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Testing Production Inventory Control Models on Maintenance Inventory: A Limited Case Study

Teresa J. K. Hall
University of Northern Iowa

Testing Production Inventory Control Models on Maintenance Inventory: A Limited Case Study

TESTING PRODUCTION INVENTORY CONTROL MODELS ON MAINTENANCE INVENTORY: A LIMITED CASE STUDY

A Research Paper Presented to the
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By
Teresa J.K. Hall
University of Northern Iowa
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Approved by:

Dr. Douglas Pine (Advisor)	12-6-91 Date
Dr. Roger Betts (Graduate Faculty)	12-6-91 Date

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CHAPTER 1
INTRODUCTION

The ability to balance maintenance, repair and operating (MRO) inventory levels with optimum service levels has been a continuing dilemma for manufacturing management (Gardner, 1990). While maintenance has a mission to support manufacturing and reduce production downtime (Herbaty, 1983), the primary goal of inventory management is to offset the expense of carrying inventory against the hazard of not having enough inventory to cover demand (Ahadiat, 1986). MRO purchasing organizations are responsible for analyzing trends and making judgments regarding the stock levels of thousands of separate items.

MRO inventory managers have difficulty making stock level decisions partially because demand forecasting for maintenance repair items have not been as well developed as forecasting for production inventory. A portion of the problem lies in the fact that each item, or group of items in MRO inventory, has discrete factors that affect demand behavior, minimum stock levels, order quantity, item cost and lead time, thus further clouding the forecast picture (Silver, 1981; Mitchell, 1987).

The economic order quantity (EOQ) model and the technique of Monte Carlo simulation have had benefit of extensive research and applications development in the production control arena. Testing these inventory control techniques on maintenance repair inventory may give some insight into the factors that must be considered in model development specific to MRO. This study will attempt to address this timely issue.

Purpose

The purpose of this research project is to:

1. Determine what effect the economic order quantity (EOQ) model has on a select group of industrial maintenance inventory items in terms of holding costs and number of stock out conditions.

2. Determine the effect of alternate reorder points combined with the optimal quantity developed by the EOQ model on this group of maintenance inventory.

3. Determine the reorder point and reorder quantity combination that causes the least number of stock outs when tested in a Monte Carlo simulation.

Statement of the Problem

The focus of this project is the application of selected inventory control systems to maintenance, repair and operating (MRO) inventory to derive a simple, yet effective, method of determining optimal order quantities and reorder points, as well as the resulting effects on holding costs and stockouts.

Research Questions

1. What effect does the Economic Order Quantity method have on maintenance repair parts holding costs and number of stock out conditions compared to the Weighted Moving Average method?

2. How does the optimal reorder point and reorder quantity developed by Monte Carlo simulation compare, in terms of holding costs and stock outs, with the Weighted Moving Average method?

Significance of the Study

Mecimore and Weeks (1987) found that, in large manufacturing organizations, service part ordering and stock level policy was determined by past experience and intuition. This philosophy is consistent with policies for MRO restocking and inventory levels. Although recent trends show application of statistical control measures are becoming more widespread, there is still some reluctance to rely on any single method or ideology (Bialous, 1984). In organizations that are using statistical inventory control, resistance to changing methods is somewhat justified since testing alternate models is time consuming for operations personnel with little time for, or experience with, this type of experimentation.

The Economic Order Quantity (EOQ) model may have the potential to generate cost savings for those MRO items with reasonably constant levels of demand by lowering stock levels over many demand periods (MacFarlane, 1984). The EOQ model was designed to regulate inventory based on ordering and holding costs (Hadley & Whitin, 1963). The high procurement cost of some MRO inventory that have steady demand patterns may lend itself to EOQ application. By varying the reorder point, the optimal solution for EOQ application to MRO inventory may be found. Monte Carlo simulation has the ability to derive an optimal solution by changing independent variable values and applying random numbers to the distribution of occurrences. By relying on historical data to determine the probabilistic distribution, an empirical simulation can be performed (Kaplan & Frazza, 1983).

Delimitations of the Study

Although MRO inventory encompasses a diverse group of items, this study only dealt with a select group of machine maintenance repair items in an expense stores system in an industrial setting. Office supplies, building and grounds maintenance, and systems repair contracts were not addressed.

The population was 800 (estimated) maintenance repair parts used for repair of a molding machine at Deere Waterloo Foundry. The sample was limited to a group of ten items with demand activity over the past two years.

Assumptions of the Study

The study assumed that the historical data from the population was reasonably accurate and reflected common traits of inventory for maintenance such as Poisson distribution of requests and stochastic demand. The study also assumed some inventory items might be interdependent on other items in the sample.

Definition of Terms

Demand. A 'purchase' or withdrawal of an item of inventory from the stores system. It can also be a requisition for an item listed in the inventory, but not currently in stock.

Economic Order Quantity Model. The optimum quantity of an item purchased with regard to ordering and holding costs of inventory (Wallace & Dougherty, 1987).

Inventory. An idle resource such as "tools, purchased parts, raw materials" and supplies that are on hand when required (Riggs, 1987, p. 456). For the purpose of this study, inventory was defined as purchased parts in a service parts stockroom available to maintenance personnel on demand.

Monte Carlo Simulation: A technique that emulates a system by setting up probability distributions for critical variables from historical data and applies random number intervals to the distribution (Heizer & Render, 1991).

Poisson distribution. Describes the situation where demand occurs randomly during a time period and the quantity of demand is dependent on the length of the time period (Heizer & Render, 1991). This study assumed demand was random over the length of the study and was proportional to the time period of observation.

Stochastic demand. A pattern of inventory needs that are said to be probabilistic or uncertain (Hadley & Whitin, 1963). Demand in this study was considered uncertain and random for any item available in the inventory.

Stock out. When the inventory level is reduced to zero.

Weighted Moving Average. An averaging method that gives weight to previous demand periods. Thus, as demand increases, inventory levels will only rise after the average demand over a specified time frame has increased significantly.

CHAPTER 2

REVIEW OF LITERATURE

Inventory control is a popular topic for a broad spectrum of practitioners, theorists and researchers (Silver, 1981). Mathematical models have been tested, applied and proven under a variety of circumstances. Yet, there remains a gap between model development and utilization by managers in inventory control.

Turban (cited in Zanakis, 1980) in 1972 found that, regarding operations research, major corporations applied traditional inventory concepts very infrequently. In a study conducted in 1987, Mecimore and Weeks found that only 8.7% of the surveyed companies used mathematical models to set service part order quantities and only 11.3% used models for safety stock levels. The similarities between production service parts and MRO inventories are not coincidental since both have demand cycles that are coupled with the failure rate of durable goods. The findings showed that 40 to 45% of the persons responsible for service parts inventory management used experience and intuition as their primary method for determining these inventory levels (Mecimore & Weeks, 1987). Likewise, MRO managers have few statistical tools that can be effective in an environment defined by lumpy and/or dependent demand, unpredictable lead times, obsolescence and immense numbers of items in the inventory itself (Gardner, 1990).

The current changes in production methods has improved manufacturing output while reducing inventory stockpiles between operations (Gilbert & Finch, 1985). This situation puts more pressure on maintenance services to reduce or eliminate downtime since entire operations can be immobilized by the failure of critical machines or equipment.

Many theories have been developed for production inventory based on assumptions such as stationary demand for items in the inventory (Graves, 1985), or that restocking the inventory occurs easily and with regularity (Mamer & Smith, 1985). These assumptions do not apply broadly to MRO inventory. On the other end of the spectrum are models that address specialized or obscure nuances of the inventory control function. Fetter and Dalleck (1961) outlined not less than seven models for inventory control with a myriad of decision rules to accompany them, but qualified their effort by advising future readers that "...it is up to the analyst to devise a model that produces useful results..."(p.5). Zanakis, et al (1980) summarized the entire modeling dilemma best:

> The result of this [effort] is an impressive collection of elegant, often exotic models, striving for mathematical optimality at the expense of unrealistic assumptions, input data and computational requirements. . . .a typical inventory manager has a limited quantitative background and must make inventory control decisions on a routine basis for thousands (or even tens of thousands) of distinct items (p.104).

There have been sporadic attempts to deal with the issues that are important to MRO. As manufacturing organizations reap the benefits of Material Requirements Planning (MRP) and Material Resource Planning (MRP II), maintenance management can also benefit. Bojanowski (1984) outlined a plan called service requirements planning (SRP) that used a ranking system for identifying critical machines. This strategy addresses the planning problems maintenance personnel encounter, but doesn't adequately cover MRO inventory control aspects of operations management. Although there is promising research and applications development in MRP linked systems for maintenance planning (Ettkin & Jahnig, 1986), these tools generally rely on forecasting repair based on production levels. Expert systems need large inputs of time, effort, and capital to create an accurate computer simulation. The result is a product developed for unique applications and thus does not have much wholesale value. These models are an excellent management tool when appropriately applied , but often the model is too complex to easily apply or doesn't account for the special circumstances of MRO inventory (Gilbert & Finch, 1985; Ahadiat, 1986). Expenditures of this magnitude are often a luxury in large industrial situations. The small or medium sized facility with limited resources and systems personnel are virtually excluded from this type of solution.

MRO inventory in any purchasing organization accounts for 80-85% of all purchasing transactions, yet only 15-20% of total purchasing dollars (Semich, 1989; Mitchell, 1987). The item that has infrequent demand or specialized application is more likely to take up shelf space and investment dollars while waiting for demand to occur. Yet, the expense of a stock out can have a much higher cost to the organization if production is stopped for lack of a critical repair part (Calaway, 1984; Gilbert & Finch, 1985; Gardner, 1990).

Once the MRO organization has made the commitment to carry inventory, there is the responsibility to wisely invest budgeted dollars. Since stochastic demand is the rule in most organizations rather than the exception, forecasting demand is scientifically limited. Setting reorder points, order quantities, as well as determining optimal ordering methods while balancing service level goals are functions MRO procurement personnel must consider on a daily basis (Handley, 1984). Controlling order size based on the holding cost of the inventory and the cost of order generation is an arena in which EOQ has been designed to function. MacFarlane (1984) calls for utilizing the EOQ formula in MRO inventory control measures, yet cautions against strict observation of the application rules. Since MRO does not precisely follow the assumptions of constant, predictable demand and fixed ordering costs, EOQ should be limited to the portion of MRO inventory that best fits the model (MacFarlane, 1984; Bialous, 1984; Ahadiat, 1986).

Monte Carlo simulation is another method that can be used in empirical situations. The development of probability distributions for demand and lead times from historical data may be a solution for persons needing a simple, low cost modeling technique (Heizer & Render, 1991). There are inventory control situations where simulation is the logical answer to emulate systems that make analytic solutions elaborate or unworkable (Banks & Malave', 1984) as in the case of MRO inventory.

The ability to assure inventory will be available to meet maintenance demand is an economic and productive advantage for any manufacturing organization. Using inventory control methods proven in production circles may be a step toward development of a mathematical model developed specifically for MRO inventory.

By testing alternate methods, managers of MRO inventory can determine the model that best satisfies organizational goals. Managers who are able to determine optimum inventory levels with some degree of confidence can control investment dollars in inventory, maintain service levels to production and, thereby, meet their organizational objectives and goals (Anderson, Cleveland & Schroeder, 1989 ; Gardner, 1990).

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

The research design for this study was descriptive. The study did not seek to specifically account for the causes of demand on the inventory or differences in lead time after ordering. The research was directed at discovering the quantitative differences the Economic Order Quantity model and Monte Carlo simulation caused in holding costs of the inventory and number of stockout conditions.

The dependent variables in this study were the inventory levels and the order quantity and number of stockouts created by the different models. Holding cost of the items was also a dependent variable since it could fluctuate with the method of inventory control applied. The independent variables were the EOQ model, Monte Carlo simulation methods of inventory manipulation and the current method of inventory control in use at the manufacturer.

The method of inventory control at Deere Foundry was based on the the Weighted Moving Average. The Deere inventory system was able to illustrate historical data on any item in the inventory through a simple query. Exception reporting showed items that were out of stock or in low supply for purchasing personnel to act upon after reviewing the historical data for recent trends. Reorder points and order quantities had input from stockroom, purchasing and maintenance management personnel.

The researcher reviewed the historical data from the past two years. The average demand, inventory levels and the number of stockouts for two years were documented for the Weighted Moving

Average method, hereafter referred to as WMA. The data from WMA was used to determine average demand per month and to calculate the reorder point for the EOQ model. The reorder point for the EOQ was determined by the average demand per month from the historical data, multiplied by the lead time (difference between order date and receipt of order). The periods of demand that occurred during the historical data were noted to use in depletion of the inventory for EOQ.

In the first method of inventory manipulation, the EOQ model was applied to ten items selected from the manufacturers' molding machine inventory listing.

The EOQ theory uses the formula:

$$Q^2 = 2DS/H$$

Where: Q = order quantity D = demand (6 mo.)
S = setup or ordering costs H = holding cost

Ordering and holding costs in this study were values currently used by the accounting department of the manufacturer. Ordering costs were estimated to be 40 dollars per order and holding cost was 20% of the purchase price per annum. Demand was calculated as a simple average of the past two years of inventory activity.

The EOQ was calculated for each of the ten items and an optimum order quantity determined. This quantity was the beginning inventory. The historical demand was used to simulate depletion of the inventory. For simplicity, the lead time for all items in EOQ were set at one month. The optimum quantity of inventory, EOQ, was ordered when the simulated inventory level reached the reorder point for the item. By comparing the EOQ and the resulting inventory levels versus the actual historical demand under WMA, a pattern could be developed for inventory levels over the two year time period.

In the Monte Carlo simulation technique, the demand and lead times from the historical data were used to develop probability distributions. These distributions were divided into percent of the total demand and lead time. These data were entered into a simulation program developed by Howard J. Weiss named POM. The program contained a random number generator, thus, the cumulative probability distributions became intervals for application of random numbers by the program. One of the strengths of the Monte Carlo simulation program was that application of random values for demand and lead times could be simulated for many different reorder points and order quantities. Also, simulation was not limited to 24 demand periods, thus, the researcher elected to double the observation periods to 48. The researcher performed seven simulation runs on each set of dependent variables. This combination of 48 observation periods and seven simulation runs had an averaging effect on the results. Due to monthly fluctuations in the historical data inventory levels, the demand was divided into monthly sectors to simplify calculation of the holding costs for all three methods.

The annual cost of holding inventory at Deere Foundry has been determined to be 20% of the purchase cost (value of the item at time of purchase). Calculating the cost of holding inventory each month created by the EOQ and the holding costs created by Monte Carlo simulation, versus the holding cost for inventory created by the Weighted Moving Average method generated a comparison of the three methods in terms of dollars per year holding cost.

The number of stockouts were also counted for each method. In WMA, the historical data illustrated the actual stockout conditions when they occurred. In the EOQ method and Monte Carlo simulation, a stockout occurred when the inventory 'created' by each method was entirely depleted.

CHAPTER 4

RESULTS

Reported in this chapter are the results of the comparison of the Weighted Moving Average method with the Economic Order Quantity and the Monte Carlo simulation and their impact on the maintenance inventory. The case study originated with ten items, however, two items were eliminated after the researcher found them to be unacceptable for use in the study. Item number seven was rejected due to insufficient historical data. Item number eight was rejected because the part was classified as obsolete by Deere foundry during the historical period under study.

Effect on Holding Costs

After the historical demand was applied to the EOQ generated inventory, the holding costs were calculated and compared to WMA holding costs. The number of items to order and the reorder point for the Monte Carlo simulation method was derived from an average of the seven simulation runs for each reorder point and reorder quantity combination. An order point, order size combination was selected from the simulation data that appeared to be optimal in terms of holding costs and number of stockouts.

The calculation for holding costs for all three methods was derived from the average per period inventory, multiplied by 12, multiplied by annual holding cost for each item.

Holding Costs = (Average Inventory/Month) 12 x (Item Cost x 20%)

The total holding costs for all three methods during the historical demand period are shown in Table 1. The percentage of difference from the WMA is noted under each figure. This data is also shown graphically in Appendix A.

Table 1

Holding Cost Comparison for EOQ, WMA and Simulation

Item Number	EOQ (percent change)	WMA	Simulation (percent change)
1	$46.42 (-4%)	$48.42	$6.42 (-87%)
2	$323.40 (+42%)	$227.98	$129.85 (-43%)
3	$259.53 (-10%)	$289.53	$60.16 (-79%)
4	$1508.09 (+42%)	$1062.50	$1419.20 (+25%)
5	$109.08 (+237%)	$32.32	$58.32 (+80%)
6	$479.40 (+14%)	$418.20	$418.20 (-0%)
9	$81.81 (+114%)	$38.18	$21.90 (-43%)
10	$962.95 (+49%)	$647.15	$566.90 (-12%)
Average change:	(+60.5%)		(-20%)

Effects on Number of Stockouts

The number of stockouts in the inventory as a result of the EOQ method were similar to WMA for most of the items in the study. However, two items, number five and six, had 75% less stockout conditions under EOQ as shown in Table 2. The average number of stockouts for EOQ and WMA were 1 and 1.6 respectively.

The results of the Monte Carlo simulation showed a higher average number of stockouts than both EOQ and WMA. The comparison of all three methods is graphically illustrated in Appendix A. On average, the simulation method generated nearly twice as many stockouts as WMA.

Table 2

Comparison of Number of Stockouts for EOQ and WMA

Item	EOQ	WMA	SIM
1	0	0	0
2	2	2	4
3	2	2	3
4	1	0	0
5	1	4	2
6	1	4	2
9	1	0	3
10	0	1	0
Average:	1 stockout	1.6 stockouts	3.1 stockouts

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The data shows that the Economic Order Quantity produces higher holding costs for maintenance inventory than the Weighted Moving Average method of inventory control. The EOQ produced higher holding costs in 75% of the items in the case study and was 60.5% higher on average for all items used in this study, while the holding costs generated by the Monte Carlo simulation were 20% lower on average for all items in the study. This would seem to indicate that simulation can have a positive impact on holding costs of inventory. In terms of holding costs, the current method (WMA) performed better than EOQ in six of eight items in the study as documented in Appendix B. Some of the holding costs for each of the three methods may have been artificially reduced due to periods when the item was out of stock.

The results show that holding cost reduction using Monte Carlo simulation appears to be feasible. However, the ability to determine the best combination of values for order quantity and reorder point through repeated testing is somewhat laborious. It should be noted that the researcher made a decision to attempt to strike a balance between the optimal reorder point, order size combination to generate both low holding costs and reduced stockouts. Using a slightly different reorder point, order size combination could possibly produce lower stockouts and higher holding costs.

The higher number of stockouts caused by the Monte Carlo simulation derived order quantities is a cause for concern. This would suggest that decision rules must be applied before simulation is used. For example, if reducing the number of stockouts was critical to an organization, then the optimal reorder point and order quantity for this result should be selected.

The results of this study show some promise for both EOQ and Monte Carlo simulation, but are not conclusive. Since MRO inventory has a wide variety of factors that define its importance to the manufacturing organization, each method appears to have application opportunities.

Recommendations

The results of the case study indicate further research in this area would be warranted. These are the recommendations for further study:

1. There is a need for more empirical studies on the effects of non-traditional inventory methods for industrial maintenance inventory.

2. Application to a larger sample of inventory may determine which items are best suited to EOQ or Monte Carlo simulation as inventory control measures.

3. From this larger study, decision rules for determining the most suitable model application for unique maintenance inventory systems may be developed.

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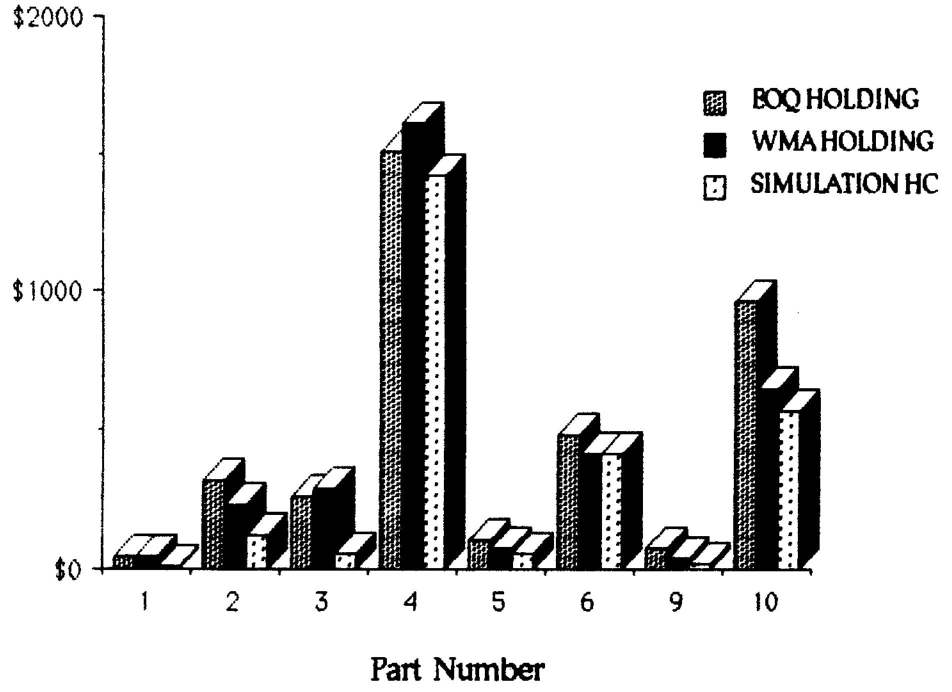
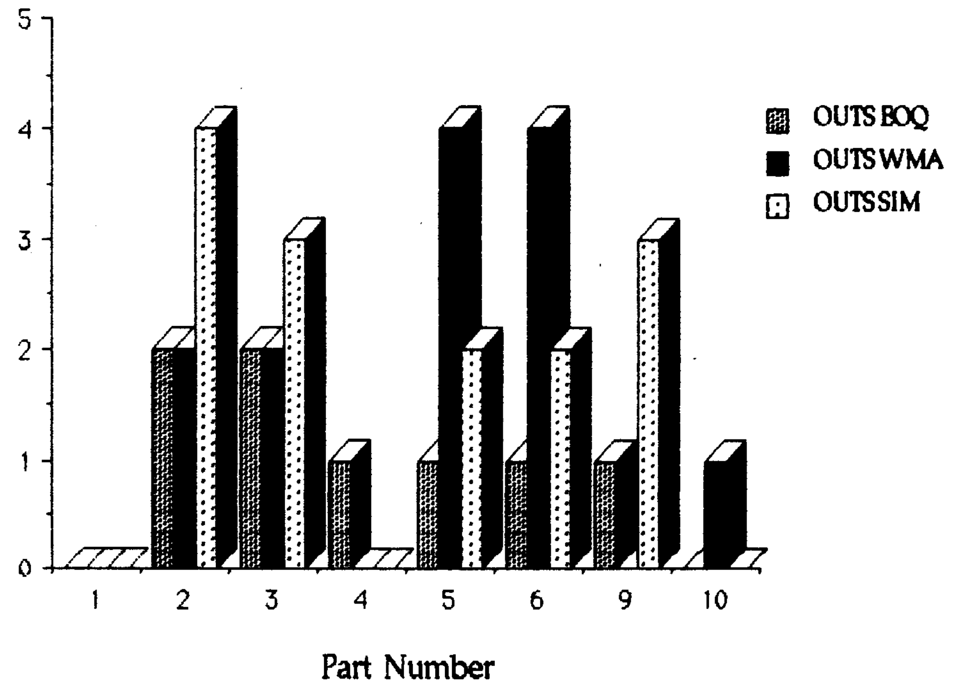
APPENDIX A

Holding Cost and Stockout Data.

Comparison of Holding Costs



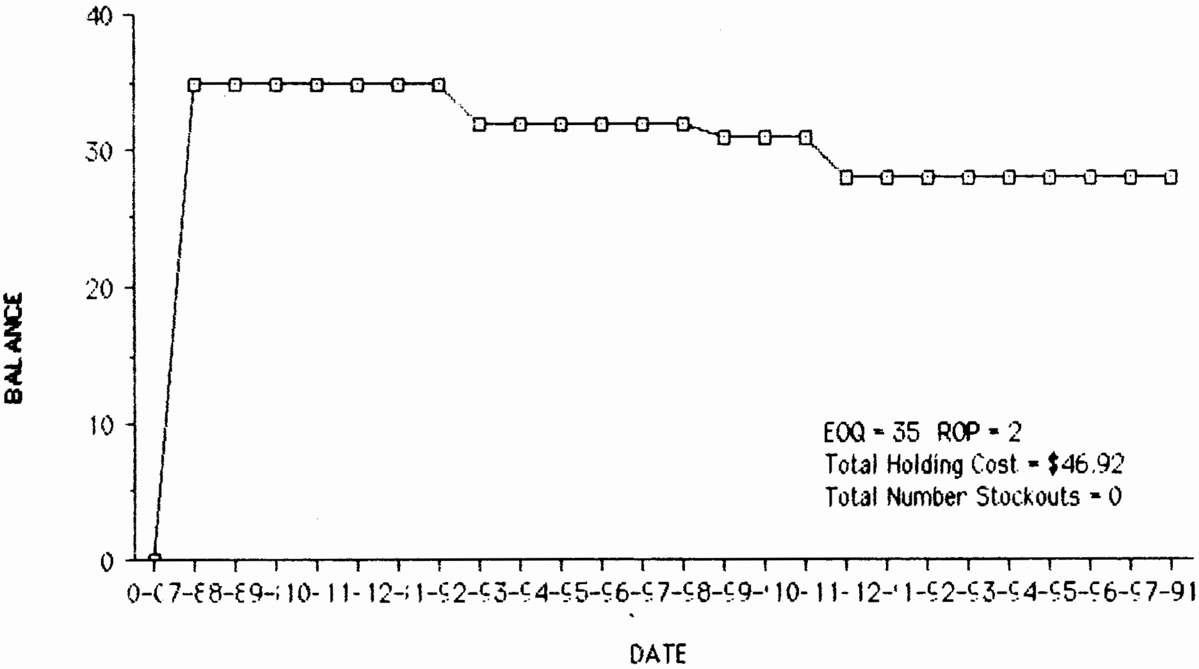
Comparison of Number of Stockouts



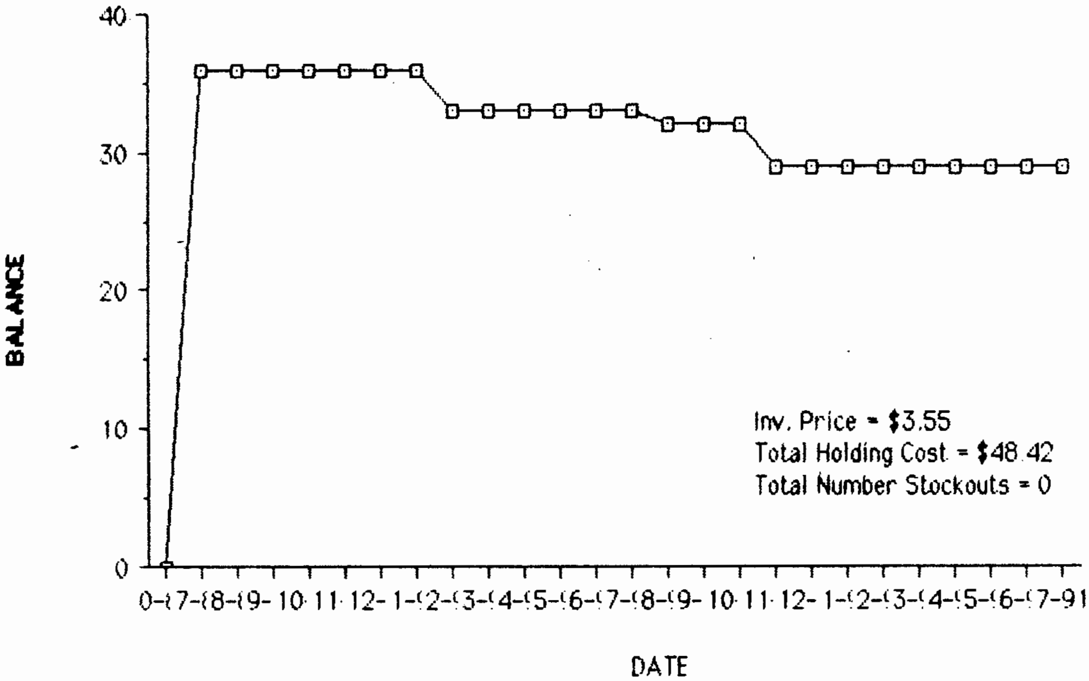
APPENDIX B

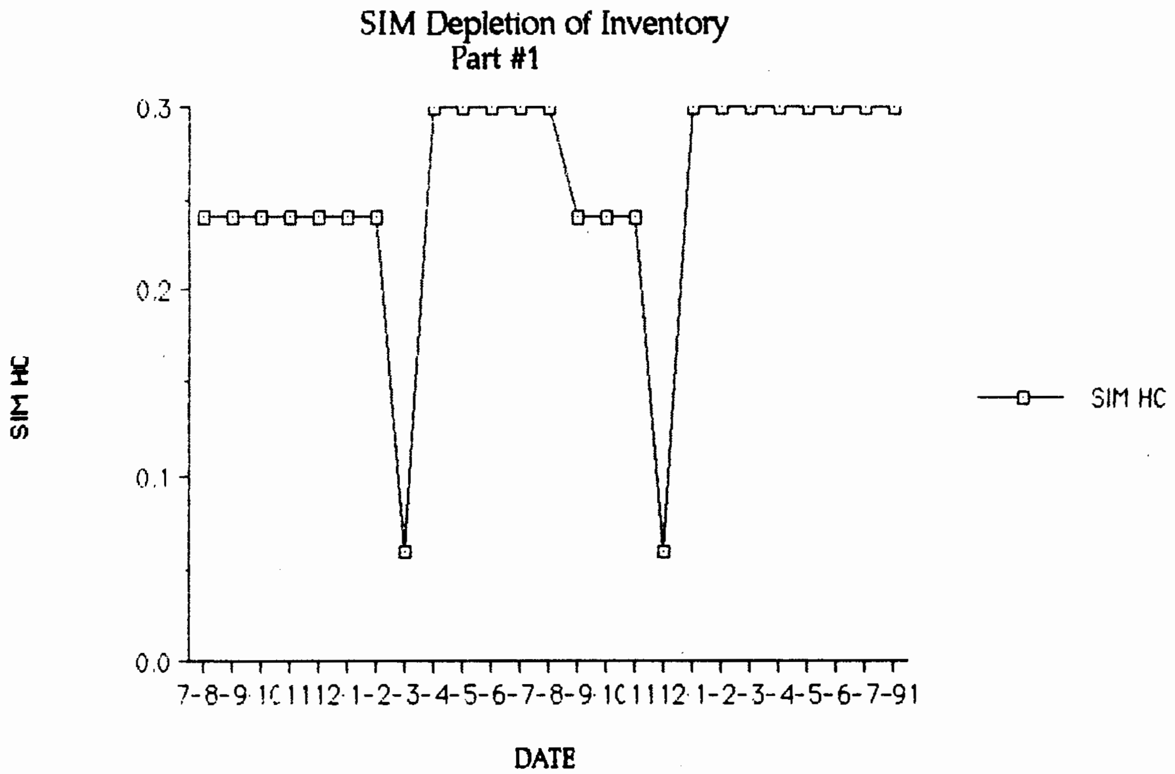
Historical Data and Methods Comparison Data

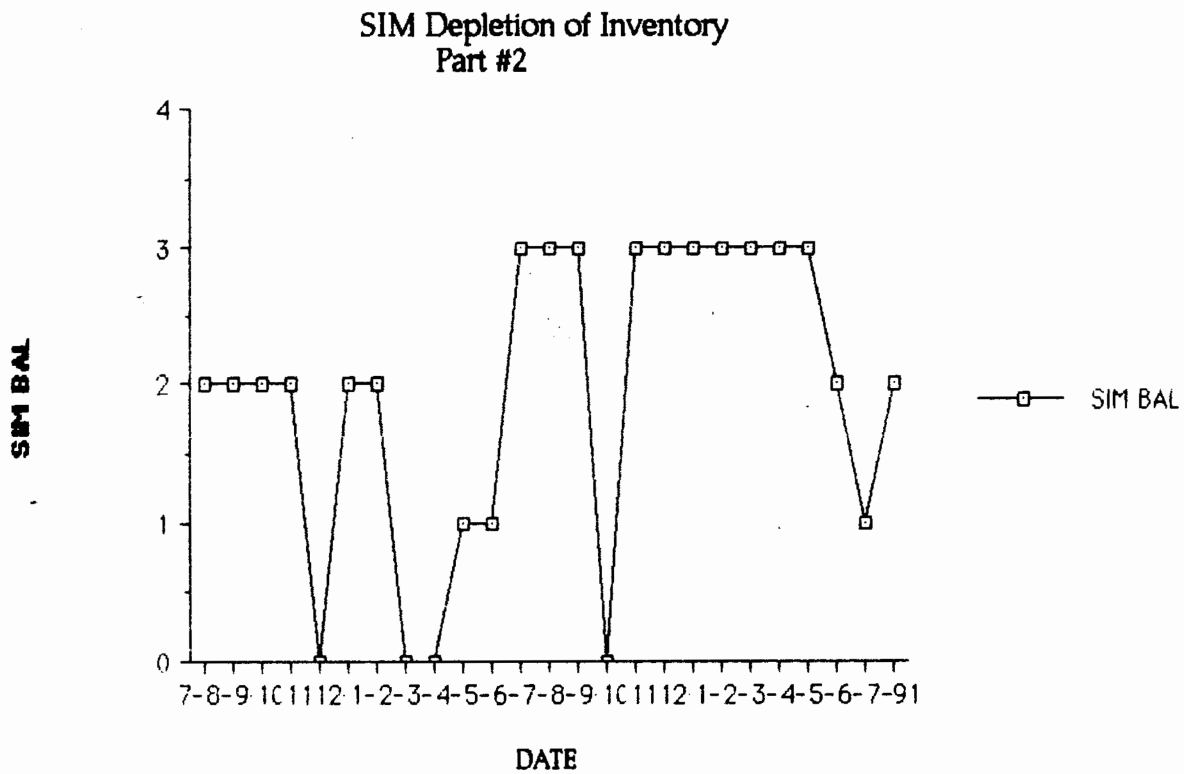
EOQ Depletion of Inventory
Part #1

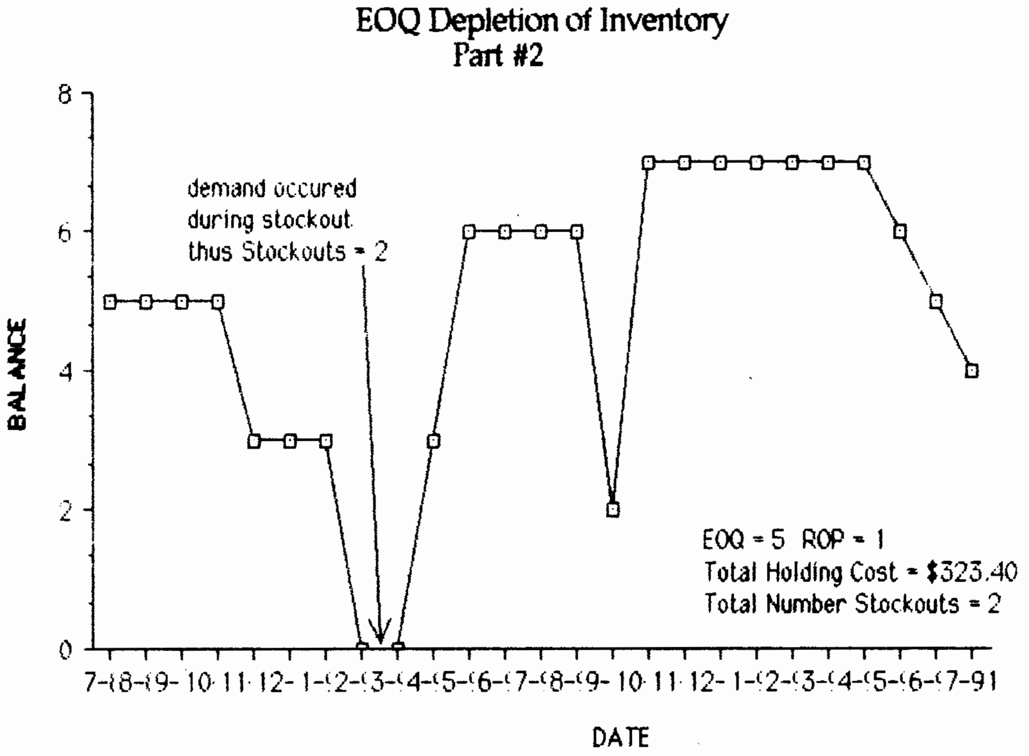


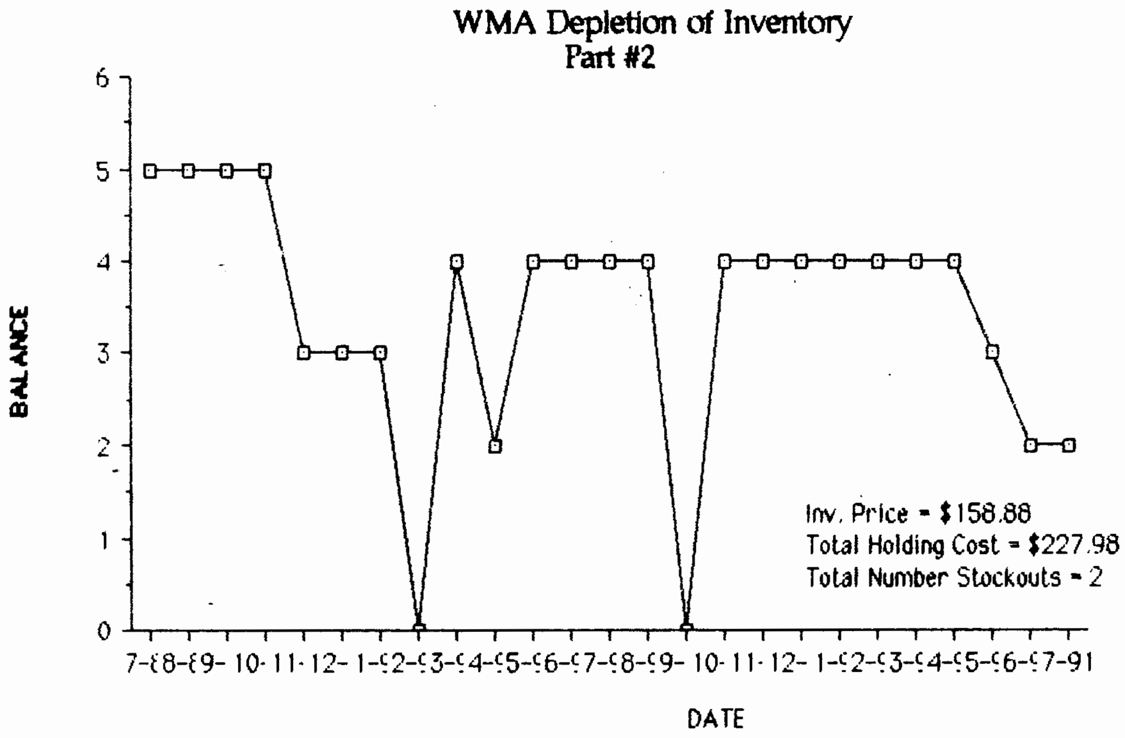
WMA Depletion of Inventory
Part # 1

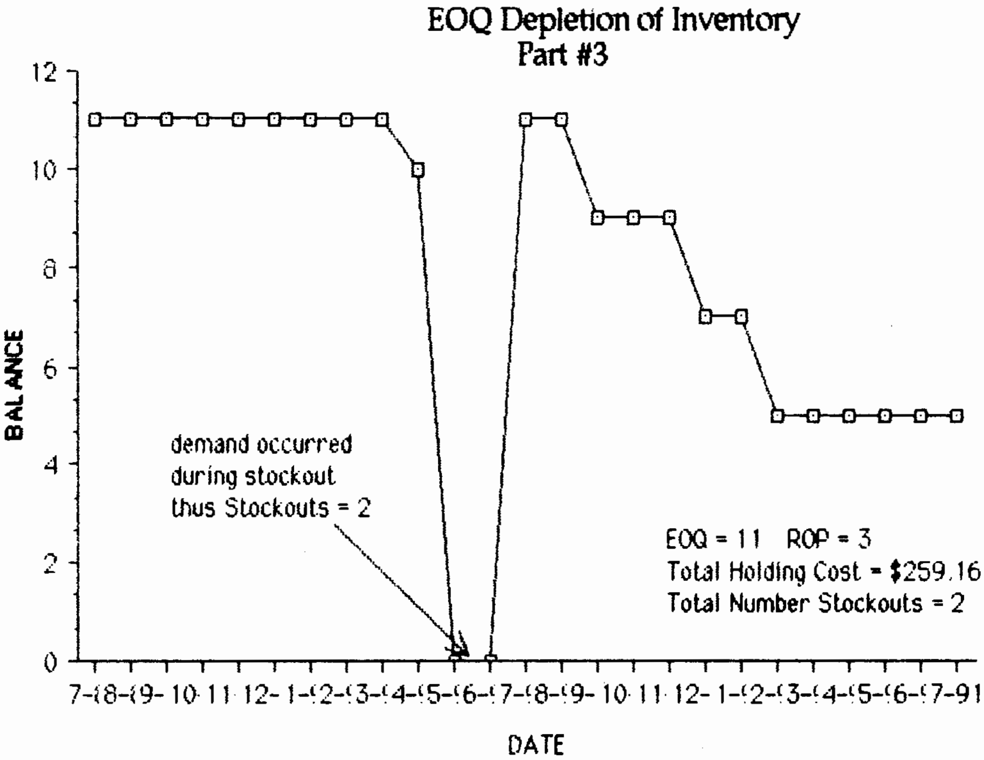


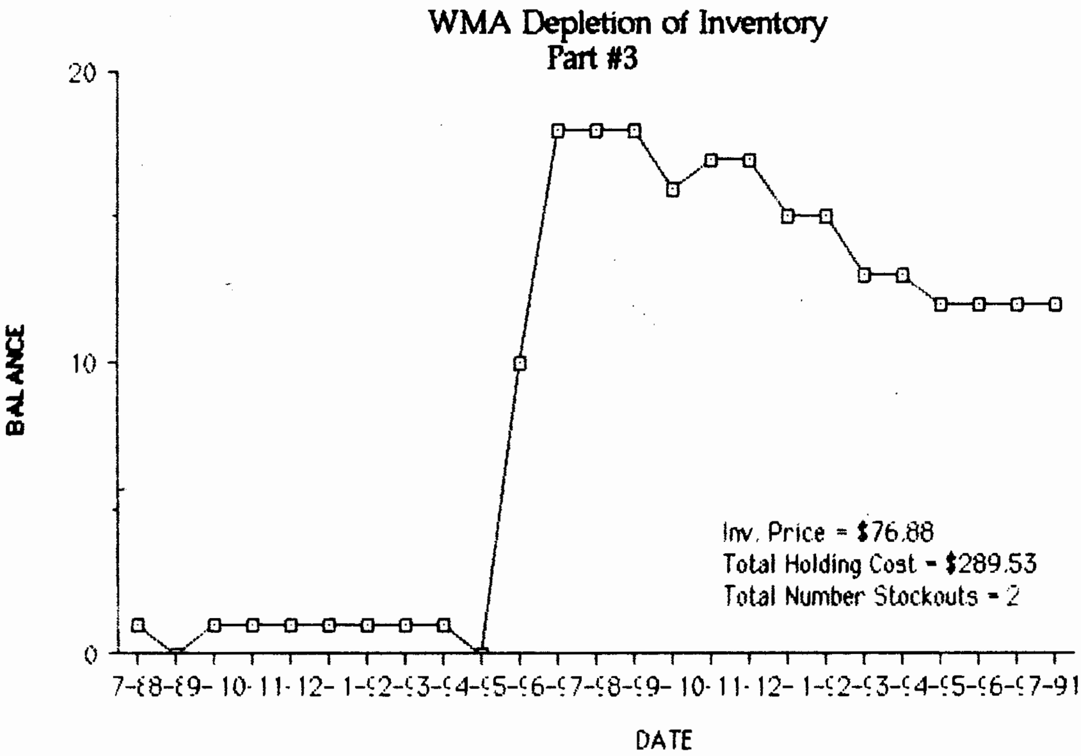

SIM Depletion of Inventory
Part #1
0.3
0.2
0.1
0.0
SIM HC
7-8-9-1C 11 12-1-2-3-4-5-6-7-8-9-1C 11 12-1-2-3-4-5-6-7-91
DATE
SIM HC


SIM Depletion of Inventory
Part #2
4
3
2
1
0
SIM BAL
7-8-9-1C 11 12-1-2-3-4-5-6-7-8-9-1C 11 12-1-2-3-4-5-6-7-91
DATE
SIM BAL

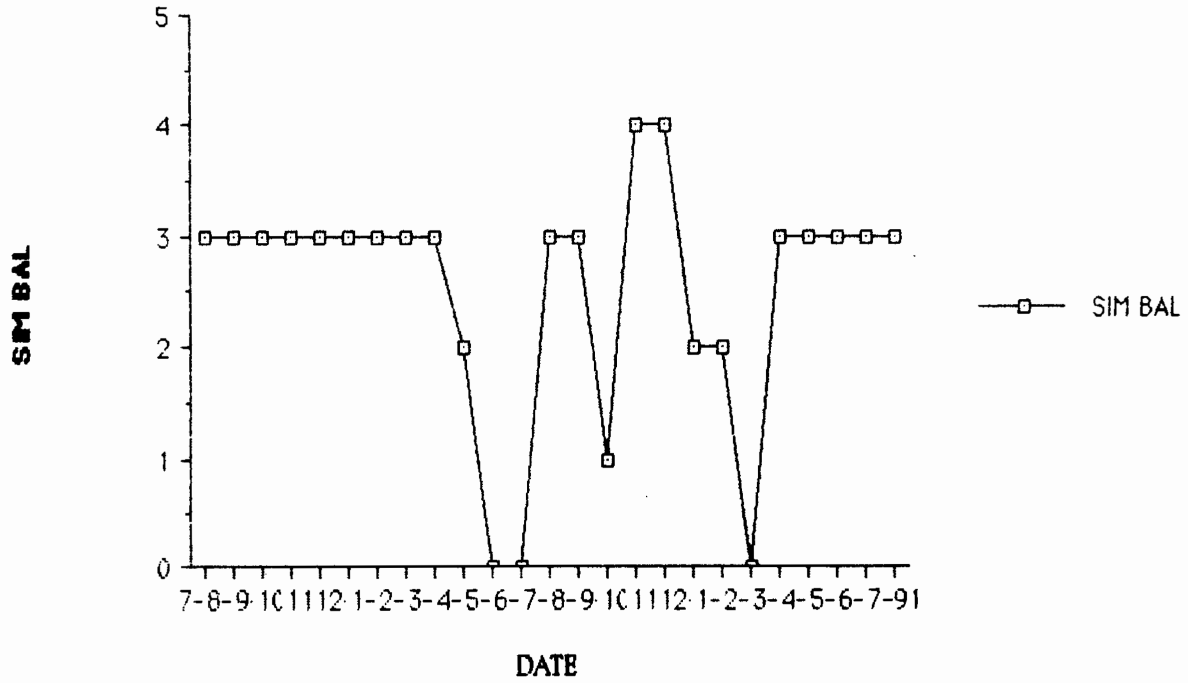

EOQ Depletion of Inventory
Part #2
demand occured
during stockout
thus Stockouts = 2
EOQ = 5 ROP = 1
Total Holding Cost = $323.40
Total Number Stockouts = 2
BALANCE
DATE


WMA Depletion of Inventory
Part #2
Inv. Price = $158.88
Total Holding Cost = $227.98
Total Number Stockouts = 2
BALANCE
DATE

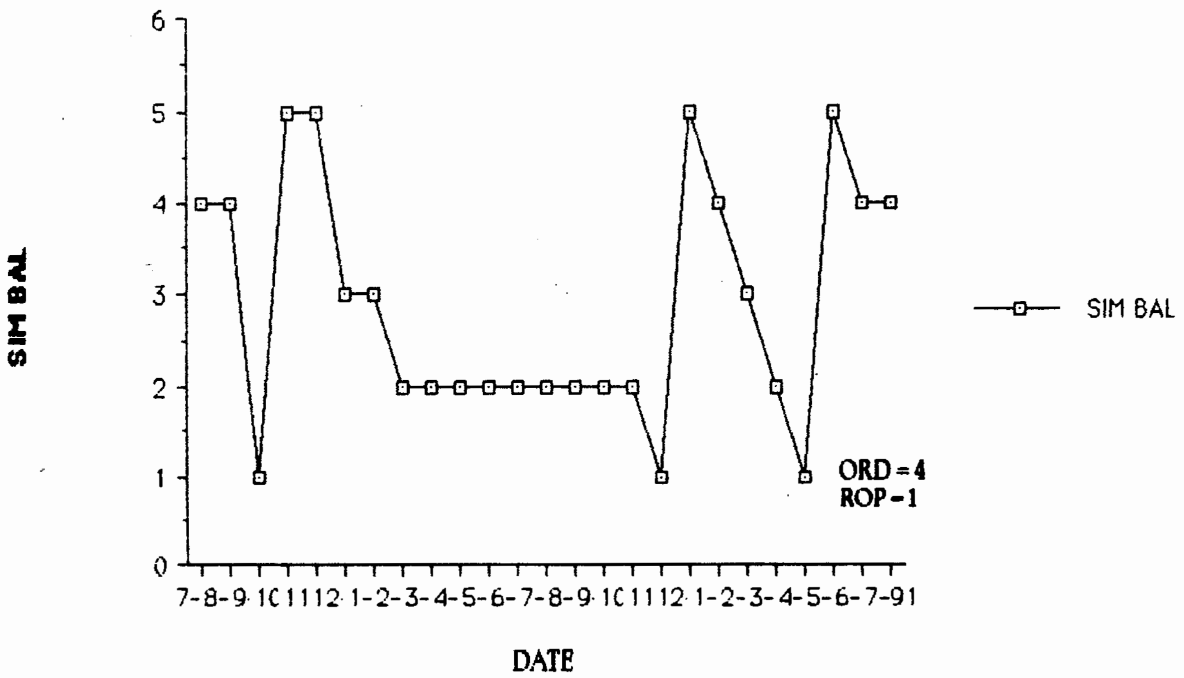

EOQ Depletion of Inventory
Part #3
BALANCE
12
10
8
6
4
2
0
demand occurred during stockout thus Stockouts = 2
EOQ = 11 ROP = 3
Total Holding Cost = $259.16
Total Number Stockouts = 2
DATE

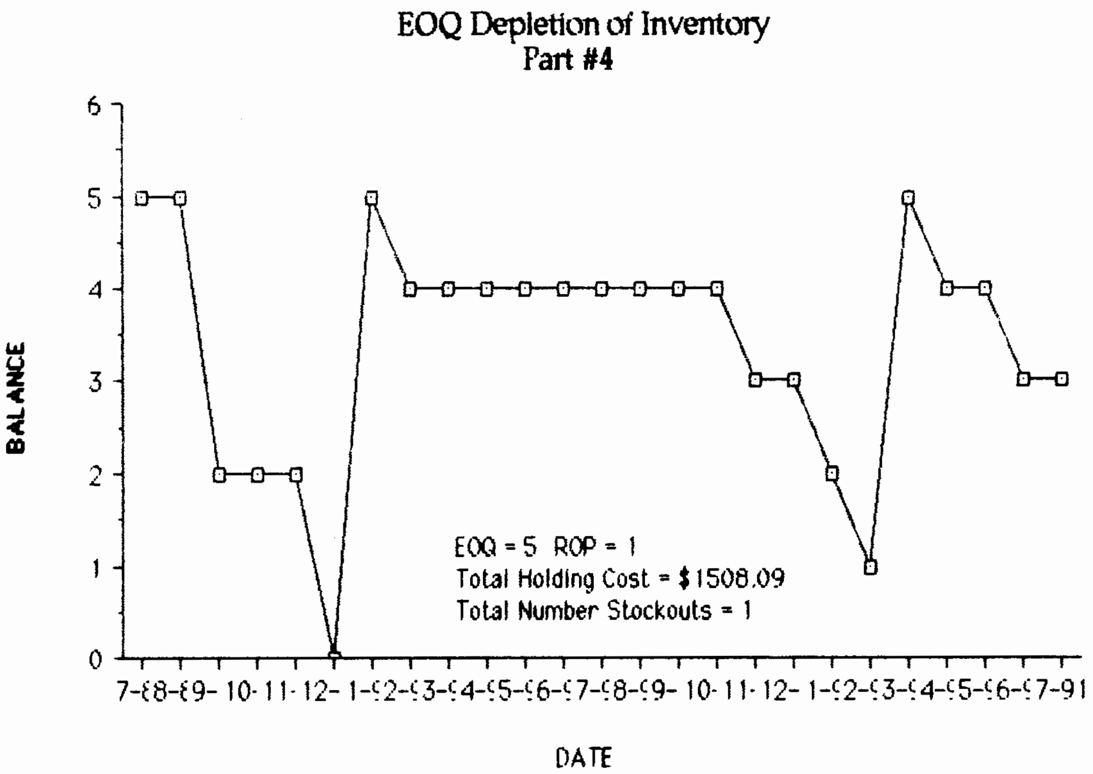

WMA Depletion of Inventory
Part #3
BALANCE
20
10
0
Inv. Price = $76.88
Total Holding Cost = $289.53
Total Number Stockouts = 2
DATE

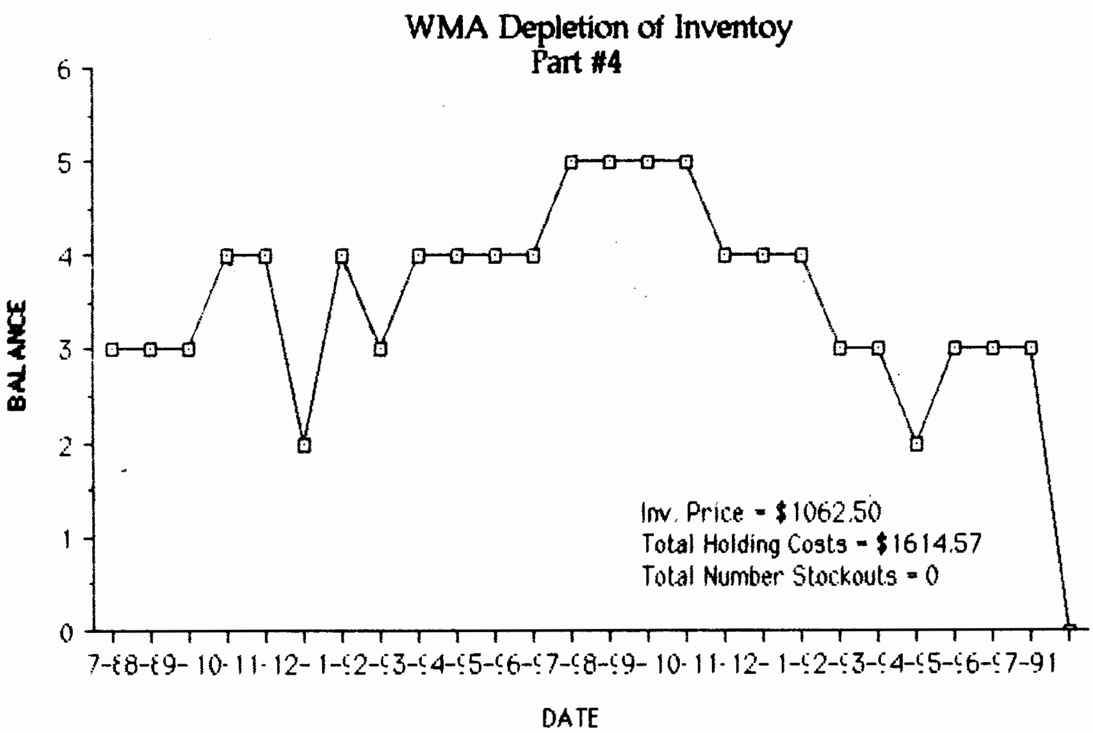
SIM Depletion of Inventory
Part #3



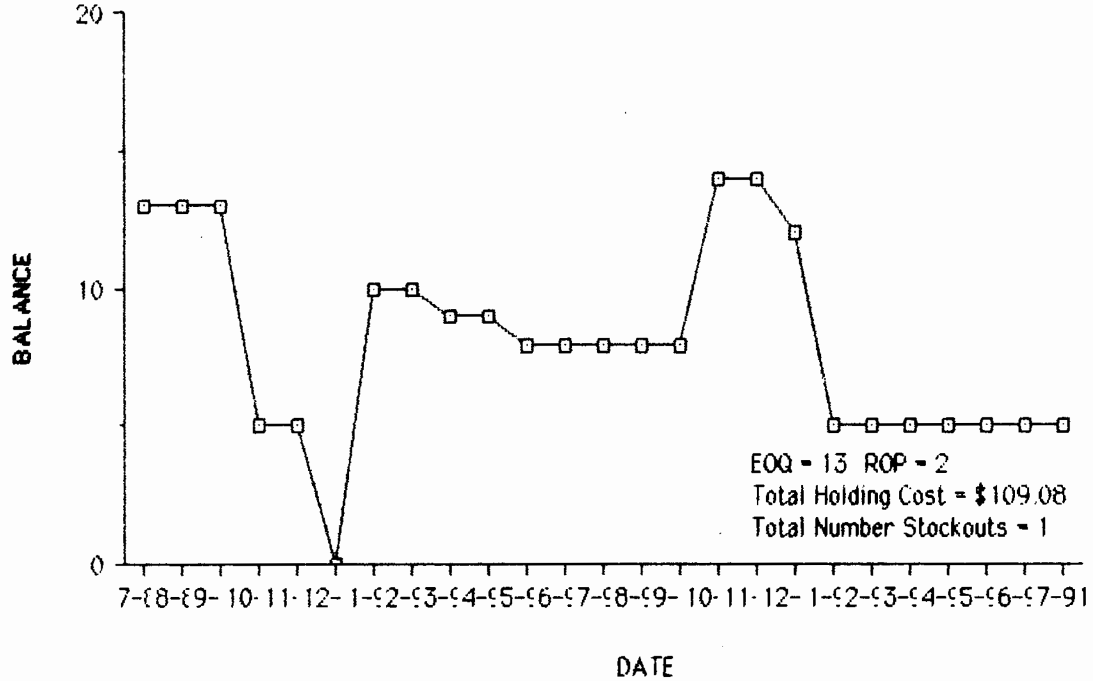
SIM Depletion of Inventory
Part #4



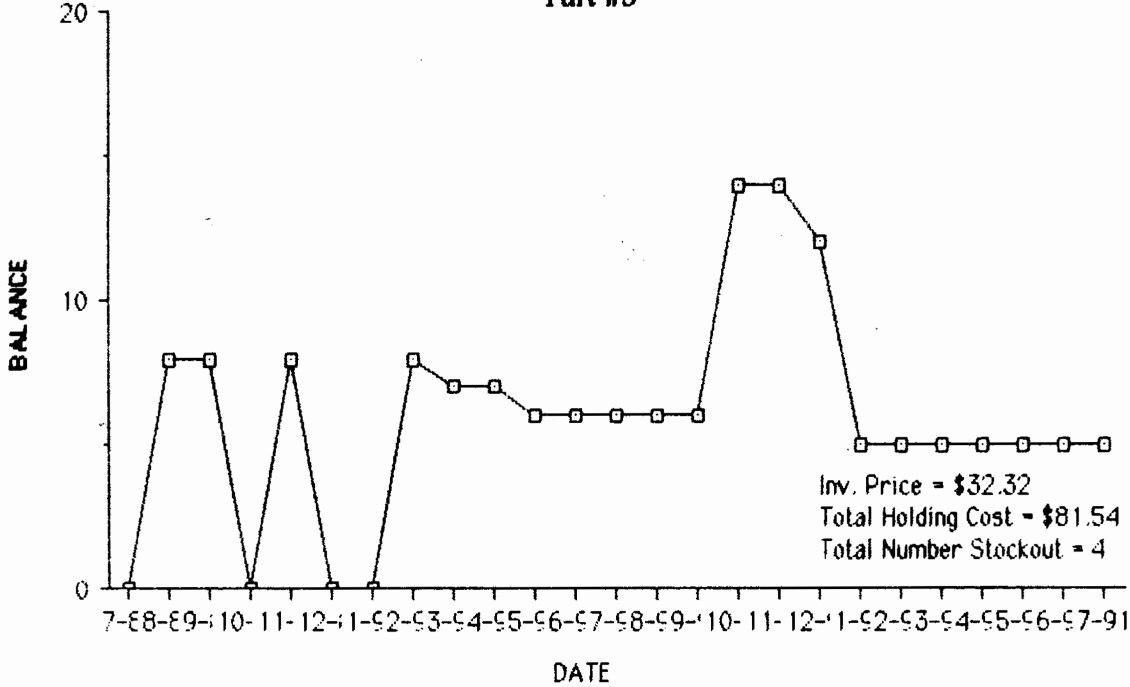

EOQ Depletion of Inventory
Part #4
BALANCE
6
5
4
3
2
1
0
EOQ = 5 ROP = 1
Total Holding Cost = $1508.09
Total Number Stockouts = 1
7-88-89- 10- 11- 12- 1-92-93-94-95-96-97-98-99- 10- 11- 12- 1-92-93-94-95-96-97-91
DATE


WMA Depletion of Inventoy
Part #4
BALANCE
6
5
4
3
2
1
0
Inv. Price = $1062.50
Total Holding Costs = $1614.57
Total Number Stockouts = 0
7-88-89- 10- 11- 12- 1-92-93-94-95-96-97-98-99- 10- 11- 12- 1-92-93-94-95-96-97-91
DATE

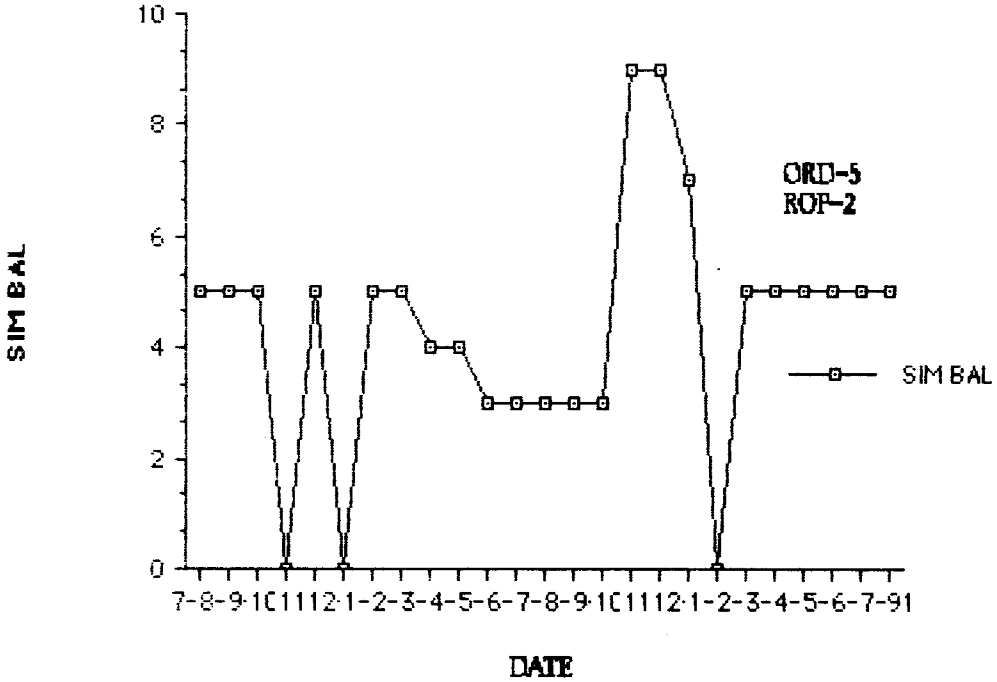
EOQ Depletion of Inventory
Part #5



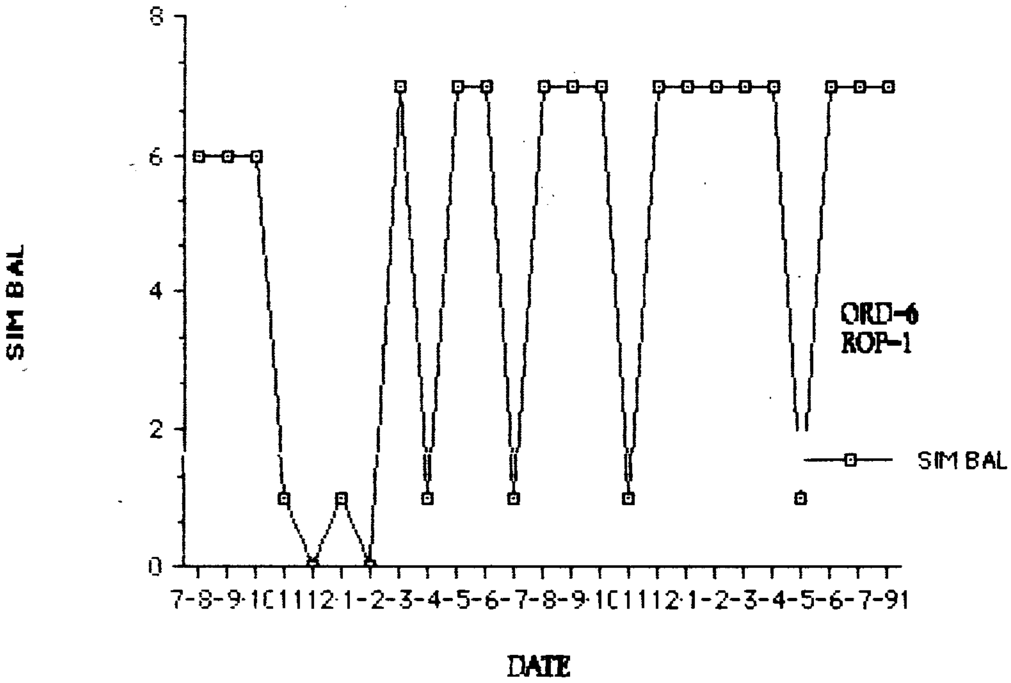
WMA Depletion of Inventory
Part #5



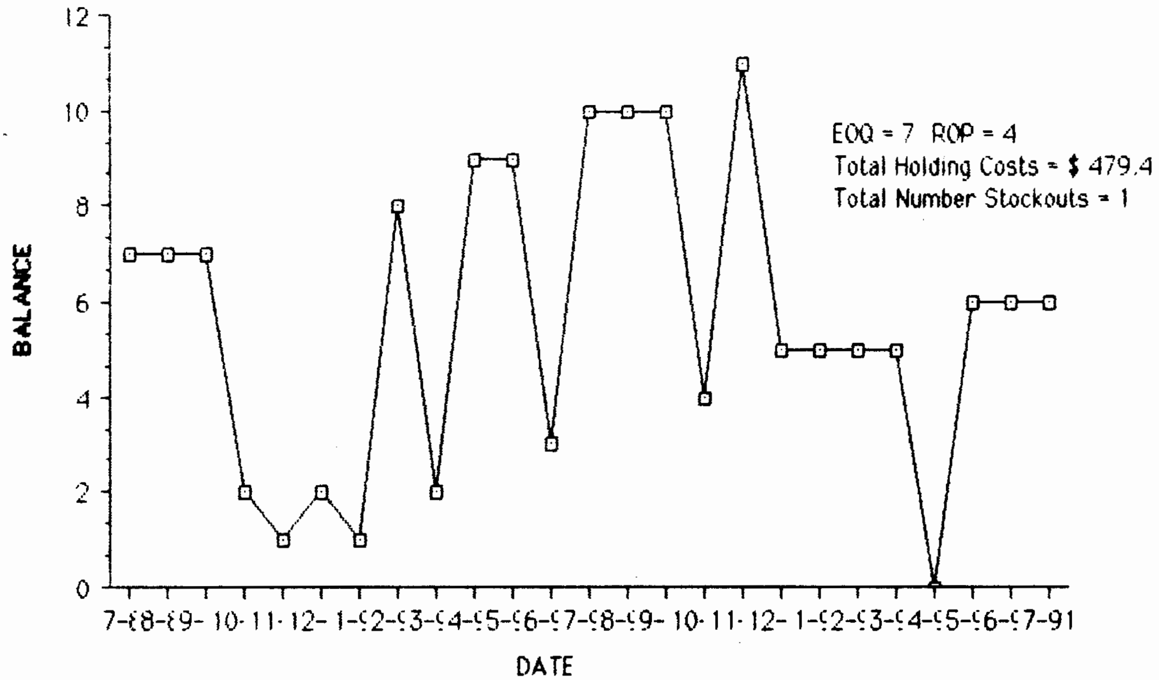
SIM Depletion of Inventory
Part #5



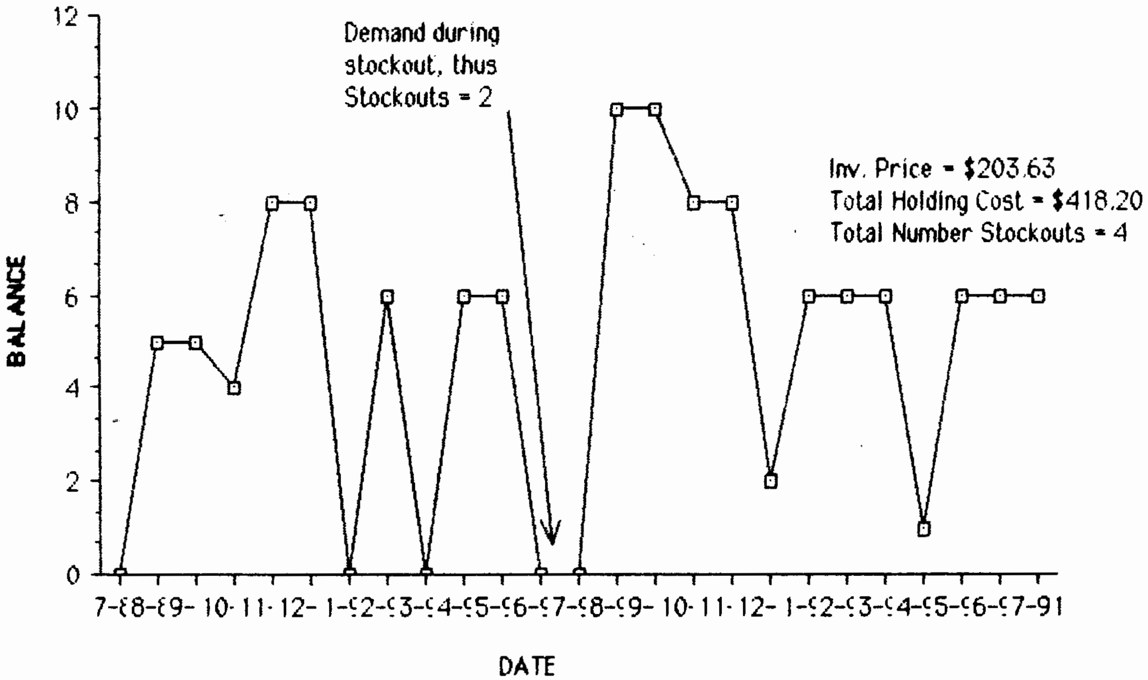
SIM Depletion of Inventory
Part #6

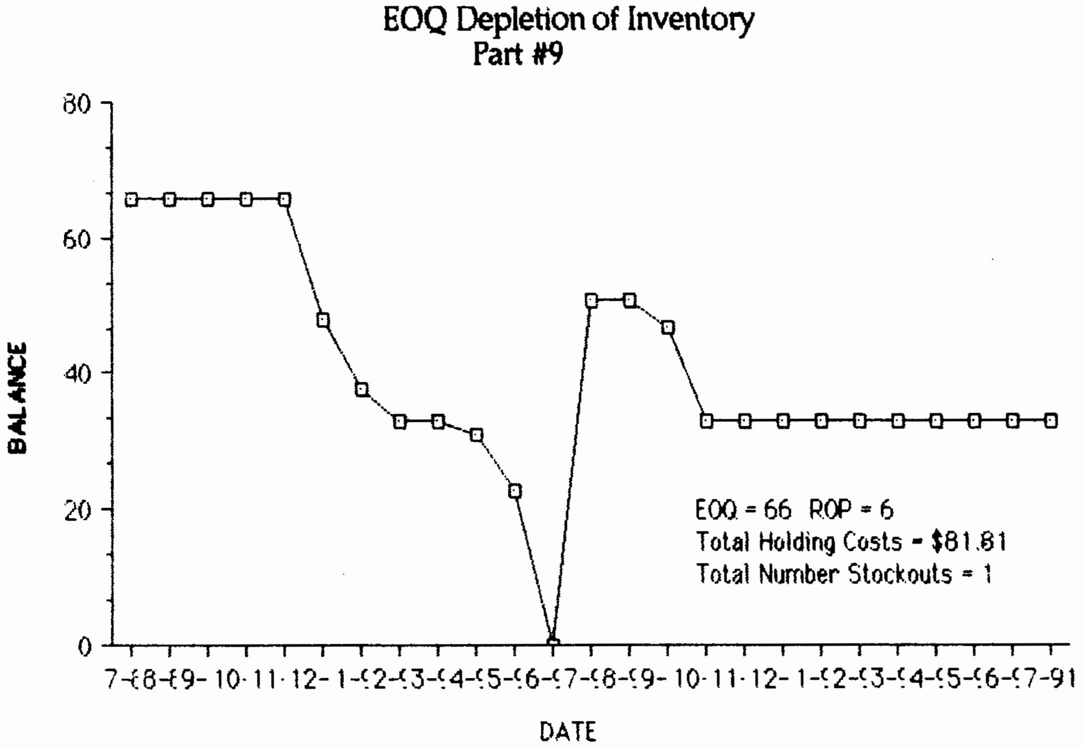


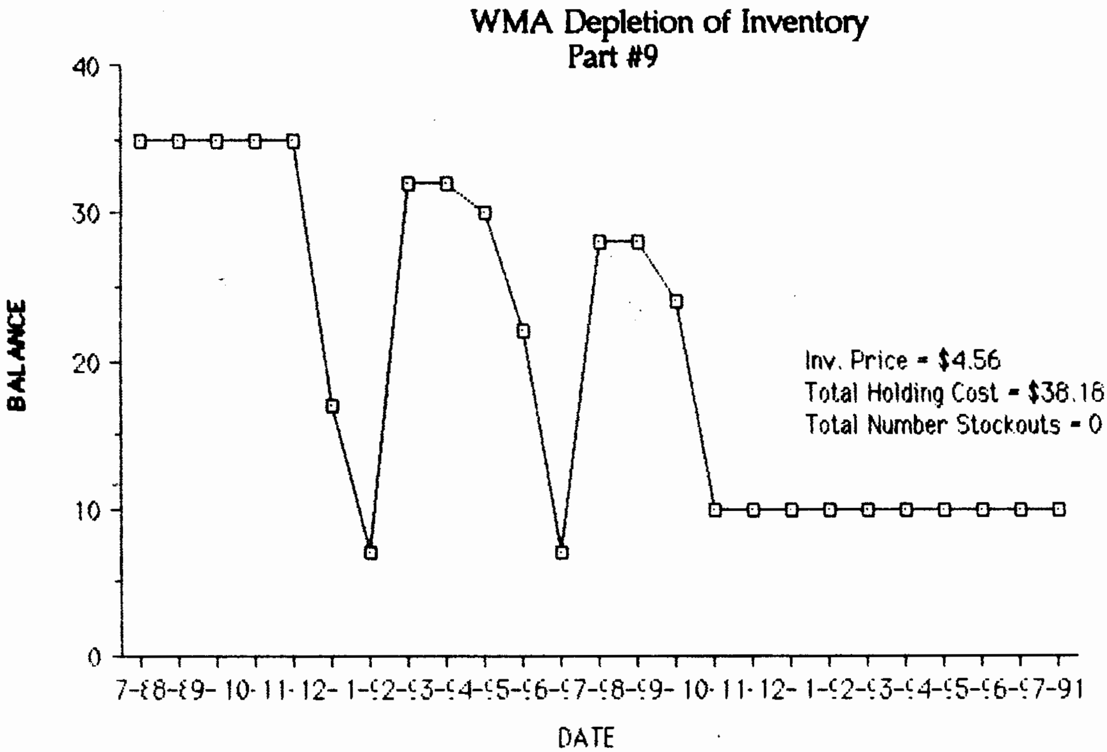
EOQ Depletion of Inventory
Part #6

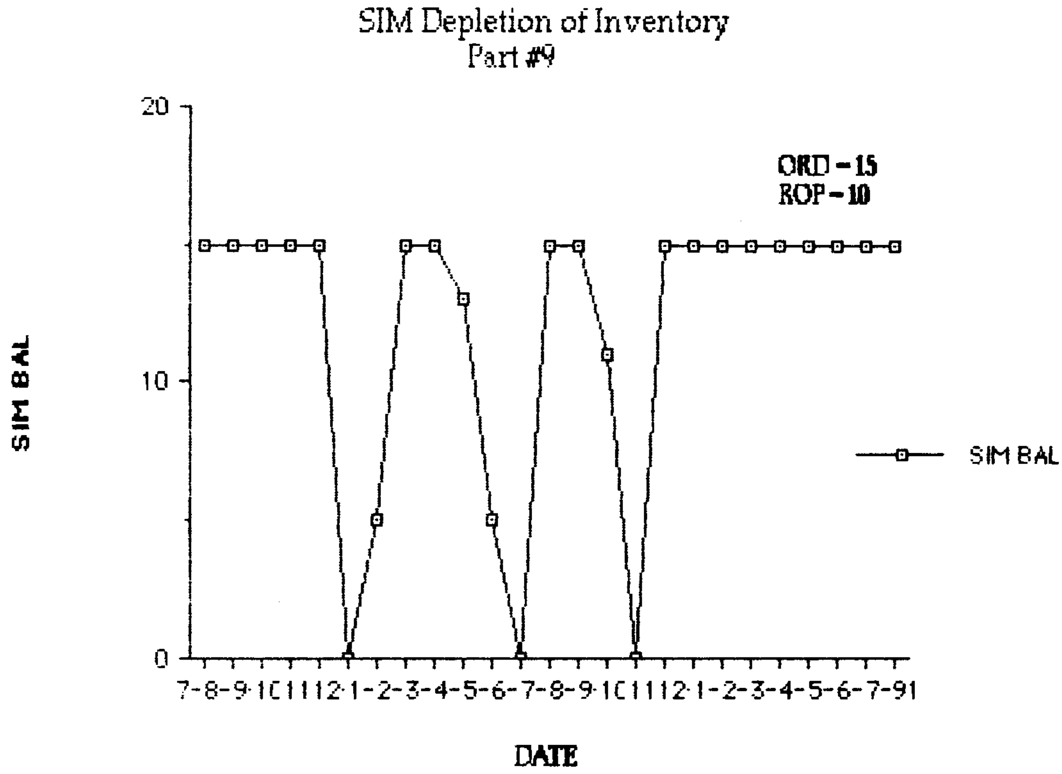


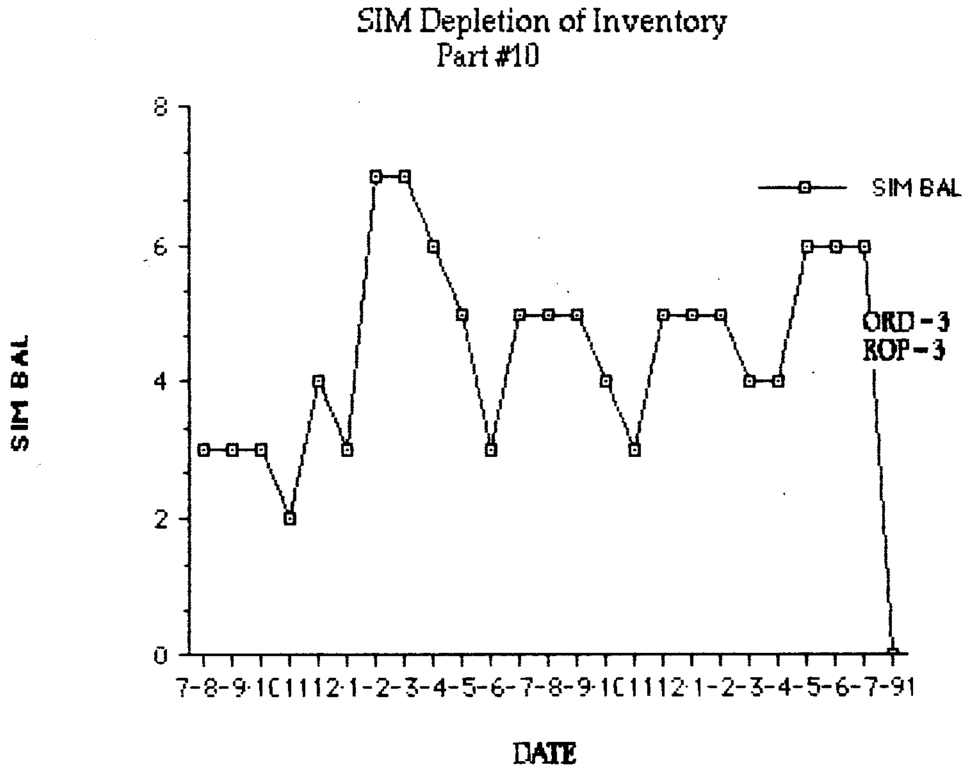
WMA Depletion of Inventory
Part #6



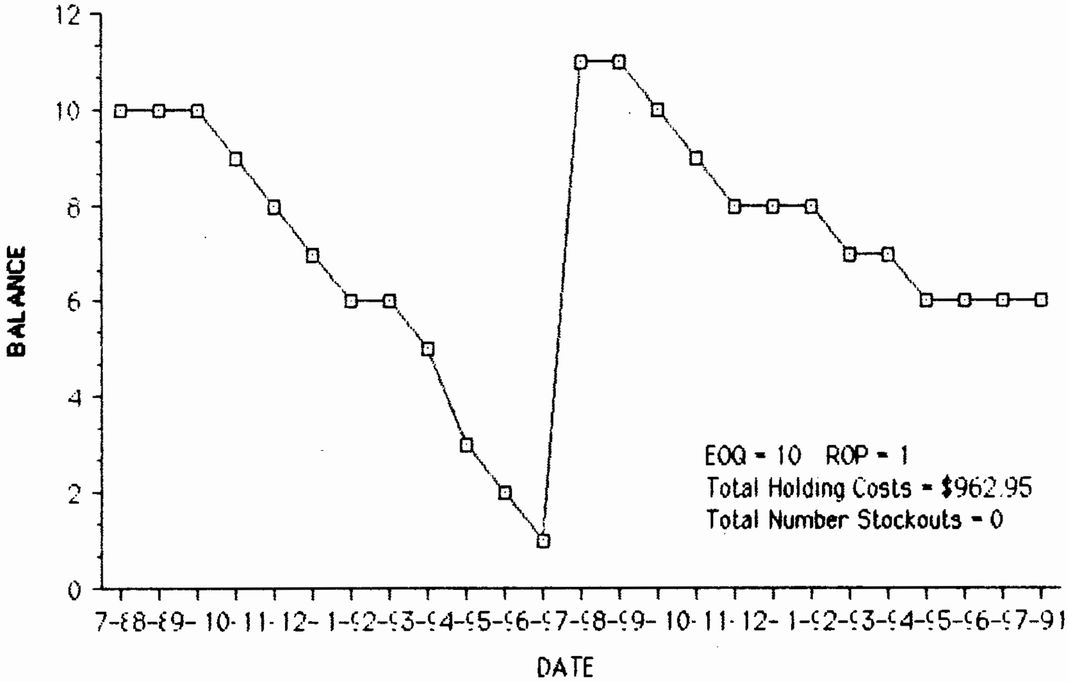

EOQ Depletion of Inventory
Part #9
BALANCE
80
60
40
20
0
7-{8-{9- 10- 11- 12- 1-{2-{3-{4-{5-{6-{7-{8-{9- 10- 11- 12- 1-{2-{3-{4-{5-{6-{7-91
DATE
EOQ = 66 ROP = 6
Total Holding Costs = $81.81
Total Number Stockouts = 1


WMA Depletion of Inventory
Part #9
BALANCE
40
30
20
10
0
7-{8-{9- 10- 11- 12- 1-{2-{3-{4-{5-{6-{7-{8-{9- 10- 11- 12- 1-{2-{3-{4-{5-{6-{7-91
DATE
Inv. Price = $4.56
Total Holding Cost = $38.18
Total Number Stockouts = 0


SIM Depletion of Inventory
Part #9
20
10
0
SIM BAL
ORD - 15
ROP - 10
SIM BAL
7-8-9-10 11 12 1-2-3-4-5-6-7-8-9-10 11 12 1-2-3-4-5-6-7-91
DATE


SIM Depletion of Inventory
Part #10
8
6
4
2
0
SIM BAL
SIM BAL
ORD - 3
ROP - 3
7-8-9-10 11 12 1-2-3-4-5-6-7-8-9-10 11 12 1-2-3-4-5-6-7-91
DATE

EOQ Depletion of Inventory
Part #10



WMA Depletion of Inventory
Part #10