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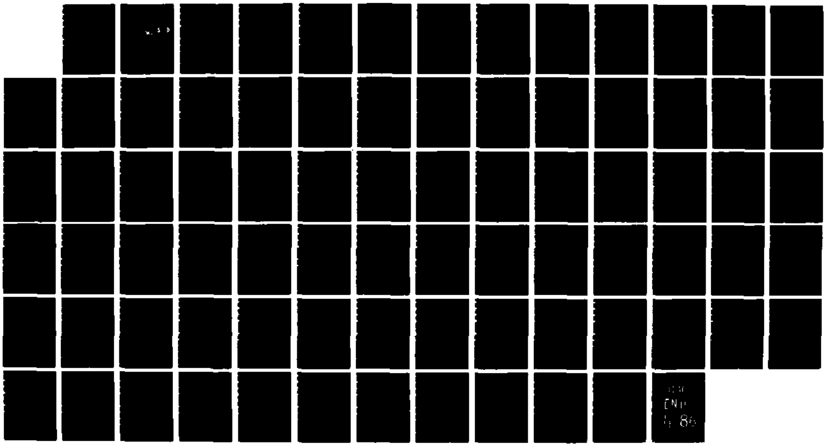

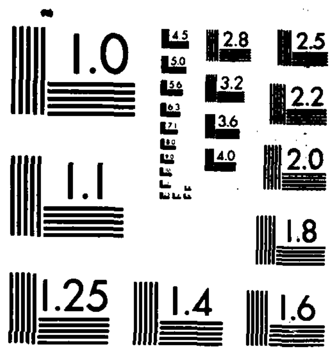

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

ANALYSIS
OF AN
AGGREGATE DEMAND REPAIRABLES MODEL

by

Richard B. Gormly

December 1985

Thesis Advisor: Alan W. McMasters

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Analysis of an Aggregate Demand Repairables Model

by

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requirements for the degree of

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ABSTRACT

This thesis develops an aggregate demand inventory model for repairable items. It uses minimization of wholesale stock investment level as the objective function subject to a given mean supply response time (MSRT) goal. Also addressed are annual budget constraints encountered by Inventory Control Points (ICPs) as well as a constraint placed on the total wholesale investment level which is implied by ceilings on the Navy Stock Fund (NSF). Preliminary parametric analyses of the model showed that the wholesale stock investment levels increase at a decreasing rate as repair induction batch sizes are increased and attainable MSRT values decrease exponentially as investment levels increase.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. BACKGROUND

The Department of Defense, and specifically the Navy, is facing one of its greatest challenges. As increasing defense dollars are authorized and appropriated for both old and new weapon systems and their support, many in Congress and the general public are demanding that maximum measurable benefit be received from each dollar expended/invested. In particular, the military services are being asked to demonstrate an improvement in readiness and sustainability consistent with the increases in investment. These increases in investment have come in many resource areas ranging from manpower to weapon systems.

One such resource area is the investment in spare parts which is required to ensure the operational readiness of the Navy. As increasingly complex weapon systems are introduced into the Navy, the availability of spare parts to support these systems becomes all the more critical. If complex and expensive systems are not operational when they are needed, then all funds invested in their research, development, production and introduction into the Navy will have been basically for naught. Therefore, the proper management of spare parts is of prime importance to the Navy in accomplishing its mission.

The rapid expansion the Navy has experienced in recent years combined with significant advances in technology have resulted in much more sophisticated equipment. This increase in sophistication has increased the complexity of the Navy Supply System's efforts to maintain sufficient stocks of replacement components and repair parts. In particular, more and more attention is being focused on the management of depot-level repairable spare parts. Items designated as depot-level repairables or DLRs are those items which must be removed from their weapon system and returned to a designated overhaul point (DOP) for repair when they fail.

The uniqueness of the military requires that its objective in inventory management differ from that in the private sector. In the private sector the objective utilized in inventory models is cost minimization due to the profit motive of private firms. However, in the Navy, the Chief of Naval Operations (CNO) has directed that Supply Material Availability (SMA) be the measure of effectiveness at the wholesale level [Ref. 1]. The wholesale level contains back-up inventories which may be requisitioned by any customer worldwide.

Although SMA has been specified as the measure of effectiveness, the Navy Inventory Control Points (ICPs) which are assigned responsibility for wholesale management of repairable items continue to use inventory models based primarily on cost minimization and relate SMA to backorder cost. This is a consequence of the DOD Instruction 4140.39, "Procurement Cycles and Safety Levels of Supply for Secondary Items" which specifies a consumable model of minimization of annual ordering and holding costs subject to a constraint on time-weighted, essentiality-weighted units short. No instruction has been written for repairables but the Navy assumes it would be of a comparable form. However, alternative objective functions can be considered which incorporate SMA or time-weighted units short. The recent wholesale initial provisioning model developed by Richards and McMasters [Ref. 2] and approved for Navy implementation in December 1984 had as its objective the minimization of mean supply response time (MSRT). MSRT is directly related to time-weighted units short. As a consequence, MSRT was also chosen by Apple as the objective function for replenishment of repairable items at the wholesale level [Ref. 3]. His model serves as a foundation for this thesis.

B. OBJECTIVES

Apple [Ref. 3] proposed an inventory model for management of repairable items at the wholesale level which is readiness - vice cost - oriented. However, the Navy cannot focus on readiness alone, because it must operate within various budgets which are authorized by Congress. These budgetary constraints, both annual procurement/repair budgets and long-term budgets implied by Congressional ceilings on the Navy Stock Fund (NSF), must be considered in any model designed for inventory management in the military. Therefore, the first objective of this thesis is to expand upon Apple's model by converting it to an aggregate-demand model for repairables management which seeks to minimize wholesale stock investment subject to budgetary constraints and a mean supply response time goal. The second objective is to conduct parametric analyses of the model to ascertain how it will perform under a variety of parametric changes.

C. PREVIEW

A brief discussion of the repairables system is provided in Chapter II. It is followed by a detailed review of the multi-echelon wholesale model proposed by Apple which has minimization of mean supply response time (MSRT) as its objective. Chapter III presents the conversion of the Apple multi-echelon model to an aggregate-demand model which can be used at the ICP level with the current UICP demand forecasting program. It also proposes minimization of wholesale stock investment levels as the objective. Finally, it formulates the annual budget constraints on procurement and repair which are encountered by the ICPs. The model developed in Chapter III is analyzed parametrically in Chapter IV and the results and conclusions of the analyses are discussed. Chapter V provides a brief summary and some final observations and recommendations of areas for further study of the aggregate-demand model.

II. MEAN SUPPLY RESPONSE TIME REPAIRABLES MODEL

A. THE REPAIRABLES SYSTEM

An item of supply is designated as a repairable if it can be repaired faster and/or less expensively than it can be procured. The management of repairables begins with the designation of an item as a repairable during Weapons System Acquisition and continues with the procurement process and the repair cycle. This complete management system is called the repairables system.

Repair is accomplished at one of three maintenance levels: (1) the organizational or lowest level (i.e., a ship); (2) the intermediate level (i.e., a tender, carrier, or a shore Intermediate Maintenance Activity); (3) the depot level (i.e., Naval Shipyard, Industrial Naval Air Rework Facility or a commercial repair activity). Figure 2.1 depicts the repair cycle for a depot level repairable (DLR).

The process begins when the ship or customer registers a demand for a DLR at the nearest stock point (NSC) (which is the point of entry). If the item is available directly from that NSC, it is issued to the customer. The demand for an item that is not available is referred to the inventory manager at the ICP (SPCC) who must either refer the requisition to another stock point holding the item or record the requisition as a backorder against stock that is due-in.

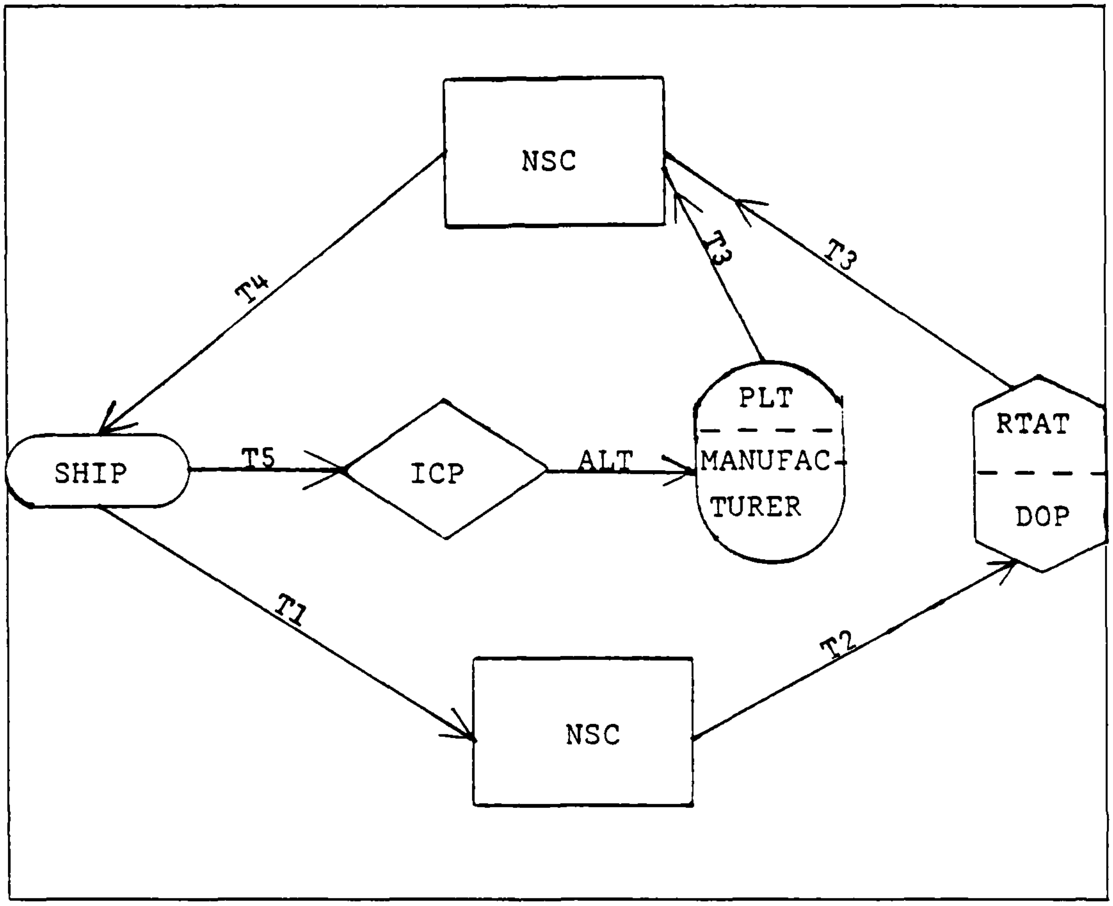


Figure 2.1 Repairables Cycle.

Once the demand for the repairable is satisfied, the inventory manager is concerned with the customer getting the not-ready-for-issue (NRFI) carcass into the repair cycle. The repair process for a DLR begins when the NRFI is shipped to a specified NSC where it is held until a predetermined quantity, R, (based upon existing inventory management policy) is available for induction to the Designated

Overhaul Point (DOP) for repair. Once repairs are complete, the DOP ships the ready-for-issue (RFI) unit to the NSC designated by the inventory manager.

Since there is some attrition of the repairables in this closed loop system due to items being lost or being beyond economic repair, the inventory manager must ensure that a fixed level of total units, SW (both RFI and NRFI), are available within the wholesale system. This is accomplished by procurring a quantity, Q, from a manufacturer whenever the wholesale system stock falls below a predetermined reorder point, ROP = SW - Q. The manufacturer ships these units to the NSCs as directed by the inventory manager.

Let the items defined below represent the average times it takes for the described events to occur:

T1: carcass turn-in time; i. e. the time it takes for a carcass to be received at the collection point (Naval Supply Center - NSC) after a demand has been registered (this includes shipboard turn-in time and shipping time);

T2: shipping time for a carcass from the NSC to the DOP;

T3: shipping time for an RFI unit from the DOP or a manufacturer to the NSC;

T4: shipping time for an RFI unit from the NSC to a ship;

T5: time required for the ICP to determine that a carcass will not be returned to the system;

RTAT: time required for the DOP to repair an item or a batch and return the batch to RFI condition.

ALT: administrative lead time required by the ICP to prepare a purchase order or contract and the ordering data to purchase a replacement item;

PLT: production lead time required by the manufacturer to manufacture the quantity of an item being purchased.

B. APPLE'S THESIS

Apple [Ref. 3] provides a detailed overview of the repairables system and its importance to the Department of Defense readiness, the roles of the Inventory Control Points (ICPs) in managing repairables, and a description of the mathematical models in use today for the management of repairables at one of the Navy's ICPs, the Ships Parts Control Center (SPCC). This is followed by a review of two multi-echelon inventory models developed specifically for the military: (1) the Multi-Echelon Technique for Recoverable Item Control (METRIC) developed by Rand Corporation in 1966 for the Air Force; and (2) the Availability Centered Inventory Model (ACIM) developed by CACI in 1981 for the Navy's use in determining consumer level stockage quantities for selected equipments. Both models recognize that the purpose of a supply system is to provide sufficient support so that a weapon system is operational when it is needed.

The objective of ACIM is to determine stock levels for all repair parts in the equipment in addition to the stock levels for the repairable item, while considering where each item should be stocked (i.e., what echelon), such that the Mean Supply Response Time is minimized subject to a given inventory budget. Mean Supply Response Time (MSRT) is the mean time it takes the supply system to respond to the demand for a replacement part or component. The current Navy supply-system goal is 125 hours for ships in CONUS and 135 hours for ships EXCONUS [Ref. 4: Ch. 4]. ACIM assumes a policy of one-for-one ordering between echelons and repairing at the wholesale level. Attrition is assumed to not occur. Finally, it should be noted that both the ACIM and METRIC models are extremely difficult to use because of the level of detail of the data and the long computational times.

The Apple Model is a multi-echelon model designed for the Navy's wholesale level of repairables and also focuses on Mean Supply Response Time, while including a specified protection level at the shipboard level as an input parameter. It shows that unless economic reasons dictate, the supply system should follow a one-for-one ordering policy for stock lost through attrition and should have a one-for-one repair policy also; i.e., no batching of procurements or repairs.

The protection level specified at the shipboard level consists of stocks of repairable components which are maintained on board to repair weapon systems while ships are deployed and without access to the wholesale supply system. By varying this protection level, Apple was able to identify situations where the Navy's MSRT goal could not be obtained because the shipboard protection level was inadequate.

The following are the assumptions applicable to his model:

1 failures are generated by a Poisson process;

2 ships use a one-for-one reorder policy for stock authorized on board;

3 the minimum protection level of spares is the same for all ships;

4 designated overhaul points (DOPs) are established for all items;

5 attrition of items, due to not being turned in or being beyond economic repair, is allowed;

6 repair batch size and procurement lot size are input parameters which are determined outside the model;

7 all demands for stock are satisfied by the wholesale system - no lateral resupply (i.e. no resupply between ships or NSCs); and

8 times used throughout are average times expressed in quarters.

Analyses of Apple's model showed that:

> the wholesale stock level of an item can be greatly affected by the repair and procurement policies in effect; i.e., a lower stock level is required, if one-for-one repair and procurement policies are used. Also, by reducing the repair time required for an item, the stock level can be reduced...and by increasing the shipboard stock level in our computations, the stock required by the wholesale system was greatly reduced.... [Ref. 3: p. 86]

C. TWO RESUPPLY CYCLES

Two resupply cycles exist in the U. S. Navy - the repair and the procurement cycles. Each is discussed separately.

The repair cycle resupplies the wholesale system by receiving not-ready-for issue (NRFI) carcasses from ships, inducting them into the repair cycles at a DOP, repairing the carcasses, and returning them to the wholesale system in a ready-for-issue (RFI) state. The times that affect the turnaround time in the repair cycle are: T1, T2, RTAT, T3, and any delay resulting from batching of repairs.

Utilizing Ross [Ref. 5: p. 152], Apple derives the average time added to the repair cycle, W(R), given that the repair batch size has been predetermined to be R. His formula is presented as equation 2.1 (Note: When batch size R equals 1, W(R) = 0.)

$$W(R) = (R-1)/(2*D*RSR*CRR), \qquad \text{(eqn 2.1)}$$

where: R: repair quantity;

D: quarterly total expected failure rate;

RSR: repair survival rate - rate at which NRFI carcasses survive the repair process and are returned to RFI condition;

CRR: carcass return rate - rate at which NRFI carcasses are returned to the wholesale system from the ship for induction into the repair process.

Combining all times that affect the turnaround time in the repair cycle, the mean length of the repair cycle (TT1) is:

$$TT1 = T1 + T2 + RTAT + T3 + W(R) \qquad \text{(eqn 2.2)}$$

or

$$TT1 = CRT + RTAT + ((R-1)/(2*D*RSR*CRR)), \qquad \text{(eqn 2.3)}$$

if we let CRT be the carcass return time (equal to the sum of T1 and T2).

The procurement cycle replenishes the wholesale system by procuring new items to replace those which have attrited. Attrition occurs in the system due to items not being turned in for repair or being beyond economic repair. The times that affect the mean procurement time in the procurement cycle are: T5, ALT, PLT, T3, and any delays resulting from the batching of attrited units to accumulate an economic order quantity before placing a procurement order.

Similar to the procedure used above for the repair cycle, Apple calculates the delay from accumulating attrited units into a batch size of Q before procuring to be:

$$W(Q) = (Q-1)/(2*D*(1-(RSR*CRR))). \qquad \text{(eqn 2.4)}$$

Again, note that when Q equals 1, W(Q) = 0. The mean length of the procurement cycle (TT2) is obtained by combining the pertinent time variables to obtain:

TT2 = T5 + ALT + PLT + T3 + W(Q) (eqn 2.5)

or

TT2 = PCLT+T5+((Q-1)/(2*D*(1-(RSR*CRR))) (eqn 2.6)

where: PCLT: procurement cycle lead time (equal to ALT + PLT + T3).

With both the mean repair cycle and the mean procurement cycle times known, Apple then develops the mean resupply time and the mean number of units in resupply.

The mean resupply cycle time is obtained by multiplying the mean length of the repair cycle (equation 2.3) by the probability that a failed unit can be returned to RFI condition through repair (RSR*CRR) and summing this with the product of the mean length of the procurement cycle (equation 2.6) and the probability that an item must be replaced through procurement (1-(RSR*CRR)). Thus, the equation for the mean resupply cycle time is:

MU = (RSR*CRR)*(CRT + RTAT + (eqn 2.7)
((R-1)/(2*D*RSR*CRR))) + (1-(RSR*CRR))
*(PCLT + T5 + (Q-1)/(2*D*(1-(RSR*CRR))))

The mean number of units of item i in resupply (μi) is simply the demand or failure rate (Di) times the mean resupply cycle time (equation 2.7) which yields:

$$\mu i = Di * MUi \qquad \text{(eqn 2.8)}$$

D. THE OBJECTIVE FUNCTION

The expected number of backorders at a randomly selected time is equivalent computationally to the total expected time-weighted units short (TWUS) per unit of time [Ref. 6: p. 185]. That is:

$$TWUSi(SWi) = (\mu i - SWi) + \sum_{xi=0}^{SWi-1} (SWi - xi) * pi(xi; \mu i). \qquad \text{(eqn 2.9)}$$

By dividing the TWUSi by the total expected failure rate, Di, Apple obtained the average delay per failure or the mean supply response time for item 'i'. Adding this to T4, which accounts for shipping time from the NSC to a given ship, gives the mean supply response time of the wholesale system for a given ship. This is expressed as:

$$MSRTi = T4 + MSRTRSi(SWi), \qquad \text{(eqn 2.10)}$$

where: MSRTRSi(SWi): mean supply response time for the resupply cycle (which is equivalent to TWUSi(SWi)/Di).

He then derives the average MSRT across all ships for item 'i' to be:

$$MSRTi(SWi) = \sum_{j=1}^{J} Bij(SSij, SWi; \theta ij)/Di, \qquad \text{(eqn 2.11)}$$

where: Bij: expected number of backorders for item 'i' at a random selected time for ship 'j';

SSij: ship stock level for item 'i';

θij: MSRTi*Dij is the mean demand at ship 'j' for item 'i' during an average resupply time and is a function of SWi;

SWi: Wholesale stock level of item 'i'; and

Di: $\sum_{j=1}^{J} Dij$.

MSRTi(SWi) is constrained to be no larger than the MSRT goal.

The average supply system MSRT over all items then becomes:

$$MSRT = \sum_{i=1}^{I} Di*MSRTi(SWi) / \sum_{i=1}^{I} Di. \qquad \text{(eqn 2.12)}$$

Through an iterative process, Apple's model can be used to add units of stock at the wholesale level until the MSRT reaches the specified MSRT goal.

The Navy consistently faces funding limitations which necessitate prioritization of requirements. This is accomplished by identifying weapon systems with respect to their criticality or essentiality. The Navy is able then to determine which items will reduce the difference between what is required and what is available given a budget while doing the least amount of damage to the established MSRT goal. Apple incorporated this concept of essentiality in his model and then stated the problem as:

$$\text{Minimize: } \sum_{i=1}^{I} Ei*Di*MSRTi(SWi)$$

$$\text{Subject to: } \sum_{i=1}^{I} Ci*SWi \leq B,$$

where: Ei: Item Mission Essentiality Code associated with item "i"; [Ref. 4: p. 4-40]

Ci: procurement cost of item 'i';

B: total budget dollar constraint.

Although Apple's problem was presented as above, he actually had initially stated it as:

> The objective is to find the level of wholesale stock, SWi, (consisting of both RFI and NRFI assets) for each of the 'i' items in the supply system required either to minimize the MSRT subject to a budget constraint or to determine the minimum cost solution which attains a predetermined MSRT goal. [Ref. 3: p. 60]

Apple analyzed the former. The latter can be written as follows:

$$\text{Minimize:} \quad \sum_{i=1}^{I} Ci*SWi$$

$$\text{Subject to:} \quad \sum_{i=1}^{I} Ei*Di*MSRTi(SWi) / \sum_{i=1}^{I} Ei*Di \leq \text{MSRT goal}$$

This problem statement will be the basis for the aggregate demand model which will be developed in Chapter III and analyzed in Chapter IV.

The final step of Apple's thesis was to use marginal analysis in the selection of a wholesale stock level to meet a specified MSRT goal at the shipboard level for an example system consisting of one ship (or customer).

III. THE AGGREGATE DEMAND MODEL

This chapter will develop a conversion of Apple's model to an aggregate demand model which retains the same assumptions as outlined in Chapter II.

A. AGGREGATION OF DEMAND

The Navy's ICPs are concerned with managing the wholesale supply system based on an aggregate demand from many customers (i.e., many ships, shore stations, Foreign Military Sales, other branches of the Department of Defense, etc.). This aggregate demand is currently forecasted in the Uniform Inventory Control Programs (UICP), which are various computer programs that the Fleet Material Support Office (FMSO) has developed to provide the ICPs with scientific inventory management techniques. Since this capability is available, it is appropriate to utilize the forecasted aggregate demand as an estimate of Di. By using this aggregated data, the problems of obtaining customer level data, such as Apple's model requires, are avoided.

B. OBJECTIVE FUNCTION AND MSRT GOAL

If we follow the current UICP approach, we would set an MSRT goal for the supply system just as the current Supply Material Availability goal of 85% has been set by the Chief of Naval Operations. Selection of that goal implies a wholesale stock (SWi) level for each item (i) and its related monetary value or investment level in the system. Summing these investment levels, we get:

$$\sum_{i=1}^{I} Cli*SWi$$

where: Cli: unit procurement cost or price.

Ideally, it would be nice to always possess the resources necessary to achieve the lowest possible MSRT (i.e. zero, where all items are always immediately available). However, in reality, the Navy has funding limitations that restrict the size of the Navy Stock Fund (NSF). The NSF is a revolving fund managed by the Naval Supply Systems Command and consists of money and/or stock. The stock fund is reimbursed by the customer when stock is issued and these funds are used to procure new items or to repair NRFI items to replace the inventory that has been issued. Therefore, a continual concern for the Navy is that investment in wholesale stock be minimized to achieve the established MSRT goal.

Because of our concern over the money tied up in investments, we would like to minimize it. Therefore, we can write our problem now as:

Find SWi which

$$\text{Minimizes:} \quad \sum_{i=1}^{I} Cli*SWi$$

$$\text{Subject to:} \quad \sum_{i=1}^{I} Di*Ei*MSRTi(SWi) / \sum_{i=1}^{I} Di*Ei \leq \text{MSRT Goal}$$

where: MSRTi(SWi): the mean supply response time for the wholesale system for item (i) when the wholesale stock level of item (i) is SWi.

C. ITEM MISSION ESSENTIALITY CODE

Recent analyses have developed a replacement for Ei known as the Item Mission Essentiality Code (IMEC). Each item (i) is categorized by this code which is a weighting factor to indicate that certain weapon systems are more critical than others. IMECs are defined in NAVSUP Publication 553 [Ref. 4: p. 4-40] as follows:

IMEC	Definition
4	Loss of primary mission capability
3	Severe degradation of a primary mission capability
2	Loss of a secondary mission capability
1	Minor mission impact

They were chosen to replace the Ei values for Apple's model. The problem with using these integer values, as Apple observed, is that an item with an IMEC of 4 is not necessarily twice as important as an item with an IMEC of 2. This problem can be overcome by establishing four separate MSRT goals to correspond to the four IMEC levels and by the deletion of the IMEC in the MSRT constraint.

The aggregate model will thus assume the separation of all items into IMEC categories and the assignment of an appropriate MSRT goal for each level (i.e. possibly 24 hours for IMEC 4; 72 hours for IMEC 3; 125 hours for IMEC 2; and 150 hours for IMEC 1).

D. THE AGGREGATE MODEL SOLUTION

Our problem now is to find SWi for all i = 1,2,...,I, (having a given IMEC code) which

$$\text{Minimizes:} \quad \sum_{i=1}^{I} Cli*SWi$$

$$\text{Subject to:} \quad \sum_{i=1}^{I} Di*MSRTi(SWi) / \sum_{i=1}^{I} Di \leq \text{MSRT Goal.}$$

In order to compute the aggregate MSRTi(SWi) value corresponding to a given level of wholesale system stock, SWi, it is necessary to recall equation 2.10 from Chapter II:

$$MSRTi(SWi) = T4 + MSRTRSi(SWi) \qquad \text{(eqn 3.1)}$$

For simplification we will assume T4 to be zero since shipment of a RFI unit to a customer can be expected to take negligible time relative to RTAT and PCLT. Thus, the aggregate MSRTi may be rewritten as:

$$MSRTi(SWi) = TWUSi(SWi)/Di \qquad \text{(eqn 3.2)}$$

and the constraint is then

$$\sum_{i=1}^{I} TWUSi(SWi) / \sum_{i=1}^{I} Di \leq MSRT\ Goal. \qquad \text{(eqn 3.3)}$$

An iterative process can be utilized to search for each optimum SWi. The initial step in the solution of this problem is to obtain the mean number of units in resupply (μi) which was derived in Chapter II and resulted in equation 2.8. Expanded, this equation becomes equation 3.4 where the argument i has been surpressed for clarity.

$$\mu = D*((RSR*CRR)*(CRT + RTAT + ((R - 1)/(2*D*RSR*CRR))) + (1-(RSR*CRR)) *(PCLT+T5 + (Q-1)/(2*D*(1-(RSR*CRR))))) \qquad \text{(eqn 3.4)}$$

Values for all variables in equation 3.4 are available from forecasted and historical data maintained in the UICP files except for repair induction (R) and procurement (Q) quantities. These two variables are specified as a result of budgetary and policy considerations. For this model, both Q and R will equal 1 in the base model which is presented in Chapter IV and they will be allowed to vary in the subsequent parametric analyses.

Once μi is known, it is easy to calculate the total expected time-weighted units short (TWUS) per quarter for each item (presented in equation 2.9 and repeated here for convenience).

$$TWUSi(SWi) = (\mu i - SWi) + \sum_{xi=0}^{SWi-1} (SWi - xi)*Pi(xi; \mu i). \qquad \text{(eqn 3.5)}$$

We next calculate TWUSi for SWi = 0 for all items. We then combine the result with each item's forecasted demand, as shown in the left-hand side of inequality 3.3, to arrive at the system-wide MSRT that will be provided when SWi equals zero for all items. This calculated MSRT, denoted as CMSRT, is compared to our MSRT goal and, if CMSRT is less than or equal to MSRT, we stop with SWi being zero across all items.

If CMSRT when all SWi = 0 is greater than the MSRT goal, we implement a marginal analysis procedure to determine SWi. This procedure makes use of a weighting factor for each item of stock based upon cost and time-weighted units short. This expression is represented as:

$$WTi = C1i/(TWUS(SWi-1) - TWUS(SWi)). \qquad \text{(eqn 3.6)}$$

This ratio expresses the increase in investment cost of each item relative to the benefit in reduced response time derived from adding one additional unit of the item to the wholesale stock.

For each item being considered, we compute WTi assuming SWi = 1 and then add one unit to that item k for which WTk = $\min_{i} \{ WTi \}$. We again check to see if the MSRT goal is satisfied by computing the left-hand side of the constraint (inequality 3.3) and comparing it to the MSRT goal value. If the computed MSRT is greater than the MSRT goal, a new value of WTk is computed assuming SWk = 2 before comparing it with other WT values. Again, we select that item having the smallest WTi and increase its wholesale level by one unit. This process continues until the computed MSRT is less than or equal to the MSRT goal.

Finally, with all SWi values known from this last step of the marginal analysis procedure, the value of the objective function is computed by summing Cli*SWi over all items. This will provide approximately the minimum total investment required to meet the given MSRT goal.

The SWi values calculated by the model represent the maximum values of the inventory position. As demands occur the inventory position will decrease. When a repair induction is made, the inventory position for item i will be increased by the value of the expected successful regenerations (or Ri/RSRi). When the inventory position immediately after an induction reaches or falls below SWi - Qi, a procurement of Qi should be made. This will immediately return the inventory position to SWi.

E. PROCUREMENT AND REPAIR INDUCTION VALUES

The two variables playing significant roles in both this aggregate model and Apple's model are the procurement quantity Qi and the repair induction quantity Ri. Their values have a major impact upon the wholesale stock levels (SWi) required to achieve the specified MSRT goal. Therefore, a brief discussion concerning Qi and Ri and their relationship to the model and to existing budgetary practice in the Navy is appropriate prior to discussing the model analysis and results.

Apple considered a problem for making a one-time buy of SWi, given quantities of size Qi and Ri would be bought and inducted for repairs, respectively, whenever necessary. In reality, this may not be possible. The annual UICP budgets are designed to pay for procurements and repairs (rather than buying SWi), but the amounts received from Congress may not be sufficient to buy Qi and Ri whenever necessary. Thus a limited UICP budget imposes additional constraints on our problem. These are:

$$\sum_{i=1}^{I} (Cli * ni * Qi) \leq BP \text{ (procurement budget)}; \qquad \text{(eqn 3.7)}$$

$$\sum_{i=1}^{I} (C2i * mi * Ri) \leq BR \text{ (regeneration budget)} \qquad \text{(eqn 3.8)}$$

where: C1: unit procurement cost or price;

C2: unit repair cost;

n: number of procurement buys per year;

m: number of repair inductions per year;

The annual number of buys and the annual number of inductions would depend on the expected annual number of attritions and regenerations. Thus:

$$n = \text{Number of attritions}/Q \qquad \text{(eqn 3.9)}$$

and

$$m = \text{Number of regenerations}/R. \qquad \text{(eqn 3.10)}$$

When we introduce these expressions into the budget constraints above, we get:

$$\sum_{i=1}^{I} (C1i * \text{Number of i attritions}) \leq BP \qquad \text{(eqn 3.11)}$$

$$\sum_{i=1}^{I} (C2i * \text{Number of i regenerations}) \leq BR \qquad \text{(eqn 3.12)}$$

An implicit assumption of the Apple model is that the annual number of attritions can always be bought and the annual number of regenerations can always be funded. If BP and BR do not allow this, then the wholesale stocks cannot sustain the SWi levels and the MSRT provided by those levels.

The problem of a limited budget is currently handled by adjusting the reorder points of the current UICP models each year. In particular, the reorder points are lowered and result in postponement of buys and inductions when the budget constraints are severe. Thus, Qi and Ri are not necessarily always procured or inducted for repair "whenever necessary". Any new repairables model must therefore have provisions for handling these severe budget constraints.

The incorporation of the constraints, given by inequalities (3.11) and (3.12), into the aggregate model would make the model much more complex. Thus, this thesis will not attempt to solve this larger problem. Instead it will assume Qi and Ri to be given, derived perhaps from some initial optimization step. Once parametric analyses have been conducted and the impact of Qi and Ri are well understood, a methodology for optimization of the three constraint problem may become obvious.

IV. MODEL RESULTS AND PARAMETRIC ANALYSIS

This chapter begins with a brief description of the computer program developed for solving the aggregate demand model discussed in Chapter III. This description includes the characteristics of the input and output variables. The rest of the chapter is devoted to several parametric analyses.

A. COMPUTER PROGRAM

A flow chart of the solution procedure for the aggregate demand repairables model derived in Chapter III is provided in Appendix A. The procedure was programmed in FORTRAN and run with the WATFIV compiler on the IBM 3033 at the Naval Postgraduate School. Appendix B contains a listing of the program.

The program's input and output variables are detailed in Table I. As was mentioned in Chapter III, MSRT represents the mean supply response time goal of the wholesale system for a group of items having the same Item Material Essentiality Code (IMEC). As a consequence, there is no need to incorporate an essentiality weighting factor in any of the formulas used in this program. CMSRT is the computed mean supply response time for a given set of input variable values. Both CMSRT and MSRT are stated in days in the output.

TABLE I

VARIABLE DESCRIPTIONS

	Input Variables
N:	Number of line items
MSRT:	Mean Supply Response Time Goal (in quarters)
NIIN:	National Item Identification Number
ATT:	Carcass Attrition Rate (in number of units per quarter)
REG:	Carcass Regeneration Rate (in number of units per quarter)
RSR:	Carcass Repair Survival Rate (probability)
CRR:	Carcass Return Rate (probability)
CRT:	Carcass Return Time
RTAT:	Repair Turn Around Time
PCLT:	Procurement Cycle Lead Time
D:	Quarterly demand rate
Q:	Procurement size
R:	Repair induction size
C1:	Cost to procure one unit
C2:	Cost to repair one unit
	Output Variables
CMSRT:	Computed mean supply response time (in days)
MSRT:	Mean supply response time (in days)
SW:	Computed wholesale stock level
COSTSW:	Total investment cost per line item
INVEST:	Minimum total investment required over all line items

As with Apple's model, the probability distribution assumed for demand is the Poisson. For those items with a mean number of units in resupply (μi) greater than 20, a normal distribution with continuity corrections was used as an approximation.

B. PARAMETRIC ANALYSES

1. Base Case Data Set

The parametric analyses of the proposed aggregate demand model used a reference or base set of data to facilitate analytic comparison when input parameters were varied. The complexity of this model, with respect to the number of parameters, both for the system (i.e., R, Q, and MSRT values) and for each individual item (i.e., RTAT, CRR, CRT, RSR, PCLT, C1, and D), required that the base case also fix as many factors as feasible at common values across all items. In fact, all were so fixed except for the unit costs C1 and C2. In addition, the number of items was limited to two. The common input data values for the two items are provided in Appendix C.

The key system input variables in the model are the procurement and repair induction quantities, Q and R respectively, and the Mean Supply Response Time (MSRT) goal. Although Apple [Ref. 3] argued that the optimum values for Q and R are unity, larger values of Q and R are often necessary because of budgetary constraints. However, as a base case for reference, both Q and R are assumed to be unity.

The MSRT goal for the base case was 125 hours (or .0572 quarters) which is the same goal established for CONUS ships [Ref. 4], and discussed in Chapter II.

Thus, the base case consisted of a two-item population, with neither item batched for repair or procurement (i.e., R=Q=1). The only varying input parameters were the unit costs C1 and C2. For item one C1 was $10,000 and C2 was $5,000 and for item two C1 was $150,000 and C2 was $75,000.

For the base case, the minimum investment levels of wholesale stock were 33 and 27 units for items one and two, respectively. The total aggregate dollar investment was 4.38 million dollars. The computed system MSRT was 4.7224 days which was the closest the solution could come to the goal (5.2052 days) without exceeding it.

2. Effects of Varying Repair Induction Quantities

As discussed in the previous section the base case assumed no batching for repair or procurement. However, because a severe budget constraint may require batching, it is important to study the impact of batching. Although batching of both Q and R quantities is feasible, our analysis considers only the results of variations to the repair induction quantity, R. For our sample input data the model was insensitive to large changes in Q.

Table II provides, in matrix form, the results of thirty-six combinations of R for the two items, denoted by NIIN 1 and NIIN 2. For ease of discussion, each cell in the matrix is identified by (row,column). Contained within each cell are the quantities of wholesale stock (SW) calculated from the model assuming the specified R1 and R2 values and the established MSRT goal of 5.2052 days. The SW1 for NIIN 1 is in the upper right of each cell and SW2 for NIIN 2 is in the lower left. The base case results are found in cell (1,1).

The impact on investment level when the R2 quantities for NIIN 2 are held constant and the R1 values for NIIN 1 are allowed to vary from one to six can be seen by considering each row. The SW2 level for NIIN 2 remains constant for a specified R2 value, while the SW1 level for NIIN 1 increases from either 33 or 34 to a high of 36, as the batch size, R1 of NIIN 1, increases. This analysis suggests that in the aggregate demand model, as the R value for a single item increases, the investment level for that item either remains constant between cells or it increases by one unit. This is graphically depicted in Figure 4.1 and Figure 4.2. Note that Figure 4.1 corresponds to the odd values of R2, and Figure 4.2 corresponds to the even values. The differences between the two figures are addressed below.

The R2 analysis obtained similar results as the R1 analysis. The results of holding R1 values constant and allowing the R2 values to vary from one to six can be seen by considering each column. Figure 4.3 shows the stepwise behavior (it is the same for all R1 values).

An interesting interaction effect can be observed in column one, where the SW1 value alternated between 33 and 34

TABLE II

INVESTMENT LEVELS (SW1,SW2) AS A FUNCTION OF R1 AND R2

R2 \ R1	1	2	3	4	5	6
1	27 \ 33	27 \ 34	27 \ 35	27 \ 35	27 \ 36	27 \ 36
2	28 \ 34	28 \ 34	28 \ 35	28 \ 35	28 \ 36	28 \ 36
3	28 \ 33	28 \ 34	28 \ 35	28 \ 35	28 \ 36	28 \ 36
4	29 \ 34	29 \ 34	29 \ 35	29 \ 35	29 \ 36	29 \ 36
5	29 \ 33	29 \ 34	29 \ 35	29 \ 35	29 \ 36	29 \ 36
6	30 \ 34	30 \ 34	30 \ 35	30 \ 35	30 \ 36	30 \ 36

even though the R1 remained constant at one. The reason for this oscillation is not obvious and further study of this situation is needed.

Several other results are worthy of comment. First, Table III is a matrix presentation of the computed MSRT (in days) where the model terminated once the MSRT goal of 5.2052 days was achieved. These computed MSRT figures consistently remained constant across rows. This is attributed to the fact that the model stops increasing the investment level of SW1 when the computed time weighted units short (CTWUS) is either zero or so close to zero that NIIN 1 does not contribute any significant value to the numerator of equation 3.3 (used to calculate MSRT). The model then continues to add to the investment level of SW2 until the MSRT goal is achieved. Actually, it turned out that the normal approximation gave small negative values for CTWUS1. These continued to be used for the marginal analysis but the MSRT values were assumed to be zero as soon as CTWUS1 went negative. The reason for the normal approximation giving a negative CTWUS1 is not clear and needs to be studied further. Perhaps the break point for using the normal approximation should be much larger than the value of 20 assumed for the aggregate demand rate.

The column behavior of CMSRT is different from the row behavior. This is because the CTWUS for NIIN 2 does not reach a value near zero until R2 is much larger than six.

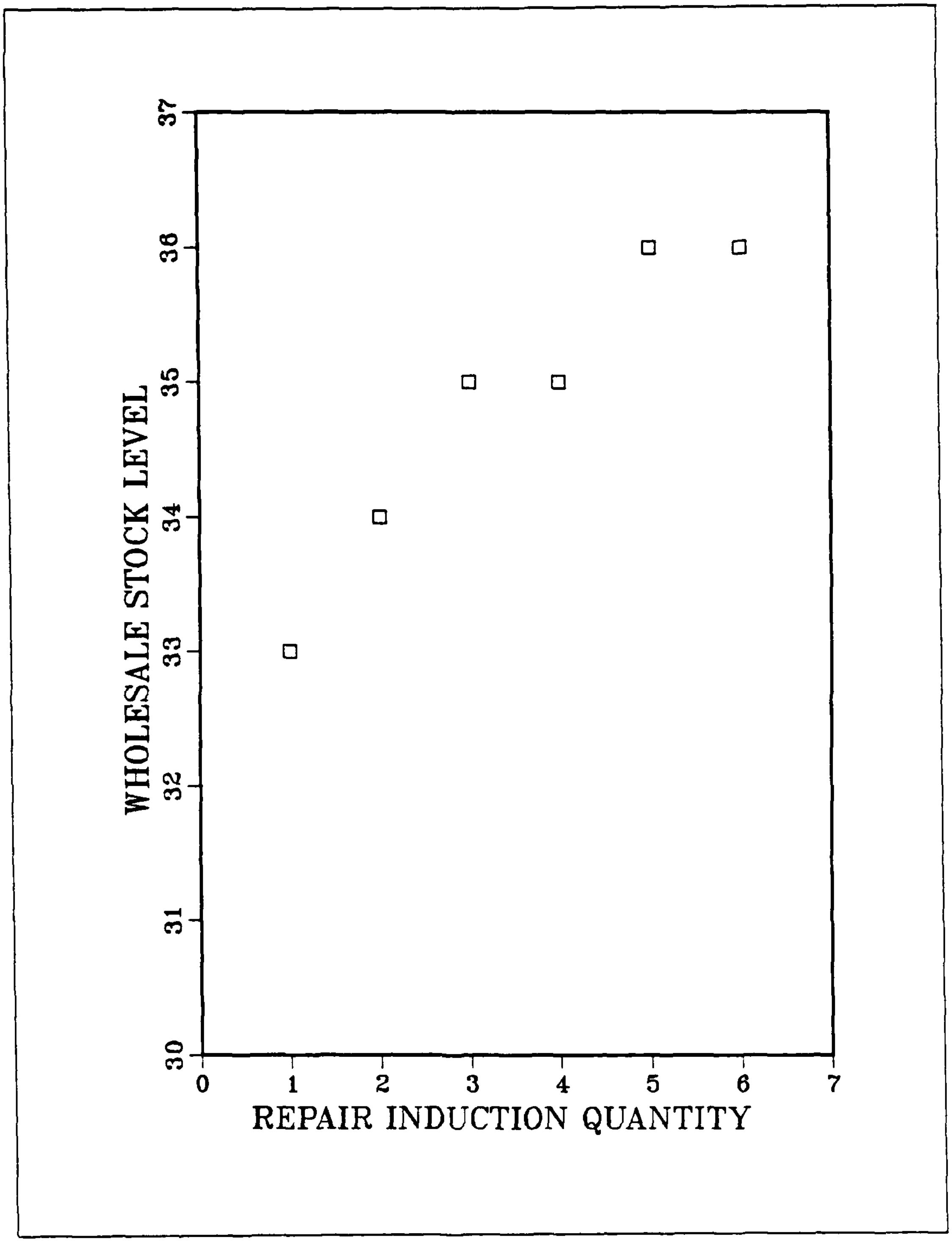


Figure 4.1 SW1 Sensitivity to R1 when R2 = 1.

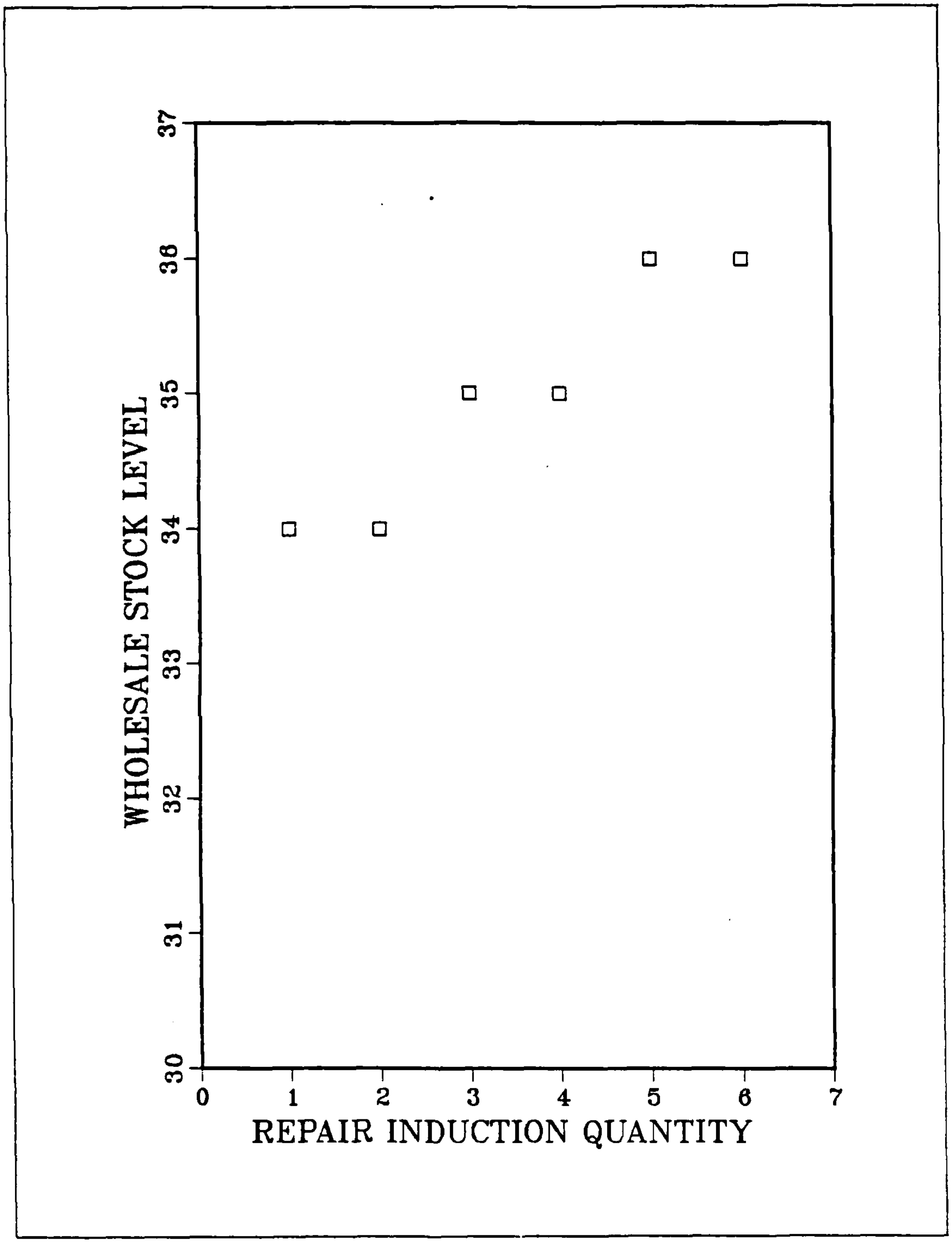


Figure 4.2   SW1 Sensitivity to R1 when R2 = 2.

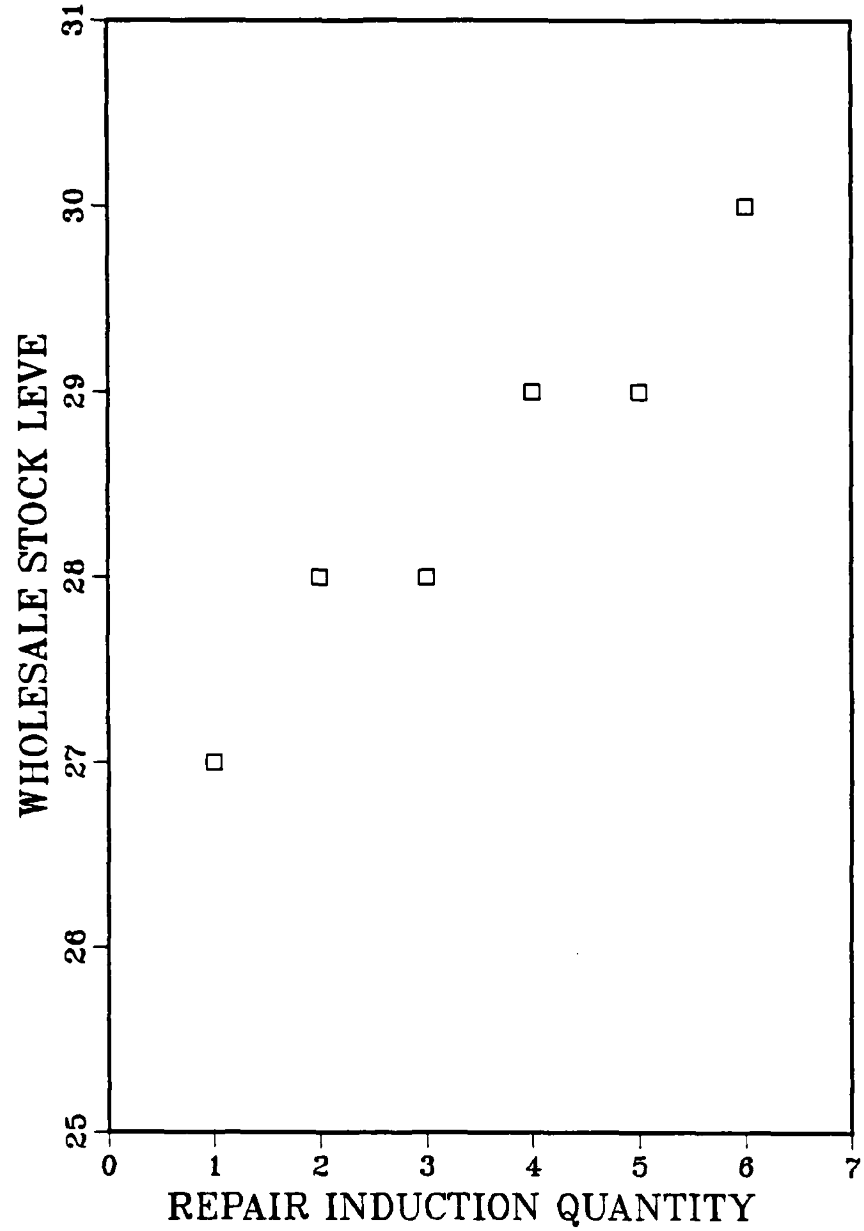


Figure 4.3 SW2 Sensitivity to R2 for $1 \leq R1 \leq 6$.

TABLE III

COMPUTED MSRT WITH REPAIR INDUCTION QUANTITY VARIED

		R1					
		1	2	3	4	5	6
R2	1	4.7224	4.7224	4.7224	4.7224	4.7224	4.7224
	2	3.9546	3.9546	3.9546	3.9546	3.9546	3.9546
	3	4.7980	4.7980	4.7980	4.7980	4.7980	4.7980
	4	4.0280	4.0280	4.0280	4.0280	4.0280	4.0280
	5	4.8559	4.8559	4.8559	4.8559	4.8559	4.8559
	6	4.0983	4.0983	4.0983	4.0983	4.0983	4.0983

Comparison of the matrices of Table II and Table III shows that two consecutive cells, in a column may have the same SW for their respective NIINs, but the computed MSRT (CMSRT) varies. An example of this occurs in cells (2,3) and (3,3), where SW1 and SW2 remain at 35 and 28, respectively, while the CMSRT in cell (2,3) is 3.9546 days and 4.7908 days in cell (3,3). The explanation for this rests with the manner in which the value of R2 contributes to the calculation of time weighted units short (CTWUS). As a result of R2 increasing by one unit the CTWUS for NIIN 2 is increased slightly, which, in turn, causes the CMSRT to increase. However, the increase in CMSRT is not large enough to exceed the MSRT goal. If the CMSRT had exceeded the MSRT goal, an additional unit of NIIN 2 would have been added to SW2 (This is what happens in cell (4,3)). The reason that no similar change is observed when we examine neighboring row cells is that CTWUS1 is essentially zero as discussed earlier.

The final observation with respect to these matrices is that the total investment level SW1 + SW2 along the main diagonal always increased between cells. This continues until both SW levels reach a point where any further additions would not provide any improvement to the calculated MSRT since each CTWUS would be zero. In this example, as discussed earlier, this level would be where SW1 and SW2 equaled 33 and 36 respectively.

3. <u>Wholesale Investment Stock Level Impact on MSRT</u>

Because the Mean Supply Response Time (MSRT) goal is one of the major system input parameters, we should also study the impact of changing this parameter. To accomplish this efficiently, two cells were selected arbitrarily from Table II (cells (1,6) and (6,1)), and the MSRT goal was set at zero days. Then one wholesale stock level (SW) was allowed to increase while the second SW was held fixed. With each addition to SW, a new CMSRT was computed and represents the attainable MSRT for that step. (The basic computer program for the model, presented in Appendix B, was modified to conduct this analysis. The modifications are provided in Appendix D).

Figure 4.4 shows the results for cell (1,6). This shows how CMSRT decreases as SW1 increases when R1 = 6, R2 = 1, and SW2 = 27. A similar result is obtained (Figure 4.5) when R1 = 1, R2 = 6, SW1 = 34, and SW2 is allowed to increase.

This analysis confirms an observation from the previous section that beyond a certain SW value for each item the computed time weighted units short (CTWUS) is essentially zero and additional investment in that SW will not result in an improvement in CMSRT. As a consequence, it seems appropriate to set a bound on each item's CMSRT so that further investments won't be made. Reference 2 found a bound of 0.001 days to be reasonable.

C. CONCLUSIONS

This chapter described the computer program used to compute optimal SWi and has presented preliminary parametric analyses of the aggregate demand repairables model proposed in Chapter III. Based upon this limited analysis, some conclusions may be drawn.

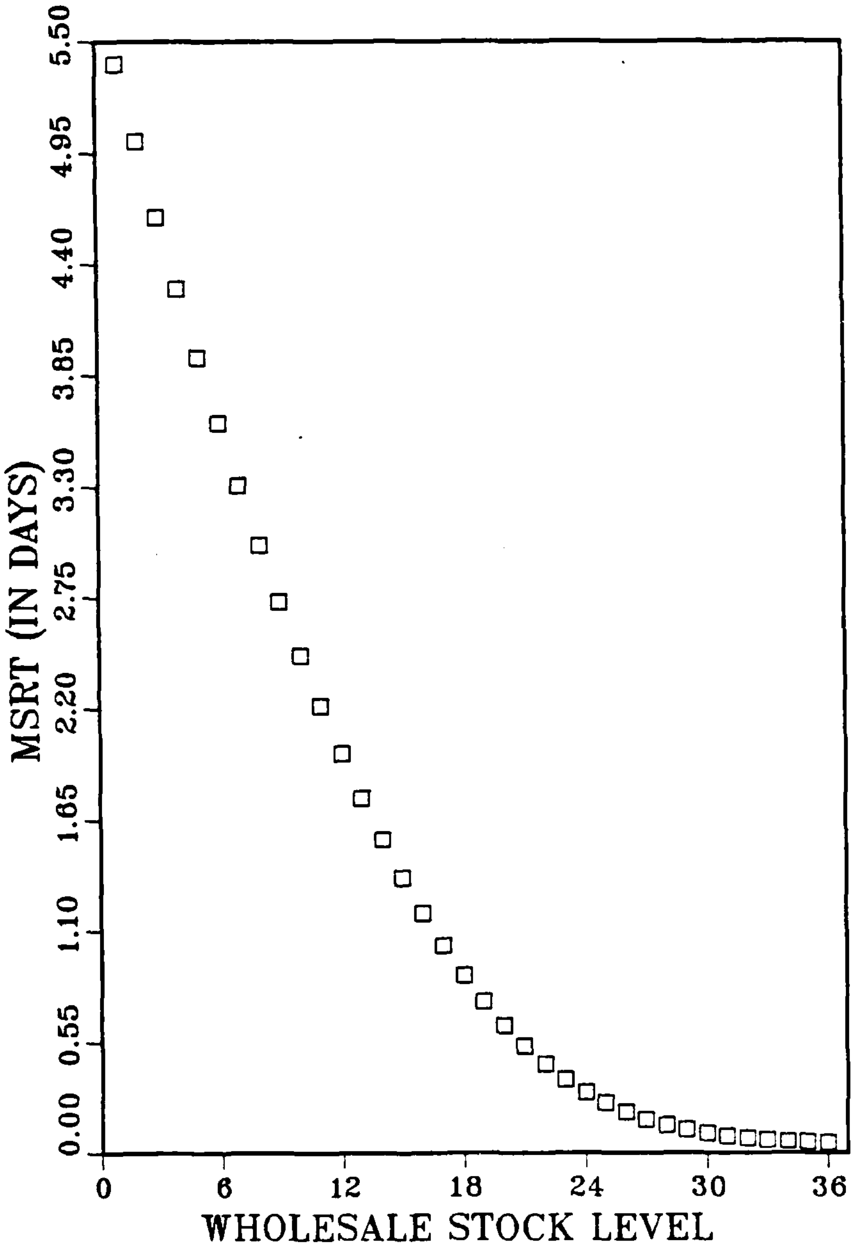


Figure 4.4 Sensitivity of Attained MSRT to Changes SW1 when R1 =6, R2 = 1, and SW2 = 27.

Although Apple showed that optimal Q and R are equal to one, we realize that the values of Q and R may not be able to be that small and may be larger than unity for some items because of severe budget constraints. Their values will depend on the relative unit costs of the various items.

The model also assumes that Q and R are bought and inducted, respectively, whenever necessary. This implies that annual procurement and repair budgets must be adequate to fund these procurements and repairs once Q and R are selected. If later years' budgets are less than that used to determine Q and R, then quantities of sizes Q and R cannot continue to be bought and repaired. Larger Q and R values are then needed so that the total annual buys and repairs cost less. The result is that a larger investment in wholesale stock levels and hence an increase in the stock fund ceiling will be required to achieve the established MSRT goal or the goal must be lowered.

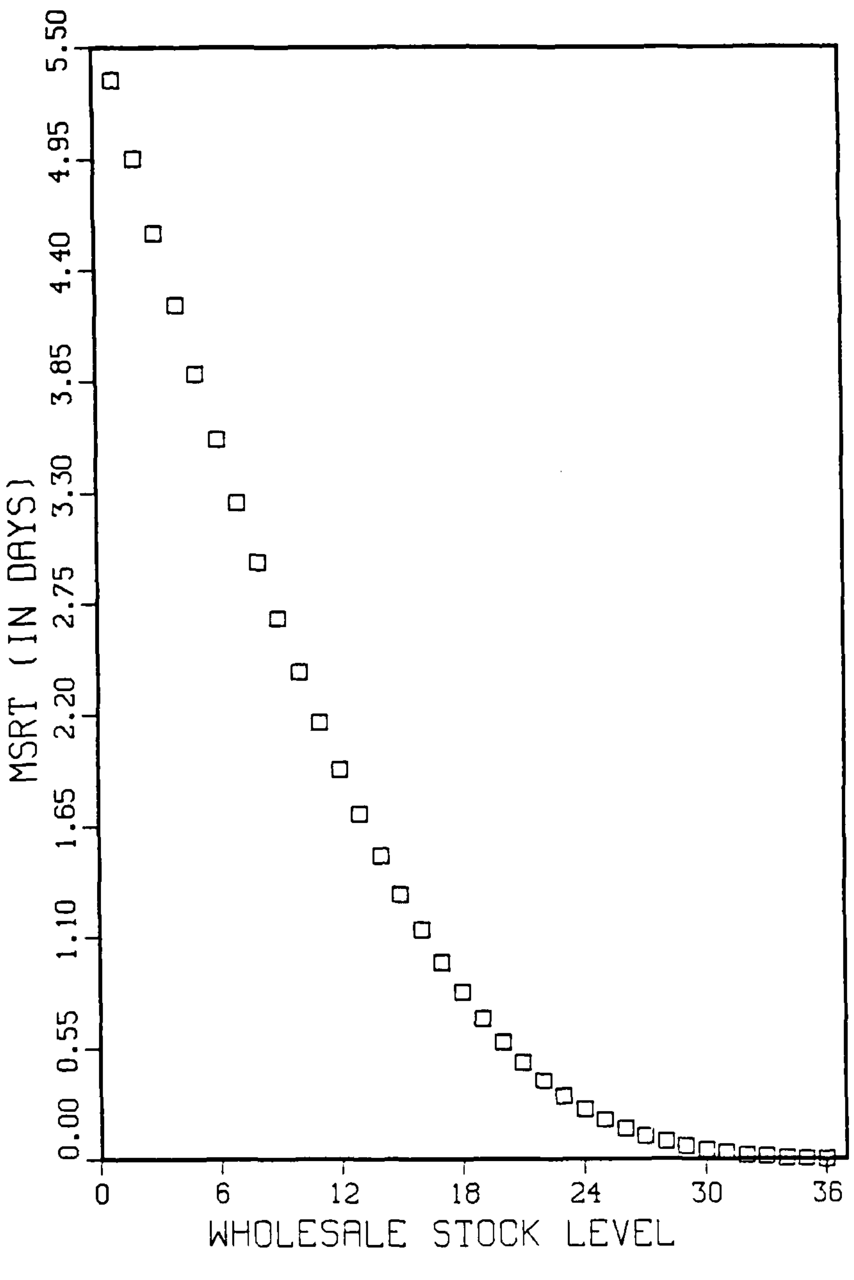


Figure 4.5 Sensitivity of Attained MSRT to Changes in SW2 when R1 = 1, R2 = 6, and SW2 = 34.

V. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

A brief overview of the repairables system was provided as an introduction to the review of Apple's thesis [Ref. 3] in Chapter II. His model is a performance and Navy oriented multi-echelon model using mean supply response time (MSRT) as an objective function. It incorporated considerations of both repair and procurement to sustain inventories at the wholesale and shipboard levels. It was identified as being less complex from a computational perspective than other performance oriented models (i.e., ACIM and METRIC). Nonetheless, it was clear from its development that many parameters must interact to obtain a solution to the problem of minimizing MSRT.

Chapter III used Apple's model as a foundation to develop an aggregate demand model which requires fewer parameters than Apple's and can use existing data from the UICP. The objective of this model was to minimize the wholesale stock level investment while attempting to achieve an established MSRT goal. By stating the model in this way, it is able to address both the issue of readiness, which is implied by the MSRT goal, and the Navy's concern over investment levels since they are directly related to the value of the Navy Stock Fund. The Navy must be continually aware of its position with respect to the Navy Stock Fund so that stock levels are not built up unnecessarily when it does not aid in achieving the desired MSRT goal.

Finally, grouping of items with the same IMEC and establishing individual MSRT goals for each IMEC category allowed the model to account for essentiality. Marginal analysis was proposed as the optimization technique for this model.

The last issues addressed in Chapter III were the annual procurement and repair budget constraints. It was noted that when these two constraints were added then marginal analysis could no longer be used for optimization. No alternative optimization technique has been developed as yet to solve this larger problem.

Chapter IV presented limited parametric analyses of the aggregate model for the case of two items and assumed identical values for most of the various item parameters. The procurement costs, repair costs, and repair quantities were allowed to differ. In particulular, the effect of varying the repair induction quantity was examined. The results showed that the required wholesale stock investment level had to be increased when the repair quantity is increased in order to achieve an established MSRT goal.

Chapter IV also showed that by holding all parameters constant and allowing one item's SW level to increase, the aggregate attained MSRT decreased exponentially. A point of diminishing return is reached such that continuing to increase an item's investment level results in inefficient use of resources. A lower bound on a given item's MSRT was proposed to prevent such inefficiency.

B. RECOMMENDATIONS

The most critical area requiring further research is how to incorporate the annual procurement and budget constraints into the model. Annual procurement and regeneration budgets typically change yearly. Implementation of the aggregate demand repairables model by an ICP requires that these varying budget constraints be accommodated. In addition, the impact of these constraints on attainable MSRT goals and investment levels must be understood.

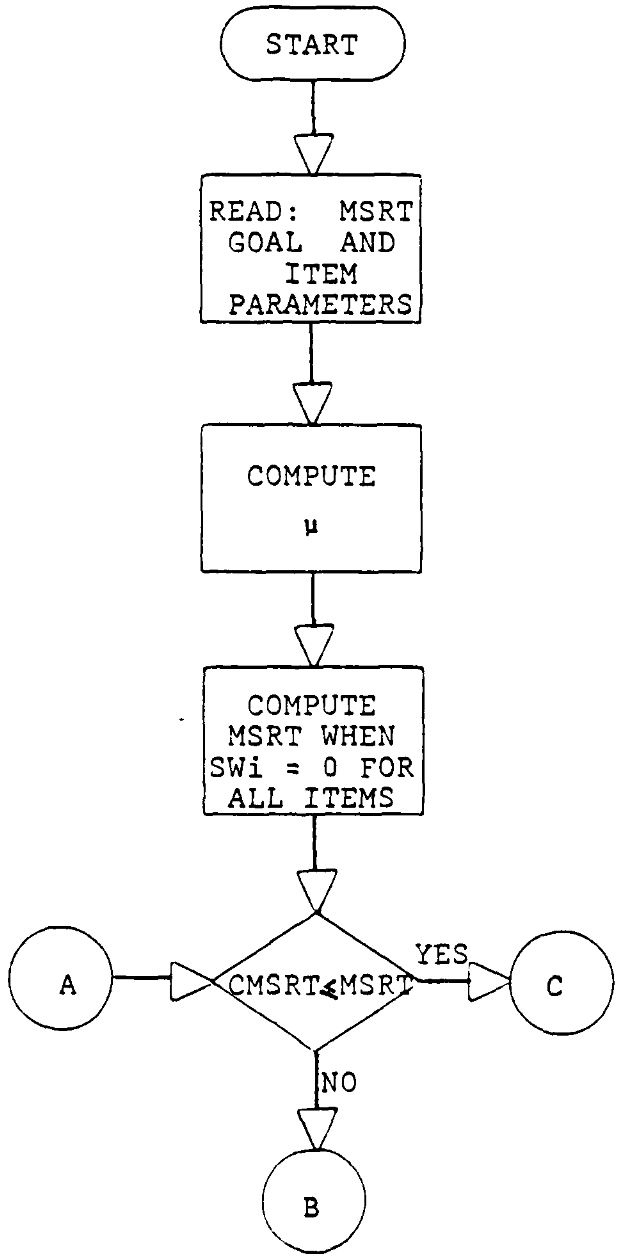
A procedure must be developed for determining the optimum procurement (Q) and repair induction (R) sizes which will be feasible given the annual procurement and regeneration budgets. If the annual budgets are sufficient to fund all procurements and regenerations when Q and R are unity, then obviously both should remain at unity for input to the model since the investment levels will be lowest. If the budgets are insufficient to allow this, larger values of Q and R must be determined so that buys and repair inductions can be postponed until the next year. Because the maximum value of the inventory position must then be increased for some items, it is important to increase those which have the best trade-off between the costs of increased investment levels and the amounts of procurement and regeneration budgets consumed.

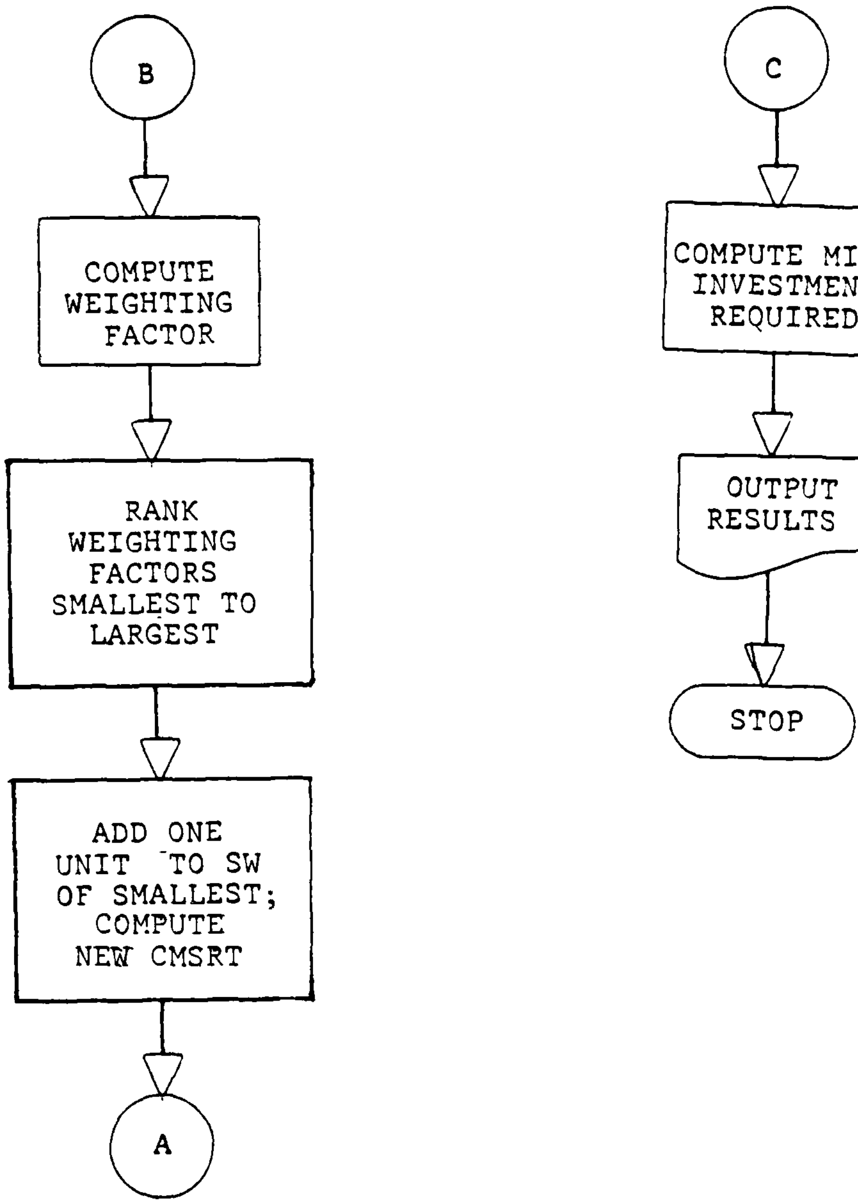
As discussed in Chapter IV, further study is needed to determine the reason that the normal approximation gives small negative values for CTWUS1. Also, additional study is required to identify the cause of the oscillation that occurred in the SW1 values of column one in Table II.

Since this thesis only studied a simplified example, further study is needed with a large number of items and with changes to the parameters held fixed in Chapter IV. Finally, actual data for repairable items from the UICP data base should be used in a performance evaluation of the aggregate model as compared to the current UICP repairables model.

APPENDIX A

AGGREGATE DEMAND MODEL FLOW CHART




B
COMPUTE WEIGHTING FACTOR
RANK WEIGHTING FACTORS SMALLEST TO LARGEST
ADD ONE UNIT TO SW OF SMALLEST; COMPUTE NEW CMSRT
A
C
COMPUTE MIN INVESTMENT REQUIRED
OUTPUT RESULTS
STOP

APPENDIX B

COMPUTER PROGRAM LISTING

```
$JOB
C
C      ****************************************
C      * THIS PROGRAM COMPUTES THE APPROXIMATE*
C      * MINIMUM TOTAL INVESTMENT REQUIRED OF *
C      * WHOLESALE SYSTEM STOCK TO MEET AN    *
C      * ESTABLISHED MSRT GOAL.               *
C      *                                      *
C      ****************************************
C
C          **** VARIABLES  DESCRIPTION ****
C
C      ARR    :  ARRAY STORAGE
C      ATT    :  ATTRITION RATE (NUMBER OF UNITS)
C      CMSRT  :  COMPUTED MEAN SUPPLY RESPONSE TIME
C      COSTSW:  EXTENDED COST OF OPTIMUM WHOLESALE STOCK LEVEL (C1*SWR)
C      CRR    :  CARCASS RETURN RATE(PROBABILITY)
C      CRT    :  CARCASS RETURN TIME
C      CTWUS1:  COMPUTED TIME WEIGHTED UNIT SHORT FOR SW
C      CTWUS2:  COMPUTED TIME WEIGHTED UNIT SHORT FOR SW + 1
C      C1     :  PROCUREMENT COST PER UNIT
C      C2     :  REPAIR COST PER UNIT
C      D      :  DEMAND FOR AN ITEM
C      I      :  INDEX VARIABLE
C      INVEST:  MINIMUM REQUIRED INVESTMENT
C      J      :  INDEX VARIABLE
C      JJ     :  INDEX VARIABLE
C      K      :  INDEX VARIABLE
C      L      :  INDEX VARIABLE
C      LL     :  INDEX VARIABLE
C      N      :  INDEX VARIABLE
C      NN     :  INDEX VARIABLE
```

```
C     MSRT  :  MEAN SUPPLY RESPONSE TIME GOAL
C     MU    :  TOTAL PROGRAM PROBLEM VARIABLE
C     MUP   :  PROCUREMENT PROBLEM VARIABLE
C     MUR   :  REPAIR PROBLEM VARIABLE
C     NIIN  :  NATIONAL ITEM IDENTIFICATION NUMBER
C     PCLT  :  PROCUREMENT CYCLE LEAD TIME
C     Q     :  PROCUREMENT LOT SIZE
C     R     :  REPAIR BATCH SIZE
C     REG   :  REGENERATION RATE (NUMBER UNITS)
C     RSR   :  REPAIR SURVIVAL RATE (PROBABILITY)
C     RTAT  :  REPAIR TURN-AROUND TIME
C     S     :  TEMPORARY STORAGE
C     S1    :  TEMPORARY STORAGE
C     S2    :  TEMPORARY STORAGE
C     S3    :  TEMPORARY STORAGE
C     S4-S10:  TEMPORARY STORAGE
C     SW    :  WHOLESALE SYSTEM STOCK LEVEL
C     SWR   :  FINAL WHOLESALE SYSTEM STOCK LEVEL
C     TWUS  :  TIME WEIGHTED UNITS SHORT
C     TT1   :  MEAN LENGTH OF REPAIR CYCLE
C     TT2   :  MEAN LENGTH OF PROCUREMENT CYCLE
C     WT    :  COMPUTED WEIGHT FOR MARGINAL ANALYSIS
C
C          **** VARIABLE DECLARATION ****
C
      REAL ATT(2),REG(2),C1(2),C2(2),MU(2),Q(2),R(2),
     *MUP(2),MUR(2),RSR(2),CRR(2),CRT(2),RTAT(2),PCLT(2),D(2),
     *WT(2),INVEST,MSRT,CMSRT,ARR(2,10),S,
     *CTWUS1(2),CTWUS2(2),COSTSW(2)
C
C
C
      INTEGER NIIN(2),S1,S2,S3,SW(2),SWR(2)
      N=2
    1 CALL READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
     *CRR,CRT,RTAT,PCLT,D,Q,R)
 5000 CALL COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,NIIN)
```

```
      DO 6000 I=1,N
         SW(I)=0
 6000 CONTINUE
 7000 CALL CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
 8000 CALL MINVST (N,INVEST,C1,SWR,COSTSW)
 9000 CALL WRITER (CMSRT,MSRT,N,NIIN,ARR,MU,CTWUS1,WT,SWR,C1,
     *COSTSW,INVEST,Q,R)
 9999 STOP
      END
C
C     *****ROUTINE TO READ IN INITIAL DATA*****
C
 0001 SUBROUTINE READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
     *CRR,CRT,RTAT,PCLT,D,Q,R)
      INTEGER N,NIIN(N)
      REAL MSRT,ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),Q(N),R(N)
      READ (5,900) N,MSRT
      DO 10 I=1,N
         READ (5,910) NIIN(I),(ARR(I,J),J=1,10),Q(I),R(I)
   10 CONTINUE
      CALL ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
  900 FORMAT (I3,3X,F8.5)
  910 FORMAT (2X,I9,1X,4F10.2,2(F6.4,1X),F5.2,1X,F6.3/2X,F6.3,2X,
     *F7.3,2(2X,F5.2))
      RETURN
      END
C
C*** ROUTINE TO REARRANGE ARRAY ASSIGNMENTS *******
C
  601 SUBROUTINE ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
      INTEGER N
      REAL ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N)
      DO 600 I=1,N
         ATT(I)=ARR(I,1)
```

```
          REG(I)=ARR(I,2)
          C1(I) =ARR(I,3)
          C2(I) =ARR(I,4)
          RSR(I)=ARR(I,5)
          CRR(I)=ARR(I,6)
          CRT(I)=ARR(I,7)
          RTAT(I)=ARR(I,8)
          PCLT(I)=ARR(I,9)
          D(I)=ARR(I,10)
  600 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO COMPUTE MUP,MUR,MU*****
C
 5001 SUBROUTINE COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,
     *NIIN)
      INTEGER N,NIIN(N)
      REAL RSR(N),CRR(N),CRT(N),RTAT(N),D(N),PCLT(N),Q(N),R(N),
     *MU(N),MUR(N),MUP(N)
      DO 5310 I=1,N
         MUR(I)=(RSR(I)*CRR(I))*(CRT(I)+RTAT(I)+((R(I)-1.)/
     *   (2.*D(I)*RSR(I)*CRR(I))))
         MUP(I)=(1.-(RSR(I)*CRR(I)))*(PCLT(I)+((Q(I)-1.))/
     *   (2.*D(I)*(1.-(RSR(I)*CRR(I)))))
         MU(I)=(D(I)*(MUR(I)+MUP(I)))
 5310 CONTINUE
      RETURN
      END
C
C     **** ROUTINE TO COMPUTE TIME WEIGHTED UNIT SHORT FOR SW ****
C
 7001 SUBROUTINE CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
      INTEGER N,SW(N),K,NIIN(N),SWR(N)
      REAL CTWUS1(N),CTWUS2(N),MU(N),P,C,MSRT,WT(N),ARR(N,10),ATT(N),
     *REG(N),C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),
```

```
     *CMSRT,Q(N),R(N)
      CALL CTWSWO (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT)
      IF (CMSRT.LE.MSRT) GO TO 7090
      J=1
 7005 DO 7080 I=1,N
         IF (J.EQ.1) GO TO 7050
         K=SW(I)+ J- 1
         SWR(I)=K
         Z=MU(I)
         IF (Z.GE.20.) GO TO 7010
         CALL CDFP (Z,K,P,C)
         CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
         GO TO 7020
 7010    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS1(I)=CTWUS
 7020    CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
C        WRITE (6,9999) CMSRT,MSRT,CTWUS1(I),SWR(I),NIIN(I)
C9999    FORMAT (/2X,'CMSRT:',F10.4,2X,'MSRT:',F10.4,2X,'CTWUS1:',
C    *   F10.4,2X,'SW:',I4,2X,'NIIN:',I9)
         IF (CMSRT.LE.MSRT) GO TO 7090
C
C     **** COMPUTE TIME WEIGHTED UNITS SHORT FOR SW + 1 ****
C
 7050    Z=MU(I)
         K=SWR(I)+1
         IF (Z.GE.20.) GO TO 7060
         CALL CDFP (Z,K,P,C)
         CTWUS2(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
         IF(J.EQ.1.AND.I.NE.N) GO TO 7080
         GO TO 7070
 7060    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS2(I)=CTWUS
         IF(J.EQ.1.AND.I.NE.N) GO TO 7080
 7070    MM=NIIN(I)
         CALL CPWTS (WT,CTWUS1,CTWUS2,SWR,ARR,N,NIIN,ATT,REG,
```

```
     *   C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,MU,Q,R)
         IF (MM.NE.NIIN(I)) GO TO 7075
         GO TO 7085
 7075    J=SWR(I)+1
         GO TO 7085
 7080 CONTINUE
 7085 J=J+1
      I=1
      GO TO 7005
 7090 RETURN
      END
C
C*****ROUTINE TO COMPUTE TWUS WITH SW=0*****
C
 7100 SUBROUTINE CTWSW0 (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT)
      INTEGER N,SW(N),K,SWR(N)
      REAL CTWUS1(N),MU(N),P,C,MSRT,Z,D(N),PCLT(N),CMSRT
      DO 7130 I=1,N
         K=SW(I)
         SWR(I)=K
         Z=MU(I)
         IF (Z.GE.20.) GO TO 7110
         CALL CDFP (Z,K,P,C)
         CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
         GO TO 7120
 7110    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS1(I)=CTWUS
 7120    IF (I.NE.N) GO TO 7130
         CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
 7130 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO COMPUTE POISSON PROBABILITIES*****
C
 7200 SUBROUTINE CDFP (Z,K,P,C)
```

```
      REAL  ZZZ,PP,CC
      REAL Z,P,C
      INTEGER K,J
      ZZZ=Z
      PP=EXP(-ZZZ)
      CC=PP
      IF (K.EQ.0) GO TO 7220
      DO 7210 J=1,K
         PP=PP*ZZZ/DFLOAT(J)
         CC=CC+PP
 7210 CONTINUE
 7220 P=PP
      C=CC
      RETURN
      END
C
C    *****ROUTINE TO CALCULATE NORMAL PROBABILITIES AND TWUS*****
C
 7300 SUBROUTINE NORMAL (Z,K,I,PCLT,CTWUS,N)
      INTEGER K,I,N
      REAL S,Z,T1,T2,CA,CB,PCLT(N)
      S=FLOAT(K) + 0.5
      T1=(S-Z)/SQRT(Z)
      T2=(S-Z-1.0)/SQRT(Z)
      CALL MDNOR (T1,CA)
      CALL MDNOR (T2,CB)
      CTWUS=(PCLT(I)/2.)*(CA*(K-(K*(K+1)/Z))-CB*(Z-K)+
     *(Z-2.*K+K*(K+1)/Z))
      RETURN
      END
C
C  **** ROUTINE TO COMPUTE MSRT AND COMPARE TO MSRT GOAL ****
C
 7400 SUBROUTINE CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
      INTEGER N
      REAL CMSRT,D(N),CTWUS1(N),MSRT,CCTWUS,DD
      CCTWUS=0.0
```

```
      DD=0.0
      DO 7410 I=1,N
         X=CTWUS1(I)
         IF(CTWUS1(I).LT.0) X=0.
         CCTWUS=CCTWUS + X
         DD=DD+D(I)
 7410 CONTINUE
      CMSRT=CCTWUS/DD
      RETURN
      END
C
C     **** ROUTINE TO COMPUTE WEIGHTS AND FIND SMALLEST ****
C
 7500 SUBROUTINE CPWTS (WT,CTWUS1,CTWUS2,SWR,ARR,N,NIIN,
     *ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,MU,Q,R)
      INTEGER N,SWR(N),NIIN(N)
      REAL WT(N),CTWUS1(N),CTWUS2(N),ARR(N,10),ATT(N),REG(N),Q(N),
     *C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),MU(N),R(N)
      DO 7510 I=1,N
         WT(I)=C1(I)/(CTWUS1(I)-CTWUS2(I))
 7510 CONTINUE
      CALL SORTS (ARR,N,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,
     *PCLT,D,WT,SWR,MU,CTWUS1,CTWUS2,Q,R)
      RETURN
      END
C
C     *****ROUTINE TO SORT FROM SMALLEST TO LARGEST*****
C
 7600 SUBROUTINE SORTS (ARR,N,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,
     *RTAT,PCLT,D,WT,SWR,MU,CTWUS1,CTWUS2,Q,R)
      INTEGER N,NIIN(N),S1,S4,SWR(N)
      REAL ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),CRR(N),CRT(N),
     *RTAT(N),PCLT(N),D(N),WT(N),MU(N),CTWUS1(N),CTWUS2(N),Q(N),R(N)
      NN=N-1
      DO 7630 J=1,NN
         L=J
         JJ=J+1
```

```
         DO 7610 K=JJ,N
            IF (WT(L).LT.WT(K)) GO TO 7610
            L=K
7610     CONTINUE
         DO 7620 M=1,10
            S=ARR(L,M)
            ARR(L,M)=ARR(J,M)
            ARR(J,M)=S
7620     CONTINUE
         CALL ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
         S1=NIIN(L)
         NIIN(L)=NIIN(J)
         NIIN(J)=S1
         S4=SWR(L)
         SWR(L)=SWR(J)
         SWR(J)=S4
         S5=MU(L)
         MU(L)=MU(J)
         MU(J)=S5
         S6=WT(L)
         WT(L)=WT(J)
         WT(J)=S6
         S7=CTWUS1(L)
         CTWUS1(L)=CTWUS1(J)
         CTWUS1(J)=S7
         S8=CTWUS2(L)
         CTWUS2(L)=CTWUS2(J)
         CTWUS2(J)=S8
         S9=Q(L)
         Q(L)=Q(J)
         Q(J)=S9
         S10=R(L)
         R(L)=R(J)
         R(J)=S10
7630  CONTINUE
      RETURN
      END
```

```
C
C     *****ROUTINE TO COMPUTE MINIMUM INTITIAL INVESTMENT*****
C
 8001 SUBROUTINE MINVST (N,INVEST,C1,SWR,COSTSW)
      INTEGER N,SWR(N)
      REAL INVEST,C1(N),COSTSW(N)
      INVEST=0.0
      DO 8650 I=1,N
         COSTSW(I)=C1(I)*SWR(I)
         INVEST=INVEST+COSTSW(I)
 8650 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO WRITE ALL DATA*****
C
 9001 SUBROUTINE WRITER(CMSRT,MSRT,
     *N,NIIN,ARR,MU,CTWUS1,WT,SWR,C1,COSTSW,INVEST,Q,R)
      INTEGER N,NIIN(N),SWR(N)
      REAL CMSRT,MSRT,ARR(N,10),
     *MU(N),CTWUS1(N),WT(N),C1(N),COSTSW(N),INVEST,Q(N),R(N)
      WRITE (6,9020)
      WRITE (6,9107)
      DO 9120 I=1,N
         WRITE (6,9108) NIIN(I),Q(I),R(I)
 9120 CONTINUE
      WRITE (6,9020)
      CMSRT=CMSRT*91.
      MSRT=MSRT*91.
 9740 WRITE (6,9741) CMSRT,MSRT
      WRITE (6,9020)
 9760 WRITE (6,9761)
      DO 9762 I=1,N
         WRITE (6,9763) NIIN(I),(ARR(I,J),J=1,10),MU(I),CTWUS1(I),
     *   WT(I),SWR(I)
 9762 CONTINUE
      WRITE (6,9020)
```

```
 9800 WRITE (6,9890)
      DO 9810 I=1,N
         WRITE (6,9896) NIIN(I),SWR(I),C1(I),COSTSW(I)
 9810 CONTINUE
      WRITE (6,9010)
      WRITE (6,9898) INVEST
 9010 FORMAT (//)
 9020 FORMAT (/////)
 9107 FORMAT (5X,'NIIN',10X,'Q',13X,'R')
 9108 FORMAT (/2X,I9,3X,F10.2,3X,F10.2)
 9741 FORMAT (/'+++++++++CMSRT:',F10.4,1X,'DAYS',3X,'MSRT:',F10.4,1X,
     *'DAYS','+++++++++++')
 9761 FORMAT (/5X,'NIIN',9X,'ATT',7X,'REG',5X,'C1',8X,'C2',6X,
     *'RSR',4X,'CRR',4X,'CRT',3X,'RTAT',3X,'PCLT',5X,'D',10X,'MU',7X,
     *'CTWUS1',6X,'WT',6X,'SWR')
 9763 FORMAT (/2X,I9,1X,4F10.2,1X,2(F6.4,1X),F5.2,1X,F6.3,1X,F6.3,
     *1X,F7.3,1X,2(F10.4,1X),E11.4,1X,I4)
 9890 FORMAT (5X,'NIIN',5X,'SWR',5X,'COST C1',8X,'COSTSW')
 9896 FORMAT (/2X,I9,3X,I3,3X,F10.2,3X,F14.2)
 9898 FORMAT (////2X,'********** TOTAL MINIMUM INITIAL INVESTMENT:$',
     *F14.2,2X,'TOTAL MINIMUM INITIAL INVESTMENT **********')
      RETURN
      END
$ENTRY
```

APPENDIX C

DATA INPUT FILE

```
Items   MSRT
  2   000.0572

   NIIN          ATT        REG      C1          C2     RSR      CRR    CRT   RTAT
 111111111        .36       8.24  10000.00     5000.000.9850   .9725   .75   1.990

  PCLT      D       Q       R
 7.140    8.600   1.00    1.00

   NIIN          ATT        REG      C1          C2     RSR      CRR    CRT   RTAT
 222222222        .36       8.24 150000.00   75000.00 .9850   .9725   .75   1.990

  PCLT      D       Q       R
 7.140    8.600   1.00    1.00
```

APPENDIX D

MODIFIED PROGRAM TO FIX ONE SW VALUE

```
$JOB
C
C      ***************************************
C      *                                     *
C      *                                     *
C      *                                     *
C      *                                     *
C      *                                     *
C      ***************************************
C
C          **** VARIABLES  DESCRIPTION ****
C
C      ARR    :  ARRAY STORAGE
C      ATT    :  ATTRITION RATE (NUMBER OF UNITS)
C      CMSRT  :  COMPUTED MEAN SUPPLY RESPONSE TIME
C      COSTSW:   EXTENDED COST OF OPTIMUM WHOLESALE STOCK LEVEL (C1*SWR)
C      CRR    :  CARCASS RETURN RATE(PROBABILITY)
C      CRT    :  CARCASS RETURN TIME
C      CTWUS1:   COMPUTED TIME WEIGHTED UNIT SHORT FOR SW
C      CTWUS2:   COMPUTED TIME WEIGHTED UNIT SHORT FOR SW + 1
C      C1     :  PROCUREMENT COST PER UNIT
C      C2     :  REPAIR COST PER UNIT
C      D      :  DEMAND FOR AN ITEM
C**** FSW    :  FIXED WHOLESALESYSTEM STOCK LEVEL
C      I      :  INDEX VARIABLE
C      INVEST:   MINIMUM REQUIRED INVESTMENT
C      J      :  INDEX VARIABLE
C      JJ     :  INDEX VARIABLE
C      K      :  INDEX VARIABLE
C      L      :  INDEX VARIABLE
C      LL     :  INDEX VARIABLE
C      N      :  INDEX VARIABLE
```

```
C     NN     :  INDEX VARIABLE
C     MSRT   :  MEAN SUPPLY RESPONSE TIME GOAL
C     MU     :  TOTAL PROGRAM PROBLEM VARIABLE
C     MUP    :  PROCUREMENT PROBLEM VARIABLE
C     MUR    :  REPAIR PROBLEM VARIABLE
C     NIIN   :  NATIONAL ITEM IDENTIFICATION NUMBER
C     PCLT   :  PROCUREMENT CYCLE LEAD TIME
C     Q      :  PROCUREMENT LOT SIZE
C     R      :  REPAIR BATCH SIZE
C     REG    :  REGENERATION RATE (NUMBER UNITS)
C     RSR    :  REPAIR SURVIVAL RATE (PROBABILITY)
C     RTAT   :  REPAIR TURN-AROUND TIME
C     S1     :  TEMPORARY STORAGE
C     S2     :  TEMPORARY STORAGE
C     S3     :  TEMPORARY STORAGE
C     S4     :  TEMPORARY STORAGE
C     S5     :  TEMPORARY STORAGE
C     S6     :  TEMPORARY STORAGE
C     S7     :  TEMPORARY STORAGE
C     S8     :  TEMPORARY STORAGE
C     S4-S10:  TEMPORARY STORAGE
C     SW     :  WHOLESALE SYSTEM STOCK LEVEL
C     SWR    :  FINAL WHOLESALE SYSTEM STOCK LEVEL
C     TWUS   :  TIME WEIGHTED UNITS SHORT
C     TT1    :  MEAN LENGTH OF REPAIR CYCLE
C     TT2    :  MEAN LENGTH OF PROCUREMENT CYCLE
C     WT     :  COMPUTED WEIGHT FOR MARGINAL ANALYSIS
C
C          **** VARIABLE DECLARATION ****
C
      REAL ATT(2),REG(2),C1(2),C2(2),MU(2),Q(2),R(2),
     *MUP(2),MUR(2),RSR(2),CRR(2),CRT(2),RTAT(2),PCLT(2),D(2),
     *WT(2),INVEST,MSRT,CMSRT,ARR(2,10),
     *CTWUS1(2),CTWUS2(2),COSTSW(2)
C
C
C
```

```
****  INTEGER NIIN(2),SW(2),SWR(2),FSW
      N=2
    1 CALL READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
**** *CRR,CRT,RTAT,PCLT,D,Q,R,FSW)
 5000 CALL COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,NIIN)
      DO 6000 I=1,N
         SW(I)=0
 6000 CONTINUE
 7000 CALL CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,FSW,****
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
 8000 CALL MINVST (N,INVEST,C1,SWR,COSTSW)
 9000 CALL WRITER (CMSRT,MSRT,N,NIIN,ARR,MU,CTWUS1,WT,SWR,C1,
     *COSTSW,INVEST,Q,R)
 9999 STOP
      END
C
C     *****ROUTINE TO READ IN INITIAL DATA*****
C
 0001 SUBROUTINE READA (N,MSRT,NIIN,ARR,ATT,REG,C1,C2,RSR,
**** *CRR,CRT,RTAT,PCLT,D,Q,R,FSW)
****  INTEGER N,NIIN(N),FSW
      REAL MSRT,ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),Q(N),R(N)
      READ (5,900) N,MSRT
      DO 10 I=1,N
         READ (5,910) NIIN(I),(ARR(I,J),J=1,10),Q(I),R(I)
   10 CONTINUE
****  READ (5,920) FSW
      CALL ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
  900 FORMAT (I3,3X,F8.5)
  910 FORMAT (2X,I9,1X,4F10.2,2(F6.4,1X),F5.2,1X,F6.3/2X,F6.3,2X,
     *F7.3,2(2X,F5.2))
  920 FORMAT (I3)
      RETURN
      END
C
C*** ROUTINE TO REARRANGE ARRAY ASSIGNMENTS *******
```

```
C
  601 SUBROUTINE ARRAYS (ARR,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,N)
      INTEGER N
      REAL ARR(N,10),ATT(N),REG(N),C1(N),C2(N),RSR(N),
     *CRR(N),CRT(N),RTAT(N),PCLT(N),D(N)
      DO 600 I=1,N
         ATT(I)=ARR(I,1)
         REG(I)=ARR(I,2)
         C1(I) =ARR(I,3)
         C2(I) =ARR(I,4)
         RSR(I)=ARR(I,5)
         CRR(I)=ARR(I,6)
         CRT(I)=ARR(I,7)
         RTAT(I)=ARR(I,8)
         PCLT(I)=ARR(I,9)
         D(I)=ARR(I,10)
  600 CONTINUE
      RETURN
      END
C
C     *****ROUTINE TO COMPUTE MUP,MUR,MU*****
C
 5001 SUBROUTINE COMPMU (N,RSR,CRR,CRT,RTAT,R,D,PCLT,Q,MU,MUP,MUR,
     *NIIN)
      INTEGER N,NIIN(N)
      REAL RSR(N),CRR(N),CRT(N),RTAT(N),D(N),PCLT(N),Q(N),R(N),
     *MU(N),MUR(N),MUP(N)
      DO 5310 I=1,N
         MUR(I)=(RSR(I)*CRR(I))*(CRT(I)+RTAT(I)+((R(I)-1.)/
     *   (2.*D(I)*RSR(I)*CRR(I))))
         MUP(I)=(1.-(RSR(I)*CRR(I)))*(PCLT(I)+((Q(I)-1.))/
     *   (2.*D(I)*(1.-(RSR(I)*CRR(I)))))
         MU(I)=(D(I)*(MUR(I)+MUP(I)))
 5310 CONTINUE
      RETURN
      END
C
```

```
C     **** ROUTINE TO COMPUTE TIME WEIGHTED UNIT SHORT FOR SW ****
C
*7001 SUBROUTINE CPTWUS (N,SW,CTWUS1,CTWUS2,MU,P,C,MSRT,CMSRT,SWR,FSW,
     *WT,ARR,NIIN,ATT,REG,C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,Q,R)
****  INTEGER N,SW(N),K,NIIN(N),SWR(N),FSW
      REAL CTWUS1(N),CTWUS2(N),MU(N),P,C,MSRT,WT(N),ARR(N,10),ATT(N),
     *REG(N),C1(N),C2(N),RSR(N),CRR(N),CRT(N),RTAT(N),PCLT(N),D(N),
     *CMSRT,Q(N),R(N)
****  CALL CTWSWO (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT,FSW)
      IF (CMSRT.LE.MSRT) GO TO 7090
      J=1
 7005 DO 7080 I=1,N
****     IF (J.EQ.1) GO TO 7085
         K=SW(I)+ J- 1
****     IF (I.EQ.2) K = FSW
         SWR(I)=K
         Z=MU(I)
         IF (Z.GE.20.) GO TO 7010
         CALL CDFP (Z,K,P,C)
         CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
         GO TO 7020
 7010    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS1(I)=CTWUS
 7020    CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
****     WRITE (6,9999) CMSRT,MSRT,CTWUS1(I),SWR(I),NIIN(I)
*9999    FORMAT (/2X,'CMSRT:',F10.4,2X,'MSRT:',F10.4,2X,'CTWUS1:',
**** *   F10.4,2X,'SW:',I4,2X,'NIIN:',I9)
         IF (CMSRT.LE.MSRT) GO TO 7090
C
C     **** COMPUTE TIME WEIGHTED UNITS SHORT FOR SW + 1 ****
C
C**********NEXT 17 LINES COMMENTED OUT FOR THE FIXED SW
C***********RUN (THRU STATEMENT 7075)
C7050    Z=MU(I)
C        K=SWR(I)+1
C        IF (Z.GE.20.) GO TO 7060
```

```
C        CALL CDFP (Z,K,P,C)
C        CTWUS2(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
C        (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
C        IF(J.EQ.1.AND.I.NE.N) GO TO 7080
C        GO TO 7070
C7060    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
C        CTWUS2(I)=CTWUS
C        IF(J.EQ.1.AND.I.NE.N) GO TO 7080
C7070    MM=NIIN(I)
C        CALL CPWTS (WT,CTWUS1,CTWUS2,SWR,ARR,N,NIIN,ATT,REG,
C     *  C1,C2,RSR,CRR,CRT,RTAT,PCLT,D,MU,QR,RR)
C        IF (MM.NE.NIIN(I)) GO TO 7075
C        GO TO 7085
C7075    J=SWR(I)+1
         GO TO 7085
 7080 CONTINUE
 7085 J=J+1
      I=1
      GO TO 7005
 7090 RETURN
      END
C
C*****ROUTINE TO COMPUTE TWUS WITH SW=0*****
C
*7100 SUBROUTINE CTWSWO (N,SW,CTWUS1,MU,P,C,CMSRT,MSRT,SWR,D,PCLT,FSW)
****  INTEGER N,SW(N),K,SWR(N),FSW
      REAL CTWUS1(N),MU(N),P,C,MSRT,Z,D(N),PCLT(N),CMSRT
      DO 7130 I=1,N
         K=SW(I)
****     IF (I.EQ.2) K = FSW
         SWR(I)=K
         Z=MU(I)
         IF (Z.GE.20.) GO TO 7110
         CALL CDFP (Z,K,P,C)
         CTWUS1(I)=(1.-C)*((Z**2.)-(2.*FLOAT(K)*Z)+(FLOAT(K)*
     *   (FLOAT(K)+1.)))*(1./(2.*D(I)))+(P*(Z-FLOAT(K))*Z/(2.*D(I)))
         GO TO 7120
```

```
 7110    CALL NORMAL (Z,K,I,PCLT,CTWUS,N)
         CTWUS1(I)=CTWUS
 7120    IF (I.NE.N) GO TO 7130
         CALL CPMSRT (CMSRT,N,D,CTWUS1,MSRT)
 7130 CONTINUE
      RETURN
      END
**** NO FURTHER CHANGES BEYOND THIS POINT TO BASIC PROGRAM
**** PRESENTED IN APPENDIX A TO FIX ONE SW VALUE WHILE ALLOWING
**** THE OTHER SW TO VARY.
```

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4-86