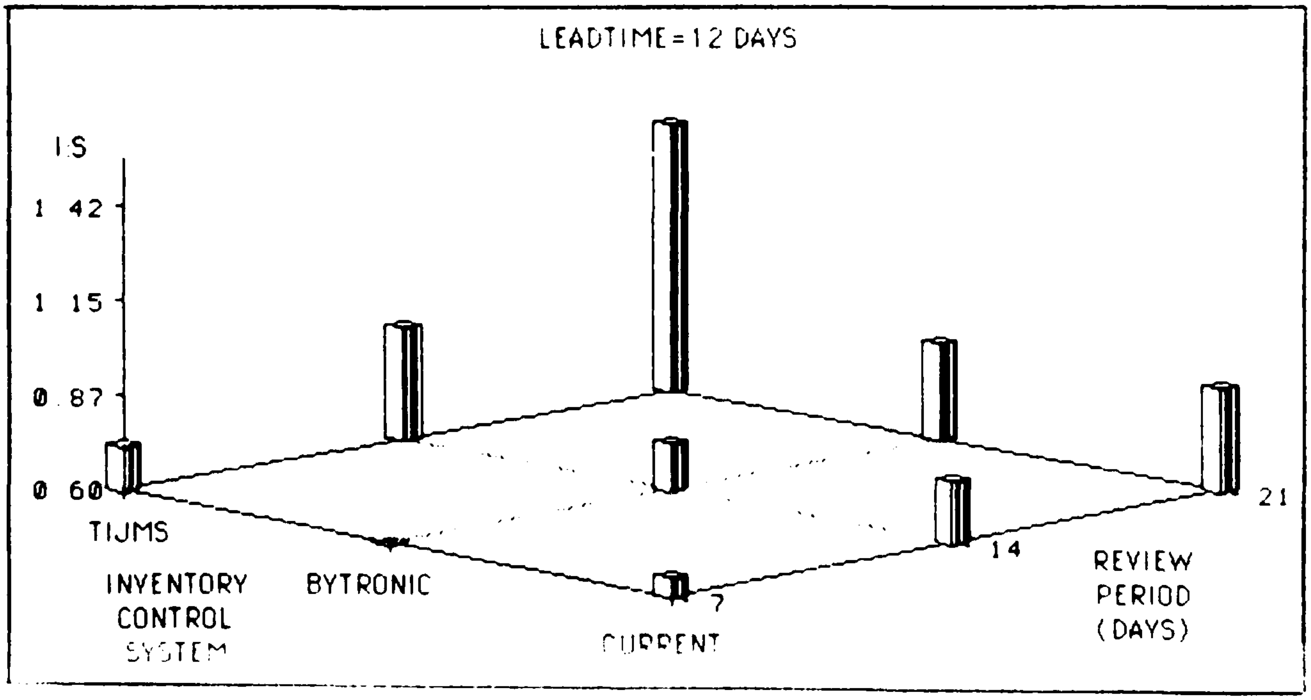


Figure 11. 3-D Plot of I:S vs System and Review Period for Leadtime=12

Across the range of factor combinations tested, none of the inventory control systems produced NIS ratios in excess of the critical value of .02. As a result, all three of the systems produced results that were "acceptable" in a very rudimentary sense. However, the values of the inventory-to-sales ratios (I:S) varied widely as a function of the model specified and the values of the review period and the lead time used. The values of the other performance measures also varied widely in a similar fashion according to the combination of these three factors used. The performance of each of the three models at the aggregate level with respect to these measures are presented in Tables 4 through 6. Each of these tables is broken down into subsets based on review period and leadtime. In addition, 95% confidence intervals are provided for all of the random variables that exhibited any variability.

In general, the results demonstrate the superiority of the Bytronic inventory control strategy over both the Current and the Tijms and Groenevelt procedures for the sample of products studied. Although the gap between the performances of the Bytronic and the Tijms and Groenevelt models was rather sizable at all six treatment levels, the difference in performance between the Bytronic and the Current models was much less pronounced--especially at the largest value of review period used. However, it is likely that the performance of the Bytronic procedure could be improved somewhat by further refinements of the multi-item classification scheme used to partition the 90 items in the sample. In other words, smaller buffers could be carried for some of the items while keeping NIS rates at acceptable levels. This possibility is explored further in a following section of this chapter.

Table 4. Summary of Performance Measures for the Current Model at the Aggregate Level

RVW	L	IP	OH	QTY	B	I:S	NIS
7	8	470.0*	233.6±0.68	207.4±0.68	147.0*	.53*	0.00*
	12	587.2±0.56	234.0±1.52	207.4±0.58	147.0*	.66*	0.00*
14	8	571.8±0.56	337.0±1.24	414.6±0.68	147.0*	.65*	0.00*
	12	689.2±0.56	337.6±2.08	414.4±0.68	147.0*	.78*	0.00*
21	8	675.0±0.88	439.6±2.08	621.6±1.11	147.0*	.76*	0.00*
	12	793.0±0.88	440.2±3.09	621.4±0.68	147.0*	.90*	0.00*

Table 5. Summary of Performance Measures for the Bytronic Model at the Aggregate Level

RVW	L	IP	OH	QTY	B	I:S	NIS
7	8	393.0±0.56	160.0±1.52	205.6±0.68	69.0*	.44*	0.01*
	12	529.0*	177.0±2.03	206.*	88.0*	.60*	0.01*
14	8	527.0±0.56	293.2±1.04	413.0±0.88	107.0*	.59*	0.00*
	12	662.8±0.56	311.8±2.03	413.6±0.68	120.0*	.74*	0.00*
21	8	662.2±1.04	426.0±2.08	621.0±1.24	134.0*	.74*	0.00*
	12	798.0±0.88	445.0±3.09	621.6±1.11	152.0*	.89*	0.00*

Table 6. Summary of Performance Measures for the Tijms and Groenevelt Model at the Aggregate Level

RVW	L	IP	OH	QTY	B	I:S	NIS
7	8	529.0±0.56	294.4±0.68	410.4±0.68	0.0*	.60*	0.00*
	12	648.0*	295.6±0.68	409.4±0.68	1.0*	.73*	0.00*
14	8	833.2±1.04	597.4±2.08	830.8±2.04	0.0*	.94*	0.00*
	12	950.6±0.68	598.4±2.08	830.6±2.42	0.0*	1.07*	0.00*
21	8	1140.0±4.39	899.2±3.87	1248.6±4.35	0.0*	1.29*	0.00*
	12	1258.0±4.39	898.2±2.83	1248.6±4.35	0.0*	1.42*	0.00*

*denotes values that did not exhibit any variability across replications

Multiple Comparisons. The analysis of variance indicated that all three of the main effects were significant. Consequently, Duncan's Multiple Range Test was useful in making comparisons among these three factors to discover specific differences. In spite of the two significant interactions present, Table 7 below clearly demonstrates that the mean values of I:S were significantly different across the three main effects.

Table 7. Duncan's Multiple Range Test

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT

ALPHA=0.05 DF=72 MSE=3.9E-06

NUMBER OF MEANS	2	3
CRITICAL RANGE	.00101671	.00106909

DUNCAN GROUPING	MEAN	N	SYS
A	1.0091794	30	3
B	0.7121104	30	1
C	0.6736204	30	2

ALPHA=0.05 DF=72 MSE=3.9E-06

NUMBER OF MEANS	2	3
CRITICAL RANGE	.00101671	.00106909

DUNCAN GROUPING	MEAN	N	RVW
A	1.0020668	30	21
B	0.7971066	30	14
C	0.5957368	30	7

ALPHA=0.05 DF=72 MSE=3.9E-06

NUMBER OF MEANS	2
CRITICAL RANGE	.00083014

DUNCAN GROUPING	MEAN	N	L
A	0.8681649	45	12
B	0.7284419	45	8

Diagnostic Checking of Model Adequacy

Before the conclusions from the analysis of variance can be adopted, the adequacy of the underlying model must be checked. The normal probability plot of the residuals is given in Figure 12 below and does not reveal anything particularly troublesome.

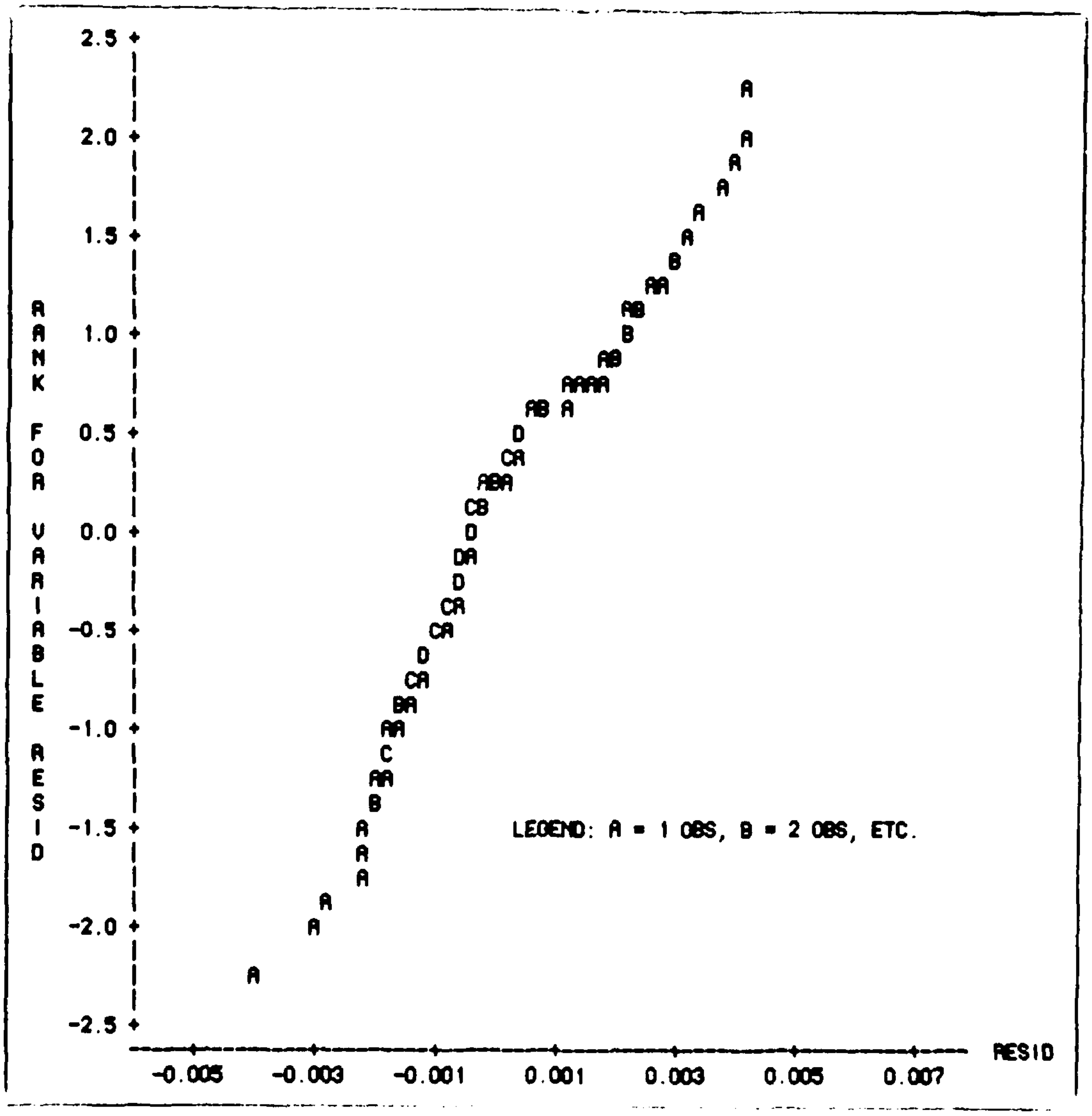


Figure 12. Normal Probability Plot of Residuals

Figure 13 below plots the residuals versus the fitted values of the inventory-to-sales ratio. This plot indicates a mild tendency for the variance of the residuals to increase as the inventory-to-sales ratio increases. However, since the absolute magnitudes of the residuals were

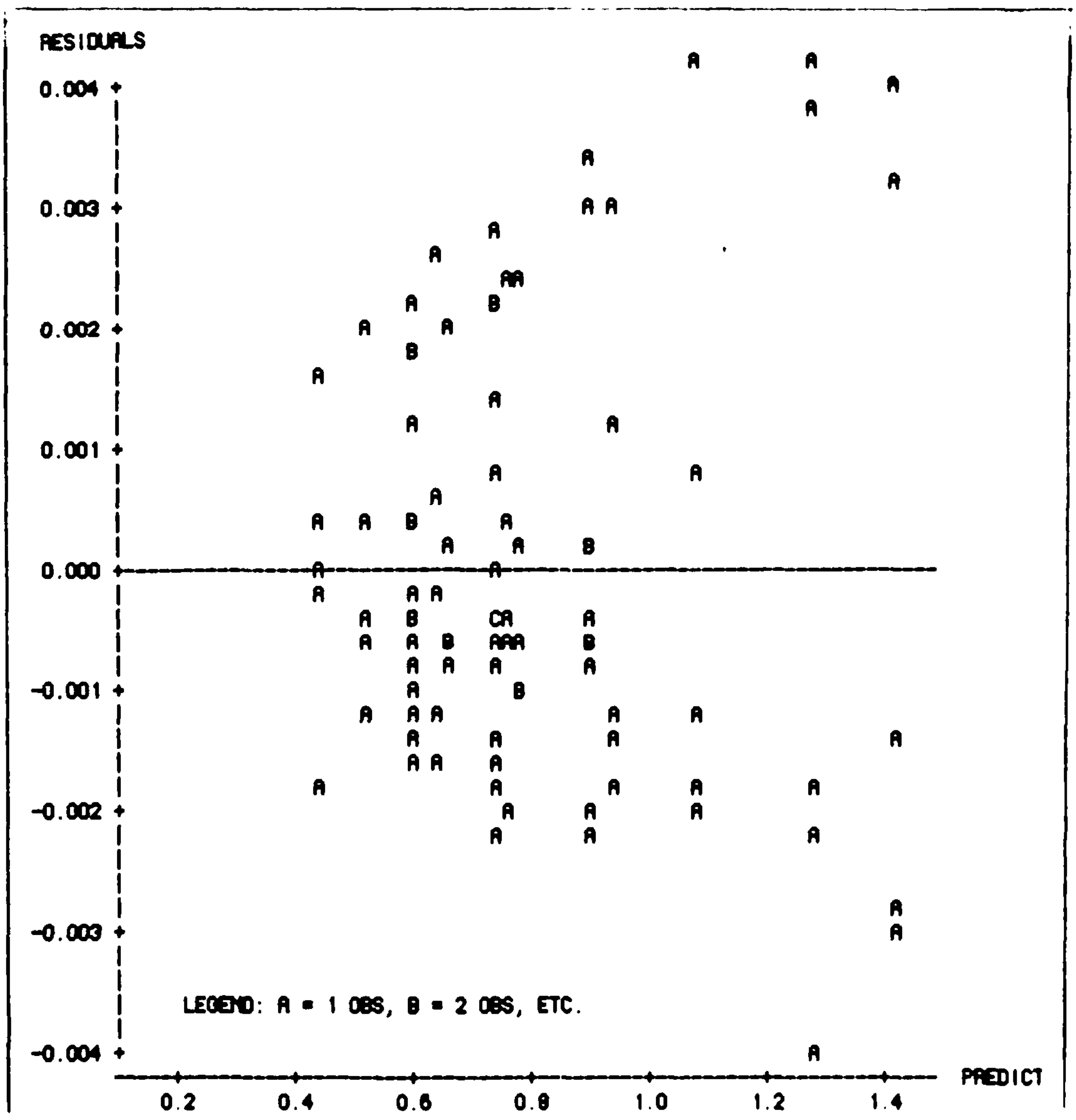


Figure 13. Residuals versus Fitted Values

so small across the entire range of 90 observations, this problem was not judged severe enough to have a significant impact on the adequacy of the model or the assumptions upon which it is based.

Detailed Analysis of Bytronic Model

In view of the demonstrated superior performance of the Bytronic inventory control strategy across the entire spectrum of performance criteria for the products studied, this procedure was reviewed in greater detail.

The two basic goals of the Commissary Service with respect to inventory management are to provide a given level of customer service and to maintain the smallest inventory levels possible. Striking a delicate balance between these two conflicting objectives can be simplified if the relationships among inventory levels, customer service, and inventory "performance" are explicitly known.

Figures 14, 15, and 16 below give graphical representations of the trade-offs implicit in these relationships. In Figure 14, relative buffer "size" (stated as a percentage of the average demand during the review period plus the leadtime) is used as a measure of the inventory levels carried, while NIS rate is used as the measure of customer service. In Figure 15, relative buffer size is used in a similar fashion, but is plotted against I:S which is used as the measure of inventory performance. Finally, Figure 16 gives the trade-off between NIS and I:S directly.

Since the performance of the Bytronic inventory control system is also a function of the variability of demand of the items under its control, plots of buffer size versus NIS, buffer size versus I:S, and NIS

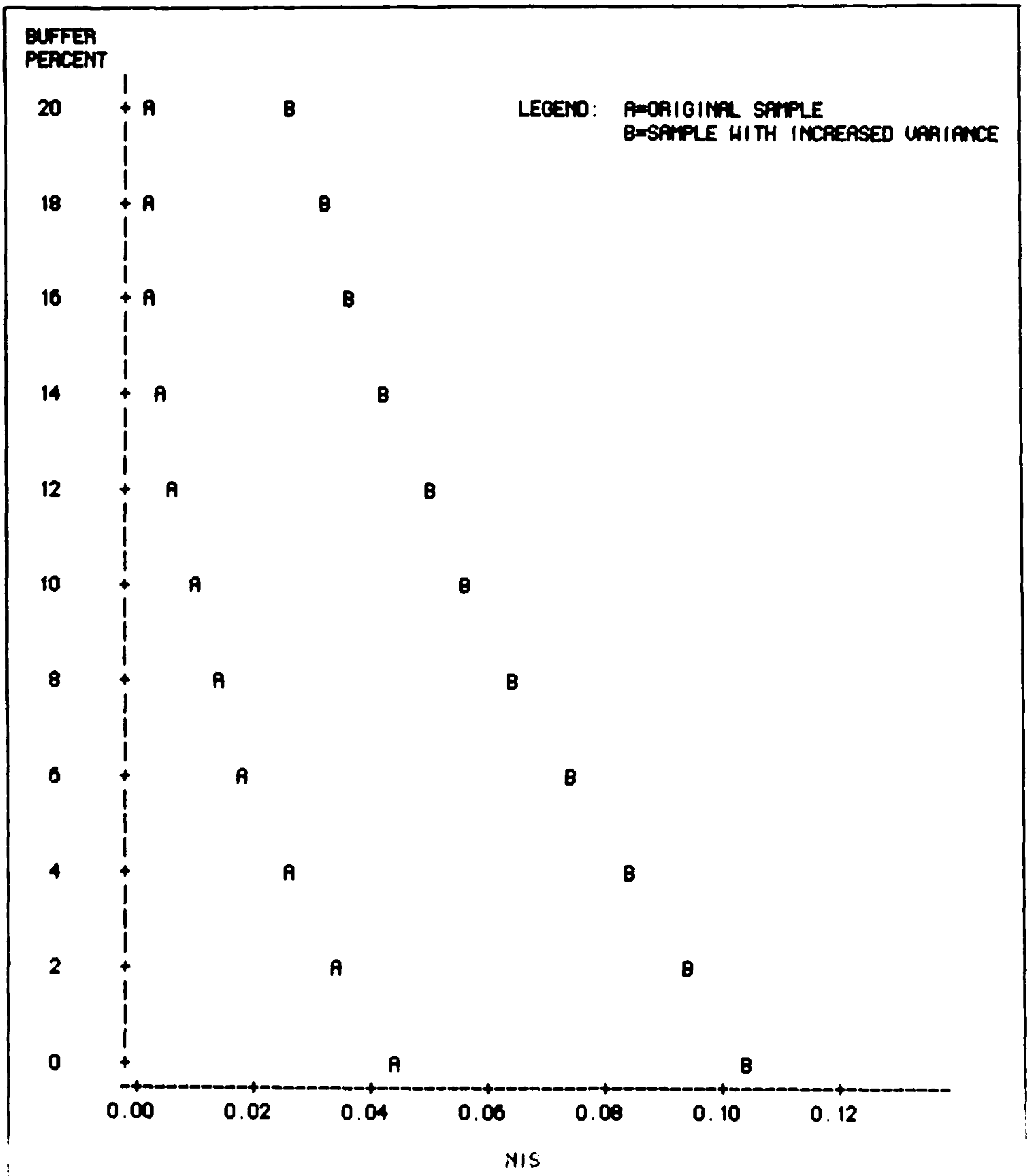


Figure 14. Plot of Buffer Size versus NIS

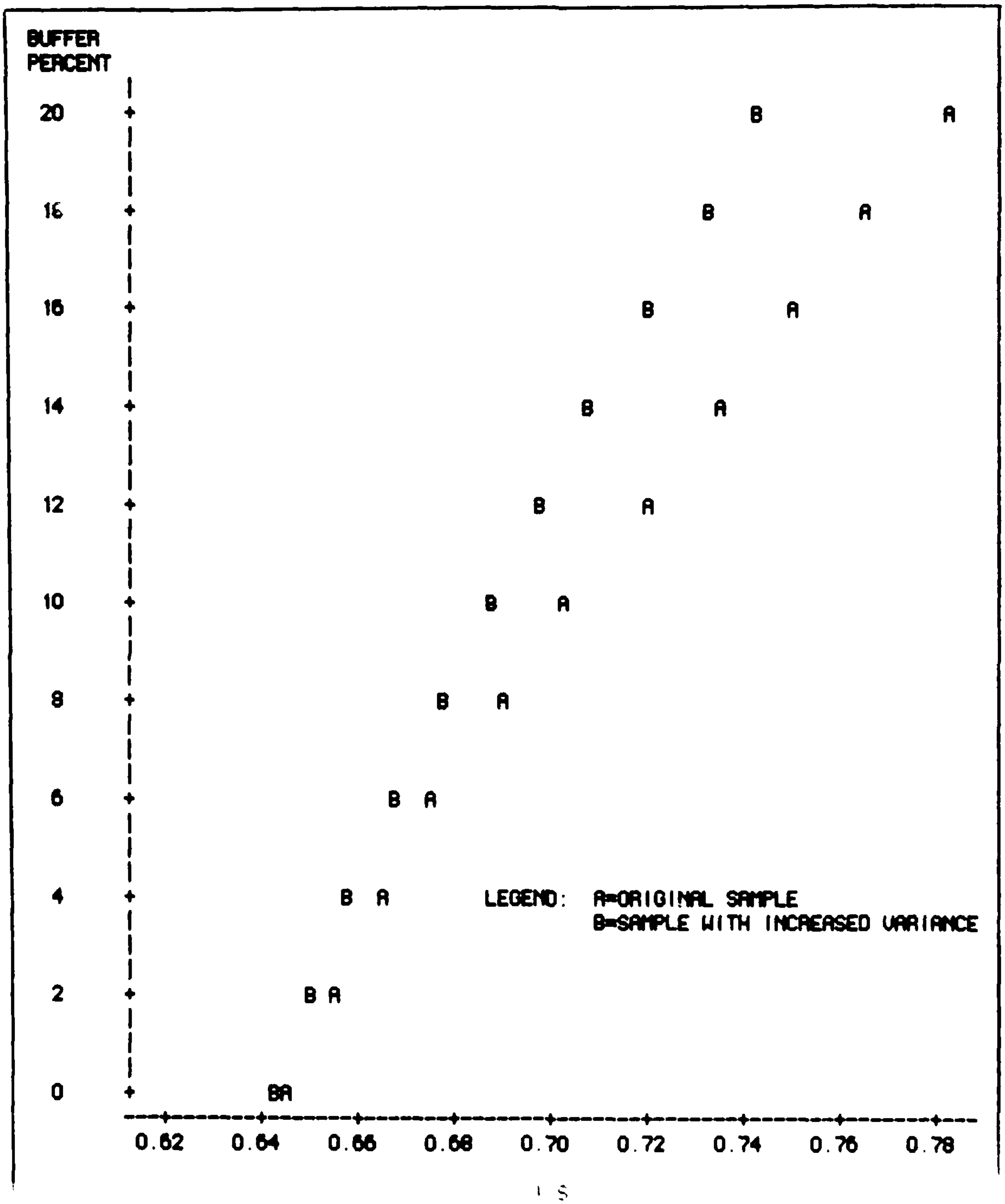


Figure 15. Plot of Buffer Size versus I:S

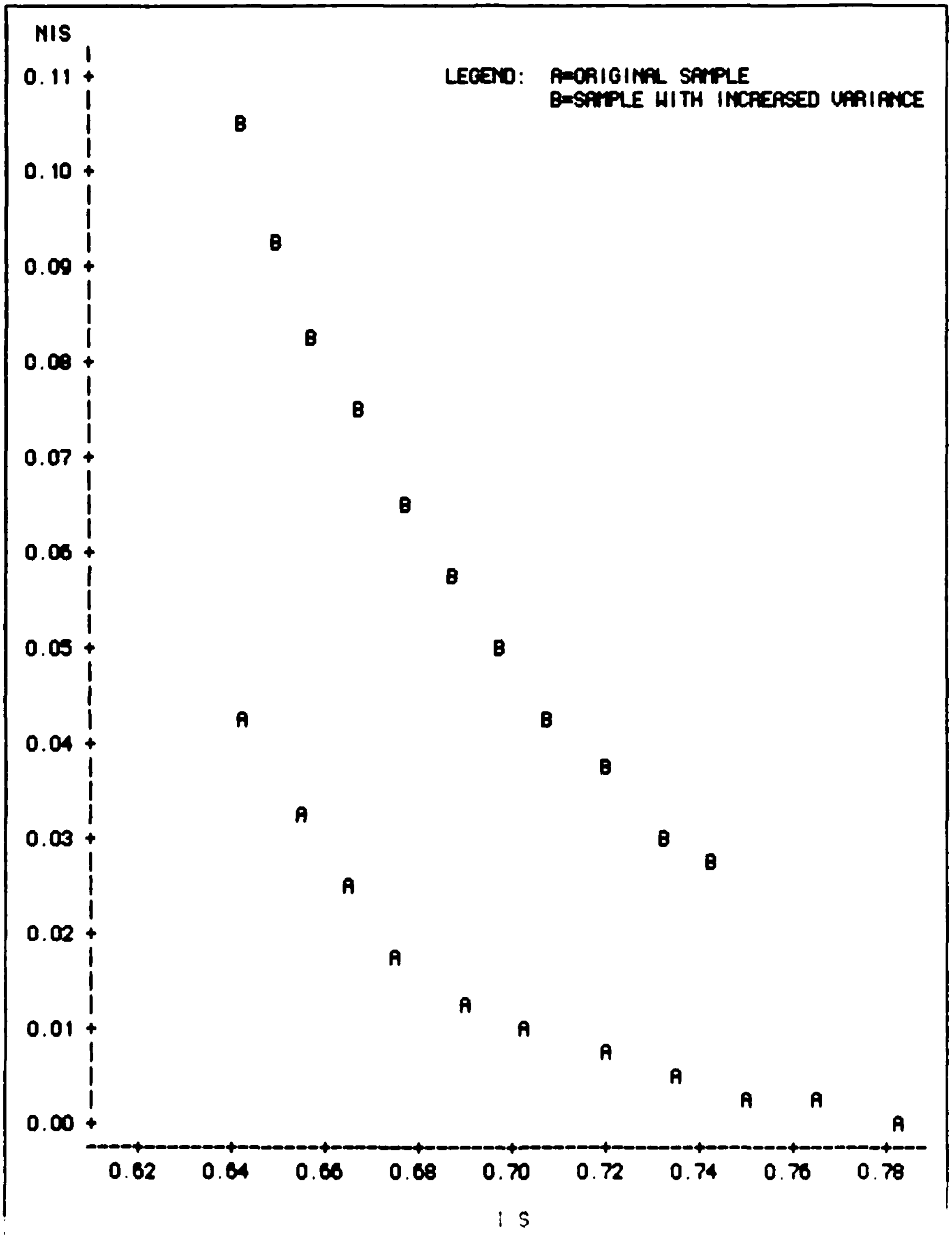


Figure 16. Plot of NIS versus I:S

versus I:S are also given in Figures 14,15, and 16 for a second sample of 90 items which possessed exactly twice the standard deviation of daily demand as the original sample. All other properties of the items in this new sample were identical to those of the corresponding products in the original sample. From Figures 14 and 16 it is clear that for the sample with twice the variance of the original to attain the stated objective of an NIS of .02 or less, larger buffers would be required. In turn, these larger buffers would correspond to higher I:S ratios in Figure 15. As a final note, the consistency of the results presented in these three figures further establishes the validity of the simulation models used in this study.

Performance of Bytronic Model at Individual Item Level. Although aggregate results are more appropriate for managerial review, the performance of the Bytronic system at the individual item level is of interest to the store manager. For the purposes of this study, however, since attempting to assess the performance of the Bytronic model across all possible combinations of review period and leadtime at the individual item level is prohibitively awkward, only one combination of these two parameters is used here; namely, a review period of 14 days and a leadtime of 12 days. A Performance Summary Report from an actual replication of the Bytronic model is presented in Appendix J. Across the entire range of sample products, the I:S ratios ranged from 0.68 to 0.83, while NIS rates ranged from a low of 0.00 to a high of 0.014. Although none of the NIS rates of the 90 sample items exceeded the .02 threshold, in general, the Performance Summary Report is helpful in determining the accuracy of the categories assigned to the items. For instance, any UPC that exhibits an excessive NIS rate can be moved into a category which will provide an increased safety stock. On the other hand, if a particular UPC never incurs a stockout, the item could be moved into a category that will provide a reduced safety stock while still keeping NIS at an acceptable level.

As can be seen from Appendix J, the Performance Summary Report also provides a wealth of information regarding the inventory "profile" for each product produced by a particular combination of inventory control strategy, review period, and leadtime. Among some of the statistics presented are the average values of inventory position, on hand inventory, and replenishment quantity for any particular item. Furthermore, the Performance Summary Report is helpful in assessing the impact of any proposed changes (for example, review period, leadtime, or item classification) at the individual item level.

VI. Limitations, Implications, and Conclusions

Limitations of the Study

In order to accomplish the objectives of the study and to produce an analysis that was tractable, a number of simplifying assumptions regarding the commissary environment had to be made. Admittedly, the task of incorporating only the most salient factors of the commissary store operating environment while simultaneously trying to preserve the simplicity of the inventory control procedure was not an easy task. Obviously, such a procedure ignored a number of other relevant factors. Although these factors were not explicitly taken into account, however, many of their effects were present in the actual sales data used and thus these factors were dealt with implicitly by each of the three models. Consequently, some of the simplifying assumptions (such as assuming stationarity of demand and no backorders) made during the problem formulation were really not as limiting as they might have appeared initially.

Without a doubt, the most limiting constraint of this study was the time-consuming and error-prone manner in which the daily demand data had to be collected. As a result of this constraint, the study was restricted to a relatively small sample of items when compared with the total inventory population of more than 10,000 items. In fact, even with a sample size of 90 items, this sample size represented less than one percent of the total population. Compounding this constraint was the limited time horizon of this study which prevented the acquisition of long-term sales data which might possibly contain seasonal effects for some items. In spite of these limitations of the data collection procedure, from a statistical viewpoint, the sample size, simulation run length, and number of replications used in this study were all very conservative and thus the inferences based on them are well-founded in a statistical sense.

Conclusions and Practical Implications

The specific purpose of this study was to compare the performances of two alternative inventory control procedures selected from the literature with that of the strategy currently used by the Air Force Commissary Service in an attempt to answer the question: What is the most appropriate inventory control strategy to efficiently manage and control the inventory of *selected* items in the WPAFB commissary?

Extensive comparisons of the simulated performances of the three models were conducted at both the aggregate and individual item level with a sample of 90 items. Of the three procedures, the inventory control system proposed by Bytronic Technologies Corporation appears to be the most promising. Based on this *preliminary* investigation, it *appears* as though inventory levels can be substantially reduced from current levels while at the same time maintaining, and in some cases, even improving customer service as a result of adopting the Bytronic procedure. In view of the volume of business conducted by the Air Force Commissary Service, even a ten percent reduction in inventory levels across the board would be prodigious. However, before the conclusions of this study are adopted for implementation, further exploration of the performance yielded by the Bytronic procedure is clearly required

In addition to demonstrating exceptional performance for the sample of items tested, the Bytronic model also possesses a significant degree of intuitive appeal which translates into greater user acceptance. The inherently simpler nature of the Bytronic model which is reactive in nature (in contrast with the Current and the Tijms and Groenevelt procedures that both incorporate the use of forecasts) is therefore a substantial benefit to the Commissary Service.

Beyond simply identifying the Bytronic strategy as the most promising procedure and quantifying the interrelationships among inventory levels, customer service, and inventory performance, this study has laid the foundation for future research in this area. In particular, the three models that were developed to simulate the performances of the Current, the Bytronic, and the Tijms and Groenevelt procedures have already been subjected to extensive verification and validation; consequently, these models represent valuable analytical tools for the Commissary Service.

A rather significant advantage of using the simulation models is that they allow the performances of the proposed systems to be studied in detail in a totally nonobtrusive manner prior to actually being implemented. As a result, current operations remain intact until the new alternative has been thoroughly tested and evaluated in a "realistic" operating environment. Another advantage of using the models in this fashion is that "optimal" system parameter settings can be estimated in advance so a lot of time is not spent trying to determine these once the new strategy has been implemented. Finally, since the performance of a given inventory control strategy is typically a function of several parameters, using these simulation models provides a degree of sensitivity analysis that is indeed impressive when contrasted with either the computational burden of trying to do so analytically or the obvious limitations associated with attempting to do so with the actual inventory system. As a result, the impact of any proposed changes can be assessed in detail and in advance.

Recommendations for Future Study

In view of the awkward manner in which the data for this study had to be collected, a prerequisite for future research is the automation of the data collection procedure. Once this procedure has been automated, an obvious area for further study is using the three models to control a sample of items suspected of possessing a high variability of demand. Assuming that the Bytronic strategy continued to demonstrate superior performance, a more detailed sensitivity analysis of the Bytronic model with respect to changes in review period, leadtime, and variability of item demand should be performed.

Although the Performance Summary Report produced by the Bytronic model is helpful in determining the accuracy of the categories assigned to items, such a procedure is strictly trial-and-error in nature and thus potentially very time-consuming. Thus, the development of an a priori classification procedure is yet another area of possible future study. Figure 14 indicates that the relationship between buffer size and not-in-stock can be approximated by a linear function. Assuming that a sufficiently linear relationship between not-in-stock and coefficient of variation could also be established, a surface such as the one illustrated in Figure 17 below could be generated. This surface could be used to determine the required buffer size to obtain a prescribed stockage objective (stated in terms of not-in-stock rate) for a product with a known variability of demand (stated in terms of coefficient of variation). As a result, such a procedure could be used to determine the appropriate buffer size for a product in advance. In addition, since this procedure treats buffer size as a continuous variable as opposed to using only a limited number of discrete categories, a more exact match between the variability of demand of an item and the safety stock carried for that item could be achieved. Finally, by fitting an equation to the surface presented in Figure 17, determination of the required buffer size could be easily incorporated into a computerized inventory control system.

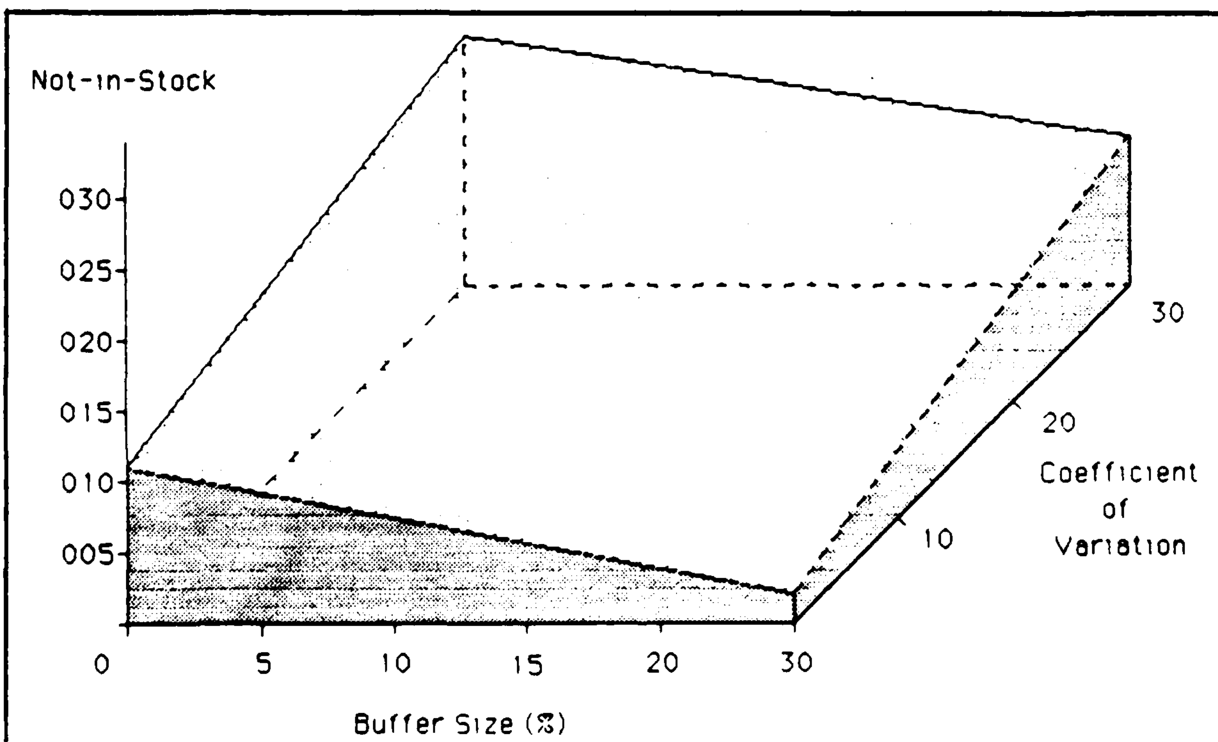


Figure 17. Hypothetical Surface Used for Buffer Size Determination

Appendix A. Computer Code for Current Model

Network Model Code: 126
Subroutine Code: 127-134

```
GEN,STARK,INVENTORY CURRENT,10/30/87,5,N,N,Y/N,N,N,72;
LIMITS,1,2,200;
STAT,1,*00287 INV POS;
STAT,2,*00287 ON HAND;
STAT,3,*00287 BUFFER;
STAT,4,*00287 ORD QTY;
STAT,5,*00287 REORDR PT;
STAT,6,*00309 INV POS;
STAT,7,*00309 ON HAND;
STAT,8,*00309 BUFFER;
STAT,9,*00309 ORD QTY;
STAT,10,*00309 REORDR PT;
 .
 .
 .
STAT,441,*91740 INV POS;
STAT,442,*91740 ON HAND;
STAT,443,*91740 BUFFER;
STAT,444,*91740 ORD QTY;
STAT,445,*91740 REORDR PT;
STAT,446,*97330 INV POS;
STAT,447,*97330 ON HAND;
STAT,448,*97330 BUFFER;
STAT,449,*97330 ORD QTY;
STAT,450,*97330 REORDR PT;
NETWORK;
      CREATE,1,1,,,1;            ****DAILY SALES TRANSACTIONS****
        EVENT,3,1;
      TERM;
      CREATE,30,1,,,1;           ****PERFORM TREND CALCULATIONS**
        EVENT,4,1;
      TERM;
      CREATE,7,7,,,1;            ****ONE WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=7;
        EVENT,1,1;
      TERM;
      CREATE,14,14,,,1;          ****TWO WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=14;
        EVENT,1,1;
      TERM;
      CREATE,21,21,,,1;          ****THREE WEEK REVIEW CYCLE*****
        ASSIGN,XX(1)=21;
        EVENT,1,1;
      TERM;
      CREATE,28,28,,,1;          ****FOUR WEEK REVIEW CYCLE******
        ASSIGN,XX(1)=28;
        EVENT,1,1;
      TERM;
      END;
INIT,0,1080;
MONTR,CLEAR,360;
FIN;
```

```
      PROGRAM MAIN
      DIMENSION NSET(10000)
      INCLUDE 'PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(10000)
      COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      OPEN(10,FILE='[MSTARK.SIM]CUPC.DAT',STATUS='OLD')
      OPEN(11,FILE='[MSTARK.SIM]CUPC.OUT',STATUS='NEW')
      OPEN(12,FILE='[MSTARK.SIM]MASTERC.OUT',STATUS='NEW')
      CALL SLAM
      STOP
      END

C*********************************************************************
C     SPECIFIES EVENT CALLS AS FOLLOWS:
C
C         DAILY:  PERFORMS DAILY ON HAND, INV POSITION, LOST SALES,
C                   TOTAL SOLD, CUMULATIVE LOST SALES, AND TOTAL
C                   MONTHLY DEMAND CALCULATIONS
C      RVWCALCS:  PERFORMS CALCULATIONS REQUIRED DURING EACH REVIEW
C      SCHDLORD:  PLACES AN ORDER ON THE CALENDAR AT TNOW+LEAD TIME
C         TREND:  DETERMINES TREND FOR USE IN PRO-ACTIVE MODEL
C     -----------------------------------------------------------------
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
      GO TO (1,2,3,4) I
1     CALL RVWCALCS
      RETURN
2     CALL SCHDLORD
      RETURN
3     CALL DAILY
      RETURN
4     CALL TREND
      RETURN
      END
C*********************************************************************

C*********************************************************************
C     LEGEND FOR UPC ARRAY VARIABLES
C       WHERE: UPC(I,1) :  REVIEW PERIOD (DAYS)
C              UPC(I,2) :  N/A
```

```
C               UPC(I,3) :  UNIT COST OF ITEM
C               UPC(I,4) :  MEAN DAILY DEMAND
C               UPC(I,5) :  STD DEV OF DAILY DEMAND
C               UPC(I,6) :  MEAN LEAD TIME
C               UPC(I,7) :  STD DEV OF DAILY DEMAND ADJUSTED FOR (R+L)
C               UPC(I,8) :  N/A
C               UPC(I,9) :  INVENTORY POSITION
C               UPC(I,10):  TARGET INVENTORY LEVEL
C               UPC(I,11):  REORDER POINT
C               UPC(I,12):  REPLENISHMENT QUANTITY
C               UPC(I,13):  TOTAL MONTHLY DEMAND
C               UPC(I,14):  SAFETY STOCK
C               UPC(I,15):  LOST SALES (NUMBER)
C               UPC(I,16):  INV ON HAND
C               UPC(I,17):  SAFETY DAYS
C               UPC(I,18):  UPC NUMBER
C               UPC(I,19):  TOTAL SOLD
C               UPC(I,20):  CUMULATIVE LOST SALES (NUMBER)
C***********************************************************************


C***********************************************************************
C     PERFORMS DAILY SALES TRANSACTIONS
C     ------------------------------------------------------------------
      SUBROUTINE DAILY
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
      INTEGER I
      CALL DMDMAKE
      DO 10 I=1,90
C**DETERMINE TOTAL MONTHLY DEMAND--SATISFIED AND UNSATISFIED
        UPC(I,13)=UPC(I,13)+DMD(I)
C**WHILE UPC ON HAND, DECREASE ON HAND AND INV POS BY DMD(I)
        IF (UPC(I,16) .GT. 0.0) THEN
          UPC(I,16)=UPC(I,16)-DMD(I)
          UPC(I,9)=UPC(I,9)-DMD(I)
C**SET LOST SALES=ON HAND (ONLY USED IF ON HAND GOES NEGATIVE)
          UPC(I,15)=UPC(I,16)
C**INCREMENT TOTAL SOLD
          UPC(I,19)=UPC(I,19)+DMD(I)
C**RESET LOST SALES=0 IF ON HAND NOT EXHAUSTED
          IF (UPC(I,15) .GT. 0.0) THEN
            UPC(I,15)=0.0
          ENDIF
C**ONCE ON HAND DEPLETED, CORRECT INV POS & TOTAL SOLD & SET ON HAND=0
          IF (UPC(I,16).LE.0.0) THEN
            UPC(I,9)=UPC(I,9)-UPC(I,16)
            UPC(I,19)=UPC(I,19)+UPC(I,16)
            UPC(I,16)=0.0
          ENDIF
C**RESET INV POS=0 IF IT BECOMES NEGATIVE SINCE NO BACKORDERS ALLOWED
          IF (UPC(I,9).LE.0.0) THEN
            UPC(I,9)=0.0
          ENDIF
C**INCREMENT CUMULATIVE LOST SALES
          UPC(I,20)=UPC(I,20)+UPC(I,15)
```

```
          ELSE
C**INCREMENT CUMULATIVE LOST SALES SINCE ON HAND LESS THAN 0
            UPC(I,20)=UPC(I,20)-DMD(I)
          ENDIF
C**COLLECT OBS STATS ON INV POS AND INV ON HAND
          CALL COLCT(UPC(I,9),5*(I-1)+1)
          CALL COLCT(UPC(I,16),5*(I-1)+2)
C**CLEAR SOLD AND LOST AT TNOW=360
        IF (TNOW.EQ.360) THEN
          UPC(I,19)=0.0
          UPC(I,20)=0.0
        ENDIF
 10     CONTINUE
        RETURN
        END
C***********************************************************************
C       CALLED BY SUBROUTINE DAILY TO CREATE 1 DAY OF DEMAND FOR EACH UPC
C       -----------------------------------------------------------------
        SUBROUTINE DMDMAKE
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
        INTEGER I
        DO 10 I=1,90
          DMD(I)=RNORM(UPC(I,4),UPC(I,5),1)
          IF (DMD(I) .LT. 0.0) THEN
            DMD(I)=0.0
          ENDIF
 10     CONTINUE
        RETURN
        END
C***********************************************************************


C***********************************************************************
C       PERFORMS REVIEW CYCLE CALCULATIONS
C       -----------------------------------------------------------------
        SUBROUTINE RVWCALCS
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
        INTEGER I
        DO 10 I=1,90
          IF (UPC(I,1) .EQ. XX(1)) THEN
C**SET REORDER POINT=SCL-1
          UPC(I,11)=UPC(I,10)-1
C**ONCE INV POS GOES BELOW REORDER POINT
          IF (UPC(I,9) .LE. UPC(I,11)) THEN
C**DETERMINE NEW SCL
            UPC(I,10)=(UPC(I,1)+UPC(I,6)+UPC(I,17))*
     1                (UPC(I,4)+(STQ(I,17,1)-1))
C**COLLECT OBS STATS ON AVG SCL
            CALL COLCT(UPC(I,10),5*(I-1)+5)
C**DETERMINE NEW REPLENISHMENT QUANTITY
            UPC(I,12)=(UPC(I,1)+UPC(I,6)+UPC(I,17))*
     1                (UPC(I,4)+(STQ(I,17,1)-1))-UPC(I,9)
C**COLLECT OBS STATS ON AVG REPLENISHMENT QUANTITY
```

```
            CALL COLCT(UPC(I,12),5*(I-1)+4)
C**RESET INV POS=SCL ONCE ORDER PLACED
            UPC(I,9)=UPC(I,10)
C**SCHEDULE ORDER ARRIVAL AND INCREASE ON HAND ONCE ORDER REC'D
            ATRIB(1)=I
            ATRIB(2)=UPC(I,12)
            ORDARVL=UPC(I,6)
            CALL SCHDL(2,ORDARVL,ATRIB)
          ENDIF
        ENDIF
10      CONTINUE
        RETURN
        END
C*****************************************************************************
C       CALLED BY AVWCALCS TO SCHEDULE ORDER ARRIVAL AT TNOW+LEAD TIME
C         AND INCREMENTS INV ON HAND
C       ------------------------------------------------------------------
        SUBROUTINE SCHDLORD
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
        UPC(ATRIB(1),16)=UPC(ATRIB(1),16)+ATRIB(2)
        RETURN
        END
C*****************************************************************************
C       CALLED BY AVWCALCS TO PERFORM TREND FACTOR CALCULATIONS
C         FOR EACH UPC
C
C       LEGEND FOR STQ ARRAY VARIABLES
C         WHERE: M:  MONTH
C                STQ(I,1,1) THRU STQ(I,12,1): MONTHLY DEMAND
C                STQ(I,1,2) THRU STQ(I,12,2): TREND PERCENT
C                STQ(I,13,1): TOTAL YEARLY DEMAND
C                STQ(I,14,1): TREND TOTAL
C                STQ(I,15,1): TREND AVERAGE
C                STQ(I,16,1): TREND PERCENT
C                STQ(I,17,1): TREND
C       ------------------------------------------------------------------
        SUBROUTINE TREND
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2),M
        INTEGER I,M
        M=M+1
C**RESET MONTH TO 1 (JANUARY) AT END OF YEAR
        IF (M.GT.12) THEN
          M=1
        ENDIF
        DO 10 I=1,90
C**REPLACE ESTIMATED MONTHLY DMD WITH ACTUAL ONCE DMD ESTABLISHED
          IF (M.GE.2) THEN
            STQ(I,M,1)=UPC(I,13)
          ENDIF
C**DETERMINE TOTAL YEARLY CONSUMPTION FOR EACH UPC
          STQ(I,13,1)=STQ(I,1,1)+STQ(I,2,1)+STQ(I,3,1)+STQ(I,4,1)+
     1                STQ(I,5,1)+STQ(I,6,1)+STQ(I,7,1)+STQ(I,8,1)+
     1                STQ(I,9,1)+STQ(I,10,1)+STQ(I,11,1)+STQ(I,12,1)
```

```
C**SET TREND TOTAL=TOTAL YEARLY CONSUMPTION
        STQ(I,14,1)=STQ(I,13,1)
C**DETERMINE TREND AVERAGE
        STQ(I,15,1)=STQ(I,14,1)/12
C**DETERMINE TREND PERCENT
        DO 20 M=1,12
          STQ(I,M,2)=STQ(I,M,1)/STQ(I,15,1)
20      CONTINUE
C**DETERMINE PERCENT TOTAL
        IF (M.EQ.1) THEN
          STQ(I,16,1)=4*(STQ(I,12,2))+3*(STQ(I,11,2))+
     1                2*(STQ(I,10,2))+1*(STQ(I,9,2))
          ELSE IF (M.EQ.2) THEN
            STQ(I,16,1)=4*(STQ(I,1,2))+3*(STQ(I,12,2))+
     1                  2*(STQ(I,11,2))+1*(STQ(I,10,2))
          ELSE IF (M.EQ.3) THEN
            STQ(I,16,1)=4*(STQ(I,2,2))+3*(STQ(I,1,2))+
     1                  2*(STQ(I,12,2))+1*(STQ(I,11,2))
          ELSE IF (M.EQ.4) THEN
            STQ(I,16,1)=4*(STQ(I,3,2))+3*(STQ(I,2,2))+
     1                  2*(STQ(I,1,2))+1*(STQ(I,12,2))
          ELSE
            STQ(I,16,1)=4*(STQ(I,M-1,2))+3*(STQ(I,M-2,2))+
     1                  2*(STQ(I,M-3,2))+1*(STQ(I,M-4,2))
        ENDIF
C**DETERMINE TREND
        STQ(I,17,1)=STQ(I,16,1)/10
C**COLLECT TREND STATS
        CALL COLCT(STQ(I,17,1),5*(I-1)+3)
C**RESET CUM MONTHLY DEMAND=0
        UPC(I,13)=0.0
10    CONTINUE
      RETURN
      END
C***********************************************************************


C***********************************************************************
C     INITIALIZES VARIABLES WITH STARTING VALUES AND CONDITIONS
C     ------------------------------------------------------------------
      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2),M
      INTEGER I
      DO 10 I=1,90
C**INITIALIZES THESE VALUES OF UPC(100,25) WITH CUPC.DAT
        READ (10,*) UPC(I,18),UPC(I,1),UPC(I,3),UPC(I,4),
     1              UPC(I,5),UPC(I,6),UPC(I,17)
C**DETERMINE STARTING INV POS
        UPC(I,9)=UPC(I,4)*(UPC(I,1)+UPC(I,6))
C**SET INITIAL SCL=INV POS
        UPC(I,10)=UPC(I,9)
C**DETERMINE STATIC BUFFER BASED ON SAFETY DAYS
        UPC(I,14)=UPC(I,4)*UPC(I,17)
C**SET INITIAL ON HAND=INV POS
        UPC(I,16)=UPC(I,9)
```

```
C**INITIALIZE THE FOLLOWING WITH ZERO
        UPC(I,2)= 0.0
        UPC(I,7)= 0.0
        UPC(I,8)= 0.0
        UPC(I,11)=0.0
        UPC(I,12)=0.0
        UPC(I,13)=0.0
        UPC(I,15)=0.0
        UPC(I,19)=0.0
        UPC(I,20)=0.0
        UPC(I,21)=0.0
        UPC(I,22)=0.0
        UPC(I,23)=0.0
        UPC(I,24)=0.0
C**SET MONTHLY DEMAND FOR FIRST MONTH=AVERAGE DEMAND FOR 30 DAYS
        DO 20 M=1,12
          STQ(I,M,1)=30*UPC(I,4)
20      CONTINUE
10    CONTINUE
      RETURN
      END
C*****************************************************************


C*****************************************************************
C     CREATES PERFORMANCE REPORT
C
C     LEGEND FOR UPC ARRAY AND CCAVG SUMMARY STATISTICS
C       WHERE:  UPC(I,21):  AVERAGE INV:SALES RATIO FOR 30 DAY PERIOD
C               UPC(I,22):  AVERAGE REORDER POINT
C               UPC(I,23):  AVERAGE STOCK TURNS FOR 30 DAY PERIOD
C               UPC(I,24):  AVERAGE NIS
C         CCAVG(5*(I-1)+1):  AVERAGE INVENTORY POSITION
C         CCAVG(5*(I-1)+2):  AVERAGE ON HAND INVENTORY
C         CCAVG(5*(I-1)+3):  AVERAGE TREND VALUE
C         CCAVG(5*(I-1)+4):  AVERAGE REPLENISHMENT QUANTITY
C         CCAVG(5*(I-1)+5):  AVERAGE STOCK CONTROL LEVEL
C     ---------------------------------------------------------------
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),STQ(100,20,2)
       INTEGER I
C**CREATE INDIVIDUAL UPC PERFORMANCE REPORT HEADER
        WRITE(11,*)
     1  '    PERFORMANCE SUMMARY REPORT FOR CURRENT INV CONTROL SYSTEM'
        WRITE(11,*)
     1  '------------------------------------------------------------
     1--------------'
      DO 10 I=1,90
C**DETERMINE STD DEV ADJUSTED FOR (R+L)
        UPC(I,7)=UPC(I,5)*(SQRT(UPC(I,1)+UPC(I,6)))
C**DETERMINE AVERAGE REORDER POINT
        UPC(I,22)=CCAVG(5*(I-1)+5)-1
C**DETERMINE AVERAGE INV POS:SALES
        UPC(I,21)=CCAVG(5*(I-1)+1)/(30*(UPC(I,19)/(TNOW-360)))
C**DETERMINE AVERAGE INV TURNS
```

```
      UPC(I,23)=1/UPC(I,21)
C**DETERMINE AVERAGE NIS
      UPC(I,24)=-(UPC(I,20)/(UPC(I,19)-UPC(I,20)))
      IF (UPC(I,24) .GT. 1.0) THEN
        UPC(I,24)=1.0
      ENDIF
C**WRITE INDIVIDUAL UPC PERFORMANCE REPORT TO CUPC.OUT
      WRITE(11,*)
     1 'UPC#    UNIT COST  AVW   L    DMD   SD(DAY)   SD(R+L)   TRND
     1  SDAYS'
      WRITE(11,100) UPC(I,18),UPC(I,3),UPC(I,1),UPC(I,6),
     1               UPC(I,4),UPC(I,5),UPC(I,7),CCAVG(5*(I-1)+3),
     1               UPC(I,17)
100   FORMAT(' ',F7.5,3X,F5.2,3X,F4.0,1X,F4.0,1X,F6.2,2X,F5.2,5X,F6.2,
     1          4X,F4.2,3X,F4.0)
      WRITE(11,*)
     1 '       -------   AVERAGE VALUE AS OF DAY', TNOW,'--------'
      WRITE(11,*) '          SCL     RPT      IP     OH     QTY     B    I:S
     1 TURNS   NIS     SOLD   LOST'
      WRITE(11,200) CCAVG(5*(I-1)+5),UPC(I,22),
     1               CCAVG(5*(I-1)+1),CCAVG(5*(I-1)+2),
     1               CCAVG(5*(I-1)+4),UPC(I,14),
     1               UPC(I,21),UPC(I,23),UPC(I,24),
     1               UPC(I,19),UPC(I,20)
200   FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0,1X,F5.0,1X,F4.0,1X,
     1       F5.2,1X,F4.1,3X,F5.3,2X,F7.0,1X,F5.0,/)
10    CONTINUE
C**CREATE AGGREGATE HEADER
      WRITE(11,*)
     1 '       -------   AVG AGG VALUE AS OF DAY', TNOW,'--------'
      WRITE(11,*)
     1 '          SCL     RPT      IP     OH     QTY     B    I:S  TURNS   NIS
     1    SOLD   LOST'
C**CALCULATE AGGREGATE AVERAGES AND WRITE TO MASTERC.OUT
      J=1
C**INITIALIZE TOTALS TO ZERO
      TSCL=0.0
      TRPT=0.0
      TIP=0.0
      TOH=0.0
      TQTY=0.0
      TB=0.0
      TISR=0.0
      TOSR=0.0
      TTURNS=0.0
      TNIS=0.0
      TSOLD=0.0
      TLOST=0.0
30    IF (J .LT. 91)THEN
C**DETERMINE PERFORMANCE MEASURES TOTALS
        TSCL=TSCL+CCAVG(5*(J-1)+5)
        TRPT=TRPT+UPC(J,22)
        TIP=TIP+CCAVG(5*(J-1)+1)
        TOH=TOH+CCAVG(5*(J-1)+2)
        TQTY=TQTY+CCAVG(5*(J-1)+4)
        TB=TB+UPC(J,14)
        TISR=TISR+UPC(J,21)
```

```
      TOSA=TOSA+UPC(J,22)
      TTURNS=TTURNS+UPC(J,23)
      TNIS=TNIS+UPC(J,24)
      TSOLD=TSOLD+UPC(J,19)
      TLOST=TLOST+UPC(J,20)
      J=J+1
      GOTO 30
C**ONCE ALL 90 INDIVIDUAL VALUES ADDED, DETERMINE AVERAGES
     ELSE
      ASCL=TSCL/90
      ARPT=TRPT/90
      AIP=TIP/90
      AOH=TOH/90
      AQTY=TQTY/90
      AB=TB/90
      AISA=TISA/90
      AOSA=TOSA/90
      ATURNS=TTURNS/90
      ANIS=TNIS/90
      ASOLD=TSOLD/90
      ALOST=TLOST/90
     ENDIF
     MODEL=1
     WRITE(11,300) ASCL,ARPT,AIP,AOH,AQTY,AB,AISA,ATURNS,ANIS,
    1              ASOLD,ALOST
300  FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0,1X,F5.0,1X,F4.0,
    1             1X,F5.2,1X,F4.1,3X,F5.3,2X,F6.0,1X,F5.0)
     WRITE(12,400) MODEL,UPC(1,1),UPC(1,6),TNOW,ASCL,ARPT,AIP,AOH,
    1              AQTY,AB,AISA,ANIS,ASOLD,ALOST
400  FORMAT(' ',I2,1X,F3.0,1X,F3.0,1X,F5.0,1X,F5.0,1X,F5.0,1X,F5.0,1X,
    1            F5.0,1X,F5.0,1X,F5.0,1X,F5.2,1X,F5.2,1X,F7.0,1X,F6.0)
     RETURN
     END
C*****************************************************************
```

Appendix B. Computer Code for Bytronic Model

```
GEN,STARK,INVENTORY BYTRONIC,10/30/87,5,N,N,Y/N,N,N,72;
LIMITS,1,2,200;
STAT,1,*00287 INV POS;
STAT,2,*00287 ON HAND;
STAT,3,*00287 BUFFER;
STAT,4,*00287 ORD QTY;
STAT,5,*00287 REORDR PT;
STAT,6,*00309 INV POS;
STAT,7,*00309 ON HAND;
STAT,8,*00309 BUFFER;
STAT,9,*00309 ORD QTY;
STAT,10,*00309 REORDR PT;
.
.
.
STAT,441,*91740 INV POS;
STAT,442,*91740 ON HAND;
STAT,443,*91740 BUFFER;
STAT,444,*91740 ORD QTY;
STAT,445,*91740 REORDR PT;
STAT,446,*97330 INV POS;
STAT,447,*97330 ON HAND;
STAT,448,*97330 BUFFER;
STAT,449,*97330 ORD QTY;
STAT,450,*97330 REORDR PT;
NETWORK;
      CREATE,1,1,,,1;          ****DAILY SALES TRANSACTIONS****
        EVENT,3,1;
      TERM;
      CREATE,7,7,,,1;          ****ONE WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=7;
        EVENT,1,1;
      TERM;
      CREATE,14,14,,,1;        ****TWO WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=14;
        EVENT,1,1;
      TERM;
      CREATE,21,21,,,1;        ****THREE WEEK REVIEW CYCLE*****
        ASSIGN,XX(1)=21;
        EVENT,1,1;
      TERM;
      CREATE,28,28,,,1;        ****FOUR WEEK REVIEW CYCLE******
        ASSIGN,XX(1)=28;
        EVENT,1,1;
      TERM;
      END;
INIT,0,1080;
MONTR,CLEAR,360;
FIN;
```

```
      PROGRAM MAIN
      DIMENSION NSET(10000)
      INCLUDE '[MSTARK.SIM]PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(10000)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      OPEN(10,FILE='[MSTARK.SIM]BUPC.DAT',STATUS='OLD')
      OPEN(11,FILE='[MSTARK.SIM]BUPC.OUT',STATUS='NEW')
      OPEN(12,FILE='[MSTARK.SIM]MASTERB.OUT',STATUS='NEW')
      CALL SLAM
      STOP
      END

C***********************************************************************
C     SPECIFIES EVENT CALLS AS FOLLOWS:
C
C          DAILY:  PERFORMS DAILY ON HAND, INV POSITION, LOST SALES,
C                    TOTAL SOLD, AND CUMULATIVE LOST SALES CALCULATIONS
C       RVWCALCS:  PERFORMS CALCULATIONS REQUIRED DURING EACH REVIEW
C       SCHDLORD:  PLACES AN ORDER ON THE CALENDAR AT TNOW+LEAD TIME
C     ------------------------------------------------------------------
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      GO TO (1,2,3) I
1     CALL RVWCALCS
      RETURN
2     CALL SCHDLORD
      RETURN
3     CALL DAILY
      RETURN
      END
C***********************************************************************

C***********************************************************************
C     LEGEND FOR UPC ARRAY VARIABLES
C       WHERE: UPC(I,1) :  REVIEW PERIOD (DAYS)
C              UPC(I,2) :  CATEGORY
C              UPC(I,3) :  UNIT COST OF ITEM
C              UPC(I,4) :  MEAN DAILY DEMAND
C              UPC(I,5) :  STD DEV OF DAILY DEMAND
C              UPC(I,6) :  MEAN LEAD TIME
```

```
C               UPC(I,7) :  STD DEV OF DAILY DEMAND ADJUSTED FOR (R+L)
C               UPC(I,8) :  EXPECTED WORST LEAD TIME
C               UPC(I,9) :  INVENTORY POSITION
C               UPC(I,10):  TARGET INVENTORY LEVEL
C               UPC(I,11):  REORDER POINT
C               UPC(I,12):  REPLENISHMENT QUANTITY
C               UPC(I,13):  N/A
C               UPC(I,14):  SAFETY STOCK
C               UPC(I,15):  LOST SALES
C               UPC(I,16):  ON HAND INV
C               UPC(I,17):  N/A
C               UPC(I,18):  UPC NUMBER
C               UPC(I,19):  TOTAL SOLD
C               UPC(I,20):  CUMULATIVE LOST SALES (NUMBER)
C*************************************************************************


C*************************************************************************
C     PERFORMS DAILY SALES TRANSACTIONS
C     -------------------------------------------------------------------
      SUBROUTINE DAILY
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      INTEGER I
      CALL DMDMAKE
      DO 10 I=1,90
C**WHILE UPC ON HAND, DECREASE ON HAND AND INV POS BY DMD(I)
         IF (UPC(I,16) .GT. 0.0) THEN
           UPC(I,16)=UPC(I,16)-DMD(I)
           UPC(I,9)=UPC(I,9)-DMD(I)
C**SET LOST SALES=ON HAND (ONLY USED IF ON HAND GOES NEGATIVE)
           UPC(I,15)=UPC(I,16)
C**INCREMENT TOTAL SOLD
           UPC(I,19)=UPC(I,19)+DMD(I)
C**RESET LOST SALES=0 IF ON HAND NOT EXHAUSTED
           IF (UPC(I,15) .GT. 0.0) THEN
             UPC(I,15)=0.0
           ENDIF
C**ONCE ON HAND DEPLETED, CORRECT INV POS & TOTAL SOLD & SET ON HAND=0
           IF (UPC(I,16).LE.0.0) THEN
             UPC(I,9)=UPC(I,9)-UPC(I,16)
             UPC(I,19)=UPC(I,19)+UPC(I,16)
             UPC(I,16)=0.0
           ENDIF
C**RESET INV POS=0 IF IT BECOMES NEGATIVE SINCE NO BACKORDERS ALLOWED
           IF (UPC(I,9).LE.0.0) THEN
             UPC(I,9)=0.0
           ENDIF
C**INCREMENT CUMULATIVE LOST SALES SINCE INV POS IS NOW=0
           UPC(I,20)=UPC(I,20)+UPC(I,15)
         ELSE
C**INCREMENT CUMULATIVE LOST SALES SINCE ON HAND LESS THAN 0
           UPC(I,20)=UPC(I,20)-DMD(I)
         ENDIF
C**COLLECT OBS STATS ON INV POS AND ON HAND INV
         CALL COLCT(UPC(I,9),5*(I-1)+1)
```

```
         CALL COLCT(UPC(I,16),5*(I-1)+2)
C**CLEAR SOLD AND LOST AT TNOW=360
        IF (TNOW.EQ.360) THEN
         UPC(I,19)=0.0
         UPC(I,20)=0.0
        ENDIF
10      CONTINUE
        RETURN
        END
C***********************************************************************
C       CALLED BY SUBROUTINE DAILY TO CREATE 1 DAY OF DEMAND FOR EACH UPC
C       -----------------------------------------------------------------
        SUBROUTINE DMDMAKE
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100)
        INTEGER I
        DO 10 I=1,90
          DMD(I)=RNORM(UPC(I,4),UPC(I,5),1)
          IF (DMD(I) .LT. 0.0) THEN
            DMD(I)=0.0
          ENDIF
10      CONTINUE
        RETURN
        END
C***********************************************************************


C***********************************************************************
C       PERFORMS REVIEW CYCLE CALCULATIONS
C       -----------------------------------------------------------------
        SUBROUTINE RVWCALCS
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100)
        INTEGER I
        DO 10 I=1,90
C**DETERMINE IF UPC SHOULD BE REVIEWED
          IF (UPC(I,1) .EQ. XX(1)) THEN
C**SET REORDER POINT=SCL-1
            UPC(I,11)=UPC(I,10)-1
C**ONCE INV POS GOES BELOW REORDER POINT,DETERMINE BUFFER
            IF (UPC(I,9) .LE. UPC(I,11)) THEN
C**DETERMINE APPROPRIATE BUFFER BASED ON CATEGORY
C**FOR TYPE A1 USE:
              IF (UPC(I,2) .EQ. 0.0) THEN
                UPC(I,14)=(2.25)*UPC(I,5)*(SQRT(UPC(I,1)+UPC(I,6)))
C**COLLECT OBS STATS ON BUFFER SIZE
                CALL COLCT(UPC(I,14),5*(I-1)+3)
C**FOR TYPE A2 USE:
              ELSE IF (UPC(I,2) .EQ. 1.0) THEN
                UPC(I,14)=UPC(I,4)*(UPC(I,8)-UPC(I,6))
C**COLLECT OBS STATS ON BUFFER SIZE
                CALL COLCT(UPC(I,14),5*(I-1)+3)
C**FOR TYPE B USE:
              ELSE IF (UPC(I,2) .EQ. 2.0) THEN
                UPC(I,14)=.2*UPC(I,4)*(UPC(I,1)+UPC(I,6))
```

```
C**COLLECT OBS STATS ON BUFFER SIZE
                CALL COLCT(UPC(I,14),5*(I-1)+3)
C**FOR TYPE C USE:
              ELSE
                UPC(I,14)=.1*UPC(I,4)*(UPC(I,1)+UPC(I,6))
C**COLLECT OBS STATS ON BUFFER SIZE
                CALL COLCT(UPC(I,14),5*(I-1)+3)
              ENDIF
C**DETERMINE NEW SCL
              UPC(I,10)=UPC(I,4)*(UPC(I,1)+UPC(I,6))+UPC(I,14)
C**COLLECT OBS STATS ON AVG SCL
              CALL COLCT(UPC(I,10),5*(I-1)+5)
C**DETERMINE NEW REPLENISHMENT QUANTITY
              UPC(I,12)=UPC(I,10)-UPC(I,9)
C**COLLECT OBS STATS ON AVG REPLENISHMENT QUANTITY
              CALL COLCT(UPC(I,12),5*(I-1)+4)
C**RESET INV POS=SCL ONCE ORDER PLACED
              UPC(I,9)=UPC(I,10)
C**SCHEDULE ORDER ARRIVAL AND INCREASE ON HAND ONCE ORDER REC'D
              ATRIB(1)=I
              ATRIB(2)=UPC(I,12)
              ORDARVL=UPC(I,6)
              CALL SCHDL(2,ORDARVL,ATRIB)
            ENDIF
          ENDIF
10    CONTINUE
      RETURN
      END
C*************************************************************************
C     CALLED BY RVWCALCS TO SCHEDULE ORDER ARRIVAL AT TNOW+LEAD TIME
C       AND INCREMENTS INV ON HAND
C     -----------------------------------------------------------------
      SUBROUTINE SCHDLORD
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      UPC(ATRIB(1),16)=UPC(ATRIB(1),16)+ATRIB(2)
      RETURN
      END
C*************************************************************************


C*************************************************************************
C     INITIALIZES VARIABLES WITH STARTING VALUES AND CONDITIONS
C     -----------------------------------------------------------------
      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      INTEGER I
      DO 10 I=1,90
C**INITIALIZE THESE VALUES OF UPC(100,25) WITH BUPC.DAT
        READ (10,*) UPC(I,18),UPC(I,1),UPC(I,3),UPC(I,4),
     1              UPC(I,5),UPC(I,6),UPC(I,2),UPC(I,8)
C**DETERMINE STARTING INV POS
        UPC(I,9)=UPC(I,4)*(UPC(I,1)+UPC(I,6))
C**SET INITIAL SCL=INV POS
```

```
      UPC(I,10)=UPC(I,9)
C**SET INITIAL ON HAND=INV POS
      UPC(I,16)=UPC(I,9)
C**INITIALIZE THE FOLLOWING WITH ZERO
      UPC(I,7)= 0.0
      UPC(I,11)=0.0
      UPC(I,12)=0.0
      UPC(I,13)=0.0
      UPC(I,14)=0.0
      UPC(I,15)=0.0
      UPC(I,17)=0.0
      UPC(I,19)=0.0
      UPC(I,20)=0.0
      UPC(I,21)=0.0
      UPC(I,22)=0.0
      UPC(I,23)=0.0
      UPC(I,24)=0.0
10    CONTINUE
      RETURN
      END
C*****************************************************************************


C*****************************************************************************
C     CREATES PERFORMANCE REPORT
C
C     LEGEND FOR K, UPC ARRAY, AND CCAVG SUMMARY STATISTICS
C       WHERE:  UPC(I,21):  AVERAGE INV:SALES RATIO FOR 30 DAY PERIOD
C               UPC(I,22):  AVERAGE REORDER POINT
C               UPC(I,23):  AVERAGE STOCK TURNS FOR 30 DAY PERIOD
C               UPC(I,24):  AVERAGE NIS
C        CCAVG(5*(I-1)+1):  AVERAGE INVENTORY POSITION
C        CCAVG(5*(I-1)+2):  AVERAGE ON HAND INVENTORY
C        CCAVG(5*(I-1)+3):  AVERAGE BUFFER SIZE
C        CCAVG(5*(I-1)+4):  AVERAGE REPLENISHMENT QUANTITY
C        CCAVG(5*(I-1)+5):  AVERAGE STOCK CONTROL LEVEL
C     ---------------------------------------------------------------------
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100)
      INTEGER I
      REAL K
C**CREATE INDIVIDUAL UPC PERFORMANCE REPORT HEADER
       WRITE(11,*)
     1 '    PERFORMANCE SUMMARY REPORT FOR BYTRONIC INV CONTROL SYSTEM'
       WRITE(11,*)
     1 '---------------------------------------------------------
     1---------------'
      DO 10 I=1,90
C**DETERMINE STD DEV ADJUSTED FOR (R+L)
       UPC(I,7)=UPC(I,5)*(SQRT(UPC(I,1)+UPC(I,6)))
C**DETERMINE AVERAGE REORDER POINT
       UPC(I,22)=CCAVG(5*(I-1)+5)-1
C**DETERMINE AVERAGE INV POS:SALES
       UPC(I,21)=CCAVG(5*(I-1)+1)/(30*(UPC(I,19)/(TNOW-360)))
C**DETERMINE AVERAGE INV TURNS
```

```
        UPC(I,23)=1/UPC(I,21)
C**DETERMINE AVERAGE NIS
        UPC(I,24)=-(UPC(I,20)/(UPC(I,19)-UPC(I,20)))
        IF (UPC(I,24) .GT. 1.0) THEN
          UPC(I,24)=1.0
        ENDIF
C**WRITE INDIVIDUAL UPC PERFORMANCE REPORT TO BUPC.OUT
        WRITE(11,*)
     1  'UPC#    UNIT COST   AVW   L   DMD   SD(DAY)   SD(R+L)   CAT
     1  LW'
        WRITE(11,100) UPC(I,18),UPC(I,3),UPC(I,1),UPC(I,6),
     1                UPC(I,4),UPC(I,5),UPC(I,7),UPC(I,2),UPC(I,8)
100     FORMAT(' ',F7.5,3X,F5.2,4X,F4.0,1X,F4.0,1X,F4.0,3X,F6.2,4X,F6.2,
     1            5X,F2.0,2X,F4.0)
        WRITE(11,*)
     1  '       ------   AVERAGE VALUE AS OF DAY', TNOW,'--------'
        WRITE(11,*) '          SCL    RPT     IP    OH    QTY    B    I:S
     1 TURNS   NIS     SOLD   LOST'
        WRITE(11,200) CCAVG(5*(I-1)+5),UPC(I,22),
     1                CCAVG(5*(I-1)+1),CCAVG(5*(I-1)+2),
     1                CCAVG(5*(I-1)+4),CCAVG(5*(I-1)+3),
     1                UPC(I,21),UPC(I,23),UPC(I,24),
     1                UPC(I,19),UPC(I,20)
200     FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0,1X,F5.0,1X,F4.0,1X,
     1         F5.2,1X,F4.1,3X,F5.3,2X,F7.0,1X,F5.0,/)
10    CONTINUE
C**CREATE AGGREGATE HEADER
        WRITE(11,*)
     1  '       ------   AVG AGG VALUE AS OF DAY', TNOW,'--------'
        WRITE(11,*)
     1  '          SCL    RPT     IP    OH    QTY    B    I:S   TURNS   NIS
     1     SOLD   LOST'
C**CALCULATE AGGREGATE AVERAGES AND WRITE TO MASTERB.OUT
      J=1
C**INITIALIZE TOTALS TO ZERO
      TSCL=0.0
      TRPT=0.0
      TIP=0.0
      TOH=0.0
      TQTY=0.0
      TB=0.0
      TISR=0.0
      TTURNS=0.0
      TNIS=0.0
      TSOLD=0.0
      TLOST=0.0
30      IF (J .LT. 91) THEN
C**DETERMINE PERFORMANCE MEASURES TOTALS
        TSCL=TSCL+CCAVG(5*(J-1)+5)
        TRPT=TRPT+UPC(J,22)
        TIP=TIP+CCAVG(5*(J-1)+1)
        TOH=TOH+CCAVG(5*(J-1)+2)
        TQTY=TQTY+CCAVG(5*(J-1)+4)
        TB=TB+CCAVG(5*(J-1)+3)
        TISR=TISR+UPC(J,21)
        TTURNS=TTURNS+UPC(J,23)
        TNIS=TNIS+UPC(J,24)
```

```
        TSOLD=TSOLD+UPC(J,19)
        TLOST=TLOST+UPC(J,20)
        J=J+1
        GOTO 30
C**ONCE ALL 90 INDIVIDUAL VALUES ADDED, DETERMINE AVERAGES
      ELSE
        ASCL=TSCL/90
        AAPT=TAPT/90
        AIP=TIP/90
        AOH=TOH/90
        AQTY=TQTY/90
        AB=TB/90
        AISA=TISA/90
        ATURNS=TTURNS/90
        ANIS=TNIS/90
        ASOLD=TSOLD/90
        ALOST=TLOST/90
      ENDIF
      MODEL=2
      WRITE(11,300) ASCL,AAPT,AIP,AOH,AQTY,AB,AISA,ATURNS,ANIS,
     1              ASOLD,ALOST
300   FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0, 1X,F5.0, 1X,F4.0,
     1           1X,F5.2, 1X,F4.1,3X,F5.3,2X,F7.0, 1X,F5.0)
      WRITE(12,400) MODEL,UPC(1,1),UPC(1,6),TNOW,ASCL,AAPT,AIP,AOH,
     1              AQTY,AB,AISA,ANIS,ASOLD,ALOST
400   FORMAT(' ',I2, 1X,F3.0, 1X,F3.0, 1X,F5.0, 1X,F5.0, 1X,F5.0, 1X,F5.0, 1X,
     1           F5.0, 1X,F5.0, 1X,F5.0, 1X,F5.2, 1X,F4.2, 1X,F7.0, 1X,F6.0)
      RETURN
      END
C*******************************************************************************
```

Appendix C. Computer Code for Tijms and Groenevelt Model

Network Model Code: 145
Subroutine Code: 146-153

```
GEN,STARK,INVENTORY T&G,10/30/87,5,N,N,Y/N,N,N,72;
LIMITS,1,2,200;
STAT,1,*00287 INV POS;
STAT,2,*00287 ON HAND;
STAT,3,*00287 BUFFER;
STAT,4,*00287 ORD QTY;
STAT,5,*00287 REORDR PT;
STAT,6,*00309 INV POS;
STAT,7,*00309 ON HAND;
STAT,8,*00309 BUFFER;
STAT,9,*00309 ORD QTY;
STAT,10,*00309 REORDR PT;
.
.
.
STAT,441,*91740 INV POS;
STAT,442,*91740 ON HAND;
STAT,443,*91740 BUFFER;
STAT,444,*91740 ORD QTY;
STAT,445,*91740 REORDR PT;
STAT,446,*97330 INV POS;
STAT,447,*97330 ON HAND;
STAT,448,*97330 BUFFER;
STAT,449,*97330 ORD QTY;
STAT,450,*97330 REORDR PT;
NETWORK;
      CREATE,1,1,,,1;              ****DAILY SALES TRANSACTIONS****
        EVENT,3,1;
      TERM;
      CREATE,30,1,,,1;             ****PERFORM TREND CALCULATIONS**
        EVENT,4,1;
      TERM;
      CREATE,7,7,,,1;              ****ONE WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=7;
        EVENT,1,1;
      TERM;
      CREATE,14,14,,,1;            ****TWO WEEK REVIEW CYCLE*******
        ASSIGN,XX(1)=14;
        EVENT,1,1;
      TERM;
      CREATE,21,21,,,1;            ****THREE WEEK REVIEW CYCLE*****
        ASSIGN,XX(1)=21;
        EVENT,1,1;
      TERM;
      CREATE,28,28,,,1;            ****FOUR WEEK REVIEW CYCLE******
        ASSIGN,XX(1)=28;
        EVENT,1,1;
      TERM;
      END;
INIT,0,1080;
MONTR,CLEAR,360;
FIN;
```

```
      PROGRAM MAIN
      DIMENSION NSET(10000)
      INCLUDE 'PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(10000)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=10000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      OPEN(10,FILE='[MSTARK.SIM]TUPC.DAT',STATUS='OLD')
      OPEN(11,FILE='[MSTARK.SIM]TUPC.OUT',STATUS='NEW')
      OPEN(12,FILE='[MSTARK.SIM]K.DAT',STATUS='OLD')
      OPEN(13,FILE='[MSTARK.SIM]MASTERT.OUT',STATUS='NEW')
      CALL SLAM
      STOP
      END


C***********************************************************************
C     SPECIFIES EVENT CALLS AS FOLLOWS:
C
C          DAILY:  PERFORMS DAILY ON HAND, INV POSITION, LOST SALES,
C                     TOTAL SOLD, AND CUMULATIVE LOST SALES CALCULATIONS
C       RVWCALCS:  PERFORMS CALCULATIONS REQUIRED DURING EACH REVIEW
C       SCHDLORD:  PLACES AN ORDER ON THE CALENDAR AT TNOW+LEAD TIME
C     ------------------------------------------------------------------
      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      GO TO (1,2,3) I
1     CALL RVWCALCS
      RETURN
2     CALL SCHDLORD
      RETURN
3     CALL DAILY
      RETURN
      END
C***********************************************************************


C***********************************************************************
C     LEGEND FOR UPC ARRAY VARIABLES
C       WHERE: UPC(I,1) :  REVIEW PERIOD (DAYS)
C              UPC(I,2) :  STD DEV OF DAILY DEMAND ADJUSTED FOR (R)
C              UPC(I,3) :  UNIT COST OF ITEM
C              UPC(I,4) :  MEAN DAILY DEMAND
C              UPC(I,5) :  STD DEV OF DAILY DEMAND
```

```
C              UPC(I,6) :  MEAN LEAD TIME
C              UPC(I,7) :  STD DEV OF DAILY DEMAND ADJUSTED FOR (R+L)
C              UPC(I,8) :  K VALUE FOR SCL AND REORDER POINT CALCULATIONS
C              UPC(I,9) :  INVENTORY POSITION
C              UPC(I,10):  TARGET INVENTORY LEVEL
C              UPC(I,11):  REORDER POINT
C              UPC(I,12):  REPLENISHMENT QUANTITY
C              UPC(I,13):  JU(K)
C              UPC(I,14):  SAFETY STOCK
C              UPC(I,15):  LOST SALES (NUMBER)
C              UPC(I,16):  ON HAND INV
C              UPC(I,17):  PREDETERMINED REPLENISHMENT QUANTITY
C              UPC(I,18):  UPC NUMBER
C              UPC(I,19):  TOTAL SOLD
C              UPC(I,20):  CUMULATIVE LOST SALES (NUMBER)
C*********************************************************************


C*********************************************************************
C     PERFORMS DAILY SALES TRANSACTIONS
C     ---------------------------------------------------------------
      SUBROUTINE DAILY
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      INTEGER I
      CALL DMDMAKE
      DO 10 I=1,90
C**WHILE UPC ON HAND, DECREASE ON HAND AND INV POS BY DMD(I)
         IF (UPC(I,16) .GT. 0.0) THEN
           UPC(I,16)=UPC(I,16)-DMD(I)
           UPC(I,9)=UPC(I,9)-DMD(I)
C**SET LOST SALES=ON HAND (ONLY USED IF ON HAND GOES NEGATIVE)
           UPC(I,15)=UPC(I,16)
C**INCREMENT TOTAL SOLD
           UPC(I,19)=UPC(I,19)+DMD(I)
C**RESET LOST SALES=0 IF ON HAND NOT EXHAUSTED
           IF (UPC(I,15) .GT. 0.0) THEN
             UPC(I,15)=0.0
           ENDIF
C**ONCE ON HAND DEPLETED, CORRECT INV POS & TOTAL SOLD & SET ON HAND=0
           IF (UPC(I,16).LE.0.0) THEN
             UPC(I,9)=UPC(I,9)-UPC(I,16)
             UPC(I,19)=UPC(I,19)+UPC(I,16)
             UPC(I,16)=0.0
           ENDIF
C**RESET INV POS=0 IF IT BECOMES NEGATIVE SINCE NO BACKORDERS ALLOWED
           IF (UPC(I,9).LE.0.0) THEN
             UPC(I,9)=0.0
           ENDIF
C**INCREMENT CUMULATIVE LOST SALES
           UPC(I,20)=UPC(I,20)+UPC(I,15)
         ELSE
C**INCREMENT CUMULATIVE LOST SALES SINCE ON HAND LESS THAN 0
           UPC(I,20)=UPC(I,20)-DMD(I)
         ENDIF
C**COLLECT OBS STATS ON INV POS AND ON HAND INV
```

```
        CALL COLCT(UPC(I,9),5*(I-1)+1)
        CALL COLCT(UPC(I,16),5*(I-1)+2)
C**CLEAR SOLD AND LOST AT TNOW=360
       IF (TNOW.EQ.360) THEN
        UPC(I,19)=0.0
        UPC(I,20)=0.0
      ENDIF
10    CONTINUE
      RETURN
      END
C*********************************************************************
C     CALLED BY SUBROUTINE DAILY TO CREATE 1 DAY OF DEMAND FOR EACH UPC
C     ----------------------------------------------------------------
      SUBROUTINE DMDMAKE
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      INTEGER I
      DO 10 I=1,90
        DMD(I)=RNORM(UPC(I,4),UPC(I,5),1)
        IF (DMD(I) .LT. 0.0) THEN
          DMD(I)=0.0
        ENDIF
10    CONTINUE
      RETURN
      END
C*********************************************************************


C*********************************************************************
C     PERFORMS REVIEW CYCLE CALCULATIONS
C     ----------------------------------------------------------------
      SUBROUTINE RVWCALCS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      INTEGER I
      CALL FCASTR
      DO 10 I=1,90
C**DETERMINE IF UPC SHOULD BE REVIEWED
        IF (UPC(I,1) .EQ. XX(1)) THEN
C**DETERMINE JU(K)
          UPC(I,13)=((2*(1-PTWO)*FCAST(I,1))/(FCAST(I,4)**2))*
     1    (UPC(I,17)+(((FCAST(I,3)**2)+(FCAST(I,1)**2))/(2*FCAST(I,1))))
C**CALL SUBROUTINE KFIND TO FIND K VALUE BASED ON JU(K)
          CALL KFIND(I)
C**DETERMINE THE REORDER POINT
          UPC(I,11)=FCAST(I,2)+(UPC(I,8)*FCAST(I,4))
C**COLLECT OBS STATS ON REORDER POINT
          CALL COLCT(UPC(I,11),5*(I-1)+5)
C**DETERMINE THE SCL
          UPC(I,10)=UPC(I,11)+UPC(I,17)
C**ONCE INV POS GOES BELOW REORDER POINT, DETERMINE BUFFER
        IF (UPC(I,9) .LE. UPC(I,11)) THEN
C**DETERMINE APPROPRIATE BUFFER
          UPC(I,14)=UPC(I,8)*FCAST(I,4)
C**COLLECT OBS STATS ON BUFFER SIZE
```

```
            CALL COLCT(UPC(I,14),5*(I-1)+3)
C**DETERMINE NEW ORDER QTY
            UPC(I,12)=UPC(I,10)-UPC(I,9)
C**COLLECT OBS STATS ON REPLENISHMENT QUANTITY
            CALL COLCT(UPC(I,12),5*(I-1)+4)
C**RESET INV POS=SCL ONCE ORDER PLACED
            UPC(I,9)=UPC(I,10)
C**SCHEDULE ORDER ARRIVAL AND INCREASE ON HAND ONCE ORDER REC'D
            ATRIB(1)=I
            ATRIB(2)=UPC(I,12)
            ORDARVL=UPC(I,6)
            CALL SCHDL(2,ORDARVL,ATRIB)
          ENDIF
        ENDIF
 10     CONTINUE
        RETURN
        END
C***********************************************************************
C       CALLED BY RVWCALCS TO SCHEDULE ORDER ARRIVAL AT TNOW+LEAD TIME
C         AND INCREMENTS OH
C       ----------------------------------------------------------------
        SUBROUTINE SCHDLORD
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
        UPC(ATRIB(1),16)=UPC(ATRIB(1),16)+ATRIB(2)
        RETURN
        END
C***********************************************************************
C       CALLED BY SUBROUTINE RVWCALCS TO PREDICT VALUES FOR X(R),X(R+L),
C         S(R),S(R+L)
C       ----------------------------------------------------------------
        SUBROUTINE FCASTR
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
        INTEGER I
        DO 10 I=1,90
          FCAST(I,1)=UPC(I,1)*UPC(I,4)
          FCAST(I,2)=(UPC(I,1)+UPC(I,6))*UPC(I,4)
          FCAST(I,3)=UPC(I,5)*SQRT(UPC(I,1))
          FCAST(I,4)=UPC(I,5)*(SQRT(UPC(I,1)+UPC(I,6)))
 10     CONTINUE
        RETURN
        END
C***********************************************************************
C       CALLED BY SUBROUTINE RVWCALCS TO DETERMINE THE VALUE OF K BASED
C         ON JUK [UPC(I,13)]
C       ----------------------------------------------------------------
        SUBROUTINE KFIND(I)
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
       1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
        COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
        INTEGER I,J
        DO 10 J=1,401
          IF (UPC(I,13).GE.TABLE(J,3)) THEN
            UPC(I,8)=TABLE(J,2)
```

```
        GOTO 20
       ENDIF
10    CONTINUE
       UPC(I,13)=1000
20    RETURN
      END
C*************************************************************************


C*************************************************************************
C     INITIALIZES VARIABLES WITH STARTING VALUES AND CONDITIONS
C     -------------------------------------------------------------
      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      INTEGER I,J
      DO 10 I=1,90
C**INITIALIZE THESE VALUES OF UPC(100,25) WITH TUPC.DAT
        READ (10,*) UPC(I,18),UPC(I,1),UPC(I,3),UPC(I,4),
     1              UPC(I,5),UPC(I,6)
C**DETERMINE STARTING INV POS
        UPC(I,9)=UPC(I,4)*(UPC(I,1)+UPC(I,6))
C**SET INTIAL SCL=INV POS
        UPC(I,10)=UPC(I,9)
C**SET INITIAL ON HAND=INV POS
        UPC(I,16)=UPC(I,9)
C**SET (S-s)=ONE AND A HALF TIMES AVG DEMAND DURING THE REVIEW PERIOD
        UPC(I,17)=1.5*UPC(I,4)*UPC(I,1)
        UPC(I,2) =0.0
        UPC(I,7) =0.0
        UPC(I,8) =0.0
        UPC(I,11)=0.0
        UPC(I,12)=0.0
        UPC(I,13)=0.0
        UPC(I,14)=0.0
        UPC(I,15)=0.0
        UPC(I,19)=0.0
        UPC(I,20)=0.0
        UPC(I,21)=0.0
        UPC(I,22)=0.0
        UPC(I,23)=0.0
        UPC(I,24)=0.0
10    CONTINUE
      DO 20 J=1,201
        READ (12,*) TABLE(J,1),TABLE(J,2),TABLE(J,3)
20    CONTINUE
      PTWO=.98
      RETURN
      END
C*************************************************************************


C*************************************************************************
C     CREATES PERFORMANCE REPORT
C
C     LEGEND FOR K, UPC ARRAY, AND CCAVG SUMMARY STATISTICS
```

```
C       WHERE:  UPC(I,21):  AVERAGE INV:SALES RATIO FOR 30 DAY PERIOD
C               UPC(I,22):  AVERAGE STOCK CONTROL LEVEL
C               UPC(I,23):  AVERAGE STOCK TURNS FOR 30 DAY PERIOD
C               UPC(I,24):  AVERAGE NIS
C        CCAVG(5*(I-1)+1):  AVERAGE INVENTORY POSITION
C        CCAVG(5*(I-1)+2):  AVERAGE ON HAND INVENTORY
C        CCAVG(5*(I-1)+3):  AVERAGE BUFFER SIZE
C        CCAVG(5*(I-1)+4):  AVERAGE REPLENISHMENT QUANTITY
C        CCAVG(5*(I-1)+5):  AVERAGE REORDER POINT
C     ------------------------------------------------------------
      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,NCLNR
     1,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/UPC(100,25),DMD(100),TABLE(405,3),FCAST(100,5),PTWO
      INTEGER I,J,L,M
C**CREATE INDIVIDUAL UPC PERFORMANCE HEADER
        WRITE(11,*)
     1  '    PERFORMANCE SUMMARY REPORT FOR TIJMS INV CONTROL SYSTEM'
        WRITE(11,*)
     1  '----------------------------------------------------------
     1--------------'
      DO 10 I=1,90
C**DETERMINE AVERAGE INV POS:SALES
        UPC(I,21)=CCAVG(5*(I-1)+1)/(30*(UPC(I,19)/(TNOW-360)))
C**DETERMINE STD DEV OF DAILY DEMAND ADJUSTED FOR (R)
        UPC(I,2)=UPC(I,5)*(SQRT(UPC(I,1)))
C**DETERMINE STD DEV OF DAILY DEMAND ADJUSTED FOR (R+L)
        UPC(I,7)=UPC(I,5)*(SQRT(UPC(I,1)+UPC(I,6)))
C**DETERMINE AVERAGE SCL
        UPC(I,22)=(CCAVG(5*(I-1)+5))+UPC(I,17)
C**DETERMINE AVERAGE INV TURNS
        UPC(I,23)=1/UPC(I,21)
C**DETERMINE AVERAGE NIS
        UPC(I,24)=-(UPC(I,20)/(UPC(I,19)-UPC(I,20)))
        IF (UPC(I,24) .GT. 1.0) THEN
          UPC(I,24)=1.0
        ENDIF
C**WRITE INDIVIDUAL UPC PERFORMANCE REPORT TO TUPC.OUT
        WRITE(11,*)
     1  'UPC#    UNIT COST  RVW   L    DMD    SD(DAY)  SD(R)  SD(R+L)
     1JUK    K     S-s'
        WRITE(11,100) UPC(I,18),UPC(I,3),UPC(I,1),UPC(I,6),UPC(I,4),
     1                UPC(I,5),UPC(I,2),UPC(I,7),UPC(I,13),UPC(I,8),
     1                UPC(I,17)
100     FORMAT(' ',F7.5,3X,F5.2,3X,F4.0,1X,F4.0,1X,F6.2,2X,F6.2,2X,
     1             F6.2,2X,F6.2,2X,F6.3,1X,F5.2,2X,F5.0)
        WRITE(11,*)
     1  '          -------  AVERAGE VALUE AS OF DAY', TNOW,'--------'
        WRITE(11,*) '          SCL     RPT     IP    OH     QTY    B    I:S
     1  TURNS   NIS    SOLD   LOST'
        WRITE(11,200) UPC(I,22),CCAVG(5*(I-1)+5),
     1                CCAVG(5*(I-1)+1),CCAVG(5*(I-1)+2),
     1                CCAVG(5*(I-1)+4),CCAVG(5*(I-1)+3),
     1                UPC(I,21),UPC(I,23),UPC(I,24),
     1                UPC(I,19),UPC(I,20)
200     FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0,1X,F5.0,1X,F4.0,1X,
     1          F5.2,1X,F4.1,3X,F5.3,2X,F7.0,1X,F5.0,/)
```

```
10    CONTINUE
C**CREATE AGGREGATE HEADER
        WRITE(11,*)
     1  '        -------    AVG AGG VALUE AS OF DAY', TNOW,'--------'
        WRITE(11,*)
     1  '            SCL     APT      IP     OH    QTY      B    I:S  TURNS    NIS
     1      SOLD   LOST'
C**CALCULATE AGGREGATE AVERAGES AND WRITE TO MASTERAT.OUT
      J=1
C**INITIALIZE TOTALS TO ZERO
      TSCL=0.0
      TAPT=0.0
      TIP=0.0
      TOH=0.0
      TQTY=0.0
      TB=0.0
      TISA=0.0
      TTURNS=0.0
      TNIS=0.0
      TSOLD=0.0
      TLOST=0.0
40    IF (J .LT. 91) THEN
C**DETERMINE PERFORMANCE MEASURES TOTALS
        TSCL=TSCL+UPC(J,22)
        TAPT=TAPT+CCAVG(5*(J-1)+5)
        TIP=TIP+CCAVG(5*(J-1)+1)
        TOH=TOH+CCAVG(5*(J-1)+2)
        TQTY=TQTY+CCAVG(5*(J-1)+4)
        TB=TB+CCAVG(5*(J-1)+3)
        TISA=TISA+UPC(J,21)
        TTURNS=TTURNS+UPC(J,23)
        TNIS=TNIS+UPC(J,24)
        TSOLD=TSOLD+UPC(J,19)
        TLOST=TLOST+UPC(J,20)
        J=J+1
        GOTO 40
C**ONCE ALL 90 INDIVIDUAL VALUES ADDED, DETERMINE AVERAGES
      ELSE
        ASCL=TSCL/90
        AAPT=TAPT/90
        AIP=TIP/90
        AOH=TOH/90
        AQTY=TQTY/90
        AB=TB/90
        AISA=TISA/90
        ATURNS=TTURNS/90
        ANIS=TNIS/90
        ASOLD=TSOLD/90
        ALOST=TLOST/90
      ENDIF
      MODEL=3
      WRITE(11,300) ASCL,AAPT,AIP,AOH,AQTY,AB,AISA,ATURNS,ANIS,
     1                ASOLD,ALOST
300   FORMAT(' ',8X,F5.0,2X,F5.0,2X,F5.0,2X,F5.0,1X,F5.0,1X,F4.0,
     1            1X,F5.2,1X,F4.1,3X,F5.3,2X,F7.0,1X,F5.0)
      WRITE(13,400) MODEL,UPC(1,1),UPC(1,6),TNOW,ASCL,AAPT,AIP,AOH,
     1                AQTY,AB,AISA,ANIS,ASOLD,ALOST
```

```
400   FORMAT(' ',I2, 1X,F3.0, 1X,F3.0, 1X,F5.0, 1X,F5.0, 1X,F5.0, 1X,F5.0, 1X
     1         F5.0, 1X,F5.0, 1X,F5.0, 1X,F5.2, 1X,F5.2, 1X,F7.0, 1X,F6.0)
      RETURN
      END
C**********************************************************************
```

Appendix D: Verification of Current Model

DATA INPUT FILE

(UPC*	AVW	COST	DMD	SD(DAY)	L	SDAYS)
.00001	7.00	1.99	10.00	0.00	5.0	5.0
.00002	7.00	1.99	10.00	1.00	5.0	5.0

PERFORMANCE SUMMARY REPORT

PERFORMANCE SUMMARY REPORT FOR CURRENT INV CONTROL SYSTEM

UPC*	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	TRND	S-DAYS
0.00001	1.99	7.	5.	10.00	0.00	0.00	1.00	5.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
170.	169.	124.	73.	76.	50.	0.46	2.2	0.097	542.	-58.

UPC*	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	TRND	S-DAYS
0.00002	1.99	7.	5.	10.00	1.00	3.46	1.00	5.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
170.	169.	124.	73.	76.	50.	0.46	2.2	0.097	539.	-58.

------- AVG AGG VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
170.	169.	124.	73.	76.	50.	0.46	2.2	0.097	541.	-58.

Appendix D: Verification of Current Model
(continued)

Trace Report

INV	POS	FOR	UPC	.00001	ON	DAY	1.000000	IS:	42.00000
ON	HAND	FOR	UPC	.00001	ON	DAY	1.000000	IS:	42.00000
INV	POS	FOR	UPC	.00001	ON	DAY	2.000000	IS:	32.00000
ON	HAND	FOR	UPC	.00001	ON	DAY	2.000000	IS:	32.00000
INV	POS	FOR	UPC	.00001	ON	DAY	3.000000	IS:	22.00000
ON	HAND	FOR	UPC	.00001	ON	DAY	3.000000	IS:	22.00000
INV	POS	FOR	UPC	.00001	ON	DAY	4.000000	IS:	12.00000
ON	HAND	FOR	UPC	.00001	ON	DAY	4.000000	IS:	12.00000
INV	POS	FOR	UPC	.00001	ON	DAY	5.000000	IS:	2.000000
ON	HAND	FOR	UPC	.00001	ON	DAY	5.000000	IS:	2.000000
INV	POS	FOR	UPC	.00001	ON	DAY	6.000000	IS:	0.000000
ON	HAND	FOR	UPC	.00001	ON	DAY	6.000000	IS:	0.000000
REP	QTY	FOR	UPC	.00001	ON	DAY	7.000000	IS:	170.0000
INV	POS	FOR	UPC	.00001	ON	DAY	7.000000	IS:	170.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	7.000000	IS:	0.000000
INV	POS	FOR	UPC	.00001	ON	DAY	8.000000	IS:	170.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	8.000000	IS:	0.000000
INV	POS	FOR	UPC	.00001	ON	DAY	9.000000	IS:	170.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	9.000000	IS:	0.000000
INV	POS	FOR	UPC	.00001	ON	DAY	10.00000	IS:	170.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	10.00000	IS:	0.000000
INV	POS	FOR	UPC	.00001	ON	DAY	11.00000	IS:	170.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	11.00000	IS:	0.000000
INV	POS	FOR	UPC	.00001	ON	DAY	12.00000	IS:	160.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	12.00000	IS:	160.0000
INV	POS	FOR	UPC	.00001	ON	DAY	13.00000	IS:	150.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	13.00000	IS:	150.0000
REP	QTY	FOR	UPC	.00001	ON	DAY	14.00000	IS:	20.00000
INV	POS	FOR	UPC	.00001	ON	DAY	14.00000	IS:	160.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	14.00000	IS:	140.0000
INV	POS	FOR	UPC	.00001	ON	DAY	15.00000	IS:	150.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	15.00000	IS:	130.0000
INV	POS	FOR	UPC	.00001	ON	DAY	16.00000	IS:	140.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	16.00000	IS:	120.0000
INV	POS	FOR	UPC	.00001	ON	DAY	17.00000	IS:	130.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	17.00000	IS:	110.0000
INV	POS	FOR	UPC	.00001	ON	DAY	18.00000	IS:	120.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	18.00000	IS:	100.0000
INV	POS	FOR	UPC	.00001	ON	DAY	19.00000	IS:	110.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	19.00000	IS:	110.0000
INV	POS	FOR	UPC	.00001	ON	DAY	20.00000	IS:	100.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	20.00000	IS:	100.0000
REP	QTY	FOR	UPC	.00001	ON	DAY	21.00000	IS:	70.00000
INV	POS	FOR	UPC	.00001	ON	DAY	21.00000	IS:	160.0000
ON	HAND	FOR	UPC	.00001	ON	DAY	21.00000	IS:	90.00000

Appendix D: Verification of Current Model
(continued)

Trace Report
(continued)

INV POS	FOR	UPC	.00001	ON	DAY	22.00000	IS:	150.0000
ON HAND	FOR	UPC	.00001	ON	DAY	22.00000	IS:	80.00000
INV POS	FOR	UPC	.00001	ON	DAY	23.00000	IS:	140.0000
ON HAND	FOR	UPC	.00001	ON	DAY	23.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	24.00000	IS:	130.0000
ON HAND	FOR	UPC	.00001	ON	DAY	24.00000	IS:	60.00000
INV POS	FOR	UPC	.00001	ON	DAY	25.00000	IS:	120.0000
ON HAND	FOR	UPC	.00001	ON	DAY	25.00000	IS:	50.00000
INV POS	FOR	UPC	.00001	ON	DAY	26.00000	IS:	110.0000
ON HAND	FOR	UPC	.00001	ON	DAY	26.00000	IS:	110.0000
INV POS	FOR	UPC	.00001	ON	DAY	27.00000	IS:	100.0000
ON HAND	FOR	UPC	.00001	ON	DAY	27.00000	IS:	100.0000
REP QTY	FOR	UPC	.00001	ON	DAY	28.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	28.00000	IS:	160.0000
ON HAND	FOR	UPC	.00001	ON	DAY	28.00000	IS:	90.00000
INV POS	FOR	UPC	.00001	ON	DAY	29.00000	IS:	150.0000
ON HAND	FOR	UPC	.00001	ON	DAY	29.00000	IS:	80.00000
INV POS	FOR	UPC	.00001	ON	DAY	30.00000	IS:	140.0000
ON HAND	FOR	UPC	.00001	ON	DAY	30.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	31.00000	IS:	130.0000
ON HAND	FOR	UPC	.00001	ON	DAY	31.00000	IS:	60.00000
INV POS	FOR	UPC	.00001	ON	DAY	32.00000	IS:	120.0000
ON HAND	FOR	UPC	.00001	ON	DAY	32.00000	IS:	50.00000
INV POS	FOR	UPC	.00001	ON	DAY	33.00000	IS:	110.0000
ON HAND	FOR	UPC	.00001	ON	DAY	33.00000	IS:	110.0000
INV POS	FOR	UPC	.00001	ON	DAY	34.00000	IS:	100.0000
ON HAND	FOR	UPC	.00001	ON	DAY	34.00000	IS:	100.0000
REP QTY	FOR	UPC	.00001	ON	DAY	35.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	35.00000	IS:	160.0000
ON HAND	FOR	UPC	.00001	ON	DAY	35.00000	IS:	90.00000
INV POS	FOR	UPC	.00001	ON	DAY	36.00000	IS:	150.0000
ON HAND	FOR	UPC	.00001	ON	DAY	36.00000	IS:	80.00000
INV POS	FOR	UPC	.00001	ON	DAY	37.00000	IS:	140.0000
ON HAND	FOR	UPC	.00001	ON	DAY	37.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	38.00000	IS:	130.0000
ON HAND	FOR	UPC	.00001	ON	DAY	38.00000	IS:	60.00000
INV POS	FOR	UPC	.00001	ON	DAY	39.00000	IS:	120.0000
ON HAND	FOR	UPC	.00001	ON	DAY	39.00000	IS:	50.00000
INV POS	FOR	UPC	.00001	ON	DAY	40.00000	IS:	110.0000
ON HAND	FOR	UPC	.00001	ON	DAY	40.00000	IS:	110.0000
INV POS	FOR	UPC	.00001	ON	DAY	41.00000	IS:	100.0000
ON HAND	FOR	UPC	.00001	ON	DAY	41.00000	IS:	100.0000
REP QTY	FOR	UPC	.00001	ON	DAY	42.00000	IS:	70.00000
INV POS	FOR	UPC	.00001	ON	DAY	42.00000	IS:	160.0000
ON HAND	FOR	UPC	.00001	ON	DAY	42.00000	IS:	90.00000

Appendix D: Verification of Current Model
(continued)

Trace Report
(continued)

INV POS FOR UPC	.00001 ON DAY	43.00000	IS:	150.0000
ON HAND FOR UPC	.00001 ON DAY	43.00000	IS:	80.00000
INV POS FOR UPC	.00001 ON DAY	44.00000	IS:	140.0000
ON HAND FOR UPC	.00001 ON DAY	44.00000	IS:	70.00000
INV POS FOR UPC	.00001 ON DAY	45.00000	IS:	130.0000
ON HAND FOR UPC	.00001 ON DAY	45.00000	IS:	60.00000
INV POS FOR UPC	.00001 ON DAY	46.00000	IS:	120.0000
ON HAND FOR UPC	.00001 ON DAY	46.00000	IS:	50.00000
INV POS FOR UPC	.00001 ON DAY	47.00000	IS:	110.0000
ON HAND FOR UPC	.00001 ON DAY	47.00000	IS:	110.0000
INV POS FOR UPC	.00001 ON DAY	48.00000	IS:	100.0000
ON HAND FOR UPC	.00001 ON DAY	48.00000	IS:	100.0000
REP QTY FOR UPC	.00001 ON DAY	49.00000	IS:	70.00000
INV POS FOR UPC	.00001 ON DAY	49.00000	IS:	160.0000
ON HAND FOR UPC	.00001 ON DAY	49.00000	IS:	90.00000
INV POS FOR UPC	.00001 ON DAY	50.00000	IS:	150.0000
ON HAND FOR UPC	.00001 ON DAY	50.00000	IS:	80.00000
INV POS FOR UPC	.00001 ON DAY	51.00000	IS:	140.0000
ON HAND FOR UPC	.00001 ON DAY	51.00000	IS:	70.00000
INV POS FOR UPC	.00001 ON DAY	52.00000	IS:	130.0000
ON HAND FOR UPC	.00001 ON DAY	52.00000	IS:	60.00000
INV POS FOR UPC	.00001 ON DAY	53.00000	IS:	120.0000
ON HAND FOR UPC	.00001 ON DAY	53.00000	IS:	50.00000
INV POS FOR UPC	.00001 ON DAY	54.00000	IS:	110.0000
ON HAND FOR UPC	.00001 ON DAY	54.00000	IS:	110.0000
INV POS FOR UPC	.00001 ON DAY	55.00000	IS:	100.0000
ON HAND FOR UPC	.00001 ON DAY	55.00000	IS:	100.0000
REP QTY FOR UPC	.00001 ON DAY	56.00000	IS:	70.00000
INV POS FOR UPC	.00001 ON DAY	56.00000	IS:	160.0000
ON HAND FOR UPC	.00001 ON DAY	56.00000	IS:	90.00000
INV POS FOR UPC	.00001 ON DAY	57.00000	IS:	150.0000
ON HAND FOR UPC	.00001 ON DAY	57.00000	IS:	80.00000
INV POS FOR UPC	.00001 ON DAY	58.00000	IS:	140.0000
ON HAND FOR UPC	.00001 ON DAY	58.00000	IS:	70.00000
INV POS FOR UPC	.00001 ON DAY	59.00000	IS:	130.0000
ON HAND FOR UPC	.00001 ON DAY	59.00000	IS:	60.00000
INV POS FOR UPC	.00001 ON DAY	60.00000	IS:	120.0000
ON HAND FOR UPC	.00001 ON DAY	60.00000	IS:	50.00000

Verification Calculations

for UPC 0.00001 unless otherwise noted
(in order of appearance on summary report)

```
      UPC#:  0.00001   taken directly from data input file
 UNIT COST:  $1.99     taken directly from data input file
       RVW:  7         taken directly from data input file
         L:  5         taken directly from data input file
       DMD:  10.00     taken directly from data input file
   SD(DAY):  0.00      taken directly from data input file

  SD(R+L):             SD(R+L) = SD(DAY) * SQRT(RVW + L)
 (.00002)                      = (1.00) * SQRT(7 + 5)
                               = 3.46

     TRND:                TRND = 1.00   (for stationary demand)

    SDAYS:  5          taken directly from data input file

      SCL:                 SCL = (RVW + L + SDAYS) * [DMD * (TRND - 1)]
                               = (7 + 5 + 5) * [10.0 + (1.00 - 1)]
                               = 170

      RPT:                 RPT = SCL - 1
                               = 170 - 1
                               = 169

       IP:                  IP = SUM OF IP/NUMBER OF OBSERVATIONS
                               = 7430/60
                               = 124

       OH:                  OH = SUM OF OH/NUMBER OF OBSERVATIONS
                               = 4380/60
                               = 73

      QTY:                 QTY = SUM OF QTY/NUMBER OF OBSERVATIONS
                               = 610/8
                               = 76

        B:                   B = SDAYS * DMD
                               = 5 * 10.00
                               = 50

      I:S:                 I:S = AVERAGE IP/(30 * (TOTAL SOLD/SIMULATION))
                               = 124/(30 * (542/60))
                               = .46
```

Appendix D: Verification of Current Model
(continued)

Verification Calculations
(continued)

```
TURNS:        TURNS = 1/(IP)
                    = 1/(.46)
                    = 2.2

  NIS:          NIS = LOST/TOTAL DEMAND
                    = LOST/(SOLD + LOST)
                    = 58/(542 + 58)
                    = .097

 SOLD:         SOLD = SUM OF TOTAL SOLD  (from trace report)
                    = 600

 LOST:         LOST = SUM OF TOTAL LOST  (from trace report)
                    = -58
```

Appendix E: Verification of Bytronic Model

DATA INPUT FILE

(UPC#	RVW	COST	DMD	SD(DAY)	L	CAT	LW)
.00000	7.00	1.99	10.00	1.00	5.0	0	0
.00001	7.00	1.99	10.00	0.00	5.0	1	15
.00002	7.00	1.99	10.00	0.00	5.0	2	0
.00003	7.00	1.99	10.00	0.00	5.0	3	0

PERFORMANCE SUMMARY REPORT

PERFORMANCE SUMMARY REPORT FOR BYTRONIC INV CONTROL SYSTEM

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00000	1.99	7.	5.	10.	1.00	3.46	0.	0.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
128.	127.	85.	37.	72.	8.	0.31	3.2	0.091	554.	-54.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00001	1.99	7.	5.	10.	0.00	0.00	1.	15.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
220.	219.	169.	114.	83.	100.	0.62	1.6	0.097	542.	-58.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00002	1.99	7.	5.	10.	0.00	0.00	2.	0.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
144.	143.	100.	52.	73.	24.	0.37	2.7	0.097	542.	-58.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00003	1.99	7.	5.	10.	0.00	0.00	3.	0.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
132.	131.	90.	42.	72.	12.	0.33	3.0	0.097	542.	-58.

------- AVG AGG VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
156.	155.	111.	61.	75.	36.	0.41	2.6	0.096	543.	-57.

Appendix E: Verification of Bytronic Model
(continued)

Trace Report

INV POS FOR UPC .00001 ON DAY	1.000000	IS:	42.00000
ON HAND FOR UPC .00001 ON DAY	1.000000	IS:	42.00000
INV POS FOR UPC .00001 ON DAY	2.000000	IS:	32.00000
ON HAND FOR UPC .00001 ON DAY	2.000000	IS:	32.00000
INV POS FOR UPC .00001 ON DAY	3.000000	IS:	22.00000
ON HAND FOR UPC .00001 ON DAY	3.000000	IS:	22.00000
INV POS FOR UPC .00001 ON DAY	4.000000	IS:	12.00000
ON HAND FOR UPC .00001 ON DAY	4.000000	IS:	12.00000
INV POS FOR UPC .00001 ON DAY	5.000000	IS:	2.000000
ON HAND FOR UPC .00001 ON DAY	5.000000	IS:	2.000000
INV POS FOR UPC .00001 ON DAY	6.000000	IS:	0.000000
ON HAND FOR UPC .00001 ON DAY	6.000000	IS:	0.000000
REP QTY FOR UPC .00001 ON DAY	7.000000	IS:	220.0000
INV POS FOR UPC .00001 ON DAY	7.000000	IS:	220.0000
ON HAND FOR UPC .00001 ON DAY	7.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	8.000000	IS:	220.0000
ON HAND FOR UPC .00001 ON DAY	8.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	9.000000	IS:	220.0000
ON HAND FOR UPC .00001 ON DAY	9.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	10.00000	IS:	220.0000
ON HAND FOR UPC .00001 ON DAY	10.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	11.00000	IS:	220.0000
ON HAND FOR UPC .00001 ON DAY	11.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	12.00000	IS:	210.0000
ON HAND FOR UPC .00001 ON DAY	12.00000	IS:	210.0000
INV POS FOR UPC .00001 ON DAY	13.00000	IS:	200.0000
ON HAND FOR UPC .00001 ON DAY	13.00000	IS:	200.0000
REP QTY FOR UPC .00001 ON DAY	14.00000	IS:	20.00000
INV POS FOR UPC .00001 ON DAY	14.00000	IS:	210.0000
ON HAND FOR UPC .00001 ON DAY	14.00000	IS:	190.0000
INV POS FOR UPC .00001 ON DAY	15.00000	IS:	200.0000
ON HAND FOR UPC .00001 ON DAY	15.00000	IS:	180.0000
INV POS FOR UPC .00001 ON DAY	16.00000	IS:	190.0000
ON HAND FOR UPC .00001 ON DAY	16.00000	IS:	170.0000
INV POS FOR UPC .00001 ON DAY	17.00000	IS:	180.0000
ON HAND FOR UPC .00001 ON DAY	17.00000	IS:	160.0000
INV POS FOR UPC .00001 ON DAY	18.00000	IS:	170.0000
ON HAND FOR UPC .00001 ON DAY	18.00000	IS:	150.0000
INV POS FOR UPC .00001 ON DAY	19.00000	IS:	160.0000
ON HAND FOR UPC .00001 ON DAY	19.00000	IS:	160.0000
INV POS FOR UPC .00001 ON DAY	20.00000	IS:	150.0000
ON HAND FOR UPC .00001 ON DAY	20.00000	IS:	150.0000
REP QTY FOR UPC .00001 ON DAY	21.00000	IS:	70.00000
INV POS FOR UPC .00001 ON DAY	21.00000	IS:	210.0000
ON HAND FOR UPC .00001 ON DAY	21.00000	IS:	140.0000

Appendix E: Verification of Bytronic Model
(continued)

Trace Report
(continued)

INV POS	FOR UPC	.00001	ON DAY	22.00000	IS:	200.0000
ON HAND	FOR UPC	.00001	ON DAY	22.00000	IS:	130.0000
INV POS	FOR UPC	.00001	ON DAY	23.00000	IS:	190.0000
ON HAND	FOR UPC	.00001	ON DAY	23.00000	IS:	120.0000
INV POS	FOR UPC	.00001	ON DAY	24.00000	IS:	180.0000
ON HAND	FOR UPC	.00001	ON DAY	24.00000	IS:	110.0000
INV POS	FOR UPC	.00001	ON DAY	25.00000	IS:	170.0000
ON HAND	FOR UPC	.00001	ON DAY	25.00000	IS:	100.0000
INV POS	FOR UPC	.00001	ON DAY	26.00000	IS:	160.0000
ON HAND	FOR UPC	.00001	ON DAY	26.00000	IS:	160.0000
INV POS	FOR UPC	.00001	ON DAY	27.00000	IS:	150.0000
ON HAND	FOR UPC	.00001	ON DAY	27.00000	IS:	150.0000
REP QTY	FOR UPC	.00001	ON DAY	28.00000	IS:	70.00000
INV POS	FOR UPC	.00001	ON DAY	28.00000	IS:	210.0000
ON HAND	FOR UPC	.00001	ON DAY	28.00000	IS:	140.0000
INV POS	FOR UPC	.00001	ON DAY	29.00000	IS:	200.0000
ON HAND	FOR UPC	.00001	ON DAY	29.00000	IS:	130.0000
INV POS	FOR UPC	.00001	ON DAY	30.00000	IS:	190.0000
ON HAND	FOR UPC	.00001	ON DAY	30.00000	IS:	120.0000
INV POS	FOR UPC	.00001	ON DAY	31.00000	IS:	180.0000
ON HAND	FOR UPC	.00001	ON DAY	31.00000	IS:	110.0000
INV POS	FOR UPC	.00001	ON DAY	32.00000	IS:	170.0000
ON HAND	FOR UPC	.00001	ON DAY	32.00000	IS:	100.0000
INV POS	FOR UPC	.00001	ON DAY	33.00000	IS:	160.0000
ON HAND	FOR UPC	.00001	ON DAY	33.00000	IS:	160.0000
INV POS	FOR UPC	.00001	ON DAY	34.00000	IS:	150.0000
ON HAND	FOR UPC	.00001	ON DAY	34.00000	IS:	150.0000
REP QTY	FOR UPC	.00001	ON DAY	35.00000	IS:	70.00000
INV POS	FOR UPC	.00001	ON DAY	35.00000	IS:	210.0000
ON HAND	FOR UPC	.00001	ON DAY	35.00000	IS:	140.0000
INV POS	FOR UPC	.00001	ON DAY	36.00000	IS:	200.0000
ON HAND	FOR UPC	.00001	ON DAY	36.00000	IS:	130.0000
INV POS	FOR UPC	.00001	ON DAY	37.00000	IS:	190.0000
ON HAND	FOR UPC	.00001	ON DAY	37.00000	IS:	120.0000
INV POS	FOR UPC	.00001	ON DAY	38.00000	IS:	180.0000
ON HAND	FOR UPC	.00001	ON DAY	38.00000	IS:	110.0000
INV POS	FOR UPC	.00001	ON DAY	39.00000	IS:	170.0000
ON HAND	FOR UPC	.00001	ON DAY	39.00000	IS:	100.0000
INV POS	FOR UPC	.00001	ON DAY	40.00000	IS:	160.0000
ON HAND	FOR UPC	.00001	ON DAY	40.00000	IS:	160.0000
INV POS	FOR UPC	.00001	ON DAY	41.00000	IS:	150.0000
ON HAND	FOR UPC	.00001	ON DAY	41.00000	IS:	150.0000
REP QTY	FOR UPC	.00001	ON DAY	42.00000	IS:	70.00000
INV POS	FOR UPC	.00001	ON DAY	42.00000	IS:	210.0000
ON HAND	FOR UPC	.00001	ON DAY	42.00000	IS:	140.0000

Appendix E: Verification of Bytronic Model (continued)

Trace Report
(continued)

INV POS FOR UPC .00001 ON DAY	43.00000	IS:	200.0000
ON HAND FOR UPC .00001 ON DAY	43.00000	IS:	130.0000
INV POS FOR UPC .00001 ON DAY	44.00000	IS:	190.0000
ON HAND FOR UPC .00001 ON DAY	44.00000	IS:	120.0000
INV POS FOR UPC .00001 ON DAY	45.00000	IS:	180.0000
ON HAND FOR UPC .00001 ON DAY	45.00000	IS:	110.0000
INV POS FOR UPC .00001 ON DAY	46.00000	IS:	170.0000
ON HAND FOR UPC .00001 ON DAY	46.00000	IS:	100.0000
INV POS FOR UPC .00001 ON DAY	47.00000	IS:	160.0000
ON HAND FOR UPC .00001 ON DAY	47.00000	IS:	160.0000
INV POS FOR UPC .00001 ON DAY	48.00000	IS:	150.0000
ON HAND FOR UPC .00001 ON DAY	48.00000	IS:	150.0000
REP QTY FOR UPC .00001 ON DAY	49.00000	IS:	70.00000
INV POS FOR UPC .00001 ON DAY	49.00000	IS:	210.0000
ON HAND FOR UPC .00001 ON DAY	49.00000	IS:	140.0000
INV POS FOR UPC .00001 ON DAY	50.00000	IS:	200.0000
ON HAND FOR UPC .00001 ON DAY	50.00000	IS:	130.0000
INV POS FOR UPC .00001 ON DAY	51.00000	IS:	190.0000
ON HAND FOR UPC .00001 ON DAY	51.00000	IS:	120.0000
INV POS FOR UPC .00001 ON DAY	52.00000	IS:	180.0000
ON HAND FOR UPC .00001 ON DAY	52.00000	IS:	110.0000
INV POS FOR UPC .00001 ON DAY	53.00000	IS:	170.0000
ON HAND FOR UPC .00001 ON DAY	53.00000	IS:	100.0000
INV POS FOR UPC .00001 ON DAY	54.00000	IS:	160.0000
ON HAND FOR UPC .00001 ON DAY	54.00000	IS:	160.0000
INV POS FOR UPC .00001 ON DAY	55.00000	IS:	150.0000
ON HAND FOR UPC .00001 ON DAY	55.00000	IS:	150.0000
REP QTY FOR UPC .00001 ON DAY	56.00000	IS:	70.00000
INV POS FOR UPC .00001 ON DAY	56.00000	IS:	210.0000
ON HAND FOR UPC .00001 ON DAY	56.00000	IS:	140.0000
INV POS FOR UPC .00001 ON DAY	57.00000	IS:	200.0000
ON HAND FOR UPC .00001 ON DAY	57.00000	IS:	130.0000
INV POS FOR UPC .00001 ON DAY	58.00000	IS:	190.0000
ON HAND FOR UPC .00001 ON DAY	58.00000	IS:	120.0000
INV POS FOR UPC .00001 ON DAY	59.00000	IS:	180.0000
ON HAND FOR UPC .00001 ON DAY	59.00000	IS:	110.0000
INV POS FOR UPC .00001 ON DAY	60.00000	IS:	170.0000
ON HAND FOR UPC .00001 ON DAY	60.00000	IS:	100.0000

Verification Calculations

for UPC 0.00001 unless otherwise noted
(in order of appearance on summary report)

UPC#:	0.00001	taken directly from data input file
UNIT COST:	$1.99	taken directly from data input file
RVW:	7	taken directly from data input file
L:	5	taken directly from data input file
DMD:	10.00	taken directly from data input file
SD(DAY):	0.00	taken directly from data input file

SD(R+L): (.00000)

SD(R+L) = SD(DAY) * SQRT(RVW + L)
= (1.00) * SQRT(7 + 5)
= 3.46

CAT: 1 — taken directly from data input file

LW: 15 — taken directly from data input file

SCL:

SCL = [DMD * (RVW + L)] + B
= [10.00 * (7 + 5)] + 100
= 220

RPT:

RPT = SCL - 1
= 220 - 1
= 219

IP:

IP = SUM OF IP/NUMBER OF OBSERVATIONS
= 6830/60
= 114

OH:

OH = SUM OF OH/NUMBER OF OBSERVATIONS
= 6830/60
= 114

QTY:

QTY = SUM OF QTY/NUMBER OF OBSERVATIONS
= 660/8
= 83

Verification Calculations
(continued)

B: (.00000)

B = 2.25 * SD(DAY) * SQRT(RVW + L)
= 2.25 * 1.00 * SQRT(7 + 5)
= 8

B: (.00001)

B = DMD * (LW - L)
= 10.00 * (15 - 5)
= 100

B: (.00002)

B = (0.20) * DMD * (RVW + L)
= (0.20) * 10.00 * (7 + 5)
= 24

B: (.00003)

B = (0.10) * DMD * (RVW + L)
= (0.10) * 10.00 * (7 + 5)
= 12

I:S:

I:S = AVERAGE IP/(30 * (TOTAL SOLD/SIMULATION))
= 169/(30 * (542/60))
= .62

TURNS:

TURNS = 1/(IP)
= 1/(.62)
= 1.6

NIS:

NIS = LOST/TOTAL DEMAND
= LOST/(SOLD + LOST)
= 58/(542 + 58)
= .097

SOLD:

SOLD = SUM OF TOTAL SOLD (from trace report)
= 542

LOST:

LOST = SUM OF TOTAL LOST (from trace report)
= -58

Appendix F: Verification of Tijms Model

DATA INPUT FILE

(UPC*	RVW	COST	DMD	SD(DAY)	L
.00001	7.00	1.99	10.00	0.00	15.0
.00002	7.00	1.99	10.00	7.00	15.0

PERFORMANCE SUMMARY REPORT

PERFORMANCE SUMMARY REPORT FOR TIJMS INV CONTROL SYSTEM

UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R)	SD(R+L)	JUK	K	S-s
0.00001	1.99	7.	15.	10.00	0.00	0.00	0.00	*****	0.00	105.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
325.	220.	249.	107.	198.	0.	1.13	0.9	0.263	442.	-158.

UPC*	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R)	SD(R+L)	JUK	K	S-s
0.00002	1.99	7.	15.	10.00	7.00	18.52	32.83	0.378	0.18	105.

------- AVERAGE VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
331.	226.	257.	104.	175.	6.	1.08	1.0	0.181	475.	-109.

------- AVG AGG VALUE AS OF DAY 60.00000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
328.	223.	253.	106.	187.	3.	1.11	1.0	0.225	459.	-134.

Appendix F: Verification of Tijms Model
(continued)

Trace Report

INV POS FOR UPC .00001 ON DAY	1.000000	IS:	42.00000
ON HAND FOR UPC .00001 ON DAY	1.000000	IS:	42.00000
INV POS FOR UPC .00001 ON DAY	2.000000	IS:	32.00000
ON HAND FOR UPC .00001 ON DAY	2.000000	IS:	32.00000
INV POS FOR UPC .00001 ON DAY	3.000000	IS:	22.00000
ON HAND FOR UPC .00001 ON DAY	3.000000	IS:	22.00000
INV POS FOR UPC .00001 ON DAY	4.000000	IS:	12.00000
ON HAND FOR UPC .00001 ON DAY	4.000000	IS:	12.00000
INV POS FOR UPC .00001 ON DAY	5.000000	IS:	2.000000
ON HAND FOR UPC .00001 ON DAY	5.000000	IS:	2.000000
INV POS FOR UPC .00001 ON DAY	6.000000	IS:	0.000000
ON HAND FOR UPC .00001 ON DAY	6.000000	IS:	0.000000
REP QTY FOR UPC .00001 ON DAY	7.000000	IS:	325.0000
INV POS FOR UPC .00001 ON DAY	7.000000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	7.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	8.000000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	8.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	9.000000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	9.000000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	10.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	10.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	11.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	11.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	12.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	12.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	13.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	13.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	14.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	14.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	15.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	15.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	16.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	16.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	17.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	17.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	18.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	18.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	19.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	19.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	20.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	20.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	21.00000	IS:	325.0000
ON HAND FOR UPC .00001 ON DAY	21.00000	IS:	0.000000
INV POS FOR UPC .00001 ON DAY	22.00000	IS:	315.0000
ON HAND FOR UPC .00001 ON DAY	22.00000	IS:	315.0000

Appendix F: Verification of Tijms Model
(continued)

Trace Report
(continued)

INV POS	FOR	UPC	.00001	ON	DAY	23.00000	IS:	305.0000
ON HAND	FOR	UPC	.00001	ON	DAY	23.00000	IS:	305.0000
INV POS	FOR	UPC	.00001	ON	DAY	24.00000	IS:	295.0000
ON HAND	FOR	UPC	.00001	ON	DAY	24.00000	IS:	295.0000
INV POS	FOR	UPC	.00001	ON	DAY	25.00000	IS:	285.0000
ON HAND	FOR	UPC	.00001	ON	DAY	25.00000	IS:	285.0000
INV POS	FOR	UPC	.00001	ON	DAY	26.00000	IS:	275.0000
ON HAND	FOR	UPC	.00001	ON	DAY	26.00000	IS:	275.0000
INV POS	FOR	UPC	.00001	ON	DAY	27.00000	IS:	265.0000
ON HAND	FOR	UPC	.00001	ON	DAY	27.00000	IS:	265.0000
INV POS	FOR	UPC	.00001	ON	DAY	28.00000	IS:	255.0000
ON HAND	FOR	UPC	.00001	ON	DAY	28.00000	IS:	255.0000
INV POS	FOR	UPC	.00001	ON	DAY	29.00000	IS:	245.0000
ON HAND	FOR	UPC	.00001	ON	DAY	29.00000	IS:	245.0000
INV POS	FOR	UPC	.00001	ON	DAY	30.00000	IS:	235.0000
ON HAND	FOR	UPC	.00001	ON	DAY	30.00000	IS:	235.0000
INV POS	FOR	UPC	.00001	ON	DAY	31.00000	IS:	225.0000
ON HAND	FOR	UPC	.00001	ON	DAY	31.00000	IS:	225.0000
INV POS	FOR	UPC	.00001	ON	DAY	32.00000	IS:	215.0000
ON HAND	FOR	UPC	.00001	ON	DAY	32.00000	IS:	215.0000
INV POS	FOR	UPC	.00001	ON	DAY	33.00000	IS:	205.0000
ON HAND	FOR	UPC	.00001	ON	DAY	33.00000	IS:	205.0000
INV POS	FOR	UPC	.00001	ON	DAY	34.00000	IS:	195.0000
ON HAND	FOR	UPC	.00001	ON	DAY	34.00000	IS:	195.0000
REP QTY	FOR	UPC	.00001	ON	DAY	35.00000	IS:	130.0000
INV POS	FOR	UPC	.00001	ON	DAY	35.00000	IS:	315.0000
ON HAND	FOR	UPC	.00001	ON	DAY	35.00000	IS:	185.0000
INV POS	FOR	UPC	.00001	ON	DAY	36.00000	IS:	305.0000
ON HAND	FOR	UPC	.00001	ON	DAY	36.00000	IS:	175.0000
INV POS	FOR	UPC	.00001	ON	DAY	37.00000	IS:	295.0000
ON HAND	FOR	UPC	.00001	ON	DAY	37.00000	IS:	165.0000
INV POS	FOR	UPC	.00001	ON	DAY	38.00000	IS:	285.0000
ON HAND	FOR	UPC	.00001	ON	DAY	38.00000	IS:	155.0000
INV POS	FOR	UPC	.00001	ON	DAY	39.00000	IS:	275.0000
ON HAND	FOR	UPC	.00001	ON	DAY	39.00000	IS:	145.0000
INV POS	FOR	UPC	.00001	ON	DAY	40.00000	IS:	265.0000
ON HAND	FOR	UPC	.00001	ON	DAY	40.00000	IS:	135.0000
INV POS	FOR	UPC	.00001	ON	DAY	41.00000	IS:	255.0000
ON HAND	FOR	UPC	.00001	ON	DAY	41.00000	IS:	125.0000
INV POS	FOR	UPC	.00001	ON	DAY	42.00000	IS:	245.0000
ON HAND	FOR	UPC	.00001	ON	DAY	42.00000	IS:	115.0000
INV POS	FOR	UPC	.00001	ON	DAY	43.00000	IS:	235.0000
ON HAND	FOR	UPC	.00001	ON	DAY	43.00000	IS:	105.0000
INV POS	FOR	UPC	.00001	ON	DAY	44.00000	IS:	225.0000
ON HAND	FOR	UPC	.00001	ON	DAY	44.00000	IS:	95.00000

Appendix F: Verification of Tijms Model
(continued)

Trace Report
(continued)

INV POS FOR UPC	.00001	ON DAY	45.00000	IS:	215.0000
ON HAND FOR UPC	.00001	ON DAY	45.00000	IS:	85.00000
INV POS FOR UPC	.00001	ON DAY	46.00000	IS:	205.0000
ON HAND FOR UPC	.00001	ON DAY	46.00000	IS:	75.00000
INV POS FOR UPC	.00001	ON DAY	47.00000	IS:	195.0000
ON HAND FOR UPC	.00001	ON DAY	47.00000	IS:	65.00000
INV POS FOR UPC	.00001	ON DAY	48.00000	IS:	185.0000
ON HAND FOR UPC	.00001	ON DAY	48.00000	IS:	55.00000
REP QTY FOR UPC	.00001	ON DAY	49.00000	IS:	140.0000
INV POS FOR UPC	.00001	ON DAY	49.00000	IS:	315.0000
ON HAND FOR UPC	.00001	ON DAY	49.00000	IS:	45.00000
INV POS FOR UPC	.00001	ON DAY	50.00000	IS:	305.0000
ON HAND FOR UPC	.00001	ON DAY	50.00000	IS:	165.0000
INV POS FOR UPC	.00001	ON DAY	51.00000	IS:	295.0000
ON HAND FOR UPC	.00001	ON DAY	51.00000	IS:	155.0000
INV POS FOR UPC	.00001	ON DAY	52.00000	IS:	285.0000
ON HAND FOR UPC	.00001	ON DAY	52.00000	IS:	145.0000
INV POS FOR UPC	.00001	ON DAY	53.00000	IS:	275.0000
ON HAND FOR UPC	.00001	ON DAY	53.00000	IS:	135.0000
INV POS FOR UPC	.00001	ON DAY	54.00000	IS:	265.0000
ON HAND FOR UPC	.00001	ON DAY	54.00000	IS:	125.0000
INV POS FOR UPC	.00001	ON DAY	55.00000	IS:	255.0000
ON HAND FOR UPC	.00001	ON DAY	55.00000	IS:	115.0000
INV POS FOR UPC	.00001	ON DAY	56.00000	IS:	245.0000
ON HAND FOR UPC	.00001	ON DAY	56.00000	IS:	105.0000
INV POS FOR UPC	.00001	ON DAY	57.00000	IS:	235.0000
ON HAND FOR UPC	.00001	ON DAY	57.00000	IS:	95.00000
INV POS FOR UPC	.00001	ON DAY	58.00000	IS:	225.0000
ON HAND FOR UPC	.00001	ON DAY	58.00000	IS:	85.00000
INV POS FOR UPC	.00001	ON DAY	59.00000	IS:	215.0000
ON HAND FOR UPC	.00001	ON DAY	59.00000	IS:	75.00000
INV POS FOR UPC	.00001	ON DAY	60.00000	IS:	205.0000
ON HAND FOR UPC	.00001	ON DAY	60.00000	IS:	65.00000

Appendix F: Verification of Tijms Model
(continued)

Verification Calculations

for UPC 0.00002 unless otherwise noted
(in order of appearance on summary report)

```
      UPC#:  0.00002    taken directly from data input file
 UNIT COST:  $1.99      taken directly from data input file
       RVW:  7          taken directly from data input file
         L:  5          taken directly from data input file
       DMD:  10.00      taken directly from data input file
   SD(DAY):  0.00       taken directly from data input file

     SD(R):             SD(R) = SD(DAY) * SQRT(RVW)
                              = (7.00) * SQRT(7)
                              = 18.52

   SD(R+L):           SD(R+L) = SD(DAY) * SQRT(RVW + L)
                              = (7.00) * SQRT(7 + 15)
                              = 32.83

     Ju(k):   Ju(k) = (2*{1-P2)/P2}*X(R)*[(S-s)+{(SD(R)**2+X(R)**2}/[2*X(R)]})/SD(R+L)*
                    = (2*{1-.98)/.98}*70*[(105)+{18.52**2+70**2}/[2*70]})/32.83**2
                    = .378

         k:   .18       extracted from Appendix G

     (S-s):             (S-s) = 1.5 * DMD * 7
                              = 1.5 * 10.00 * 7
                              = 105

       SCL:               SCL = RPT + (S-s)
                              = 226 + 105
                              = 331

       RPT:                   = X(R+L) + [k * SD(R+L)
                              = 220 + [(.18) * (32.83)]
                              = 226

        IP:                IP = SUM OF IP/NUMBER OF OBSERVATIONS
   (.00001)                   = 14920/60
                              = 249

        OH:                OH = SUM OF OH/NUMBER OF OBSERVATIONS
   (.00001)                   = 6415/60
                              = 106
```

Verification Calculations
(continued)

QTY: (.00001)	QTY = SUM OF QTY/NUMBER OF OBSERVATIONS = 595/3 = 198
B:	B = k * SD(AVW+L) = (0.18) * (32.83) = 6
I:S:	I:S = AVERAGE IP/(30 * (TOTAL SOLD/SIMULATION)) = 257/(30 * (475/60)) = 1.05
TURNS:	TURNS = 1/(IP) = 1/(1.05) = 1.0
NIS:	NIS = LOST/TOTAL DEMAND = LOST/(SOLD + LOST) = 58/(475 + 109) = .187
SOLD:	SOLD = SUM OF TOTAL SOLD (from trace report) = 475
LOST:	LOST = SUM OF TOTAL LOST (from trace report) = -109

Appendix G. Table of $J_u(k)$ vs k

k	Ju(k)	k	Ju(k)	k	Ju(k)	k	Ju(k)
0.00	0.500000	0.50	0.209639	1.00	0.075340	1.50	0.0228470
0.01	0.492071	0.51	0.205714	1.01	0.073689	1.51	0.0222675
0.02	0.484241	0.52	0.201850	1.02	0.072070	1.52	0.0217011
0.03	0.476510	0.53	0.198046	1.03	0.070481	1.53	0.0211476
0.04	0.468876	0.54	0.194302	1.04	0.068923	1.54	0.0206066
0.05	0.461339	0.55	0.190616	1.05	0.067395	1.55	0.0200781
0.06	0.453898	0.56	0.186989	1.06	0.065896	1.56	0.0195616
0.07	0.446552	0.57	0.183420	1.07	0.064426	1.57	0.0190570
0.08	0.439301	0.58	0.179907	1.08	0.062984	1.58	0.0185640
0.09	0.432143	0.59	0.176450	1.09	0.061571	1.59	0.0180825
0.10	0.425079	0.60	0.173049	1.10	0.060185	1.60	0.0176121
0.11	0.418106	0.61	0.169703	1.11	0.058826	1.61	0.0171527
0.12	0.411224	0.62	0.166411	1.12	0.057494	1.62	0.0167041
0.13	0.404433	0.63	0.163173	1.13	0.056188	1.63	0.0162660
0.14	0.397732	0.64	0.159987	1.14	0.054908	1.64	0.0158381
0.15	0.391119	0.65	0.156854	1.15	0.053653	1.65	0.0154204
0.16	0.384594	0.66	0.153772	1.16	0.052423	1.66	0.0150126
0.17	0.378157	0.67	0.150741	1.17	0.051218	1.67	0.0146145
0.18	0.371806	0.68	0.147761	1.18	0.050037	1.68	0.0142258
0.19	0.365541	0.69	0.144830	1.19	0.048880	1.69	0.0138465
0.20	0.359361	0.70	0.141948	1.20	0.047747	1.70	0.0134762
0.21	0.353265	0.71	0.139115	1.21	0.046636	1.71	0.0131149
0.22	0.347253	0.72	0.136329	1.22	0.045548	1.72	0.0127623
0.23	0.341323	0.73	0.133590	1.23	0.044482	1.73	0.0124182
0.24	0.335475	0.74	0.130898	1.24	0.043439	1.74	0.0120825
0.25	0.329707	0.75	0.128252	1.25	0.042416	1.75	0.0117550
0.26	0.324021	0.76	0.125651	1.26	0.041415	1.76	0.0114355
0.27	0.318413	0.77	0.123095	1.27	0.040435	1.77	0.0111239
0.28	0.312885	0.78	0.120583	1.28	0.039474	1.78	0.0108123
0.29	0.307434	0.79	0.118115	1.29	0.038534	1.79	0.0105234
0.30	0.302060	0.80	0.115690	1.30	0.037614	1.80	0.0102343
0.31	0.296763	0.81	0.113307	1.31	0.036713	1.81	0.0099523
0.32	0.291542	0.82	0.110965	1.32	0.035831	1.82	0.0096774
0.33	0.286395	0.83	0.108665	1.33	0.034968	1.83	0.0094094
0.34	0.281323	0.84	0.106406	1.34	0.034123	1.84	0.0091481
0.35	0.276323	0.85	0.104187	1.35	0.033296	1.85	0.0088933
0.36	0.271397	0.86	0.102007	1.36	0.032487	1.86	0.0086450
0.37	0.266542	0.87	0.099866	1.37	0.031695	1.87	0.0084030
0.38	0.261759	0.88	0.097764	1.38	0.030921	1.88	0.0081671
0.39	0.257046	0.89	0.095699	1.39	0.030163	1.89	0.0079373
0.40	0.252403	0.90	0.093672	1.40	0.029421	1.90	0.0077133
0.41	0.247828	0.91	0.091682	1.41	0.028696	1.91	0.0074951
0.42	0.243322	0.92	0.089728	1.42	0.027986	1.92	0.0072824
0.43	0.238883	0.93	0.087810	1.43	0.027293	1.93	0.0070753
0.44	0.234511	0.94	0.085926	1.44	0.026614	1.94	0.0068735
0.45	0.230205	0.95	0.084078	1.45	0.025950	1.95	0.0066770
0.46	0.225964	0.96	0.082264	1.46	0.025301	1.96	0.0064856
0.47	0.221788	0.97	0.080484	1.47	0.024667	1.97	0.0062991
0.48	0.217675	0.98	0.078737	1.48	0.024046	1.98	0.0061176
0.49	0.213626	0.99	0.077022	1.49	0.023440	1.99	0.0059408

Appendix H. Description of UPCs

Partial UPC number	Item Description
.00287	toothpaste, dispenser, gel, tartar control, 6.4 oz, Crest
.00309	toothpaste, gel, tartar control, mint, 6.4 oz, Crest
.00312	toothpaste, gel, mint, 6.4 oz, Crest
.00321	toothpaste, 6.4 oz, Crest
.00345	toothpaste, mint, 6.4 oz, Crest
.00354	mouthwash, mint, 40 oz, Scope
.00391	toothpaste, dispenser, tartar control, 6.4 oz, Crest
.00394	toothpaste, dispenser, 6.4 oz, Crest
.00404	oil, 48 oz, Crisco
.00405	oil, 128 oz, Crisco
.00407	peanut butter, creamy, 18 oz, Jiff
.00408	peanut butter, creamy, 28 oz, Jiff
.00411	peanut butter, crunchy, 18 oz, Jiff
.00412	peanut butter, creamy, 40 oz, Jiff
.00413	peanut butter, crunchy, 40 oz, Jiff
.00415	oil, 32 oz, Crisco
.00426	oil, 32 oz, Puritan
.00427	oil, 48 oz, Puritan
.00439	frosting mix, chocolate, 16.5 oz, Duncan-Hines
.00482	oil, 64 oz, Crisco
.00501	soap, bar, 4 pack, 14 oz, Ivory
.00523	soap, bar, 5 oz, Zest
.00555	soap, bar, white, 5 oz, Safeguard
.00580	soap, bar, gold, 5 oz, Safeguard
.00592	cleanser, 21 oz, Comet
.00618	cleanser, with phosphorous, lemon, 17 oz, Comet
.00622	cleaner, liquid, 28 oz, Mr. Clean
.00712	soap, bar, 5 oz, Coast
.00717	soap, bar, 7 oz, Coast
.00718	soap, bar, 5 oz, Coast Sun-Spray
.00735	cleaner, liquid, 28 oz, Top Job
.00775	soap, bar, 4.75 oz, Camay
.00805	dishwasher detergent, 65 oz, Cascade
.00823	dish detergent, liquid, 32 oz, Dawn

Appendix H. Description of UPCs
(continued)

Partial UPC number	Item Description
.00824	dish detergent, liquid, 48 oz, Dawn
.00844	detergent, liquid, 128 oz, Era
.00863	dish detergent, liquid, 32 oz, Ivory
.00864	dish detergent, liquid, 48 oz, Ivory
.00883	dish detergent, liquid, 32 oz, Joy
.00884	dish detergent, liquid, 48 oz, Joy
.00901	dishwasher detergent, lemon, 50 oz, Cascade
.00942	detergent, liquid, 64 oz, Cheer
.00946	detergent, liquid, 128 oz, Tide
.00988	dishwasher detergent, 85 oz, Cascade
.35000	bleach, 45 oz, Biz
.35500	fabric softener, 96 oz, Downy
.35510	fabric softener, 64 oz, Downy
.36020	fabric softener, 40 ct, Bounce
.36030	fabric softener, 60 ct, Bounce
.40010	shortening, 3 lb, Crisco
.40020	shortening, 6 lb, Crisco
.40060	shortening, butter flavor, 3 lb, Crisco
.41000	cake mix, 18.25 oz, Duncan-Hines White
.41040	cake mix, 18.25 oz, Duncan-Hines Devil's Food
.41100	cake mix, 18.25 oz, Duncan-Hines Lemon Supreme
.42027	muffin mix, 19.1 oz, Duncan-Hines Cinnamon Swirl
.42110	brownie mix, 23.6 oz, Duncan-Hines
.44014	potato chips, 7.5 oz, Pringle's Original
.44018	potato chips, 6.5 oz, Pringle's Light BBQ
.44180	potato chips, 7.0 oz, Pringle's Rippled
.44212	potato chips, 7.0 oz, Pringle's Cheez Ums
.44425	potato chips, 7.5 oz, Pringle's Butter n' Herbs
.44511	potato chips, 7.0 oz, Pringle's Sour Cream n' Onion
.48534	cookies, chocolate chip, 16 oz, Duncan-Hines
.60511	toilet paper, unscented, 24-4, Charmin Free
.60571	toilet paper, yellow/blue, 24-4, Charmin
.60641	toilet paper, white/yellow, 16-6, Charmin
.60712	toilet paper, white/yellow, 8-12, Charmin

Appendix H. Description of UPCs
(continued)

Partial UPC number	Item Description
.61222	toilet paper, white/beige, 16-6, White Cloud
.61612	toilet paper, white/beige, 24-4, White Cloud
.61652	toilet paper, yellow/blue, 24-4, White Cloud
.62112	facial tissue, white, 250 ct, Puffs
.62172	facial tissue, assorted, 250 ct, Puffs
.62312	facial tissue, white, 175 ct, Puffs
.62351	facial tissue, unscented, 130 ct, Puffs
.62372	facial tissue, assorted, 175 ct, Puffs
.62712	facial tissue, unscented, 100 ct, Puffs
.62792	facial tissue, floral, 100 ct, Puffs
.63011	paper towels, Bounty
.63031	paper towels, microwave, Bounty
.65811	diapers, large, 64 ct, Ultra Pampers
.66151	sanitary napkins, Always Super Thin
.66251	sanitary napkins, Always Plus
.67312	toilet tissue, 9 roll, Banner
.90240	detergent, family, 151 oz, Cheer
.91240	detergent, family, 151 oz, Tide
91250	detergent, regular, 400 oz, Tide
.91290	detergent, giant, 42 oz, Tide
.91740	detergent, unscented, family, 151 oz, Tide
.97330	detergent, liquid, lemon, 64 oz, Dash

Appendix I. Power Calculations

For the purposes of this study, "D_F" was used to denote the minimum detectable difference between two mean values of I:S produced by any two levels of a given factor F. D_F was calculated as follows:

$$D_F = [(2 * a * sd^2 * \phi^2)/(n * b)]^{1/2} \qquad (I.1)$$

where a represents the number of levels of the factor of interest while, for the two-factor case, b represents the number of levels of the second factor. For the three-factor case, the levels of the second and third factors can be multiplied to determine the appropriate value of b to use in Equation I.1 above. The number of replications is specified by n and the variance of the variable of interest (in this case I:S) is given by sd^2. Finally, the square root of the value ϕ^2 is determined using the appropriate operating characteristic curve. In order to calculate a value of D_F, an alpha level has to be specified and the number of numerator and denominator degrees of freedom have to be determined as follows:

$$\text{numerator degrees of freedom} = a - 1 \qquad (I.2)$$

$$\text{denominator degrees of freedom} = a * b * (n - 1) \qquad (I.3)$$

For instance, ϕ for the first factor (inventory control system) was determined as follows. Since there were three possible levels of this factor, a was set equal to 3. Multiplying the number of possible levels of the other two factors (review period and leadtime) produced b equal to 6. Consequently, there were (a-1), or 2, numerator degrees of freedom, and [ab(n-1)], or 72, denominator degrees of freedom. Assuming an alpha level of .01, ϕ was determined to be roughly 3.0, and thus ϕ^2=9.0. Using .002 as an estimate of sd and making the appropriate substitutions into Equation I.1 yielded:

$$D_{SYS} = \{[2 * 3 * (.002)^2 * 3^2]/(5 * 6)\}^{1/2} = .00268 \qquad (I.4)$$

Similarly, for the review period factor:

$$D_{RVW} = \{[2 * 3 * (.002)^2 * 3^2]/(5 * 6)\}^{1/2} = .00268 \qquad (I.5)$$

Finally, for the leadtime factor, sd^2 and ϕ^2 remained unchanged while a was now equal to 2 and b was equal to 9:

$$D_L = \{[2 * 2 * (.002)^2 * 3^2]/(5 * 9)\}^{1/2} = .00179 \qquad (I.6)$$

Appendix J. Performance Summary Report for Bytronic Model

PERFORMANCE SUMMARY REPORT FOR BYTRONIC INV CONTROL SYSTEM

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00287	1.99	14.	12.	16.	5.52	28.15	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
465.	464.	343.	150.	226.	42.	0.71	1.4	0.002	11611.	-20.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00309	1.99	14.	12.	25.	8.39	42.78	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
717.	716.	530.	232.	348.	65.	0.71	1.4	0.001	17944.	-10.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00312	1.99	14.	12.	15.	5.95	30.34	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
424.	423.	314.	138.	205.	39.	0.71	1.4	0.002	10552.	-19.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00321	1.99	14.	12.	24.	7.88	40.18	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
672.	671.	494.	211.	332.	61.	0.69	1.4	0.004	17106.	-69.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00345	1.99	14.	12.	20.	7.21	36.76	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
566.	565.	419.	186.	273.	51.	0.72	1.4	0.004	14029.	-51.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00354	1.99	14.	12.	9.	2.49	12.70	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
269.	268.	198.	85.	131.	24.	0.70	1.4	0.000	6757.	-2.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00391	1.99	14.	12.	40.	12.70	64.76	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1153.	1152.	854.	377.	558.	105.	0.71	1.4	0.001	28727.	-36.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00394	1.99	14.	12.	14.	4.61	23.51	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
398.	397.	295.	130.	193.	36.	0.71	1.4	0.001	9924.	-14.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00404	1.99	14.	12.	18.	6.17	31.46	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
509.	508.	376.	164.	248.	46.	0.71	1.4	0.004	12746.	-57.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00405	1.99	14.	12.	22.	9.34	47.62	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
696.	695.	532.	271.	305.	116.	0.81	1.2	0.000	15687.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00407	1.99	14.	12.	28.	12.48	63.64	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
882.	881.	669.	330.	396.	147.	0.79	1.3	0.000	20414.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00408	1.99	14.	12.	34.	13.94	71.08	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
986.	985.	729.	321.	476.	90.	0.72	1.4	0.005	24439.	-116.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00411	1.99	14.	12.	11.	4.38	22.33	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
315.	314.	232.	100.	154.	29.	0.70	1.4	0.009	7905.	-69.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00412	1.99	14.	12.	35.	13.79	70.32	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
996.	995.	730.	306.	495.	91.	0.69	1.5	0.009	25478.	-222.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00413	1.99	14.	12.	23.	13.36	68.12	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
723.	722.	544.	259.	333.	120.	0.76	1.3	0.006	17125.	-112.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00415	1.99	14.	12.	19.	7.70	39.26	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
549.	548.	401.	166.	274.	50.	0.68	1.5	0.008	14127.	-110.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00426	1.99	14.	12.	10.	3.00	15.30	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
273.	272.	201.	86.	135.	25.	0.70	1.4	0.003	6895.	-18.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00427	1.99	14.	12.	12.	5.02	25.60	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
377.	376.	282.	133.	174.	63.	0.76	1.3	0.000	8936.	-2.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00439	1.99	14.	12.	15.	5.75	29.32	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
421.	420.	310.	133.	206.	38.	0.70	1.4	0.007	10559.	-69.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00482	1.99	14.	12.	16.	6.37	32.48	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
464.	463.	338.	138.	233.	42.	0.68	1.5	0.014	11960.	-173.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00501	1.99	14.	12.	33.	11.73	59.81	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
932.	931.	691.	308.	446.	85.	0.72	1.4	0.003	22975.	-65

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00523	1.99	14.	12.	124.	67.60	344.69	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
3857.	3856.	2911.	1394.	1774.	643.	0.77	1.3	0.000	91159	[illegible]

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00555	1.99	14.	12.	35.	13.44	68.53	3	0

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD
1002.	1001.	741.	323.	487.	91.	0.71	1.4	0.010	[illegible]

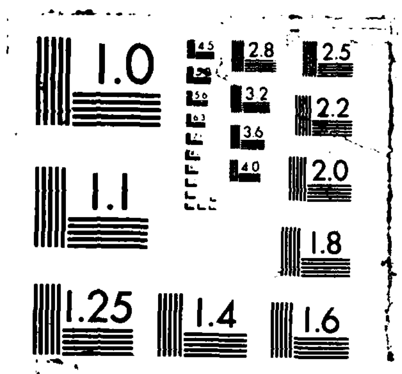
UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00580	1.99	14.	12.	68.	32.78	167.15	[illegible]	

------- AVERAGE VALUE AS OF DAY 1080.000

SCL	RPT	IP	OH	QTY	B	I:S	TURNS
2124.	2123.	1610.	795.	952	354	[illegible]	

AD-A189 461 A COMPARISON OF THE PERFORMANCE OF THREE INVENTORY CONTROL STRATEGIES IN T..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. M B STARK 3/3

UNCLASSIFIED DEC 87 AFIT/GOR/ENS/87D-20 F/G 5/1 NL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1.4
1.6

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00592	1.99	14.	12.	51.	42.21	215.23	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1586.	1585.	1190.	560.	738.	264.	0.75	1.3	0.008	38055.	-300.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00618	1.99	14.	12.	25.	14.34	73.12	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
784.	783.	597.	296.	352.	131.	0.79	1.3	0.007	18052.	-124.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00622	1.99	14.	12.	11.	3.85	19.63	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
300.	299.	222.	99.	145.	27.	0.71	1.4	0.001	7486.	-9.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00712	1.99	14.	12.	26.	13.12	66.90	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
821.	820.	626.	316.	363.	137.	0.80	1.2	0.000	18749.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00717	1.99	14.	12.	64.	25.36	129.31	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1827.	1826.	1351.	595.	885.	166.	0.71	1.4	0.007	45501.	-311.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00718	1.99	14.	12.	16.	6.99	35.64	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
512.	511.	390.	195.	228.	85.	0.80	1.3	0.000	11730.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00735	1.99	14.	12.	9.	3.18	16.21	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
244.	243.	180.	77.	120.	22.	0.70	1.4	0.007	6141.	-45.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00775	1.99	14.	12.	30.	14.01	71.44	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
923.	922.	702.	344.	420.	154.	0.78	1.3	0.000	21601.	0.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00805	1.99	14.	12.	31.	19.02	96.98	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
967.	966.	740.	378.	423.	161.	0.81	1.2	0.000	21823.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00823	1.99	14.	12.	37.	13.98	71.28	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1070.	1069.	796.	365.	504.	97.	0.74	1.4	0.002	25939.	-50.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00824	1.99	14.	12.	16.	6.58	33.55	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
455.	454.	332.	138.	227.	41.	0.69	1.5	0.010	11636.	-114.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00844	1.99	14.	12.	13.	6.34	32.33	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
416.	415.	312.	148.	192.	69.	0.76	1.3	0.000	9839.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00863	1.99	14.	12.	24.	11.54	58.84	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
736.	735.	557.	271.	333.	123.	0.78	1.3	0.002	17086.	-27.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00864	1.99	14.	12.	20.	10.80	55.07	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
624.	623.	475.	238.	276.	104.	0.80	1.2	0.000	14192.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00883	1.99	14.	12.	32.	12.12	61.80	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
920.	919.	682.	300.	447.	84.	0.71	1.4	0.003	22912.	-63.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.00884	1.99	14.	12.	12.	7.48	38.14	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
386.	385.	291.	139.	178.	64.	0.76	1.3	0.010	9160.	-94.

Appendix J. Performance Summary Report for Bytronic Model (continued)

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UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00901    1.99      14.  12.  17.    5.03      25.65     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          495.   494.   366.  161.  239.  45. 0.71  1.4  0.004   12339.  -48.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00942    1.99      14.  12.  11.    5.28      26.92     2.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          334.   333.   252.  120.  154.  56. 0.76  1.3  0.003    7922.  -23.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00946    1.99      14.  12.  22.    7.16      36.51     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          627.   626.   463.  201.  305.  57. 0.71  1.4  0.000   15754.    0.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.00988    1.99      14.  12.  16.    6.42      32.74     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          454.   453.   334.  144.  222.  41. 0.70  1.4  0.003   11415.  -33.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.35000    1.99      14.  12.  18.    6.64      33.86     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          527.   526.   392.  174.  255.  48. 0.72  1.4  0.005   13107.  -63.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.35500    1.99      14.  12.  36.   13.53      68.99     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
         1028.  1027.   749.  312.  511.  93. 0.68  1.5  0.006   26264. -150.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.35510    1.99      14.  12.  36.   12.15      61.95     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
         1027.  1026.   758.  332.  498.  93. 0.71  1.4  0.007   25686. -173.

UPC#     UNIT COST   RUW   L   DMD   SD(DAY)   SD(R+L)   CAT   LW
0.36020    1.99      14.  12.  30.   12.08      61.60     3.   0.
         -------   AVERAGE VALUE AS OF DAY   1080.000   --------
          SCL    RPT    IP    OH    QTY   B   I:S  TURNS   NIS     SOLD   LOST
          866.   865.   634.  268.  428.  79. 0.69  1.4  0.010   22032. -229.
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Appendix J. Performance Summary Report for Bytronic Model
(continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.36030	1.99	14.	12.	23.	9.40	47.93	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
704.	703.	536.	267.	314.	117.	0.80	1.3	0.000	16138.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.40010	1.99	14.	12.	42.	14.56	74.24	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1189.	1188.	878.	389.	573.	108.	0.72	1.4	0.002	29428.	-66.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.40020	1.99	14.	12.	15.	9.73	49.61	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
481.	480.	360.	168.	224.	80.	0.75	1.3	0.005	11536.	-54.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.40060	1.99	14.	12.	15.	6.20	31.61	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
438.	437.	324.	139.	216.	40.	0.70	1.4	0.001	11082.	-11.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.41000	1.99	14.	12.	17.	11.30	57.62	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
517.	516.	392.	189.	236.	86.	0.78	1.3	0.008	12086.	-97.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.41040	1.99	14.	12.	29.	18.20	92.80	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
908.	907.	689.	338.	410.	151.	0.78	1.3	0.000	21073.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.41100	1.99	14.	12.	18.	13.87	70.72	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
572.	571.	425.	193.	272.	95.	0.73	1.4	0.009	13963.	-120.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.42027	1.99	14.	12.	15.	6.49	33.09	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	APT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
472.	471.	360.	180.	210.	79.	0.79	1.3	0.000	10873.	0.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.42110	1.99	14.	12.	22.	9.46	48.24	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
686.	685.	516.	242.	320.	114.	0.75	1.3	0.002	16469.	-27.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44014	1.99	14.	12.	38.	13.30	67.82	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1078.	1077.	793.	334.	536.	98.	0.69	1.4	0.007	27534.	-185.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44018	1.99	14.	12.	20.	7.37	37.58	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
582.	581.	429.	188.	281.	53.	0.71	1.4	0.006	14515.	-80.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44180	1.99	14.	12.	11.	4.22	21.52	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
302.	301.	223.	97.	147.	27.	0.71	1.4	0.010	7559.	-75.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44212	1.99	14.	12.	14.	5.10	26.00	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
392.	391.	288.	124.	192.	36.	0.70	1.4	0.004	9864.	-41.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44425	1.99	14.	12.	11.	3.86	19.68	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
316.	315.	232.	99.	156.	29.	0.70	1.4	0.002	8015.	-18.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.44511	1.99	14.	12.	21.	7.89	40.23	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
662.	661.	503.	246.	300.	110.	0.78	1.3	0.000	15418.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.46534	1.99	14.	12.	23.	11.88	60.58	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
712.	711.	536.	256.	328.	119.	0.76	1.3	0.001	16979.	-24.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.60511	1.99	14.	12.	49.	19.60	99.94	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1515.	1514.	1151.	566.	683.	253.	0.79	1.3	0.000	35102.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.60571	1.99	14.	12.	24.	8.43	42.98	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
695.	694.	510.	221.	338.	63.	0.70	1.4	0.004	17413.	-70.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.60641	1.99	14.	12.	87.	31.20	159.09	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
2476.	2475.	1831.	788.	1220.	225.	0.70	1.4	0.003	62651.	-173.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.60712	1.99	14.	12.	66.	20.31	103.56	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1890.	1889.	1402.	611.	926.	172.	0.71	1.4	0.000	47675.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.61222	1.99	14.	12.	85.	41.18	209.98	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
2645.	2644.	2005.	972.	1209.	441.	0.77	1.3	0.000	62367.	-24.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.61612	1.99	14.	12.	42.	19.30	98.41	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1316.	1315.	994.	479.	600.	219.	0.77	1.3	0.000	30773.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.61652	1.99	14.	12.	34.	16.33	83.27	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1046.	1045.	795.	396.	466.	174.	0.80	1.3	0.000	23953.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62112	1.99	14.	12.	49.	19.39	98.87	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1524.	1523.	1158.	569.	688.	254.	0.78	1.3	0.000	35406.	0.

Appendix J. Performance Summary Report for Bytronic Model
(continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62172	1.99	14.	12.	66.	30.78	156.95	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
2049.	2048.	1554.	763.	923.	341.	0.78	1.3	0.001	47681.	-66.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62312	1.99	14.	12.	33.	15.32	78.12	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1029.	1028.	788.	406.	446.	171.	0.83	1.2	0.000	22913.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62351	1.99	14.	12.	75.	48.31	246.33	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
2354.	2353.	1777.	855.	1081.	392.	0.77	1.3	0.005	55349.	-294.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62372	1.99	14.	12.	46.	17.47	89.08	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1429.	1428.	1084.	530.	649.	238.	0.78	1.3	0.000	33410.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62712	1.99	14.	12.	41.	16.71	85.20	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1276.	1275.	968.	479.	570.	213.	0.79	1.3	0.000	29249.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.62792	1.99	14.	12.	44.	18.93	96.52	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1373.	1372.	1045.	515.	622.	229.	0.78	1.3	0.002	31966.	-52.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.63011	1.99	14.	12.	58.	42.24	215.38	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1817.	1816.	1375.	677.	817.	303.	0.79	1.3	0.004	41945.	-175.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.63031	1.99	14.	12.	58.	39.15	199.63	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
1810.	1809.	1350.	620.	851.	302.	0.74	1.4	0.012	44051.	-515.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.65881	1.99	14.	12.	23.	9.87	50.33	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
708.	707.	536.	260.	323.	118.	0.78	1.3	0.001	16567.	-11.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.66151	1.99	14.	12.	16.	7.08	36.10	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
500.	499.	379.	186.	226.	83.	0.78	1.3	0.001	11599.	-14.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.66251	1.99	14.	12.	17.	6.26	31.92	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
521.	520.	399.	203.	229.	87.	0.81	1.2	0.000	11783.	0.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.67312	1.99	14.	12.	29.	13.09	66.75	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
895.	894.	675.	326.	408.	149.	0.77	1.3	0.002	20896.	-43.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.90240	1.99	14.	12.	13.	6.62	33.76	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
407.	406.	313.	161.	177.	68.	0.82	1.2	0.000	9110.	0.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.91240	1.99	14.	12.	28.	9.15	46.66	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
790.	789.	588.	261.	381.	72.	0.72	1.4	0.001	19529.	-15.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.91250	1.99	14.	12.	14.	4.83	24.63	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
410.	409.	304.	136.	198.	37.	0.72	1.4	0.000	10168.	0.

UPC#	UNIT COST	AVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.91290	1.99	14.	12.	21.	6.36	32.43	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 -------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
593.	592.	437.	190.	289.	54.	0.70	1.4	0.001	14905.	-9.

Appendix J. Performance Summary Report for Bytronic Model (continued)

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.91740	1.99	14.	12.	12.	4.72	24.07	2.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
385.	384.	292.	144.	172.	64.	0.79	1.3	0.000	8870.	0.

UPC#	UNIT COST	RVW	L	DMD	SD(DAY)	SD(R+L)	CAT	LW
0.97330	1.99	14.	12.	16.	5.83	29.73	3.	0.

------- AVERAGE VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
463.	462.	341.	146.	228.	42.	0.70	1.4	0.003	11737.	-30.

------- AVG AGG VALUE AS OF DAY 1080.000 --------

SCL	RPT	IP	OH	QTY	B	I:S	TURNS	NIS	SOLD	LOST
885.	884.	663.	309.	414.	120.	0.74	1.3	0.003	21280.	-64.

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