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A study of multi-echelon and multi-location inventory system

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THESIS

A STUDY OF MULTI-ECHELON
AND MULTI-LOCATION INVENTORY SYSTEM

by

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The results from the mathematical model were used as input values for the simulation and measures of effectiveness were compared. An alternative procedure was proposed and simulated; and the results of the three products were compared.

A Study of Multi-Echelon

And Multi-Location Inventory System

by

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The reorder point and reorder quantity for a multi-echelon inventory system consisting of two levels were determined through the use of a mathematical model and a computer simulation was used to verify the results.

The main echelon supported two lower echelon stock points and reordered using a continuous review inventory policy. The two lower echelon stock points operated under periodic review policies.

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The results from the mathematical model were used as input values for the simulation and measures of effectiveness were compared. An alternative procedure was proposed and simulated; and the results of the three products were compared.

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I. INTRODUCTION

Despite the fact that all military supply systems and many large civilian corporations have multi-echelon and multi-location inventory systems, few multi-echelon inventory models are currently being used. The policies that have been used are the single echelon and single location inventory policies that attempt to minimize the total variable cost of a single location ignoring total system cost. The difficulties of optimizing a multi-echelon and multi-location inventory system are most likely due to the complexity of demand and the interdependency among the units in different echelons.

A mathematical model for a multi-echelon and multi-location inventory system is developed in Chapter II. The objective of this model is to minimize the total annual variable costs subject to a maximum allowable number of back orders per year for the entire system. This model consists of one first echelon location operating under a continuous review policy and two second echelon systems which operate under periodic review policies. An example is presented to obtain numerical results.

In Chapter III, a computer model is developed to simulate the multi-echelon, multi-location system. This simulation model was used to check the results obtained from

the mathematical model and to demonstrate the interaction between echelons. Graphical plots are generated which show the inventory position of each entity in the model.

In Chapter IV, comparisons are made of the simulation results and the results obtained from the mathematical model. The comparisons suggest some modifications to the operating policy.

The system was simulated again using the modified operating policy and substantial improvements in the effectiveness of the multi-echelon system were observed. These results are described in Chapter V.

Chapter VI summarizes the results of the research and concludes with some suggestions for additional research.

II. A PROBABILISTIC MATHEMATICAL MODEL FOR MULTI-ECHELON INVENTORY SYSTEM

A. DESCRIPTION OF MODEL

In this model there are three systems. One of these systems represents the highest echelon and is called the Main System. The other two, at separate locations, are the lower echelon and are called System One and System Two, respectively. Each system carries its own inventory, and receives random demands. System One and System Two are dependent upon the Main System but independent of each other. System One and System Two can only be resupplied by the Main System. In other words, they cannot order from any other suppliers. The Main System replenishes stocks by placing orders to external suppliers.

B. OBJECTIVE OF MODEL

The objective of this model is to minimize the total expected annual variable costs of three systems subject to a specified expected number of total back orders per year. In fact, this is the same as minimization of total yearly variable costs subject to a specified minimum level of customer satisfaction.

Based on these objectives, decision variables for each system will be calculated to achieve optimum levels for the entire multi-echelon supply system.

C. ASSUMPTIONS OF THE PROBABILISTIC MATHEMATICAL MODEL

1. Main System

It is assumed that the Main System under consideration consists of a single installation which utilizes transaction reporting. This system is governed by a (Q, r) type policy with back orders.

The assumptions in addition to the continuous review assumption are:

a. The cost of operating the information processing system is independent of Q (reorder quantity) and r (reorder point).

b. The unit cost C of the item is a constant independent of Q.

c. The back-order cost is constant (Π), per unit back ordered regardless of the length of time the back-orders exist.

d. There is never more than a single order outstanding. This assumption implies that when the reorder point is reached, there are no orders outstanding; therefore, the inventory position is equal to the net inventory. Thus, the reorder point will be the same regardless of whether it is based on the inventory position or net inventory.

e. Procurement lead times are independent and identically distributed (i.i.d) random variables with a gamma distribution.

f. All variables are treated as continuous.

g. The demands are Poisson distributed with the mean number of demands per year   a constant λ_m.

h. The reorder point, r, which is based on the inventory position is positive.

With a back orders constraint, it is infeasible to wait until back orders exist before placing an order. Because of this and assumption (d) there will be no back orders outstanding at the reorder point. As was discussed in assumption (d), at the reorder point, the inventory position is equal to the on-hand inventory.

For this model, any one of the three inventory levels on hand, net, or inventory position can be used to define the reorder point; and the reorder point has the same value for any one of them. It should also be noted that to use the on-hand level it must be assumed that after an order arrives, it is sufficient to fill all back orders and raise the on-hand inventory level above the reorder point. If this ever failed to happen, the reorder point would never be reached again and the system would continue to accumulate back orders indefinitely.

When the reorder point is thought of in terms of the inventory position of the system, then assumption (d) guarantees that the on-hand inventory will always exceed the reorder point when an order arrives; otherwise, it would not be possible to have only a single order outstanding.

2. <u>System One</u>

This system, which is at the lower echelon, is governed by a periodic review policy. The operating doctrine is the most widely used type of periodic review which is the order up to R policy. All demands which occur when the system is out of stock are back ordered.

For this periodic review system the time between reviews will be denoted by T, and at each review time a sufficient quantity is ordered to bring the inventory position of the system up to a level, R, regardless of the amount of on-hand inventory. This policy dictates that at review times even if the inventory position is R-1, only one item must be ordered to bring the inventory position up to R, ignoring the high cost of placing the order. Despite its appearance of being illogical, this assumption simplifies the formulation of the system and is very unlikely to occur on high demand items. When an item experiences zero demand in a review period, there is no need for order because the inventory position is already at R.

The other assumptions are:

a. The cost, J, of making a review is independent of the variables R and T.

b. The unit cost, C, of the item is constant and independent of the quantity ordered.

c. Back orders are incurred only in very small quantities. This implies that when an order arrives, it is almost always sufficient to meet any outstanding back orders.

d. The backorder cost is constant, Π, per unit back ordered regardless of the length of time the back order exists.

e. Procurement lead times are i.i.d random variables with a gamma distribution.

f. Orders are received in the same sequence in which they were placed. It should be noted that for (Q, r) models, the two assumptions that orders were received in the sequence placed and that lead times are i.i.d random variables could not both hold rigorously, since there exists a positive probability that two successive orders could be separated by an arbitrarily short time interval. In this model, orders can never be more closely spaced than by an interval of length T. If T is large enough, it is possible, provided that there is a sufficiently small range of variation in the lead time, that both assumptions hold simultaneously.

g. The demands are Poisson distributed with mean, λ.

h. All variables are treated as continuous.

3. <u>System Two</u>

This system is identical to, but independent of, System One.

D. ANALYTICAL SOLUTION TO THE MODEL

As was mentioned previously, the objective of the model is to minimize total system costs subject to a constraint on the number of back orders per year.

The determination of various annual costs of each system may be made independently and placed into a common cost formula. Instead of doing this independently, it is better to find a main system cost expression, System One cost expression and System Two cost expression, and then to add them to each other to determine the total cost formulation and then use this formulation as the objective function of total system. The systems are actually tied together through the constraint on the number of back orders.

For the following notation, the subscript m will indicate that the variables being subscripted belong to the Main Sytem where 1 and 2 indicate System One and System Two, respectively.

The costs that are of interest in this model for each system are the cost of placing an order, the cost of carrying inventory and back order costs.

1. <u>Main System</u>

As was discussed previously, the Main System has a transactions reporting policy or (Q, r) model.

In a continuous review system, a period is defined as the length of time between the receipt of two successive procurements. This time period is a random variable. Because the procurement lead times are random variables, the number of demands for a fixed time are random variables; and the number of items demanded per demand are also random variables. The review period is also a random variable. In the following material, we itemize the costs.

a. Procurement Cost

λ_m = Expected number of demands per year

Q_m = Order quantity

$\frac{\lambda_m}{Q_m}$ = Average number of procurements per year

A_m = Procurement cost per cycle

$\frac{\lambda_m}{Q_m} A_m$ = Procurement cost per year

b. Inventory Carrying Costs

Because of randomness, it is possible to accumulate a large number of back orders at the end of a cycle. To prevent this from occurring, it is advisable to provide a safety stock to buffer the system from excessive numbers

of back orders. The safety stock is the expected amount of stock on hand when an order arrives. The actual amount of stock on hand when a shipment arrives is clearly random.

S_m = Mean value of on-hand stock when an order arrives

After an order arrives, the expected on-hand inventory increases to Q+S and is reduced to a value of S on the average just before the next order arrives. Therefore, the average on-hand inventory per cycle is:

$$\frac{(Q_m+S_m)}{2} + \frac{S_m}{2} = \frac{Q}{2} + S_m$$

To write S_m in terms of the reorder point, r_m, let us first assume that the lead time τ_m is fixed. Let

$\xi_\tau(x;r_m) = r_m - x$ be the net inventory at the time an order arrives,

where x is the number of units demanded in lead time τ_m. Then,

$$S_m = E_{\tau_m} \text{ [Net inventory] } = {}_0\int^{\infty} \xi_{\tau m}(x;r_m)\ f(x;\tau_m)\ dx$$

where $f(x;\tau_m)$ = Density function of demand in time τ_m

$$S_m = {}_0\int^{\infty} (r_m-x)\ f(x;\tau_m)\ dx = r_m\ {}_0\int^{\infty} f(x;\tau_m)\ dx$$

$$- {}_0\int^{\infty} f(x;\tau_m)\ dx$$

$S_m = r_m - \mu_m$ where μ_m = Expected lead time demand.

$$\text{Then } \frac{Qm}{2} + S_m = \frac{Qm}{2} + r_m - \mu_m$$

I = Inventory carrying charge

C = Cost of an item

Total holding cost/year = $IC\,(r_m - \mu_m + \frac{Qm}{2})$

c. Stockout Costs

Let us define $\eta_{\tau_m}(x;r_m) = \begin{cases} 0 & \text{if } x-r_m<0 \\ x-r_m & \text{if } x-r_m \geq 0 \end{cases}$

where $\eta_{\tau_m}(x;r_m)$ is the number of back orders per cycle.

If $\bar{\eta}_m(r_m)$ = expected number of back orders per cycle, then

$$\bar{\eta}_m(r_m) = \int_0^{\infty} \eta_{\tau_m}(x;r_m)\ h(x)\ dx = \int_0^{\infty} (x-r_m)\ h(x)\ dx$$

$$= \int_{r_m}^{\infty} xh(x)\ dx - r_m\ H(r_m) \quad \text{where } H(r_m) = P[X>r_m]$$

and h(x) = marginal distribution of leadtime demand.

Therefore, the expected number of back orders/year =

$$\frac{\lambda_m}{Q_m}\left[\int_{r_m}^{\infty} xh(x)\ dx - r_m\ H(r_m)\right]$$

and the expected cost of back orders/year =

$$\frac{\Pi_m \lambda_m}{Q_m}\left[\int_{r_m}^{\infty} xh(x)\ dx - r_m\ H(r_m)\right]$$

All the terms in the average annual variable cost K_m have now been found:

$$K_m = \frac{\lambda_m}{Q_m} A_m + IC\left[\frac{Q_m}{2} + r_m - \mu_m\right] + \frac{\Pi\lambda_m}{Q_m}\left[\int_{r_m}^{\infty} xh(x)dx - r_m H(r_m)\right]$$

2. <u>System One and System Two</u>

It was stated in the assumptions that System One and also System Two both follow a periodic review policy with an order up to R stockage policy. Since System One and System Two are identical to each other; the equations will be derived only for System One.

For convenience, a period is assumed to be the time between the receipt of two successive orders rather than between the placement of two successive orders. Costs are described as follows:

a. Ordering and Reviewing Costs

J = Reviewing cost/cycle

A = Ordering cost/cycle

Ordering and reviewing cost/year = $\frac{J_1+A_1}{T_1}$

where T_1 is the period length defined in units of years.

b. Inventory Carrying Cost

The expected net inventory just prior to the arrival of an order is $R_1 - \mu_1 - \lambda_1 T_1$, where μ_1 = mean demand during lead time.

The mean rate of demand remains constant over time and the expected demand per period must be the expected

amount ordered, i.e., $\lambda_1 T_1$. If the expected net inventory immediately after the arrival of a procurement is $R_1 - \mu_1$, it is therefore $R_1 - \mu_1 - \lambda_1 T_1$ just prior to the arrival of a procurement.

The expected unit years of storage incurred per period is

$$T_1 \left[\frac{1}{2}(R_1 - \mu_1) + \frac{1}{2}(R_1 - \mu_1 - \lambda_1 T_1)\right] = T_1\left[R_1 - \mu_1 - \frac{\lambda_1 T_1}{2}\right]$$

and average inventory carrying cost/year $= IC\left[R_1 - \mu_1 - \frac{\lambda_1 T_1}{2}\right]$.

c. Stockout Costs

First we assume the case where the procurement lead time is constant τ. An order placed at time t will arrive in the system at time $t + \tau$, and the next procurement will arrive in the system at time $t + \tau + T_1$. After the order is placed at time t, the inventory position of the system is R_1. It is necessary to compute the expected number of back orders occurring between $t + \tau$ and $t + \tau + T_1$. A back order will occur in this period under assumption c if and only if the demand in the time period $\tau + T_1$ exceeds R_1. Assumption c also assures that after the arrival of the order placed at time t, there will be no remaining back orders, and therefore they must all occur between times $t + \tau$ and $t + \tau + T_1$. Consequently the expected number of back orders incurred per period is

$$\int_{R_1}^{\infty} (x-R_1)\ f(x;\ \tau + T_1)\ dx$$ where

$f(x;\ \tau + T_1)$ = Demand distribution during time $\tau + T_1$.

When lead time is random with density $g\ (\tau_1)$ with τ_{min} and τ_{max} being lower and upper limits respectively and τ_1 and τ_2, the lead times for the orders placed at times t and $t + T_1$, respectively, the expected number of back orders incurred per period is:

$$\int_{\tau_{min}}^{\tau_{max}} \int_{\tau_{min}}^{\tau_{max}} \int_{R_1}^{\infty} (x-R_1)\ f(x;\ \tau_2+T_1) g(\tau_2) g(\tau_1) dx\ d\tau_2 d\tau_1$$

$$= \int_{R_1}^{\infty} (x-R_1)\ \hat{h}(x;\ T_1)\ dx$$

where $\hat{h}(x;\ T_1) = \int_{\tau_{min}}^{\tau_{max}} f(x;\ \tau_2+T_1) g(\tau_2) d\tau_2$ which is the demand distribution during time $\tau_2 + T_1$ when lead time is a random variable with density function $g(\tau_2)$. The average number of back orders incurred per year is;

$E_1(R_1, T_1) = \frac{1}{T_1} \int_{R_1}^{\infty} (X-R_1)\ \hat{h}(X;\ T_1)\ dx$ and the average back order cost per year equals to $\Pi_1 E_1\ (R_1, T_1)$ and $\bar{n}_1(r) = T_1\ E_1\ (R_1, T_2)$ is the expected number of back orders per period.

Finally, the annual variable cost of System One is:

$$K_1 = \frac{L_1}{T_1} + IC\ [R_1 - \mu_1 - \frac{\lambda_1 T_1}{2}] + \Pi_1\ E_1\ (R_1, T_1) \text{ and}$$

likewise the annual variable cost of System Two is:

$$K_2 = \frac{L_2}{T_2} + IC\ [R_2 - \mu_2 - \frac{\lambda_2 T_2}{2}] + \Pi_2\ E_2\ (R_2, T_2)$$

where $Li = J_i + A_i$.

3. Objective Function and Constraints

The objective function of the model consists of the total annual variable costs of each system. Therefore;

$K = K_m + K_1 + K_2$ which is equal to the minimization of;

$$K = \frac{\lambda_m}{Q_m} A_m + IC\ [\frac{Q_m}{2} + r_m - \mu_m] + \frac{\Pi_m \lambda_m}{Q_m} \bar{\eta}_m\ (r) + \frac{L_1}{T_1}$$

$$+ IC\ [R_1 - \mu_1 - \frac{\lambda_1 T_1}{2}] + \frac{\Pi_1}{T_1} \bar{\eta}_1 (r) + \frac{L_2}{T_2} + IC\ [R_2 - \mu_2 - \frac{\lambda_2 T_2}{2}]$$

$$+ \frac{\Pi_2}{T_2} \bar{\eta}_2\ (r)$$

subject to $\frac{\lambda m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T_1} \bar{\eta}_1\ (r) + \frac{1}{T_2} \bar{\eta}_2(r) \leq b$

where b is the specified total maximum number of back orders per year for the entire system.

The problem at hand is to calculate the optimum values of Q_m, r_m, R_1, T_1, R_2, T_2. Since the objective function and the constraint are non-linear functions of the

decision variables, we solve the problem using the Lagrange multiplier approach.

4. Optimum Values of Operating Variables

After including the Lagrange multiplier in the formulation, the new objective function becomes:

Minimize

$$L = \frac{\lambda_m}{Q_m} A_m + IC[\frac{Q_m}{2} + r_m - \mu_m] + \frac{\Pi_m \lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{L_1}{T_1}$$

$$+ IC[R_1 - \mu_1 - \frac{\lambda_1 T_1}{2}] + \frac{\Pi_1}{T_1} \bar{\eta}_1(r) + \frac{L_2}{T_2} + IC[R_2 - \mu_2 - \frac{\lambda_2 T_2}{2}]$$

$$+ \frac{\Pi_2}{T_2} \bar{\eta}_2 (r) - \theta[(\frac{\lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T_1} \bar{\eta}_1(r) + \frac{1}{T_2} \bar{\eta}_2 (r)) - b]$$

where θ is the Lagrange multiplier. It is through this Lagrange multiplier that the three systems are linked together mathematically.

The optimum values of the unknown variables can be found by taking the derivatives of the objective function with respect to Q_m, R_m, R_1, T_1, R_2, T_2, θ; equating them to zero; solving the equations simultaneously; and ensuring the Kuhn-Tucker conditions are satisfied.

The derivatives were taken with respect to Q_m, r_m, R_1, R_2, θ. A different procedure was utilized to find T_1 and T_2.

The derivatives:

$$L_{Q_m} = \frac{\partial L}{\partial Q_m} = - \frac{\lambda_m A_m}{Q_m^2} + \frac{IC}{2} - \frac{\lambda_m}{Q_m^2} \bar{\eta}_m(r) \ (\Pi_m - \theta) = 0$$

$$L_{r_m} = \frac{\partial L}{\partial r_m} = IC - \frac{\lambda_m}{Q_m} \hat{H}_m(r) \ (\Pi_m - \theta) = 0$$

$$L_{R_1} = \frac{L}{R_1} = IC - \frac{1}{T_1} H_1(R_1, T_1) \ (\Pi_1 - \theta) = 0$$

$$L_{R_2} = \frac{\partial L}{\partial R_2} = IC - \frac{1}{T_2} H_2 \ (R_2, T_2) \ (\Pi_2 - \theta) = 0$$

$$L_\theta = \frac{\partial L}{\partial \theta} = [(\frac{\lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T_1} \bar{\eta}_1(r) + \frac{1}{T_2} \bar{\eta}_2(r)) - b] = 0$$

The Kuhn-Tucker conditions:

$L_{Qm} \geq 0$	$Q_m . L_{Q_m} = 0$	$Q_m \geq 0$	$g \leq 0$
$L_{r_m} \geq 0$	$r_m L_{r_m} = 0$	$r_m \geq 0$	$\theta . g = 0$
$L_{R_1} \geq 0$	$R_1 . L_{R_1} = 0$	$R_1 \geq 0$	$\theta \leq 0$
$L_{R_2} \geq 0$	$R_2 . L_{R_2} = 0$	$R_2 \geq 0$	

where $g = \frac{\lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T1} \bar{\eta}_1(r) + \frac{1}{T_2} \bar{\eta}_2(r) - b$

Therefore the following Kuhn-Tucker conditions must be satisfied:

$$-\frac{\lambda_m A_m}{Q_m^2} + \frac{IC}{2} - \frac{\lambda_m}{Q_m} \bar{\eta}_m(r) \; (\Pi_m - \theta) \geq 0$$

$$IC - \frac{\lambda_m}{Q_m} \hat{H}_m(r) \; (\Pi_m - \theta) \geq 0$$

$$IC - \frac{1}{T_1} \hat{H}_1(R_1, T_1) \; (\Pi_1 - \theta) \geq 0$$

$$IC - \frac{1}{T_2} \hat{H}_2 \; (R_2, T_2) \; (\Pi_2 - \theta) \geq 0$$

$$-\frac{\lambda_m A_m}{Q_m} + \frac{IC \; Q_m}{2} - \frac{\lambda_m}{Q_m} \bar{\eta}_m(r) \; (\Pi_m - \theta) = 0$$

$$IC \; r_m - \frac{\lambda_m \; r_m}{Q_m} \hat{H}_m(r) \; (\Pi_m - \theta) = 0$$

$$IC \; R_1 - \frac{R_1}{T_1} \hat{H}_1 \; (R_1, T_1) \; (\Pi_1 - \theta) = 0$$

$$IC \; R_2 - \frac{R_2}{T_2} \hat{H}_2 \; (R_2, T_2) \; (\Pi_2 - \theta) = 0$$

$$Q_m \geq 0$$

$$r_m \geq 0$$

$$R_1 \geq 0$$

$$R_2 \geq 0$$

$$\frac{\lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T_1} \bar{\eta}_1(r) + \frac{1}{T_2} \bar{\eta}_2(r) - b \leq 0$$

$$\theta\left[\frac{\lambda_m}{Q_m} \bar{\eta}_m(r) + \frac{1}{T_1} \bar{\eta}_1(r) + \frac{1}{T_2} \bar{\eta}_2(r) - b\right] = 0$$

$$\theta \leq 0$$

From these equations and conditions the optimum values of the unknown variables can be simplified to the following form and the exact values can be found by solving these equations simultaneously:

$$\hat{H}_m(r) = \frac{IC\ Q_m}{(\Pi_m - \theta)\ \lambda_m}$$

$$Q_m = \frac{\sqrt{2\lambda_m[A_m + \bar{\eta}_m\ (\Pi_m - \theta)]}}{IC}$$

$$\hat{H}_1\ (R_1, T_1) = \frac{IC\ T_1}{(\Pi_1 - \theta)}$$

$$\hat{H}_2\ (R_2, T_2) = \frac{IC\ T_2}{(\Pi_2 - \theta)}$$

The procedure to find T_1 and T_2 and subsequently R_1 and R_2 is through iteration and trial and error. This is not unreasonable. In realistic cases other considerations not modelled here usually dictate the length of a period. In most cases the systems control a large number of different items and the same period length is used for each item. Thus, the period length is usually some convenient calendar or financial period, such as a month or a quarter. The procedure we use is shown in the following example.

E. EXAMPLE PROBLEM

1. Additional Assumptions

For this example it is assumed that each system has Poisson arrivals independent of each other. The customers

demand only one item at a time. System One and System Two are resupplied only from the main system and the main system is resupplied from outside suppliers. To be more realistic it is also assumed that the procurement lead•times have a gamma distribution with different mean and variances.

The λ's will be assumed daily demand or arrival rate per day rather than yearly values.

2. Input Values

Before providing the input values, some clarifications must be provided regarding the demand at the main system. When it is stated that $\lambda_m = 4$/day, $\lambda_1 = 3$/day and $\lambda_2 = 1$/day. These represent the mean number of demands which arrive each day directly at the respective systems. However, since all demands at Systems One and Two eventually must filter up to the main system, the cumulative demand at the main system has an expected value of $\lambda_1 + \lambda_2 + \lambda_m = 8$. The main system supports not only Systems One and Two, but also has its own customer demands. The model assumes that the demand at the main system is the superposition of the direct demands at the main system and Systems One and Two. However, since the actual demands placed on the main system in the lower echelon are batched, the demand variability is much greater than would be expected by the superposition process. We will evaluate the seriousness of our assumption about the demand process at the main system with the simulation model described in the next chapter.

In this example the input values for each system are;

a. Main System

λ_m = 8/day (considering the individual customer arrivals and the remainder being Systems One and Two average demands)

C = \$50/item

I = 0.23

Π_m = \$5

A_m = \$500

b. System One

λ_1 = 3/day

C = \$50/item

I = 0.23

Π_1 = \$5

A_1 = \$100

J_1 = \$100

c. System Two

λ_2 = 1/day

C = \$50/item

I = 0.23

Π_2 = \$5

A_2 = \$100

J_2 = \$100

The total system is expected not to exceed $b = 175$ total number of back orders at the end of a year.

3. Solution Procedure and Results

It was assumed that for each system, procurement lead times are gamma distributed random variables.

The gamma distribution is defined as:

$$g(t) = \frac{1}{\Gamma(\alpha)\ \beta^{\alpha}}\ t^{\alpha-1}\ e^{-\frac{t}{\beta}} \quad \text{with}$$

$\mu = \alpha \cdot \beta$ and

$\text{Var} = \alpha \cdot \beta^2$

We need the lead-time demand distribution for the case in which lead times are gamma distributed and the process generating demands is Poisson. This is derived below.

The Poisson distribution is

$$f(x) = \frac{(\lambda t)^x\ e^{-\lambda t}}{x!}$$ and the demand distribution during lead time is:

$$f(x;\tau) = \int_0^{\infty} f(x)\ g(t)\ dt$$

$$= \int_0^{\infty} \frac{(\lambda t)^x\ e^{-\lambda t}}{x} \ \frac{t^{\alpha-1}\ e^{-t/\beta}}{\Gamma(\alpha)\ \beta^{\alpha}}\ dt$$

$$= \frac{\lambda^x}{\Gamma(\alpha)\ \beta^{\alpha}\, x!} \int_0^{\infty} t^{\alpha-1+x}\ e^{-(\frac{1}{\beta}+\lambda)t}\ dt$$

$$= \frac{\lambda^x}{\Gamma(\alpha)\ \beta^\alpha\ x!} \quad \frac{\Gamma(\alpha+x)}{(\frac{1}{\beta}+\lambda)^{\alpha+x}} \int_0^\infty \frac{(\frac{1}{\beta}+\lambda)^{\alpha+x} t^{\alpha-1+x} e^{-(\frac{1}{\beta}+\lambda)t}}{\Gamma(\alpha+x)} dt$$

$$\int_0^\infty \frac{(\frac{1}{\beta}+\lambda)^{\alpha+x}\ t^{\alpha-1+x}\ e^{-(\frac{1}{\beta}+\lambda)t}}{\Gamma(\alpha+x)} dt = 1 \quad \text{so}$$

$$f(x;\tau) = \frac{\lambda^x}{\Gamma(\alpha)\ \beta^\alpha\ x!} \frac{\Gamma(\alpha+x)}{(\frac{1}{\beta}+\lambda)^{\alpha+x}}$$

$$= \frac{\Gamma(\alpha+x)}{\Gamma(\alpha)\ x!} \left[\frac{\lambda}{(\frac{1}{\beta}+\lambda)}\right]^x \left[\frac{\frac{1}{\beta}}{\frac{1}{\beta}+\lambda}\right]^\alpha$$

$$= \binom{\alpha+x-1}{x} \left[\frac{\lambda}{\frac{1}{\beta}+\lambda}\right]^x \left[\frac{\frac{1}{\beta}}{\frac{1}{\beta}+\lambda}\right]^\alpha$$

$$= \binom{\alpha+x-1}{x} (1-\rho)^x\ \rho^\alpha$$

$$\mu = \frac{\alpha(1-\rho)}{\rho} = \frac{\alpha(1-\frac{1/\beta}{1/\beta+\lambda})}{\frac{1/\beta}{1/\beta+\lambda}} = \lambda\alpha\beta$$

$$\text{Var} = \frac{\alpha(1-\rho)}{\rho^2} = \frac{\alpha(1-\frac{1/\beta}{1/\beta+\lambda})}{\frac{1/\beta}{1/\beta+\lambda}} = \lambda\alpha\beta(1+\lambda\beta)$$

In fact this is a Negative Binomial distribution with

$$\rho = \frac{1/\beta}{1/\beta+\lambda} .$$

The parameters α and β for each system are:

$\alpha_m = 12.8$ $\qquad$ $\alpha_1 = 5.43$ $\qquad$ $\alpha_2 = 2.5$

$\beta_m = 3.125$ $\qquad$ $\beta_1 = 4.6$ $\qquad$ $\beta_2 = 6.$

The main system has a Negative Binomial distributed lead time demand with parameters:

$$\mu_m = 8\cdot(12.8)(3.125) = 320$$

$$var_m = 8\cdot(12.8)(3.125)\ [1+8\cdot(3.125)] = 8320$$

System One has the parameters:

$$\mu_1 = 3\cdot(5.43)\cdot(4.6) = 74.934$$

$$var_1 = 3\cdot(5.43)(4.6)\ [1+3(4.6)] = 1109.0232$$

System Two has the parameters:

$$\mu_2 = 1\cdot(2.5)\cdot 6 = 15$$

$$var_2 = 1\cdot(2.5)\cdot 6\ [1+1(6)] = 105$$

Because the negative binomial is computationally intractable, we use the normal approximation for the calculation of lead time demand probabilities. The normal distributions are assumed to have the same mean and variance as the negative binomial distributions they replace.

To solve this example problem, it is necessary to make an initial estimate for the Lagrange multiplier θ

which must be less than or equal to zero. After the initial estimate if the total number of back orders per year exceeds b, then the absolute value of θ should be increased gradually until the number of back orders converges to b.

For this problem $\theta = -1.5$ works very well. For the main system the formulas are:

$$Q_m = \sqrt{2\lambda_m[A_m + \bar{\eta}_m(r)(\Pi_m - \theta)]/IC}$$

$$H_m(r) = \frac{Q_m\ IC}{(\Pi_m - \theta)\lambda_m} = P\ [X \geq r_m]$$

Q_m is calculated to be 550 and

$$H_m(r) = P\ [X \geq r_m] = \frac{550\ (0.23) \cdot 50}{(5+1.5)\ 2920} = 0.3332455216$$

From the inverse standard normal distribution TI-59 calculator program (Appendix G), the reorder level at the main system is found to be:

$$r_m = \sigma_m \cdot (0.4305333395) + \mu_m = 359.2706827$$

$$\bar{\eta}_m(r) = (\mu_m - r_m)\ H_m(r) + \sigma_m\ \emptyset\left(\frac{r_m - \mu_m}{\sigma_m}\right)$$

where $\emptyset$ is the functional value of standard normal distribution at 0.4305333395

$\bar{\eta}_m(r) = 20.08139334$. Using this value in the Q_m formula yields

$$Q_m = \sqrt{\frac{2.2920\ [500 + 20.08139334\ (5 + 1.5)]}{(0.23)\cdot 50}} = 568.84$$

which is not equal to the first estimated value. If Q_m is taken 569 then:

$$H_m(r) = \frac{569\ (0.23)\cdot 50}{(5 + 1.5)\ 2920} = 0.3447576396$$

$$r_m = \sigma_m\ (0.399071201) + \mu_m = 356.4008941$$

$$\bar{n}_m(r) = 21.05458646$$

Using this value in the Q_m formula yields

$$Q_m = \sqrt{\frac{2.2920\ [500 + 21.05438646\ (5 + 1.5)]}{(0.23)\cdot 50}} = 568.69$$

which is very close to the initial Q_m value. A summary of the results for the main system follows:

$Q_m = 569$

$S_m = 36.400891$

$\bar{n}_m(r) = 21.05438646$/period

$\bar{n}_m(r) = 108.047115$/year

$K_m = \$6796.50$/year

To solve for the optimum values for Systems One and Two a different procedure is followed. The total annual cost of Systems One and Two is a convex function of the period length T. For different values of T there are different total annual

cost values. The minimum of these values is the optimum total annual variable cost and the corresponding T and R values are the optimum operating values. A TI-59 program was written to perform the line search for the best value of T. The program is found in Appendix G. User information and the features of the program are also in the same appendix. This program evaluates the R value, safety stock, back orders per period, back-orders per year, annual reviewing and ordering cost, annual holding cost, annual back order cost, and finally, the total annual cost.

Using this program the optimum values for Systems One and Two are:

R_1 = 306.809389

T_1 = 2.39 months (72.6958 days)

S_1 = 13.78788901

$\bar{\eta}_1(r)$ = 8.670289086/period

$\bar{\eta}_1(r)$ = 43.53283223

K_1 = \$2634.41/year

R_2 = 134.9807003

T_2 = 4.07 months (123.7958333 days)

S_2 = 0

$\bar{\eta}_2(2)$ = 8.13480099/period

$$\bar{\eta}_2(r) = 23.98467122/\text{year}$$

$$K_2 = \$1377.56/\text{year}$$

The total back orders per year are:

$$\bar{\eta}_m(r) + \bar{\eta}_1(r) + \eta_2(r) = 108.047 + 43.532 + 23.984$$

$$= 175.56$$

which is the same as b = 175.56.

The total annual variable cost is:

$$K = K_m + K_1 + K_2 = 6796.50 + 2634.41 + 1377.56$$

$$K = \$10808.47.$$

III. COMPUTER SIMULATION FOR MULTI-ECHELON MULTI-LOCATION SINGLE ITEM INVENTORY SYSTEM

To check the analytical results, a computer simulation was written which uses the same operating assumptions and input parameters that were made for the analytical model. This model, however, simulates the real world more accurately since some of the simplifying assumptions required to obtain analytical results were not necessary in the simulation. Also, the demands placed at the main system from the lower echelon systems were batched as in the real world.

A. DESCRIPTION OF THE SIMULATION MODEL

As in the analytical case, there are three systems in the simulation model; the main system, System One and System Two. The flow charts of this program are in Appendix A.

1. Main System

This system uses a continuous review policy. When the stock level reaches the reorder point, it orders the amount Q. The decision variable for reordering is the inventory position. When an order is placed, the inventory position increases by an amount of Q. If the new inventory position is less than the reorder point, the system places an additional order for another amount of size Q. Then the

inventory position increases with one more Q. This continues until the inventory position exceeds r. The order policy is thus (nQ,r). N is the smallest integer that will make the inventory position higher than the reorder point.

There are independent customer arrivals to the main system and also group demands that are placed by System One and System Two when those systems replenished their stocks at the end of their periods.

The number of units demanded per requisition is one. The number of units demanded for resupply to the lower echelon systems is random depending on the demands at the lower echelon systems and the parameters R_1, R_2. The program is capable of allowing geometrically distributed quantities demanded per requisition. Back orders at the main system are satisfied by filling the back orders to individual customers first followed by filling any back orders due to System One and System Two on a first-come, first-served basis.

When a demand occurs from the lower echelon systems for which there is not sufficient on-hand inventory at the main system, the maximum amount is filled and the rest is put into the back order queue. As soon as a shipment arrives at the main system, the back orders are filled. The times between the customer arrivals are independent of each other and exponentially distributed. The lead times are also independent of each other and gamma distributed.

2. System One and System Two

Both systems operate identically. The only difference might be in the values of the system parameters. They have the same periodic review policy which is: order up to R at each review time. The program is also capable of making a decision at each review time regarding the placement of an order if the inventory position is less than or equal to a threshold value, is an (r,R) policy. If r is taken to be R-1, then the system orders up to R at each review time even if there is only one demand in a period.

The times between customer arrivals are independent of each other and exponentially distributed. The number of units demanded per requisition is one. The lead times are independent of each other and gamma distributed.

B. HOW TO USE THE PROGRAM

Two simulations are given in Appendix C and Appendix D. The programs differ primarily in the type of output that is generated. The program given in Appendix C produces a Versatec plot output showing the inventory position for the main system and the lower echelon systems. A simulated period of up to 4 or 5 years can be run with a Class K job.

On the Versatec output for each system, there are two plots: one plot has a small triangle at each point representing the inventory position. The second plot represents the net inventory. The first figure shows the main system

values, the second figure shows the System One values and the third figure shows System Two values all plotted versus time.

The second program can be used to simulate operations over arbitrarily long periods of time. There are no dimension restrictions. This program gives the net inventory at the end of each period for all the systems; total demand in the periods of both System One and System Two; demand during a lead time for the main system; average on-hand inventory; and average number of items short per day for each system.

The input required by the programs is described by the variable definition list given in Appendix H. The programs use the IMSL subroutines for random number generation.

C. RUNS

1. Starting Conditions

There were two different starting conditions entered for the main system. In the first case the inventory position and net inventory were set initially to equal the order quantity. In the second case, the inventory position and the net inventory were set equal to the reorder point plus the order quantity. For Systems One and Two the inventory positions and net inventories were set initially at R_i.

2. <u>Results of Runs</u>

In all runs the length of time was 10 years. The average yearly results were obtained by dividing the results for the 10 year period by 10.

Using the policy parameters determined by the mathematical model and the first set of starting conditions the following simulated results were obtained.

a. Main System

The number of orders in 10 years = 51.

The number of back orders in 10 years = 3026.

The average on-hand inventory over 10 years = 313.026.

The average safety stock when an order arrives = 56.54 units.

The average annual costs are:

Ordering costs:	$2,550.00
Holding costs:	3,599.80
Back Order Costs:	1,513.00
Total Cost	$7,662.80

b. System One

Number of back orders in 10 years = 587.

The average on-hand inventory over 10 years = 114.482 units.

The average annual costs are:

Ordering and Reviewing Costs:	$1,004.18
Holding Costs:	1,316.54
Back Orders Costs:	293.50
Total Costs	$2,614.22

c. System Two

Number of back orders in 10 years = 287.

The average on-hand inventory over 10 years = 57.618 units.

The average annual costs are:

Ordering and Reviewing Costs:	$ 589.68
Holding Costs:	662.61
Back Orders Cost:	143.50
Total Costs	$1,395.79

(1) Total results

The total number of back orders for the whole system per year is 302.6 + 58.7 + 28.7 = 390.

The total annual variable cost for the whole system is $7,662.80 + $2,614.22 + $1,395.79 = $11,672.81.

The model was run again with the second set of starting conditions and the same set of policy parameter values. The simulation results are summarized below:

(a) Main System

The number of orders in 10 years = 50.

The number of back orders in 10 years = 1665.

The average on-hand inventory over 10 years = 346.937.

The average safety stock when an order arrives = 77.46.

The average annual costs are;

Ordering Costs:	$2,500.00
Holding Costs:	3,989.78
Back Order Costs:	832.50
Total Costs:	$7,322.28

(b) System One

Number of back orders in 10 years = 582.

The average on-hand inventory over 10 years = 118.696 units.

The average annual costs are;

Ordering and Reviewing Costs:	$1,004.18
Holding Costs:	1,365.00
Back Orders Costs:	291.00
Total Costs:	$2,660.18

(c) System Two

Number of back orders in 10 years: 314.

The average on-hand inventory over 10 years = 57.401 units.

The average annual costs are;

Ordering and Reviewing Costs:	$ 589.68
Holding Costs:	660.11
Back Orders Costs:	157.00
Total Costs:	$1,406.79

(2) Total Results

The total number of back orders for whole system per year is 166.5 + 58.2 + 31.4 = 256.

The total annual variable cost for whole system is $7,322.28 + $2,660.18 + $1,406.79 = $11,389.25.

3. Comparison of Both Starting Conditions

It is obvious that if both results are compared there is a considerable decrement on annual back orders but not a great difference in annual variable costs.

$$\frac{390-256}{390} = 0.3436$$

$$\frac{11672.81 - 11389.25}{11672.81} = 0.02429$$

IV. COMPARISON OF ANALYTICAL AND COMPUTER SIMULATION RESULTS

By comparing the analytical results with the simulation results, it is possible to evaluate the analytical model. If the measures of effectiveness predicted by the analytical model are reasonably close to those generated by the simulation, there is support for the analytical results. In the table below we compare the main measures of effectiveness: back orders and costs.

	Total Back Orders Per Year	Total Variable Costs Per Year
Analytical result	175.56	$10,808.17
Simulation result (For both starting conditions)	390.00	$11,672.81 or
	256.1	$11,389.25

This table shows that the average yearly back orders are considerably higher than what is estimated by the mathematical solution. In fact, the total number of back orders generated in the simulation does not even meet the constraint. Since the solutions produced by the simulation model, especially with respect to the number of back orders do not agree with the mathematical model, this suggests that some of the assumptions made in deriving the mathematical results are not reasonable. The major differences between the simulation results and the analytical results are found in the measures

of effectiveness at the main system. The results for the lower echelon track reasonably closely.

The costs are also a little higher than what is expected but much closer percentage wise.

As an explanation for the large differences observed in the number of back orders at the main system with the simulation and analytical models, let us reexamine the assumptions we made that affect back orders. Back orders results from inadequate amounts of safety stock to protect the inventory system against excessively large numbers of demands in a lead time. The safety stock is manipulated by control of the reorder point r. After the reorder point is hit and an order placed, the system is totally at the mercy of the demands that occur during the lead time. If the variance of lead time demand is underestimated, then large stockouts will occur, even if the mean lead time demand is estimated accurately. The lead time demand is affected by two random quantities: (1) the demand distribution and (2) the lead time distribution.

For purposes of making the mathematics tractable, we assumed in our analytical model that demands at the main system flowed in at a smooth continuous rate λ which was taken to be the sum of the rates of demand incurred directly at the main system λ_m and those which occurred at the lower echelon systems λ_1 and λ_2. The lead times were assumed to

be normally distributed with mean equal to $\lambda\tau$ and variance $= \lambda_{\tau}(1-\lambda_{\beta})$ where τ is the mean value of the lead time.

Because of the relatively high demand rates used in the example runs, the normal assumption should be justified by the Central Limit Theorem. However, as is illustrated by the Versatec plot output (See Appendix F) the demands at the main system are far from smooth. What happens is the demands which arrive directly at the main system cause the inventory position to drop off smoothly. However, when the replenishment orders from the lower echelon are received, large drops occur in the inventory position of the main system. Recall that the lower echelon systems order in batches once each period from the main system. If the main system simply tries to average out demands (as assumed by the analytical model), it will sometimes have very large amounts of excess stocks when shipments arrive and sometimes very large numbers of back orders. The high variance in lead time demand caused by the irregular demand actually seen at the main system causes the problem. Since all demands eventually flow through the main system and this is assumed by our analytical model, the problem cannot lie in the value used for the mean lead time demand.

Let us explore further what happens when reorders are triggered at the main system. Demands directly at the main system eat away smoothly at the inventory position. Then a

very large quantity, say X, is demanded by one of the lower echelon systems. There is a very good chance that the large order placed by the lower echelon system will trigger a reorder by the main system. However, if the demand causes a large overshoot of the reorder point, the main system may have much less stock to live off of until the shipment arrives. For example, suppose the inventory position is IP = 347, the reorder point is r = 300, and System One places it's resupply order for 200 units. An order will be placed by the main system but instead of having 300 units to keep it going until the order is received, it will have only 147 units. It is clear that if 300 is the amount of stock needed to provide reasonable protection against demands in a lead time, large numbers of back orders would be expected. Effectively, in the example above, the reorder level was not r = 300 but r = 147 and the safety stock negative. The impact of this surge in demand caused by the batching of demands received from the lower echelon systems is to reduce the "effective" reorder point from the value r to a value r'<r. Because the actual demand distribution witnessed b, the main system is difficult to describe mathematically, the actual value of r' cannot be determined analytically. However, it is clearly less than r and may be much more so.

In the next chapter we describe a policy modification for operation of the main system that was suggested by the

observations above. The modification attempts to allow the main system to anticipate the surge of demands that will be received by the lower echelon systems.

V. AN ALTERNATIVE SOLUTION

A. DESCRIPTION OF ALTERNATIVE PROCEDURE

Due to the reasons mentioned in Chapter IV, the number of back orders found by simulation were much higher than the number of back orders predicted by the mathematical model. The question is how to run the multi-echelon system so that the large number of back orders seen earlier can be reduced.

Obviously, what needs to be done is to reduce the impact of the very large demands that occur when the lower echelon systems place their resupply orders. With modern day communication and data systems, it would be feasible to allow the main system to "see" every demand that occurs anywhere in the system. If the main system is given the visibility, it will be able to take action to get the stock on its shelves in anticipation of the large demands from the lower echelon systems. The main system can do this if it uses as its reorder point the pseudo inventory position which is like the inventory position except that it decreases only when direct customer demands are encountered at any of the three systems. The pseudo inventory position is unaffected by the batch replenishment demands placed by the lower echelon systems. For example, if a customer requests

a unit from System One, the pseudo inventory position at the main system decreases by one. However, if System One places an order for 200 units at the main system, the pseudo inventory position does not change.

This new policy is referred to in this thesis as the "early warning policy." Clearly, the pseudo inventory position will always reach the reorder point before the inventory position. Therefore, orders will always be placed earlier and consequently, the number of back orders should decrease. The price paid will be in terms of extra holding costs. The results of a simulation using the early warning policy should be more nearly like those of the mathematical model since, in effect, the mathematical model makes the assumption of early warning. Implicitly, assumption of demand which is the superposition of the direct demands occurring at the main system and Systems One and Two is equivalent to the "early warning assumptions."

In the next section, results are given of a simulation of the multi-echelon system with early warning. The flowchart of the simulation model is given in Appendix B. The actual FORTRAN computer program is given in Appendix E.

B. COMPUTER SIMULATION RESULTS FOR EARLY WARNING POLICY

The same starting conditions and input parameters used in the previous simulation run were utilized here. The results are summarized as follows:

1. <u>Main System Results</u>

The number of orders in 10 years = 50.

Total number of back orders in 10 years = 126.

The average on-hand inventory = 488.093.

Average safety stock = 210.96.

The costs are:

Ordering costs =	$2,500.00
Holding costs =	5,613.00
Back order costs =	63.00
Total costs	$8,176.07

2. <u>System One Results</u>

Total number of back orders is 10 years = 665.

The average on-hand inventory over 10 years = 117.846.

The costs are:

Ordering and reviewing costs	=	$1,006.18
Holding Costs	=	1,355.23
Backorder costs	=	332.50
Total costs		$2,691.91

3. <u>System Two Results</u>

Total number of back orders in 10 years = 312.

The average on-hand inventory over 10 years = 58.552.

The costs are:

Ordering and reviewing costs	=	$ 589.68
Holding costs	=	673.35
Back orders costs	=	156.00
Total costs		$1,419.03

C. COMPARISON OF EARLY WARNING POLICY SIMULATION RESULTS WITH ANALYTICAL AND FIRST SIMULATION RESULTS

The comparison will be done with respect to total yearly back orders and total variable system costs (considering all three system entities).

	Entire System	
	Number of Back Orders Per Year	Total Cost
Analytical Result	175.56	$10,808.47
First Simulation Results	256.1	11,389.25
Early Warning Simulation Results	110.3	12,287.01

Since the effects of implementing the early warning policy will be observed primarily at the main system, we also produce the results obtained for the main system individually.

	Main System	
	Numbers of Back Orders Per Year	Total Cost
Analytical Result	108.05	$6,796.50
First Simulation Result	166.50	7,322.28
Early Warning Simulation Results	12.6	8,176.07

This table shows the differences better than the first one. The number of back orders decreases 88.3 percent, simultaneously as the costs increase about 10.44 percent. The reason for the higher cost is because the increment in safety stock increases the carrying costs.

VI. CONCLUSIONS

The differences between the results of the mathematical and the simulation model can be explained largely as a result of the assumptions made about the demand process. In the main system it was assumed that the demand was smooth (the superposition of three Poisson processes), but in the simulation model the actual demand at the main system was as it would be in actual practice. There were batches of demand placed by System One and System Two in addition to the individual customer demands directly at the main system. These demand batches in fact increased the variance in lead time demand beyond that modelled. This explains why many more back orders were generated in the simulation model than what was predicted by the mathematical model.

The simulation model developed in this thesis is useful for making comparisons and examining the effects of policy changes or parameter changes. Moreover, it is one of the best ways to check the reasonableness of all of the simplifying assumptions made in order to obtain analytical solutions.

The mathematical results described in this thesis do not adequately determine the reorder point. The predicted number of stockouts is much less than the simulated numbers. As explained earlier, this is probably due to the assumptions

made in the model about the variance of lead time demand. Further study is needed to determine what could be done in the analytical model to better approximate what happens in actual practice.

The early warning policy discussed in this thesis did provide for great reductions in the number of stockouts system wide. Since stockouts are probably the most important consideration in military supply systems, the early warning policy is recommended, even though the holding costs are larger. Additional study is required to see if the reorder level in the early warning policy can be reduced substantially from the value determined by the mathematical model. Preliminary evidence is that the reorder level can be reduced significantly (25 percent or so) without generating excessively many back orders if the early warning policy is used.

Our simulation models allow us to view the effect of changes but they cannot be used to optimize the values of the policy parameters. For that objective, additional work in the mathematical modelling area is required.

In this thesis we have tried to model a multi-echelon inventory system analytically, by linking together the individual echelons and locations through a single objective function and a constraint on backorders system wide. We, knowingly, were making various simplifying assumptions to facilitate the derivation of solutions. As reported above,

the resulting solution for the reorder level at the main system led to many more back orders than predicted. The other solutions; R_1, R_2, Q, T_1, and T_2 appear to be satisfactory.

In order to model adequately the multi-echelon system, it will probably be necessary to build into the determination of the reorder lead at the main system the values of the parameters R_1 and R_2 at the lower echelon systems. This will be the only way to accurately describe the actual demand process that is observed at the main system. We recommend future work in this area.

APPENDIX A

FLOWCHARTS OF FIRST SIMULATION MODEL

Subroutine One = Ship arrivals to System One

Subroutine Two = Ship arrivals to System Two

Subroutine Three = Ship arrivals to Main System

Subroutine Four = Periodic review of System One

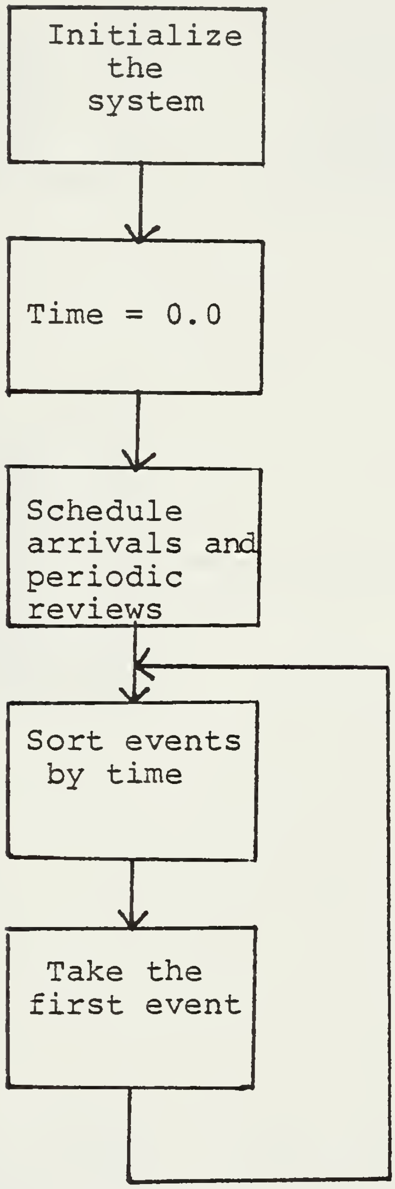
Subroutine Five = Periodic review of System Two

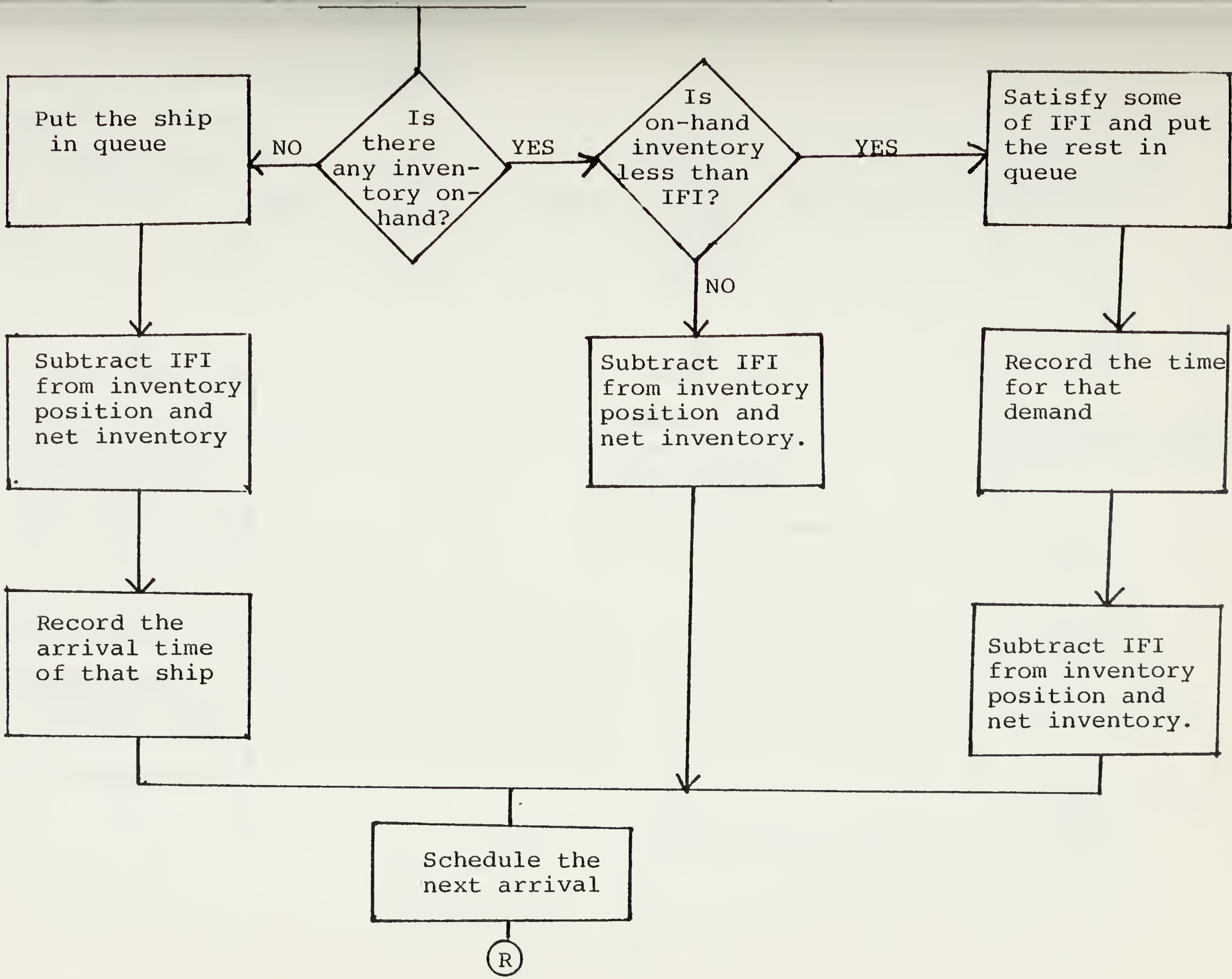
Subroutine Six = Shipment arrival to System One

Subroutine Seven = Shipment arrival to System Two

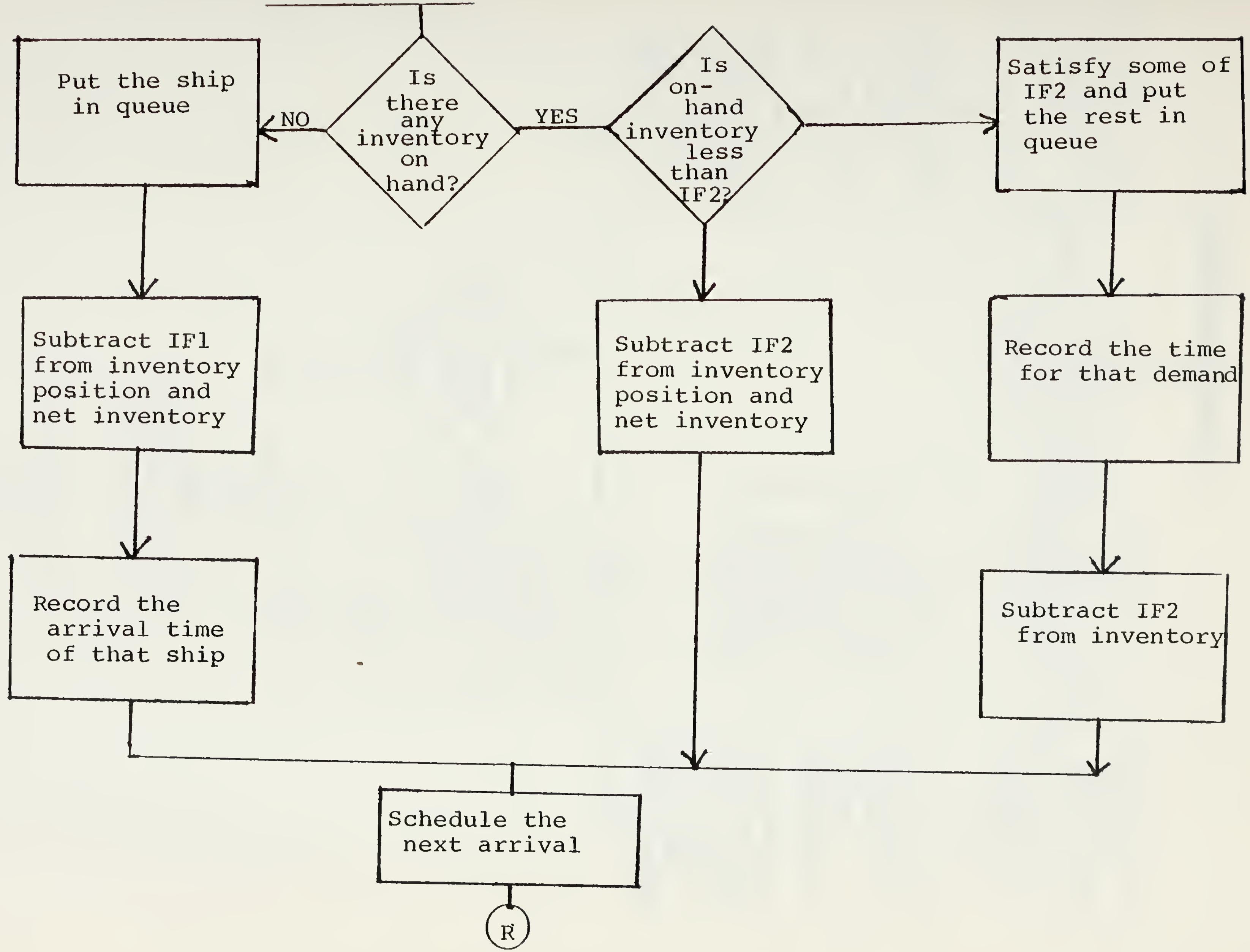
Subroutine Eight = Shipment arrival to Main System

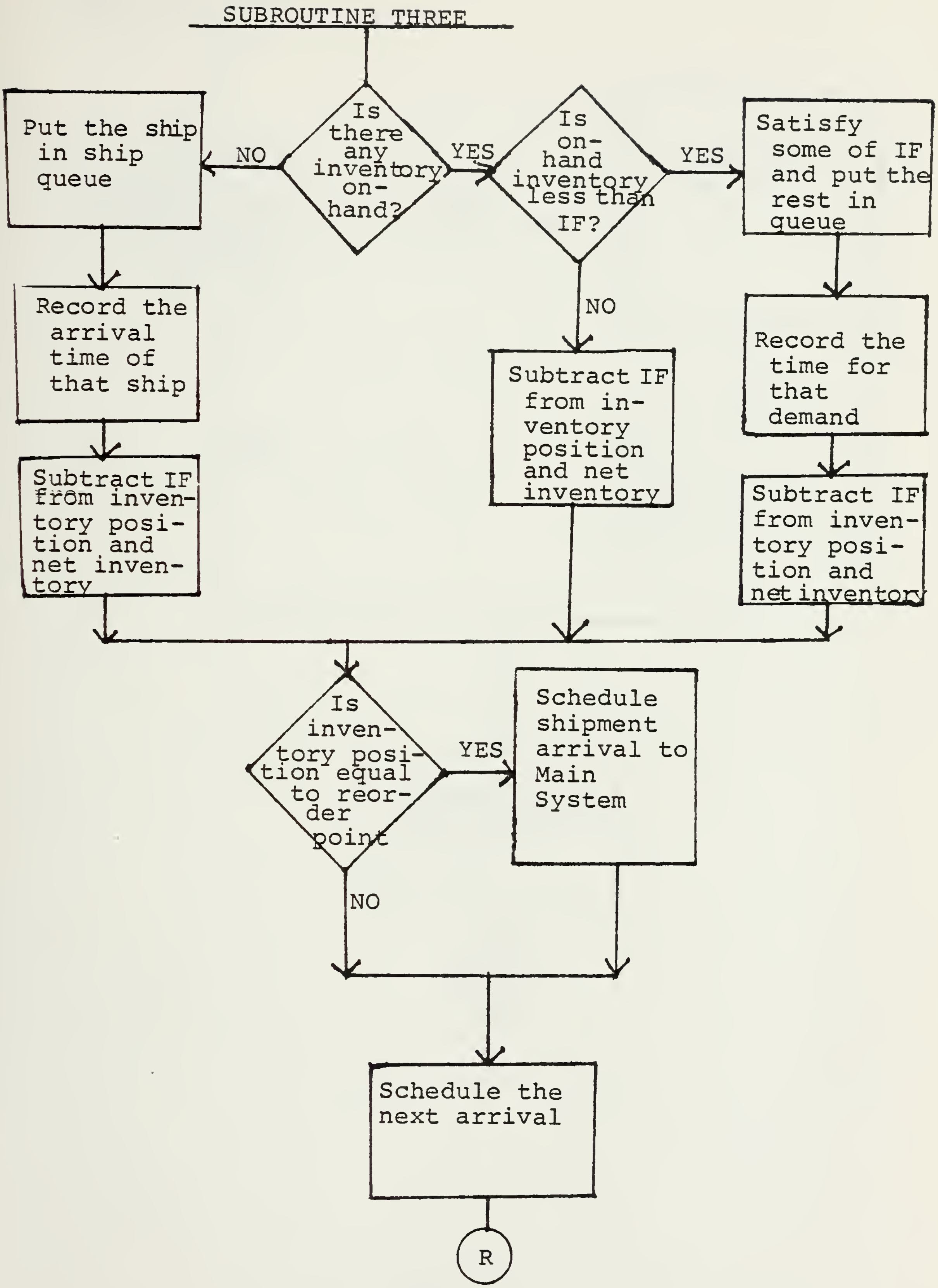
MAIN PROGRAM

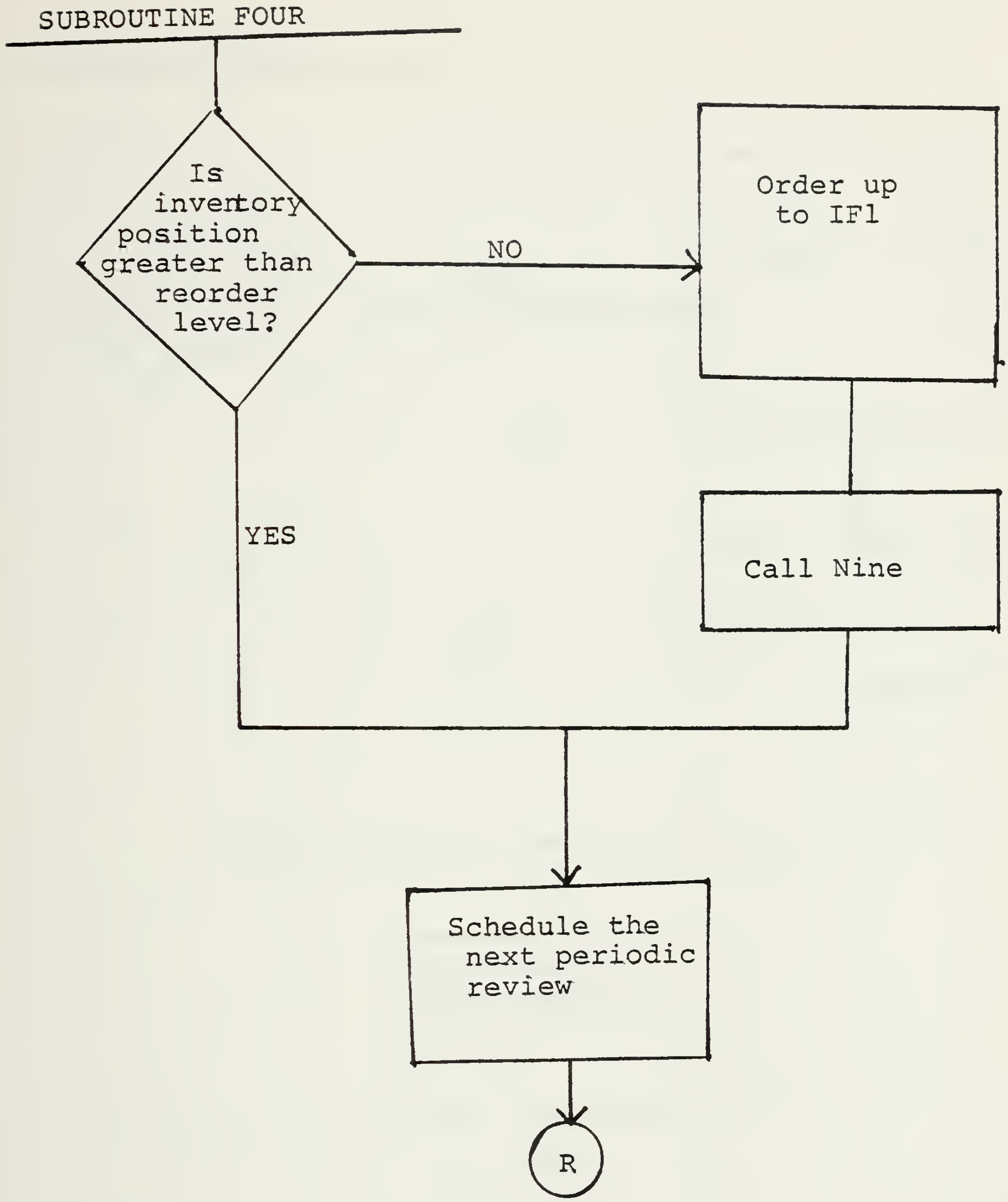


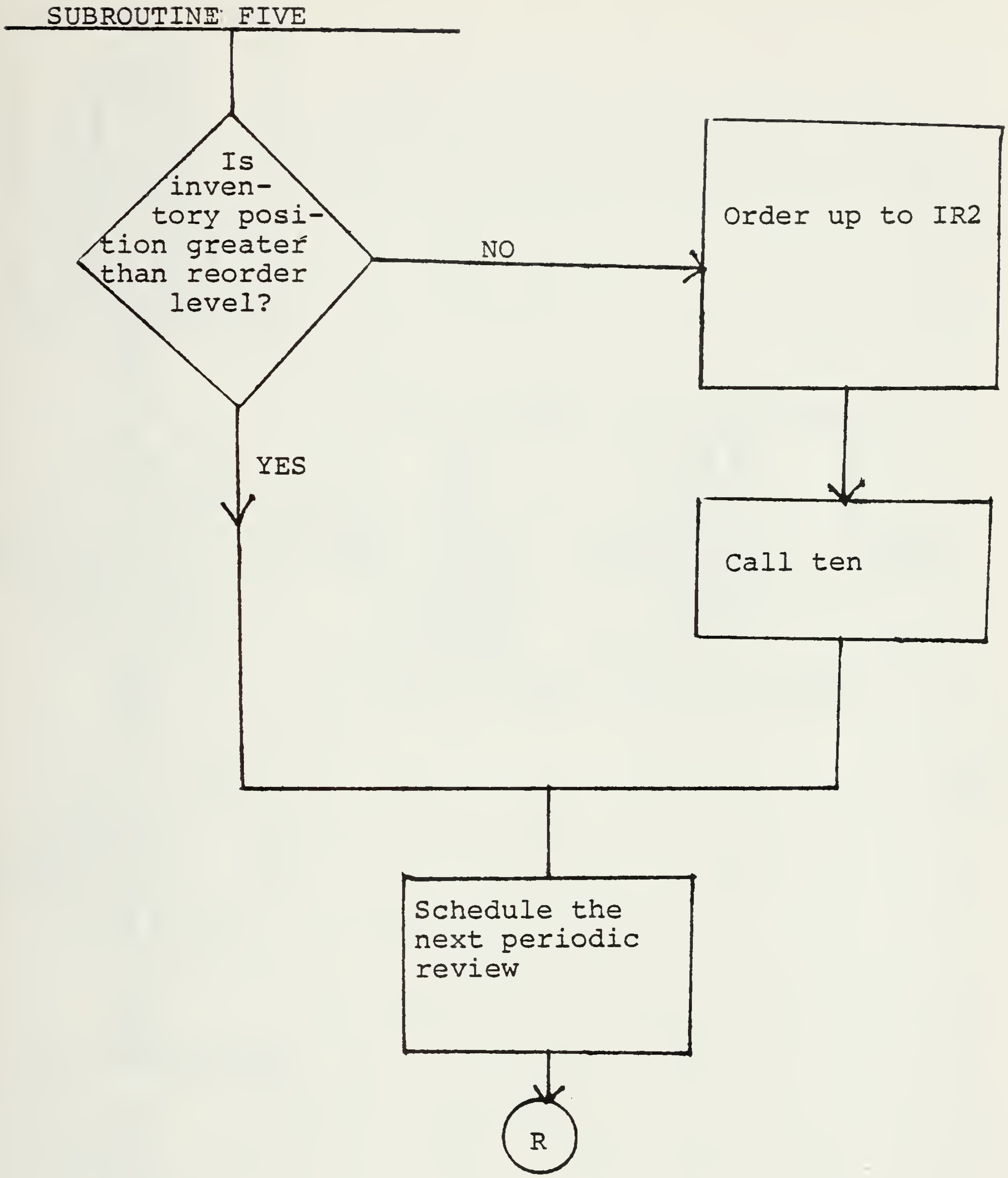

Put the ship in queue
NO
Is there any inventory on-hand?
YES
Is on-hand inventory less than IFI?
YES
Satisfy some of IFI and put the rest in queue
NO
Subtract IFI from inventory position and net inventory
Subtract IFI from inventory position and net inventory.
Record the time for that demand
Record the arrival time of that ship
Subtract IFI from inventory position and net inventory.
Schedule the next arrival
R

SUBROUTINE TWO

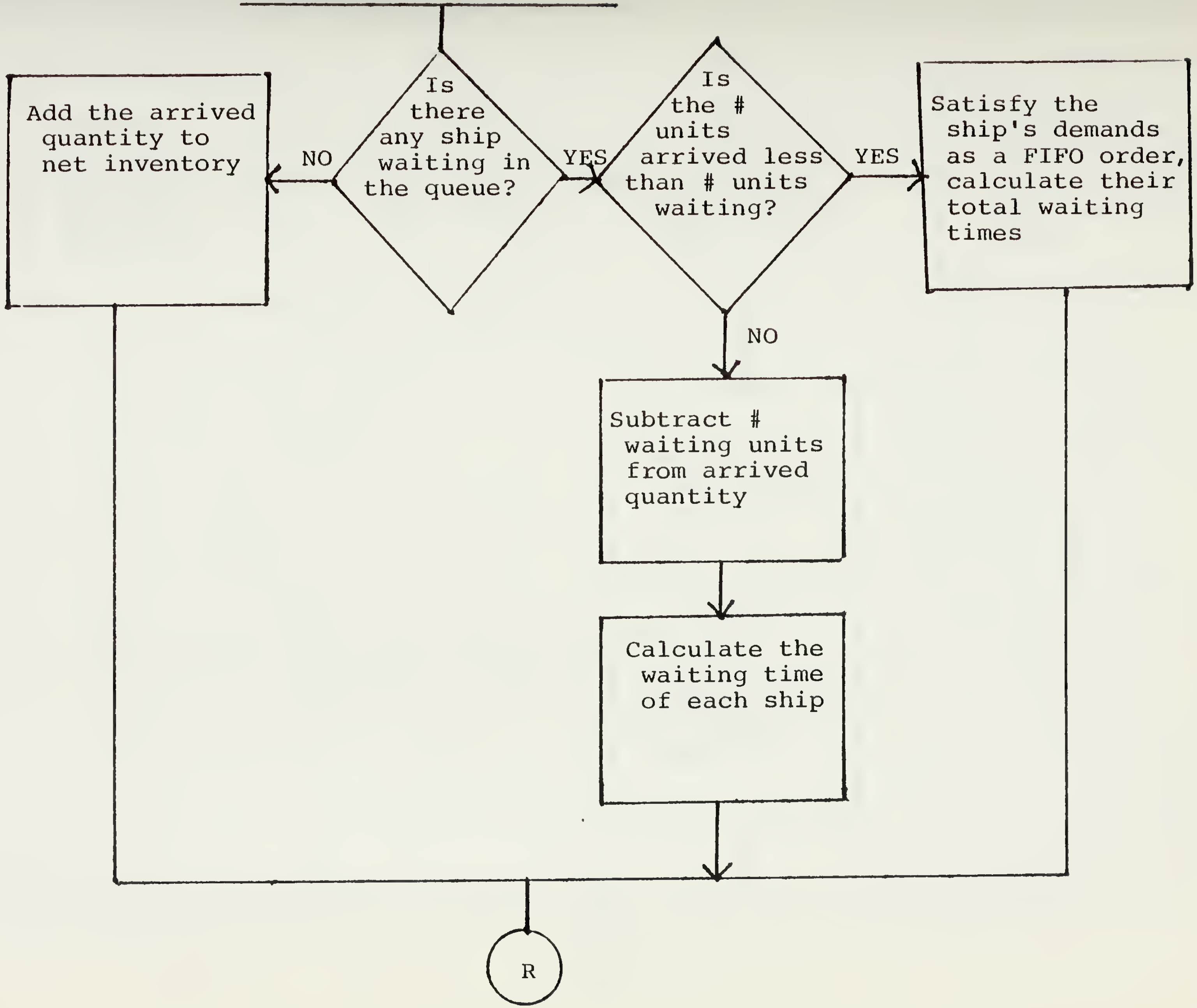



SUBROUTINE THREE
Is there any inventory on-hand?
NO
Put the ship in ship queue
Record the arrival time of that ship
Subtract IF from inventory position and net inventory
YES
Is on-hand inventory less than IF?
YES
Satisfy some of IF and put the rest in queue
Record the time for that demand
Subtract IF from inventory position and net inventory
NO
Subtract IF from inventory position and net inventory
Is inventory position equal to reorder point
YES
Schedule shipment arrival to Main System
NO
Schedule the next arrival
R

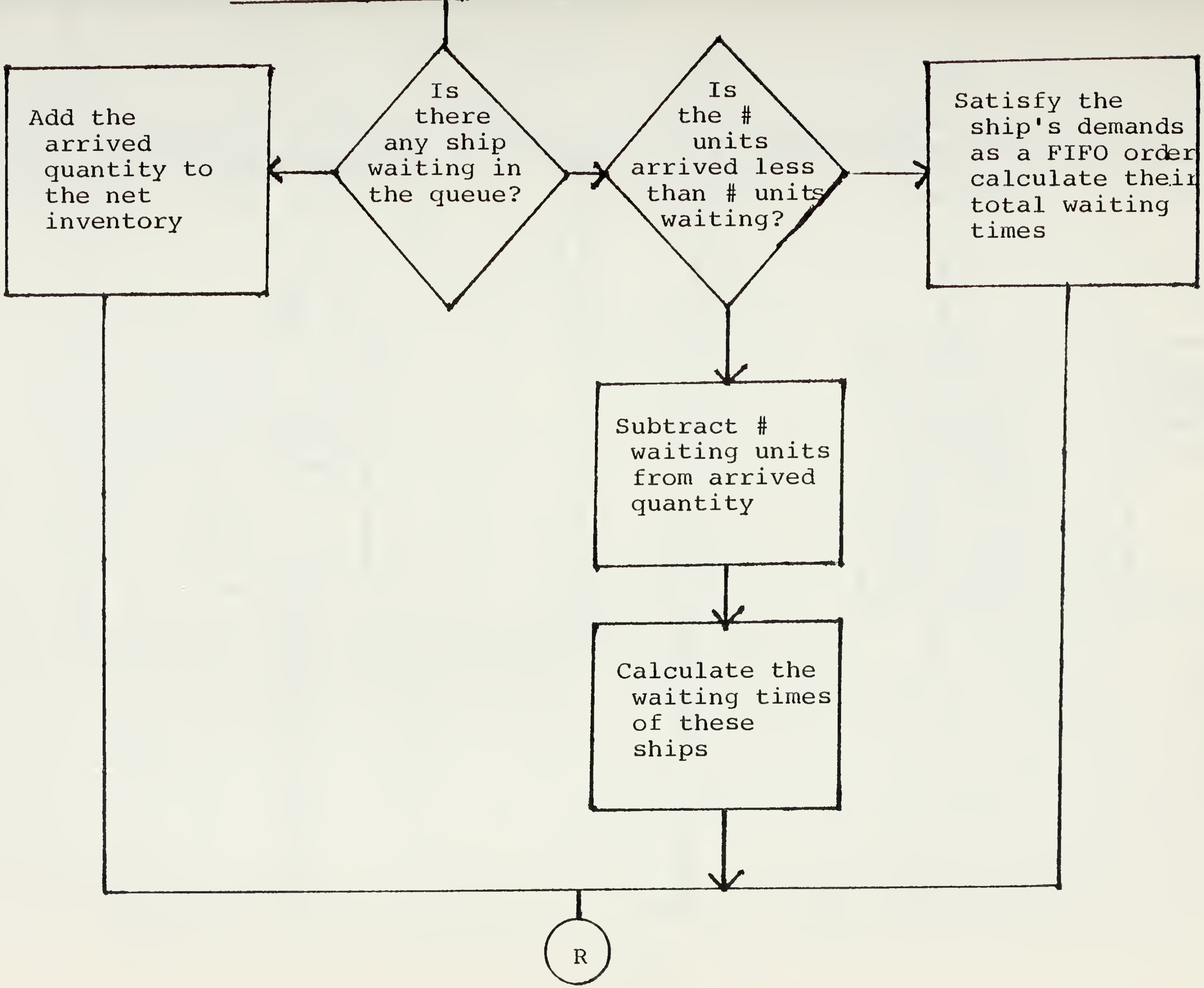

SUBROUTINE FOUR
Is inventory position greater than reorder level?
NO
YES
Order up to IF1
Call Nine
Schedule the next periodic review
R


SUBROUTINE FIVE
Is inventory position greater than reorder level?
NO
YES
Order up to IR2
Call ten
Schedule the next periodic review
R

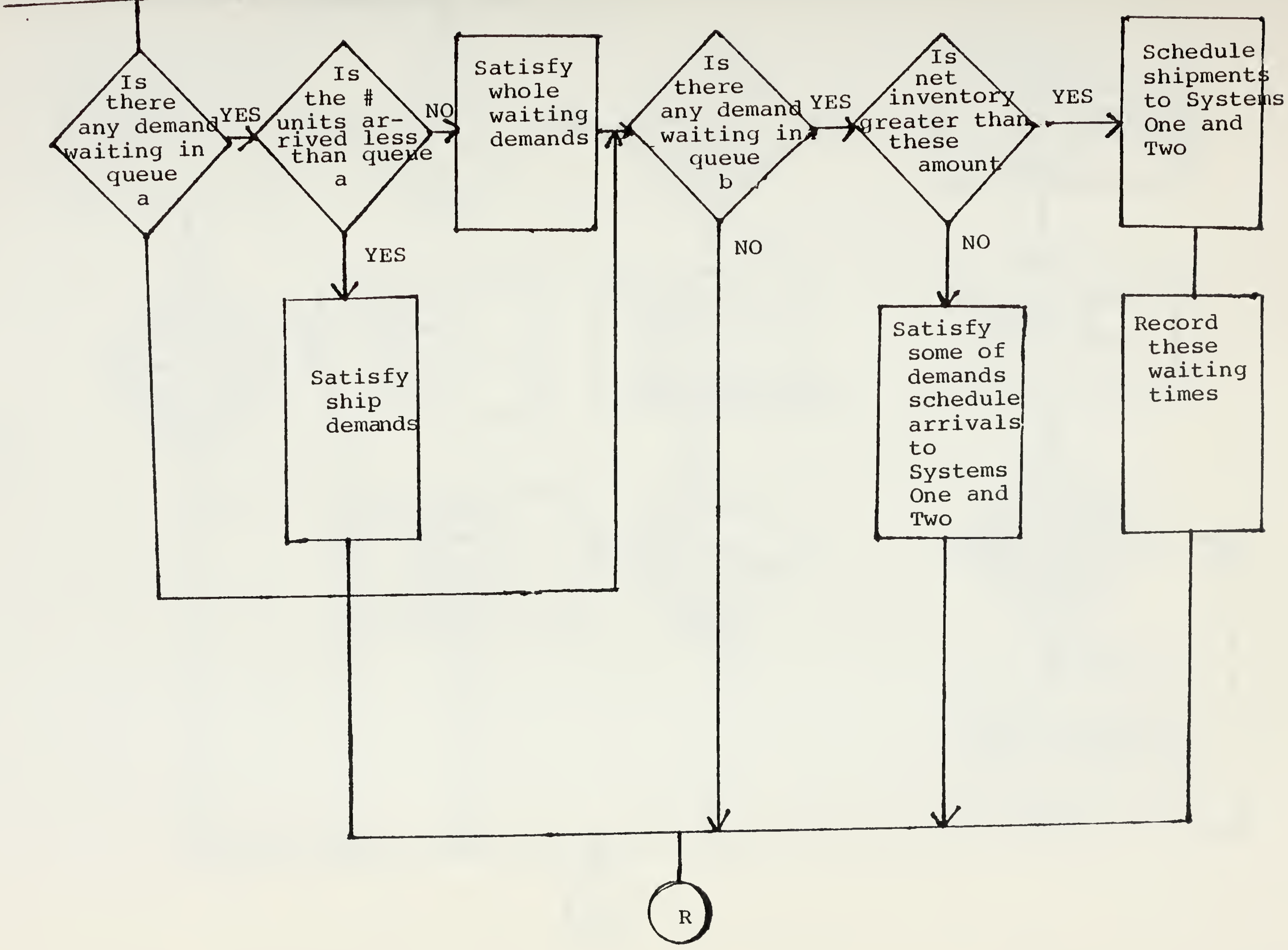
SUBROUTINE SIX



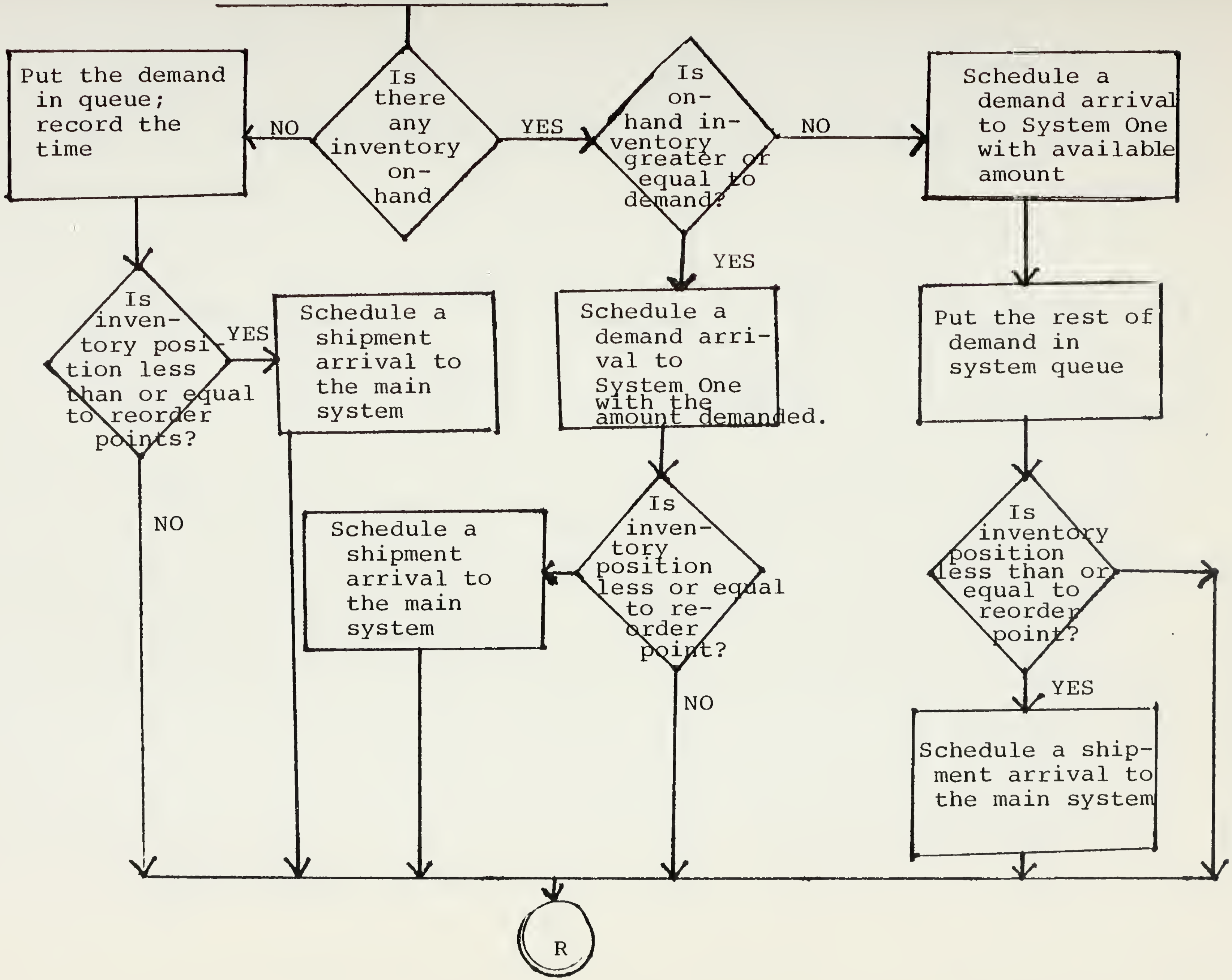
SUBROUTINE SEVEN



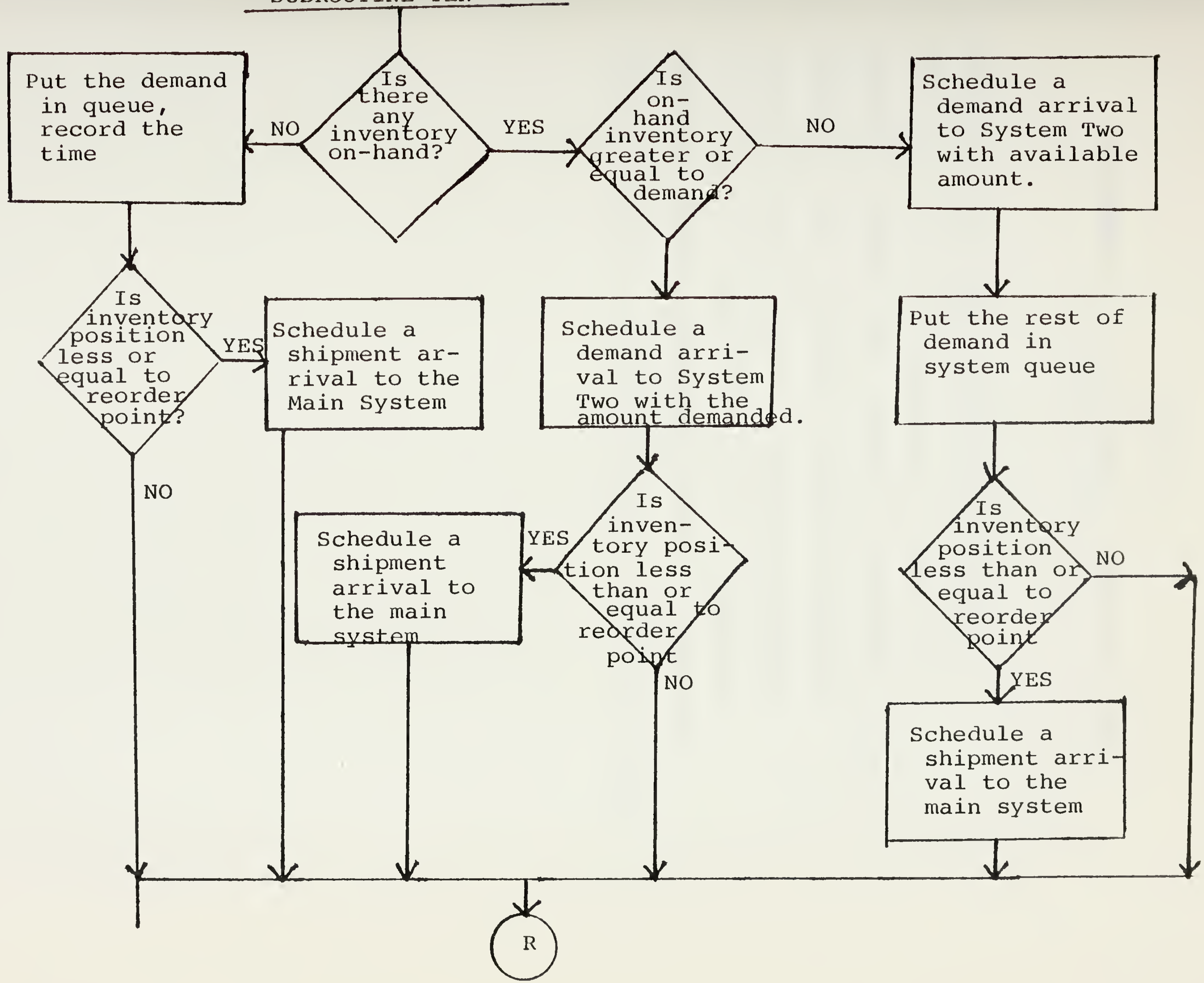
SUBROUTINE EIGHT



SUBROUTINE NINE



SUBROUTINE TEN



APPENDIX B

Flowcharts of Early Warning Simulation Model

Subroutine One = Ship arrivals to System One

Subroutine Two = Ship arrivals to System Two

Subroutine Three = Ship arrivals to the Main System

Subroutine Four = Periodic review of System One

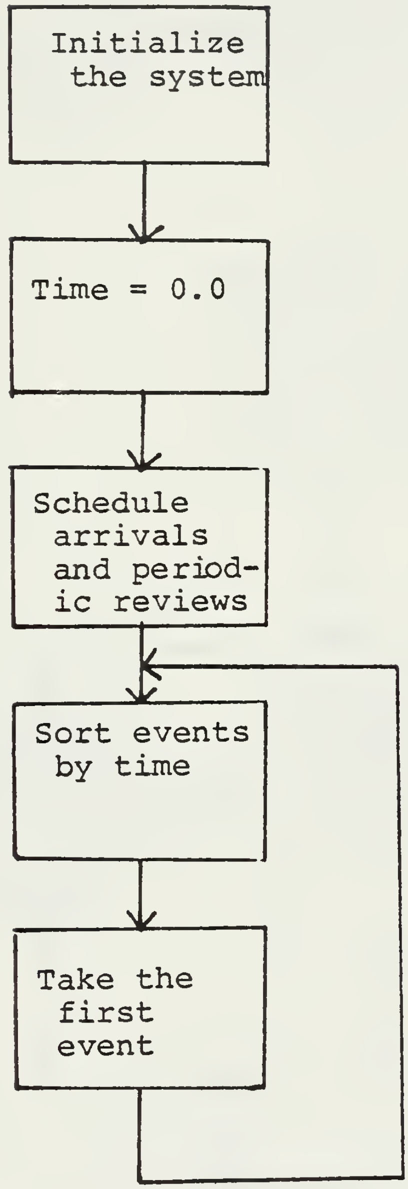
Subroutine Five = Periodic review of System Two

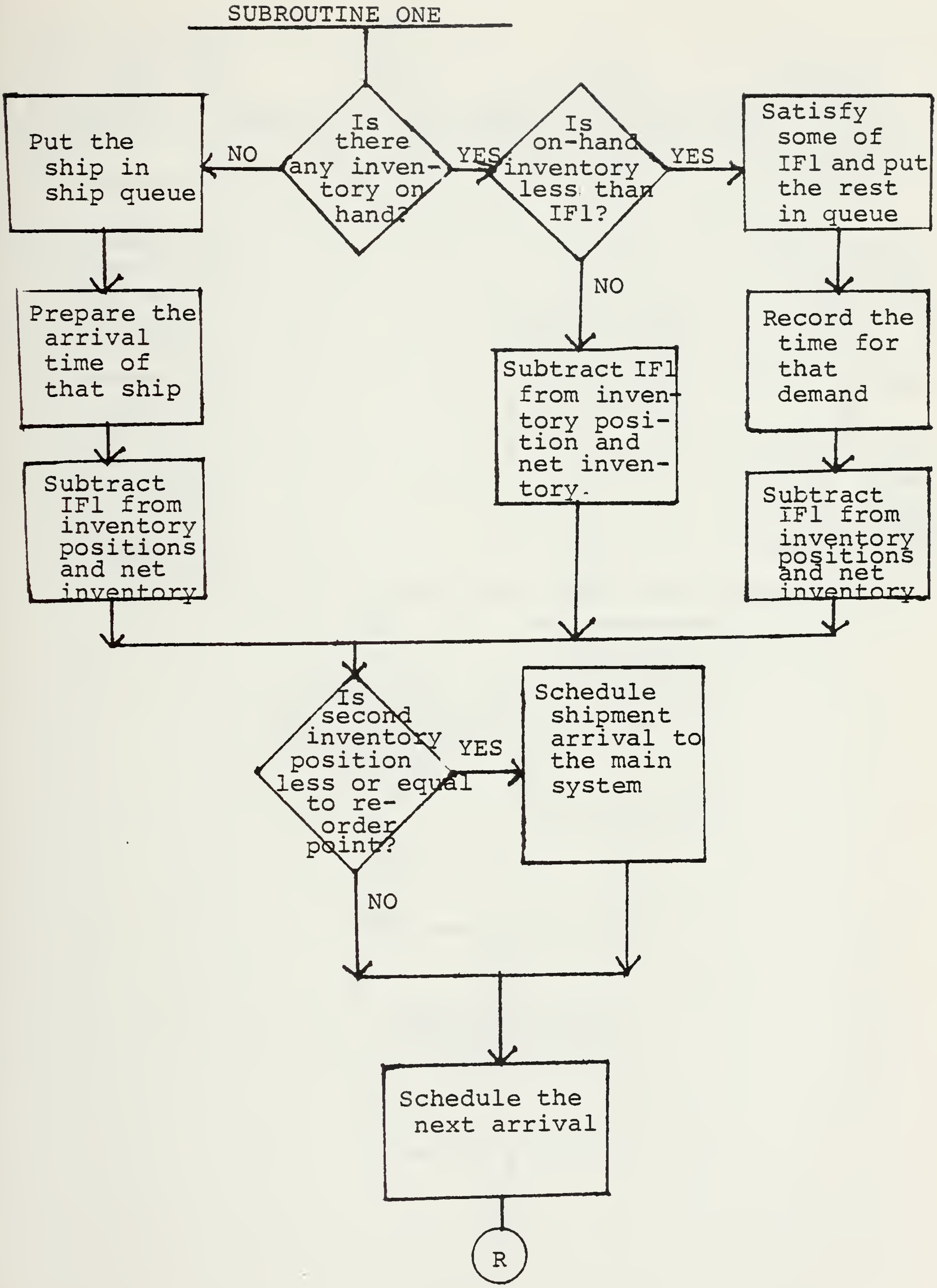
Subroutine Six = Shipment arrival to System One

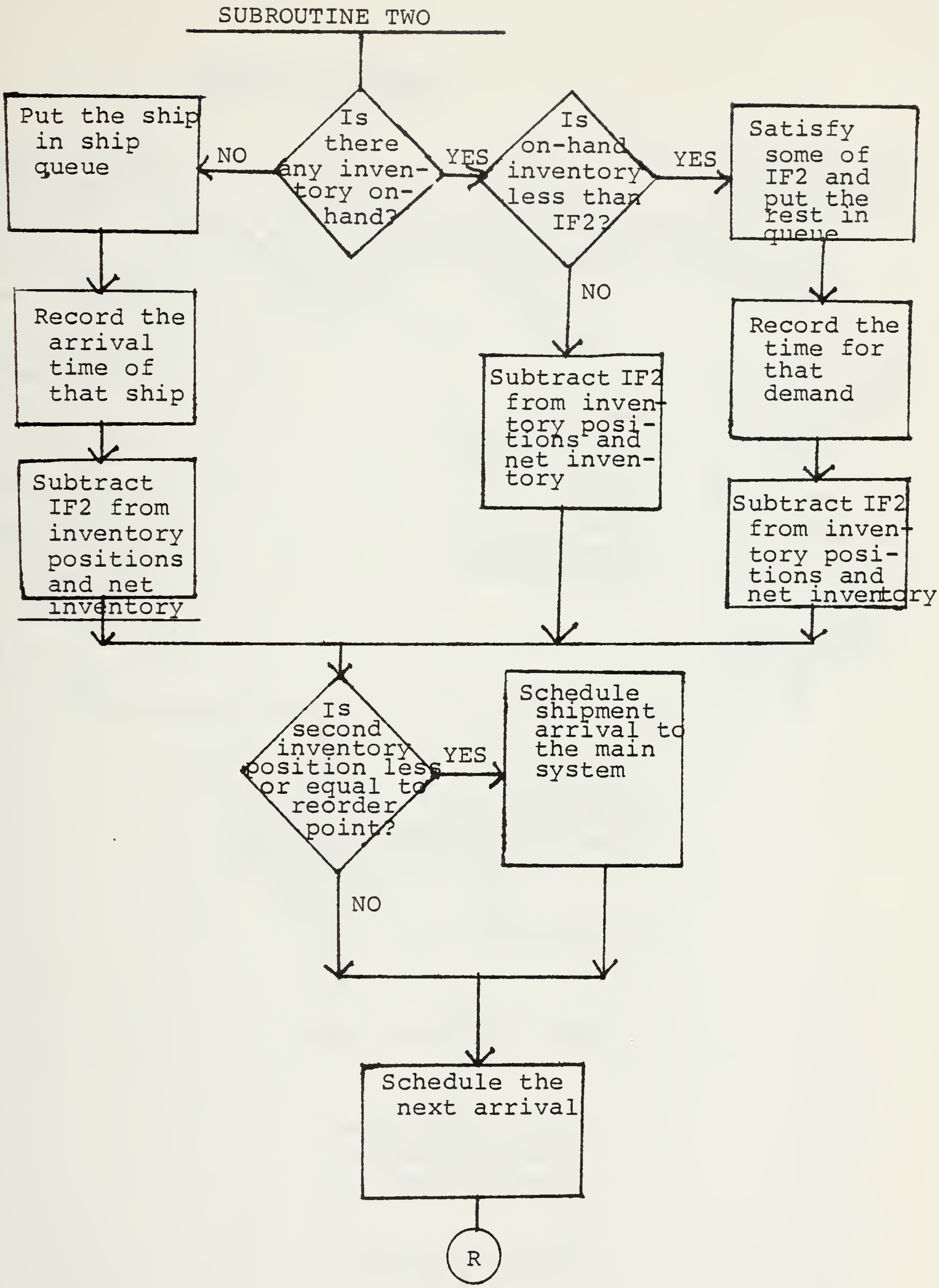
Subroutine Seven = Shipment arrival to System Two

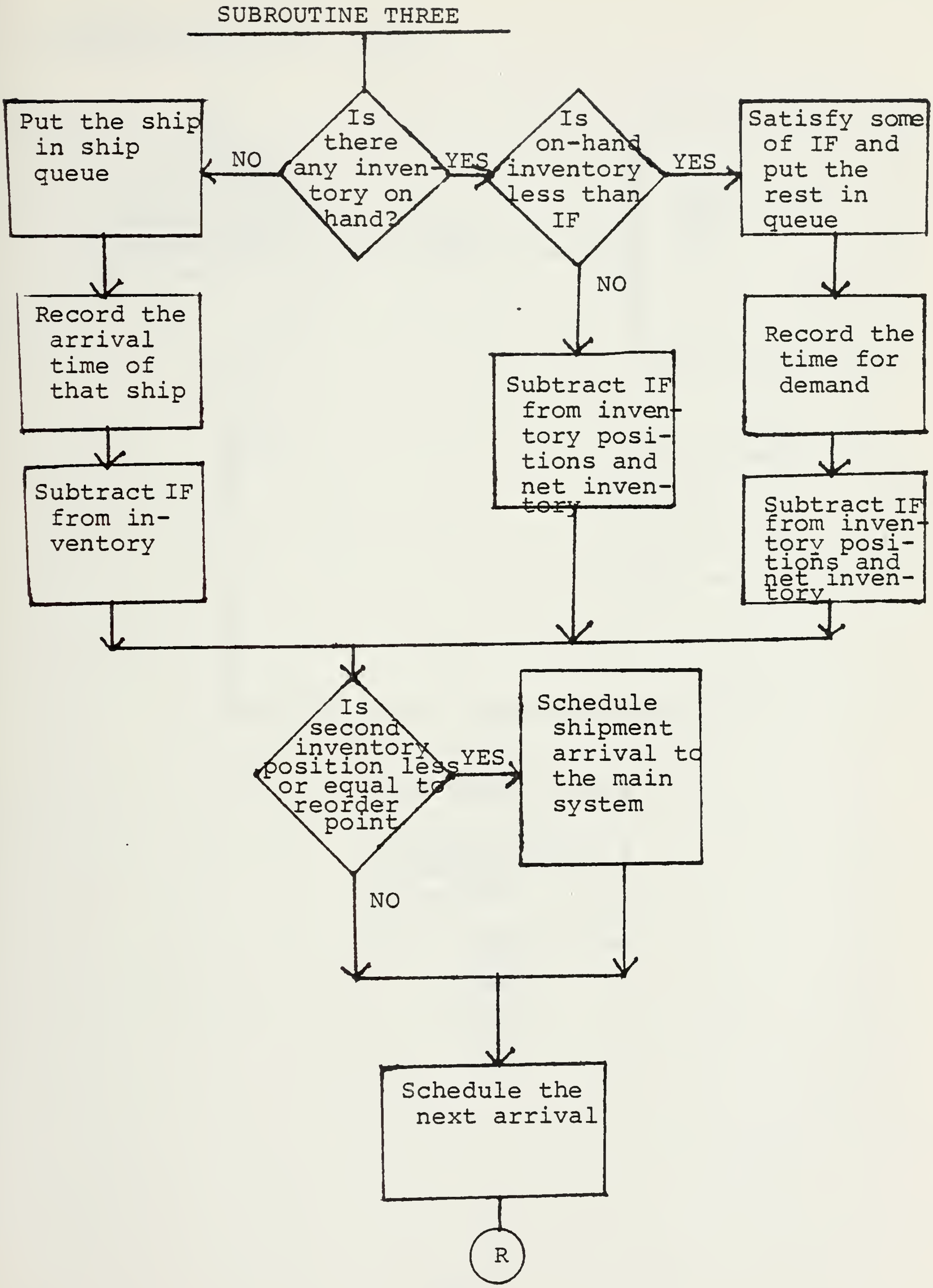
Subroutine Eight = Shipment arrival to the Main System

MAIN PROGRAM

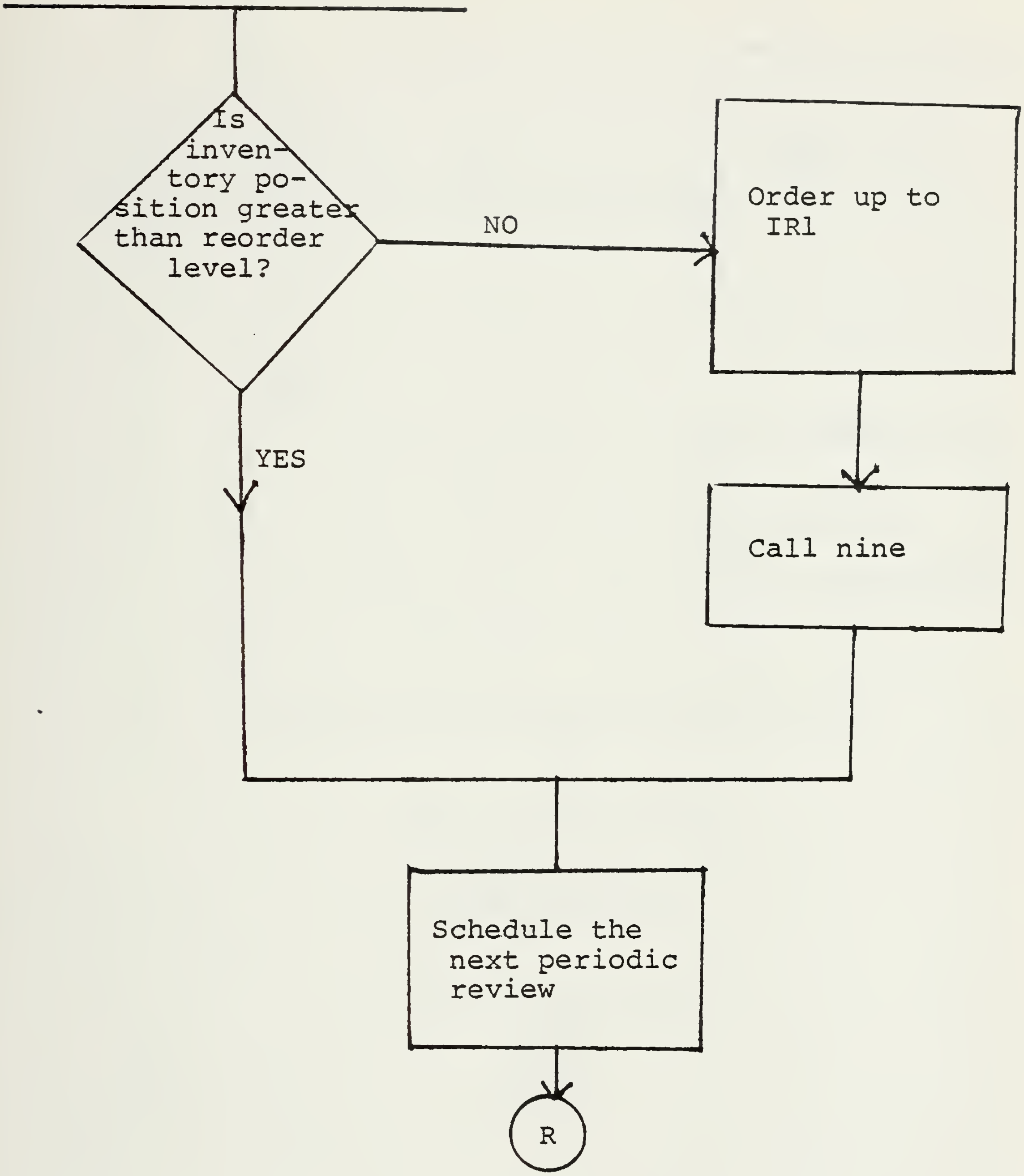


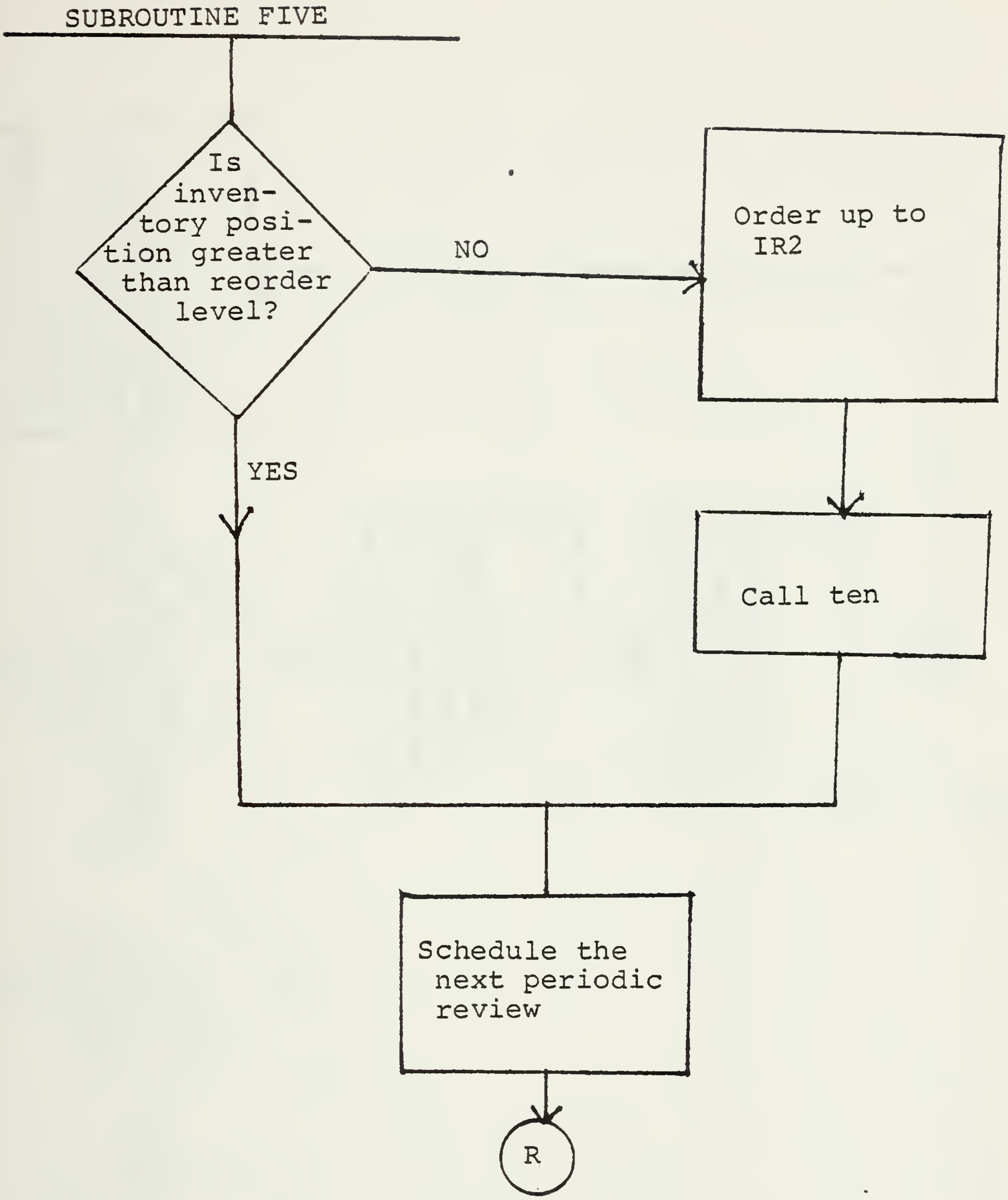

SUBROUTINE ONE
Is there any inventory on hand?
NO
Put the ship in ship queue
Prepare the arrival time of that ship
Subtract IF1 from inventory positions and net inventory
YES
Is on-hand inventory less than IF1?
YES
Satisfy some of IF1 and put the rest in queue
Record the time for that demand
Subtract IF1 from inventory positions and net inventory
NO
Subtract IF1 from inventory position and net inventory.
Is second inventory position less or equal to re-order point?
YES
Schedule shipment arrival to the main system
NO
Schedule the next arrival
R


SUBROUTINE TWO
Is there any inventory on-hand?
NO
Put the ship in ship queue
Record the arrival time of that ship
Subtract IF2 from inventory positions and net inventory
YES
Is on-hand inventory less than IF2?
YES
Satisfy some of IF2 and put the rest in queue
Record the time for that demand
Subtract IF2 from inventory positions and net inventory
NO
Subtract IF2 from inventory positions and net inventory
Is second inventory position less or equal to reorder point?
YES
Schedule shipment arrival to the main system
NO
Schedule the next arrival
R


SUBROUTINE THREE
Put the ship in ship queue
NO
Is there any inventory on hand?
YES
Is on-hand inventory less than IF
YES
Satisfy some of IF and put the rest in queue
Record the arrival time of that ship
NO
Record the time for demand
Subtract IF from inventory positions and net inventory
Subtract IF from inventory
Subtract IF from inventory positions and net inventory
Is second inventory position less or equal to reorder point
YES
Schedule shipment arrival to the main system
NO
Schedule the next arrival
R

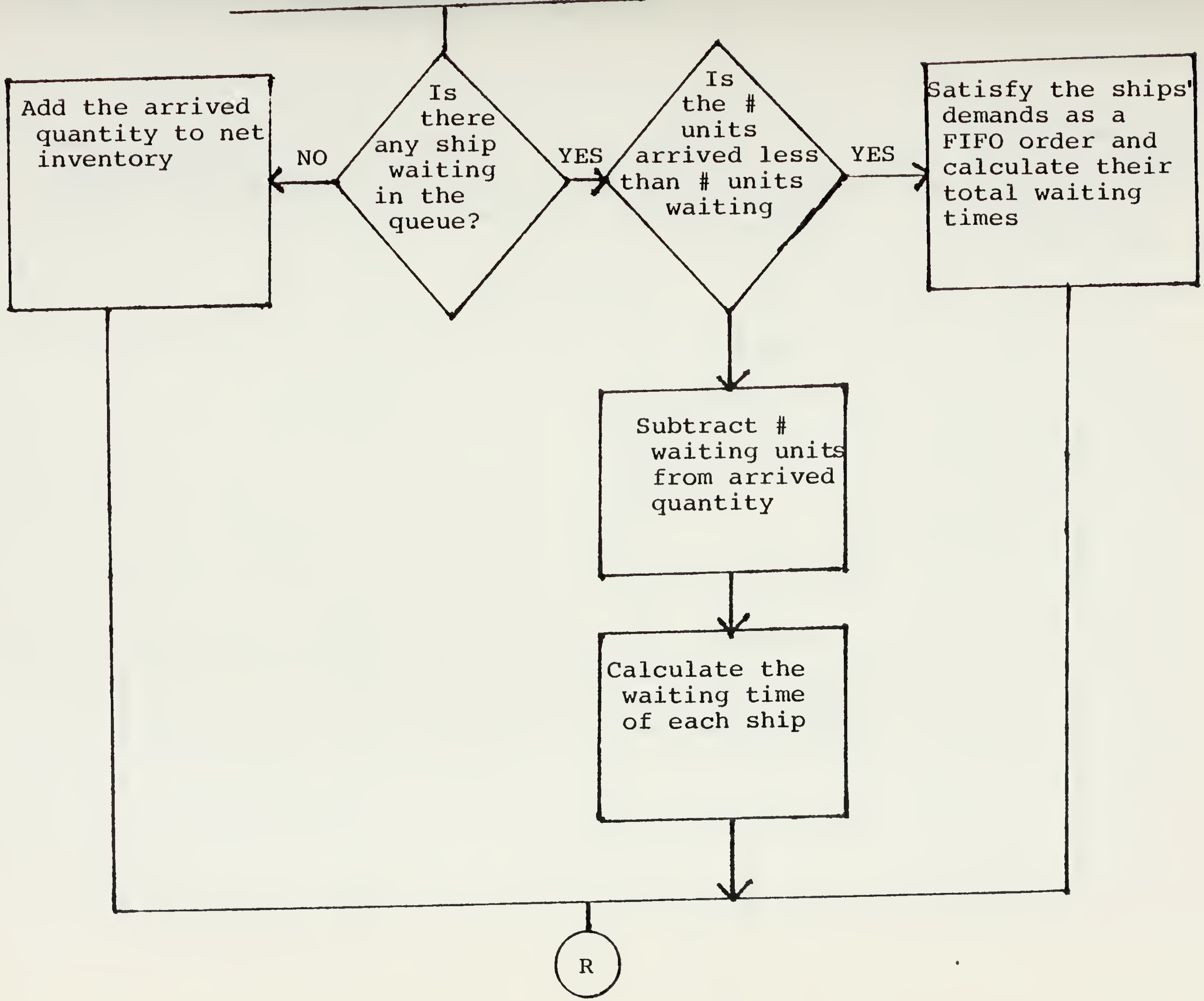
SUBROUTINE FOUR



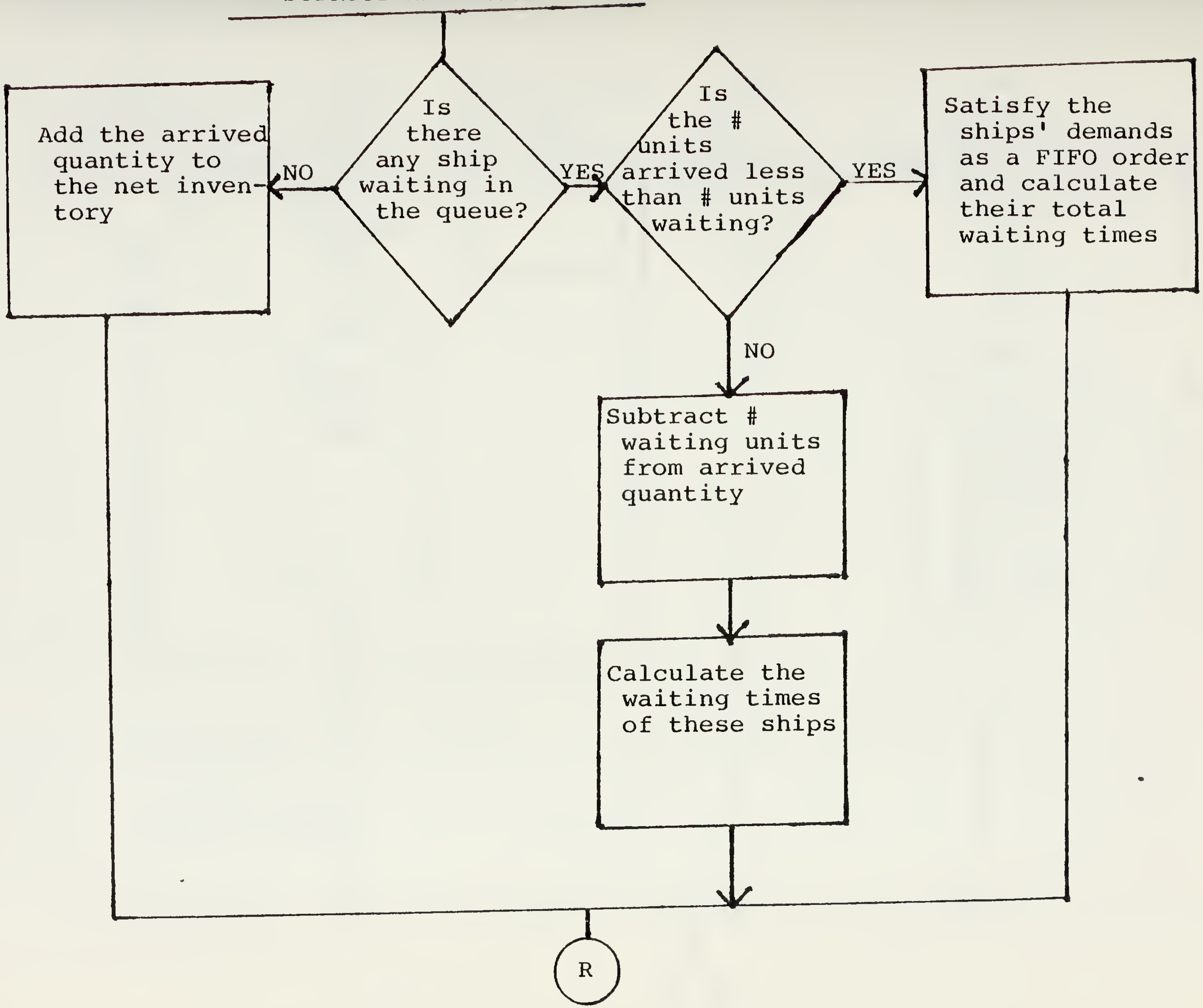


SUBROUTINE FIVE
Is inventory position greater than reorder level?
NO
YES
Order up to IR2
Call ten
Schedule the next periodic review
R

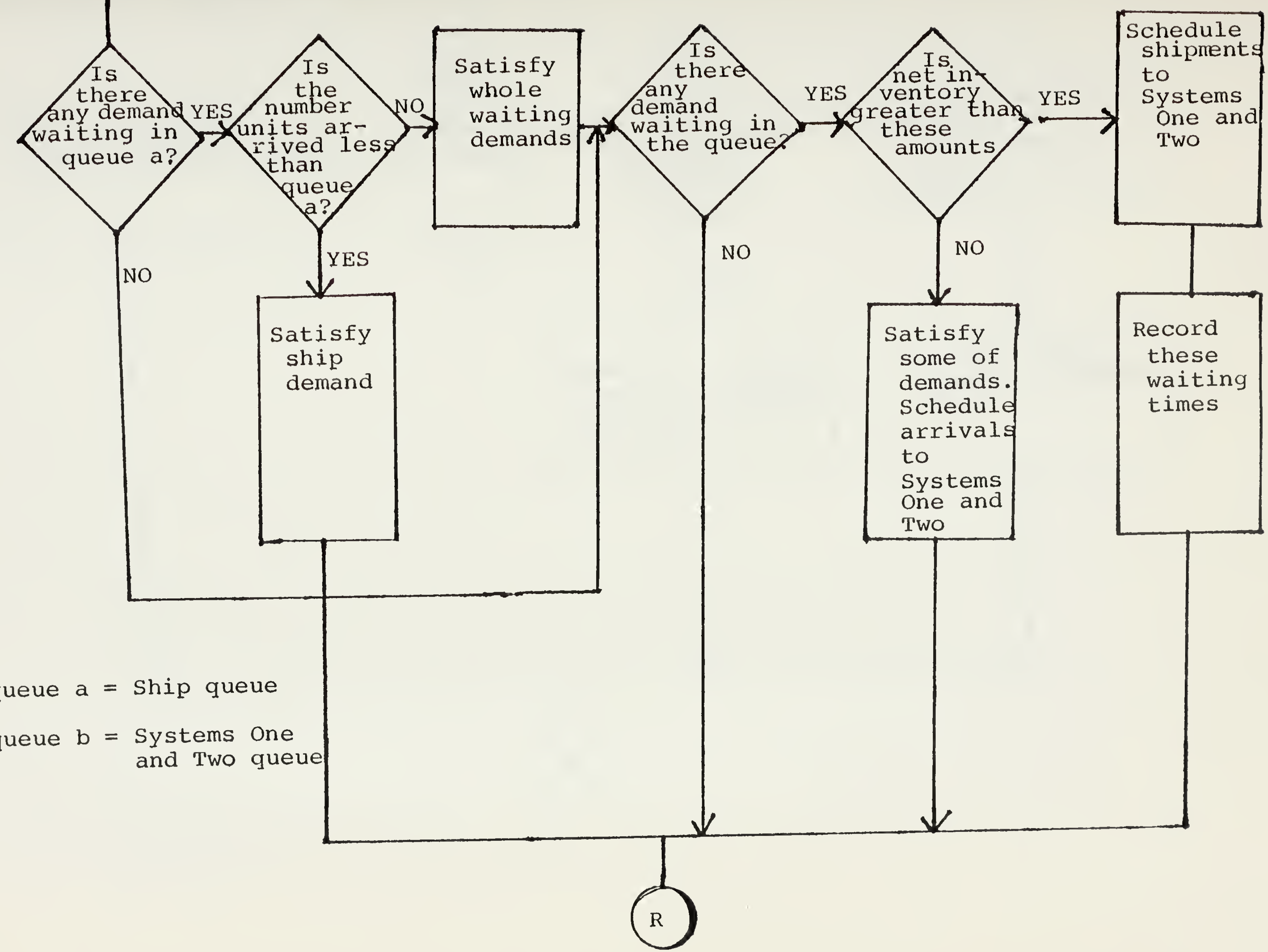
SUBROUTINE SIX



SUBROUTINE SEVEN



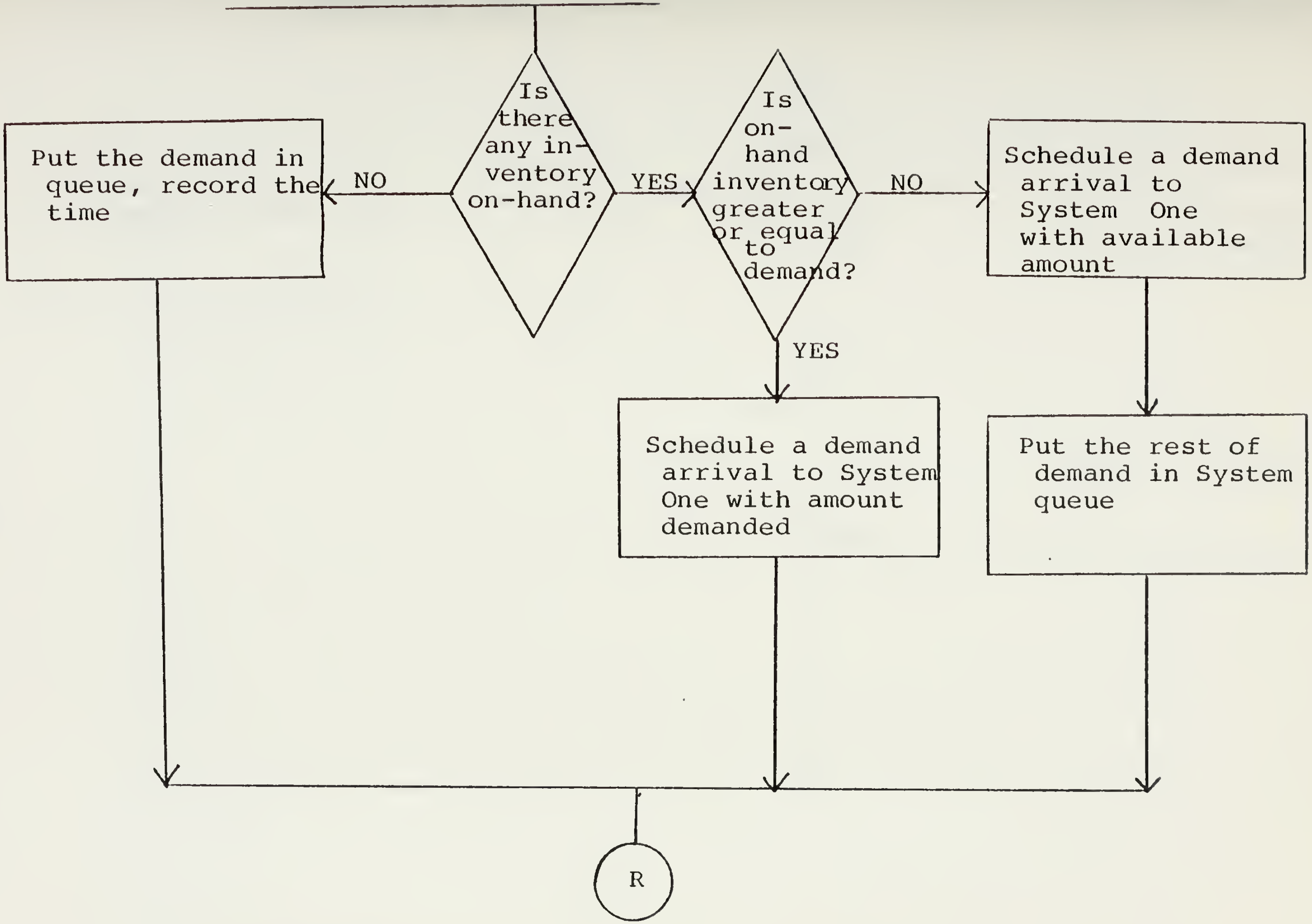
SUBROUTINE EIGHT



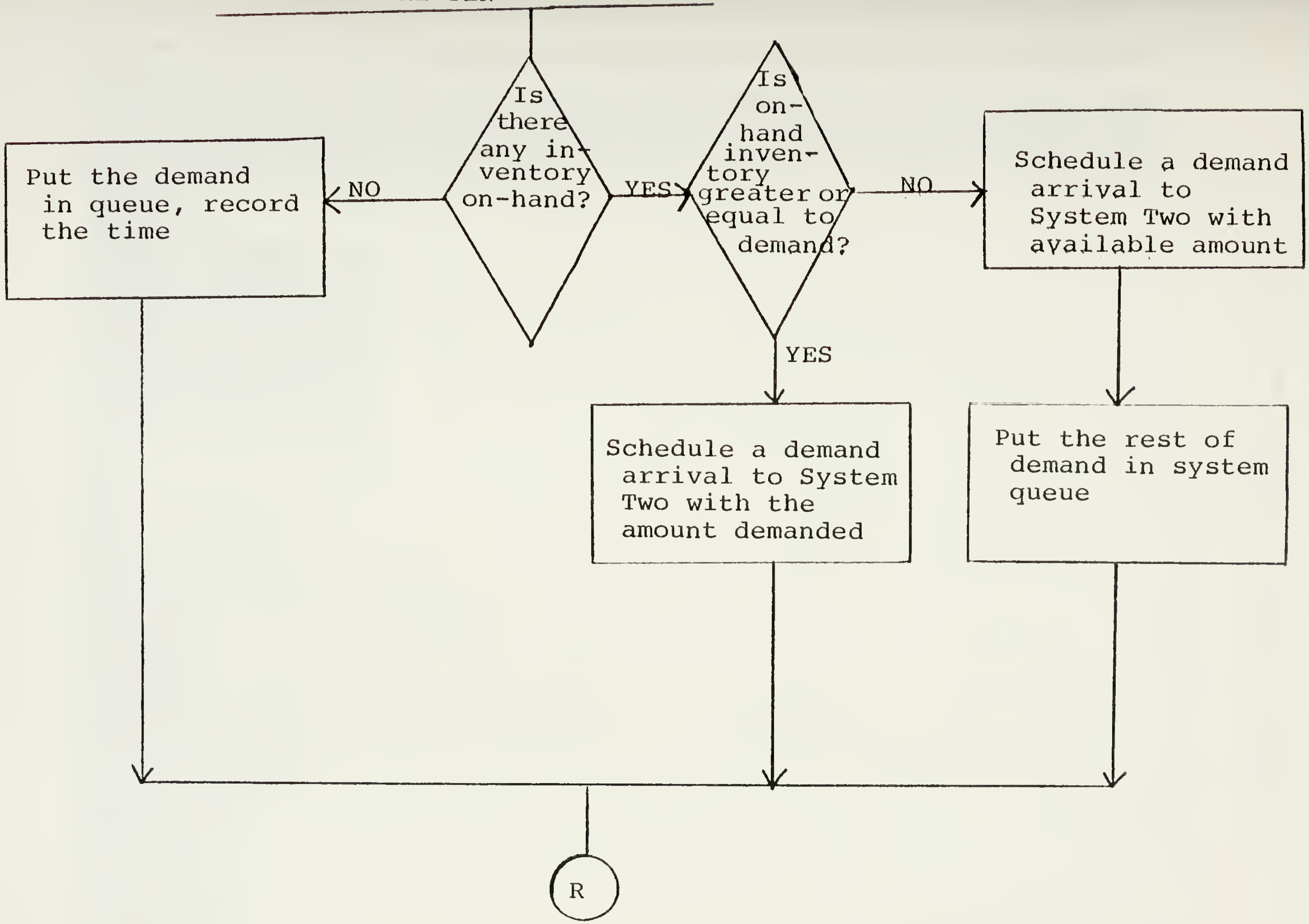
queue a = Ship queue

queue b = Systems One and Two queue

SUBROUTINE NINE



SUBROUTINE TEN



APPENDIX C

Simulation Program; Versatec Plotter

```
      REAL*8 DSEED1,DSEED2,DSEED3,DSEED4,DSEED5,DSEED6,DSEED7,DSEED8,DSE
     1ED9
      DIMENSION EVENT(900),IEVENT(900),IM(900),QU1(900),QU2(900),QU3(900
     1),QS(900),IG1(900),IG2(900),IG3(900),IG(900),IA1(900),IA2(900),IA(
     1900),Z(50),Z1(50),Z2(50),X(4000),X1(4000),X2(4000),V(4000),V1(4000
     1),V2(4000),Y(4000),Y1(4000),Y2(4000),WK(50),WS(50),WZ(50),IK1(1),I
     1K2(1),IK3(1),S1(1),S2(1),S3(1)
      NP=4000
      NS=900
      NM=30
      DSEED1=123456.0D0
      DSEED2=247658.0D0
      DSEED3=365274.0D0
      DSEED4=258732.0D0
      DSEED5=541863.0D0
      DSEED6=433215.0D0
      DSEED7=651563.0D0
      DSEED8=265418.0D0
      DSEED9=167519.0D0
      I=0
      J=0
      K=0
      L=0
      K1=1
      K2=1
      K3=1
      TW1=0.0
      TW2=0.0
      TW3=0.0
      TW4=0.0
      TW5=0.0
      TOH=0.0
      TOH1=0.0
      TOH2=0.0
      DO 1 N=1,50
      EVENT(N)=99999.
      IEVENT(N)=0
      QU1(N)=0.0
      QU2(N)=0.0
      QU3(N)=0.0
      IG1(N)=0
      IG2(N)=0
      IG3(N)=0
      IA1(N)=0
      IA2(N)=0
      IA(N)=0
    1 CONTINUE
      DO 2 N=1,10
```

```
      IM(N)=0
      QS(N)=0.0
      IG(N)=0
    2 CONTINUE
      IF=0
      IF1=0
      IF2=0
      ID=0
      ID1=0
      ID2=0
      READ(5,100) IR,IS
  100 FORMAT(2I10)
      READ (5,110) IR1,IS1,T1
  110 FORMAT(2I10,F10.0)
      READ (5,110) IR2,IS2,T2
      READ (5,120) YEAR
  120 FORMAT(F10.0)
      READ (5,130) A,B
  130 FORMAT  (2F4.0)
      READ (5,130) A1,B1
      READ (5,130) A2,B2
      READ (5,140) XM1
      READ (5,140) XM2
      READ (5,140) XM3
  140 FORMAT(F4.0)
      READ (5,150) P1
      READ (5,150) P2
      READ (5,150) P3
  150 FORMAT(F6.0)
      IQ=IR+IS
      IQ1=IR1
      IQ2=IR2
      XL=(YEAR/365.)*33.
      TIME=0.0
      IP=IR+IS
      IP1=IR1
      IP2=IR2
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      X2(K3)=IQ2
      V(K3)=IP2
      Y2(K3)=TIME
      CALL GGEXN (DSEED1,XM1,1,S1)
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)
```

```
      IF1=1
      DO 3 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 4
    3 CONTINUE
    4 EVENT(II)=TIME+S1(1)
      IEVENT(II)=1
      CALL GGEXN (DSEED2,XM2,1,S2)
      CALL GGEOT (DSEED8,1,P2,WS,IK2)
      IF2=1
      DO 5 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 6
    5 CONTINUE
    6 EVENT(II)=TIME+S2(1)
      IEVENT(II)=2
      CALL GGEXN (DSEED3,XM3,1,S3)
      CALL GGEOT (DSEED9,1,P3,WK,IK3)
      IF=1
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
    8 EVENT(II)=TIME+S3(1)
      IEVENT(II)=3
      DO 9 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 10
    9 CONTINUE
   10 EVENT(II)=TIME+T1
      IEVENT(II)=4
      DO 11 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 12
   11 CONTINUE
   12 EVENT(II)=TIME+T2
      IEVENT(II)=5
      DO 13 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 14
   13 CONTINUE
   14 EVENT(II)=YEAR
      IEVENT(II)=9
      GO TO 26
   15 EVENT(IN)=99999.
      IEVENT(IN)=0
   26 IN=1
      DO 16 KI=2,NM
```

```
      IF(EVENT(IN).GT.EVENT(KI)) IN=KI
   16 CONTINUE
      TIME=EVENT(IN)
      IL=IEVENT(IN)
      IJ=IN
      GO TO (17,18,19,20,21,22,23,24,25),IL
   17 CALL ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSEED1,DS
     1EED7,K2,NP,X1,Y1,V1,NM,NS,TOH1)
      GO TO 15
   18 CALL TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSEED2,DS
     1EED8,K3,NP,X2,Y2,V2,NM,NS,TOH2)
      GO TO 15
   19 CALL THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEED3,DS
     1EED6,DSEED9,A,B,K1,NP,X,Y,V,NM,NS,IA,IR,IS,TOH)
      GO TO 15
   20 CALL FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IR1,I
     1S,IP,A,B,A1,B1,DSEED4,DSEED6,K1,K2,NP,X,Y,V,X1,Y1,V1,NM,T1,NS,IS1,
     1TOH)
      GO TO 15
   21 CALL FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IR2,I
     1S,IP,A,B,A2,B2,DSEED5,DSEED6,K1,K3,NP,X,Y,V,X2,Y2,V2,NM,T2,NS,IS2,
     1TOH)
      GO TO 15
   22 CALL SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,K2,NP,X1,V1,Y1,NM,NS)
      GO TO 15
   23 CALL SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,K3,NP,X2,V2,Y2,NM,NS
     1)
      GO TO 15
   24 CALL EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,QU3,IG
     13,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,K1,NP,X,Y,V,NM,NS,IP)
      GO TO 15
   25 TW1=TW1/YEAR
      TW2=TW2/YEAR
      TW3=TW3/YEAR
      TW4=TW4/YEAR
      TW5=TW5/YEAR
      WRITE (6,200) TW1,TW2,TW3,TW4,TW5
  200 FORMAT (' TW1=',F10.4,' TW2=',F10.4,' TW3=',F10.4,' TW4=',F10.4,'
     1TW5=',F10.4)
      TOH=TOH/YEAR
      TOH1=TOH1/YEAR
      TOH2=TOH2/YEAR
      WRITE (6,201) TOH,TOH1,TOH2
  201 FORMAT (' TOH=',F10.3,' TOH1=',F10.3,' TOH2=',F10.3)
      CALL PLOTG (Y,X,K1,1,1,0,'TIME',4,'INVENTORY QUANTITY',18,0.0,0.0,
     10.0,0.0,XL,20.)
      CALL PLOTG (Y,V,K1,2,1,52,'TIME',4,'INVENTORY QUANTITY',18,0.0,0.0
     1,0.0,0.0,XL,20.)
```

```
      CALL PLOTG (Y1,X1,K2,1,1,0,'TIME',4,'INVENTORY QUANTITY',18,0.0,0.
     10,0.0,0.0,XL,20.)
      CALL PLOTG (Y1,V1,K2,2,1,52,'TIME',4,'INVENTORY QUANTITY',18,0.0,0
     1.0,0.0,0.0,XL,20.)
      CALL PLOTG (Y2,X2,K3,1,1,0,'TIME',4,'INVENTORY QUANTITY',18,0.0,0.
     10,0.0,0.0,XL,20.)
      CALL PLOTG (Y2,V2,K3,2,1,52,'TIME',4,'INVENTORY QUANTITY',18,0.0,0
     1.0,0.0,0.0,XL,20.)
      CALL PLOT (0.0,0.0,999)
      STOP
      DEBUG SUBCHK
      END
      SUBROUTINE ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSE
     1ED1,DSEED7,K2,NP,X1,Y1,V1,NM,NS,TOH1)
      REAL*8 DSEED1,DSEED7
      DIMENSION EVENT(NS),IEVENT(NS),QU1(NS),IG1(NS),X1(NP),Y1(NP),V1(NP
     1),WZ(50),IK1(1),S1(1)
      SS=Y1(K2)
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      IF(IQ1.GT.0) GO TO 1
      I=I+1
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      QU1(I)=TIME
      IG1(I)=IF1
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      GO TO 3
    1 WW=0.0
      WW=(TIME-SS)*X1(K2)
      TOH1=TOH1+WW
      IF(IQ1.LT.IF1) GO TO 2
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      GO TO 3
    2 I=I+1
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      QU1(I)=TIME
```

```
      IG1(I)=IF1-IQ1
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
    3 CALL GGEXN (DSEED1,XM1,1,S1)
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)
      IF1=1
      DO 4 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 5
    4 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    5 EVENT(II)=TIME+S1(1)
      IEVENT(II)=1
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSE
     1ED2,DSEED8,K3,NP,X2,Y2,V2,NM,NS,TOH2)
      REAL*8 DSEED2,DSEED8
      DIMENSION EVENT(NS),IEVENT(NS),QU2(NS),IG2(NS),X2(NP),Y2(NP),V2(NP
     1),WS(50),IK2(1),S2(1)
      SS=Y2(K3)
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      IF(IQ2.GT.0) GO TO 1
      J=J+1
      IQ2=IQ2-IF2
      IP2=IP2-IF2
      QU2(J)=TIME
      IG2(J)=IF2
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      GO TO 3
    1 WW=0.0
      WW=(TIME-SS)*X2(K3)
      TOH2=TOH2+WW
      IF(IQ2.LT.IF2) GO TO 2
      IQ2=IQ2-IF2
      IP2=IP2-IF2
      K3=K3+1
      X2(K3)=IQ2
```

```
      V2(K3)=IP2
      Y2(K3)=TIME
      GO TO 3
    2 J=J+1
      IQ2=IQ2-IF2
      IP2=IP2-IF2
      QU2(J)=TIME
      IG2(J)=IF2-IQ2
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
    3 CALL GGEXN (DSEED2,XM2,1,S2)
      CALL GGEOT (DSEED8,1,P2,WS,IK2)
      IF2=1
      DO 4 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 5
    4 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    5 EVENT(II)=TIME+S2(1)
      IEVENT(II)=2
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEE
     1D3,DSEED6,DSEED9,A,B,K1,NP,X,Y,V,NM,NS,IA,IR,IS,TOH)
      REAL*8 DSEED3,DSEED6,DSEED9
      DIMENSION EVENT(NS),IEVENT(NS),QU3(NS),IG3(NS),Z(50),X(NP),Y(NP),V
     1(NP),IA(NS),WK(50),IK3(1),S3(1),R(1)
      SS=Y(K1)
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IQ.GT.0) GO TO 1
      L=L+1
      IP=IP-IF
      IQ=IQ-IF
      QU3(L)=TIME
      IG3(L)=IF
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      GO TO 3
    1 WW=0.0
```

```
      WW=(TIME-SS)*X(K1)
      TOH=TOH+WW
      IF(IQ.LT.IF) GO TO 2
      IQ=IQ-IF
      IP=IP-IF
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      GO TO 3
    2 L=L+1
      QU3(L)=TIME
      IG3(L)=IF-IQ
      IQ=IQ-IF
      IP=IP-IF
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
    3 IF(IP.GT.IS) GO TO 6
      CALL GGAMS (DSEED6,A,B,1,Z,R)
      DO 4 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 5
    4 CONTINJE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    5 EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   70 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 70
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
    6 CALL GGEXN (DSEED3,XM3,1,S3)
      CALL GGEOT (DSEED9,1,P3,WK,IK3)
      IF=1
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+S3(1)
      IEVENT(II)=3
```

```
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR
     1,IR1,IS,IP,A,B,A1,B1,DSEED4,DSEED6,K1,K2,NP,X,Y,V,X1,Y1,V1,NM,T1,N
     1S,IS1,TOH)
      REAL*8 DSEED4,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)
     1,X(NP),Y(NP),V(NP),X1(NP),Y1(NP),V1(NP)
      ID1=0
      IF(IP1.GT.IS1) GO TO 1
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      ID1=IR1-IP1
      IP1=IR1
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      CALL NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,IP,A,B
     1,A1,B1,DSEED4,DSEED6,K1,NP,X,Y,V,NM,NS,TOH)
    1 DO 2 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 3
    2 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    3 EVENT(II)=TIME+T1
      IEVENT(II)=4
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR
     1,IR2,IS,IP,A,B,A2,B2,DSEED5,DSEED6,K1,K3,NP,X,Y,V,X2,Y2,V2,NM,T2,N
     1S,IS2,TOH)
      REAL*8 DSEED5,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)
     1,X(NP),Y(NP),V(NP),X2(NP),Y2(NP),V2(NP)
      ID2=0
      IF(IP2.GT.IS2) GO TO 1
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      ID2=IR2-IP2
      IP2=IR2
```

```
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      CALL TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,IP,A,B,
     1A2,B2,DSEED5,DSEED6,K1,NP,X,Y,V,NM,NS,TOH)
    1 DO 2 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 3
    2 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    3 EVENT(II)=TIME+T2
      IEVENT(II)=5
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,K2,NP,X1,V1,Y1,N
     1M,NS)
      DIMENSION IA1(NS),IG1(NS),QU1(NS),X1(NP),V1(NP),Y1(NP)
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      IQ1=IQ1+IA1(IJ)
      K2=K2+1
      X1(K2)=IQ1
      V1(K2)=IP1
      Y1(K2)=TIME
      ITD=0
      IF(I.EQ.0) GO TO 8
      DO 1 N=1,I
      ITD=ITD+IG1(N)
    1 CONTINUE
      IF(IA1(IJ).LT.ITD) GO TO 3
      DO 2 N=1,I
      W=0.
      W=(TIME-QU1(N))*IG1(N)
      QU1(N)=0.
      TW1=TW1+W
      IG1(N)=0
    2 CONTINUE
      IA1(IJ)=0
      I=0
      GO TO 8
    3 DO 5 N=1,I
      W=0.
      IF(IA1(IJ).GE.IG1(N)) GO TO 4
```

```
      IF(IA1(IJ).EQ.0) GO TO 6
      IG1(N)=IG1(N)-IA1(IJ)
      W=(TIME-QU1(N))*IA1(IJ)
      TW1=TW1+W
      GO TO 6
    4 IA1(IJ)=IA1(IJ)-IG1(N)
      W=(TIME-QU1(N))*IG1(N)
      TW1=TW1+W
      QU1(N)=0.
      IG1(N)=0
    5 CONTINUE
    6 MM=0
      DO 7 N=1,I
      IF(QU1(N).EQ.0.) GO TO 7
      MM=MM+1
      QU1(MM)=QU1(N)
      IG1(MM)=IG1(N)
    7 CONTINJE
      I=MM
    8 RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,K3,NP,X2,V2,Y2
     1,NM,NS)
      DIMENSION IA2(NS),IG2(NS),QU2(NS),X2(NP),V2(NP),Y2(NP)
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      IQ2=IQ2+IA2(IJ)
      K3=K3+1
      X2(K3)=IQ2
      V2(K3)=IP2
      Y2(K3)=TIME
      ITD=0
      IF(J.EQ.0) GO TO 8
      DO 1 N=1,J
      ITD=ITD+IG2(N)
    1 CONTINUE
      IF(IA2(IJ).LT.ITD) GO TO 3
      DO 2 N=1,J
      W=0.
      W=(TIME-QU2(N))*IG2(N)
      QU2(N)=0.
      TW2=TW2+W
      IG2(N)=0
    2 CONTINUE
      IA2(IJ)=0
```

```
      J=0
      GO TO 8
    3 DO 5 N=1,J
      W=0.
      IF(IA2(IJ).GE.IG2(N)) GO TO 4
      IF(IA2(IJ).EQ.0) GO TO 6
      IG2(N)=IG2(N)-IA2(IJ)
      W=(TIME-QU2(N))*IA2(IJ)
      TW2=TW2+W
      GO TO 6
    4 IA2(IJ)=IA2(IJ)-IG2(N)
      W=(TIME-QU2(N))*IG2(N)
      TW2=TW2+W
      QU2(N)=0.
      IG2(N)=0
    5 CONTINUE
    6 JJ=0
      DO 7 N=1,J
      IF(QU2(N).EQ.0.) GO TO 7
      JJ=JJ+1
      QU2(JJ)=QU2(N)
      IG2(JJ)=IG2(N)
    7 CONTINUE
      J=JJ
    8 RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,
     1QU3,IG3,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,K1,NP,X,Y,V,NM,N
     1S,IP)
      REAL*8 DSEED4,DSEED5
      DIMENSION EVENT(NS),IEVENT(NS),IA(NS),IA1(NS),IA2(NS),IG(NS),QS(NS
     1),IM(NS),QU3(NS),IG3(NS),Z1(50),Z2(50),X(NP),Y(NP),V(NP),R1(1),R2(
     11)
      ITD=0
      JZ=0
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IQ=IQ+IA(IJ)
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(L.EQ.0) GO TO 8
      DO 1 N=1,L
      ITD=ITD+IG3(N)
```

```
1 CONTINUE
  IF(IA(IJ).LT.ITD) GO TO 3
  DO 2 N=1,L
  W=0.
  W=(TIME-QU3(N))*IG3(N)
  QU3(N)=0.
  TW3=TW3+W
  IG3(N)=0
2 CONTINUE
  IA(IJ)=IA(IJ)-ITD
  L=0
  GO TO 8
3 DO 5 N=1,L
  W=0.
  IF(IA(IJ).GE.IG3(N)) GO TO 4
  IF(IA(IJ).EQ.0) GO TO 6
  IG3(N)=IG3(N)-IA(IJ)
  W=(TIME-QU3(N))*IA(IJ)
  TW3=TW3+W
  GO TO 6
4 IA(IJ)=IA(IJ)-IG3(N)
  W=(TIME-QU3(N))*IG3(N)
  TW3=TW3+W
  QU3(N)=0.
  IG3(N)=0
5 CONTINUE
6 LL=0
  DO 7 N=1,L
  IF(QU3(N).EQ.0.) GO TO 7
  LL=LL+1
  QU3(LL)=QU3(N)
  IG3(LL)=IG3(N)
7 CONTINUE
  L=LL
  GO TO 31
8 IF(K.EQ.0) GO TO 31
  ITD=0
  DO 9 N=1,K
  ITD=ITD+IG(N)
9 CONTINUE
  IF(IA(IJ).LT.ITD) GO TO 16
  IAA=0
  DO 10 N=1,K
  IF(IM(N).NE.1) GO TO 10
  W=0.
  W=(TIME-QS(N))*IG(N)
  TW4=TW4+W
  IAA=IAA+IG(N)
```

```
      QS(N)=0.
      IG(N)=0
      IM(N)=0
   10 CONTINUE
      IF(IAA.EQ.0) GO TO 32
      DO 11 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 12
   11 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
   12 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IAA
   32 IAB=0
      DO 13 N=1,K
      IF(IM(N).NE.2) GO TO 13
      W=0.
      W=(TIME-QS(N))*IG(N)
      TW5=TW5+W
      IAB=IAB+IG(N)
      QS(N)=0.
      IG(N)=0
      IM(N)=0
   13 CONTINUE
      IF(IAB.EQ.0) GO TO 31
      DO 14 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 15
   14 CONTINUE
      WRITE (6,100)
   15 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)
      EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
      IA2(II)=IAB
      GO TO 31
   16 IAA=0
      IAB=0
      DO 20 N=1,K
      IF(IM(N).NE.1) GO TO 17
      IF(IA(IJ).GE.IG(N)) GO TO 18
      IG(N)=IG(N)-IA(IJ)
      W=(TIME-QS(N))*IA(IJ)
      TW4=TW4+W
      IAA=IAA+IA(IJ)
      GO TO 21
   17 IF(IM(N).NE.2) GO TO 20
```

```
      IF(IA(IJ).GE.IG(N)) GO TO 19
      IG(N)=IG(N)-IA(IJ)
      W=(TIME-QS(N))*IA(IJ)
      TW5=TW5+W
      IAB=IAB+IA(IJ)
      GO TO 21
   18 W=0.
      IAA=IAA+IG(N)
      IA(IJ)=IA(IJ)-IG(N)
      W=(TIME-QS(N))*IG(N)
      TW4=TW4+W
      QS(N)=0.
      IG(N)=0
      IM(N)=0
      GO TO 20
   19 W=0.
      IAB=IAB+IG(N)
      IA(IJ)=IA(IJ)-IG(N)
      W=(TIME-QS(N))*IG(N)
      TW5=TW5+W
      QS(N)=0.
      IG(N)=0
      IM(N)=0
   20 CONTINUE
   21 IF(IAA.EQ.0) GO TO 24
      DO 22 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 23
   22 CONTINUE
      WRITE (6,100)
   23 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IAA
   24 IF(IAB.EQ.0) GO TO 27
      DO 25 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 26
   25 CONTINUE
      WRITE (6,100)
   26 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)
      EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
      IA2(II)=IAB
   27 NN=0
      DO 30 N=1,K
      IF(QS(N).EQ.0.) GO TO 30
      NN=NN+1
```

```
      IF(IM(N).NE.1) GO TO 28
      IM(NN)=1
      GO TO 29
   28 IM(NN)=2
   29 QS(NN)=QS(N)
      IG(NN)=IG(N)
   30 CONTINUE
      K=NN
   31 RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,
     1IP,A,B,A1,B1,DSEED4,DSEED6,K1,NP,X,Y,V,NM,NS,TOH)
      REAL*8 DSEED4,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)
     1,Z(50),Z1(50),X(NP),Y(NP),V(NP),R(1),R1(1)
      SS=Y(K1)
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IQ.LE.0) GO TO 11
      WW=0.0
      WW=(TIME-SS)*X(K1)
      TOH=TOH+WW
      IF(IQ.GE.ID1) GO TO 6
      CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      DO 1 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 2
    1 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    2 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IQ
      K=K+1
      QS(K)=TIME
      IG(K)=ID1-IQ
      IM(K)=1
      IQ=IQ-ID1
      IP=IP-ID1
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 3 KI=1,NM
```

```
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 4
    3 CONTINUE
      WRITE (6,100)
    4 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   70 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 70
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      GO TO 14
    6 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=ID1
      IQ=IQ-ID1
      IP=IP-ID1
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 9 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 10
    9 CONTINUE
      WRITE (6,100)
   10 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   71 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 71
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
```

```
      V(K1)=IP
      Y(K1)=TIME
      GO TO 14
   11 K=K+1
      QS(K)=TIME
      IG(K)=ID1
      IM(K)=1
      IQ=IQ-ID1
      IP=IP-ID1
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 12 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 13
   12 CONTINJE
      WRITE (6,100)
   13 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   72 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 72
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
   14 RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,I
     1P,A,B,A2,B2,DSEED5,DSEED6,K1,NP,X,Y,V,NM,NS,TOH)
      REAL*8 DSEED5,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)
     1,Z(50),Z2(50),X(NP),Y(NP),V(NP),R(1),R2(1)
      SS=Y(K1)
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IQ.LE.0) GO TO 11
      WW=0.0
      WW=(TIME-SS)*X(K1)
      TOH=TOH+WW
```

```
      IF(IQ.GE.ID2) GO TO 6
      CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)
      DO 1 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 2
    1 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    2 EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
      IA2(II)=IQ
      K=K+1
      QS(K)=TIME
      IG(K)=ID2-IQ
      IM(K)=2
      IQ=IQ-ID2
      IP=IP-ID2
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 3 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 4
    3 CONTINUE
      WRITE (6,100)
    4 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   70 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 70
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      GO TO 14
    6 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
```

```
      IA2(II)=ID2
      IQ=IQ-ID2
      IP=IP-ID2
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 9 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 10
    9 CONTINUE
      WRITE (6,100)
   10 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   71 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 71
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      GO TO 14
   11 K=K+1
      QS(K)=TIME
      IG(K)=ID2
      IM(K)=2
      IQ=IQ-ID2
      IP=IP-ID2
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
      IF(IP.GT.IS) GO TO 14
      DO 12 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 13
   12 CONTINUE
      WRITE (6,100)
   13 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   72 ML=ML+1
      IP=IP+IR
```

```
      IF(IP.LT.IS) GO TO 72
      IA(II)=ML*IR
      K1=K1+1
      X(K1)=IQ
      V(K1)=IP
      Y(K1)=TIME
   14 RETURN
      DEBUG SUBCHK
      END
```

APPENDIX D

Simulation Program; No Versatec Plotter Output

```
      REAL*8 DSEED1,DSEED2,DSEED3,DSEED4,DSEED5,DSEED6,DSEED7,DSEED8,DSE
     1ED9
      DIMENSION EVENT(900),IEVENT(900),IM(900),QU1(900),QU2(900),QU3(900
     1),QS(900),IG1(900),IG2(900),IG3(900),IG(900),IA1(900),IA2(900),IA(
     1900),Z(50),Z1(50),Z2(50),WK(50),WS(50),WZ(50),IK1(1),IK2(1),IK3(1)
     1,S1(1),S2(1),S3(1),KA(10),AK(10)
      NS=900
      NM=30
      DSEED1=123456.0D0
      DSEED2=247658.0D0
      DSEED3=365274.0D0
      DSEED4=258732.0D0
      DSEED5=541863.0D0
      DSEED6=433215.0D0
      DSEED7=651563.0D0
      DSEED8=265418.0D0
      DSEED9=167519.0D0
      I=0
      J=0
      K=0
      L=0
      SS=0.0
      SS1=0.0
      SS2=0.0
      TW1=0.0
      TW2=0.0
      TW3=0.0
      TW4=0.0
      TW5=0.0
      TOH=0.0
      TOH1=0.0
      TOH2=0.0
      DO 1 N=1,50
      EVENT(N)=99999.
      IEVENT(N)=0
      QU1(N)=0.0
      QU2(N)=0.0
      QU3(N)=0.0
      IG1(N)=0
      IG2(N)=0
      IG3(N)=0
      IA1(N)=0
      IA2(N)=0
      IA(N)=0
    1 CONTINUE
      DO 2 N=1,10
      IM(N)=0
      QS(N)=0.0
```

```
      IG(N)=0
      KA(N)=0
      AK(N)=0.0
    2 CONTINUE
      IF=0
      IF1=0
      IF2=0
      ID=0
      ID1=0
      ID2=0
      READ(5,100) IR,IS
  100 FORMAT(2I10)
      READ (5,110) IR1,IS1,T1
  110 FORMAT(2I10,F10.0)
      READ (5,110) IR2,IS2,T2
      READ (5,120) YEAR
  120 FORMAT(F10.0)
      READ (5,130) A,B
  130 FORMAT (2F4.0)
      READ (5,130) A1,B1
      READ (5,130) A2,B2
      READ (5,140) XM1
      READ (5,140) XM2
      READ (5,140) XM3
  140 FORMAT(F4.0)
      READ (5,150) P1
      READ (5,150) P2
      READ (5,150) P3
  150 FORMAT(F6.0)
      IQ=IR+IS
      IQ1=IR1
      IQ2=IR2
      IQQ=100000
      IQQ1=100000
      IQQ2=100000
      ND11=100000
      ND22=100000
      XL=(YEAR/365.)*48.
      TIME=0.0
      IP=IR+IS
      IP1=IR1
      IP2=IR2
      CALL GGEXN (DSEED1,XM1,1,S1)
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)
      IF1=1
      DO 3 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 4
```

```
    3 CONTINUE                                                    TUR00970
    4 EVENT(II)=TIME+S1(1)                                        TUR00980
      IEVENT(II)=1                                                TUR00990
      CALL GGEXN (DSEED2,XM2,1,S2)                                TUR01000
      CALL GGEOT (DSEED8,1,P2,WS,IK2)                             TUR01010
      IF2=1                                                       TUR01020
      DO 5 KI=1,NM                                                TUR01030
      II=KI                                                       TUR01040
      IF(EVENT(II).EQ.99999.) GO TO 6                             TUR01050
    5 CONTINUE                                                    TUR01060
    6 EVENT(II)=TIME+S2(1)                                        TUR01070
      IEVENT(II)=2                                                TUR01080
      CALL GGEXN (DSEED3,XM3,1,S3)                                TUR01090
      CALL GGEOT (DSEED9,1,P3,WK,IK3)                             TUR01100
      IF=1                                                        TUR01110
      DO 7 KI=1,NM                                                TUR01120
      II=KI                                                       TUR01130
      IF(EVENT(II).EQ.99999.) GO TO 8                             TUR01140
    7 CONTINUE                                                    TUR01150
    8 EVENT(II)=TIME+S3(1)                                        TUR01160
      IEVENT(II)=3                                                TUR01170
      DO 9 KI=1,NM                                                TUR01180
      II=KI                                                       TUR01190
      IF(EVENT(II).EQ.99999.) GO TO 10                            TUR01200
    9 CONTINUE                                                    TUR01210
   10 EVENT(II)=TIME+T1                                           TUR01220
      IEVENT(II)=4                                                TUR01230
      DO 11 KI=1,NM                                               TUR01240
      II=KI                                                       TUR01250
      IF(EVENT(II).EQ.99999.) GO TO 12                            TUR01260
   11 CONTINUE                                                    TUR01270
   12 EVENT(II)=TIME+T2                                           TUR01280
      IEVENT(II)=5                                                TUR01290
      DO 13 KI=1,NM                                               TUR01300
      II=KI                                                       TUR01310
      IF(EVENT(II).EQ.99999.) GO TO 14                            TUR01320
   13 CONTINJE                                                    TUR01330
   14 EVENT(II)=YEAR                                              TUR01340
      IEVENT(II)=9                                                TUR01350
      GO TO 26                                                    TUR01360
   15 EVENT(IN)=99999.                                            TUR01370
      IEVENT(IN)=0                                                TUR01380
   26 IN=1                                                        TUR01390
      DO 16 KI=2,NM                                               TUR01400
      IF(EVENT(IN).GT.EVENT(KI)) IN=KI                            TUR01410
   16 CONTINUE                                                    TUR01420
      TIME=EVENT(IN)                                              TUR01430
      IL=IEVENT(IN)                                               TUR01440
```

```
      IJ=IN
      GO TO (17,18,19,20,21,22,23,24,25),IL
   17 CALL ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSEED1,DS
     1EED7,NM,NS,TOH1,SS1,IQQ1)
      GO TO 15
   18 CALL TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSEED2,DS
     1EED8,NM,NS,TOH2,SS2,IQQ2)
      GO TO 15
   19 CALL THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEED3,DS
     1EED6,DSEED9,A,B,NM,NS,IA,IR,IS,TOH,SS,KA,AK,IQQ)
      GO TO 15
   20 CALL FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IR1,I
     1S,IP,A,B,A1,B1,DSEED4,DSEED6,NM,T1,NS,IS1,TOH,SS,KA,AK,IQQ,IQQ1,ND
     111)
      GO TO 15
   21 CALL FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IR2,I
     1S,IP,A,B,A2,B2,DSEED5,DSEED6,NM,T2,NS,IS2,TOH,SS,KA,AK,IQQ,IQQ2,ND
     122)
      GO TO 15
   22 CALL SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,NM,NS)
      GO TO 15
   23 CALL SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,NM,NS)
      GO TO 15
   24 CALL EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,QU3,IG
     13,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,NM,NS,IP,KA,AK,IQQ)
      GO TO 15
   25 TW1=TW1/YEAR
      TW2=TW2/YEAR
      TW3=TW3/YEAR
      TW4=TW4/YEAR
      TW5=TW5/YEAR
      WRITE (6,200) TW1,TW2,TW3,TW4,TW5
  200 FORMAT (' TW1=',F10.4,' TW2=',F10.4,' TW3=',F10.4,' TW4=',F10.4,'
     1TW5=',F10.4)
      TOH=TOH/YEAR
      TOH1=TOH1/YEAR
      TOH2=TOH2/YEAR
      WRITE (6,201) TOH,TOH1,TOH2
  201 FORMAT (' TOH=',F10.3,' TOH1=',F10.3,' TOH2=',F10.3)
      STOP
      DEBUG SUBCHK
      END
      SUBROUTINE ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSE
     1ED1,DSEED7,NM,NS,TOH1,SS1,IQQ1)
      REAL*8 DSEED1,DSEED7
      DIMENSION EVENT(NS),IEVENT(NS),QU1(NS),IG1(NS),WZ(50),IK1(1),S1(1)
      IF(IQ1.GT.0) GO TO 1
      I=I+1
```

```
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      IQQ1=IQQ1-IF1
      QU1(I)=TIME
      IG1(I)=IF1
      GO TO 3
    1 WW=0.0
      WW=(TIME-SS1)*IQ1
      TOH1=TOH1+WW
      IF(IQ1.LT.IF1) GO TO 2
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      IQQ1=IQQ1-IF1
      GO TO 3
    2 I=I+1
      IQ1=IQ1-IF1
      IP1=IP1-IF1
      IQQ1=IQQ1-IF1
      QU1(I)=TIME
      IG1(I)=IF1-IQ1
    3 CALL GGEXN (DSEED1,XM1,1,S1)
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)
      IF1=1
      DO 4 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 5
    4 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    5 EVENT(II)=TIME+S1(1)
      IEVENT(II)=1
      SS1=TIME
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSE
     1ED2,DSEED8,NM,NS,TOH2,SS2,IQQ2)
      REAL*8 DSEED2,DSEED8
      DIMENSION EVENT(NS),IEVENT(NS),QU2(NS),IG2(NS),WS(50),IK2(1),S2(1)
      IF(IQ2.GT.0) GO TO 1
      J=J+1
      IQ2=IQ2-IF2
      IP2=IP2-IF2
      IQQ2=IQQ2-IF2
      QU2(J)=TIME
      IG2(J)=IF2
      GO TO 3
    1 WW=0.0
```

```
      WW=(TIME-SS2)*IQ2                                                 TUR02410
      TOH2=TOH2+WW                                                      TUR02420
      IF(IQ2.LT.IF2) GO TO 2                                            TUR02430
      IQ2=IQ2-IF2                                                       TUR02440
      IP2=IP2-IF2                                                       TUR02450
      IQQ2=IQQ2-IF2                                                     TUR02460
      GO TO 3                                                           TUR02470
    2 J=J+1                                                             TUR02480
      IQ2=IQ2-IF2                                                       TUR02490
      IP2=IP2-IF2                                                       TUR02500
      IQQ2=IQQ2-IF2                                                     TUR02510
      QU2(J)=TIME                                                       TUR02520
      IG2(J)=IF2-IQ2                                                    TUR02530
    3 CALL GGEXN (DSEED2,XM2,1,S2)                                      TUR02540
      CALL GGEOT (DSEED8,1,P2,WS,IK2)                                   TUR02550
      IF2=1                                                             TUR02560
      DO 4 KI=1,NM                                                      TUR02570
      II=KI                                                             TUR02580
      IF(EVENT(II).EQ.99999.) GO TO 5                                   TUR02590
    4 CONTINUE                                                          TUR02600
      WRITE (6,100)                                                     TUR02610
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR02620
    5 EVENT(II)=TIME+S2(1)                                              TUR02630
      IEVENT(II)=2                                                      TUR02640
      SS2=TIME                                                          TUR02650
      RETURN                                                            TUR02660
      DEBUG SUBCHK                                                      TUR02670
      END                                                               TUR02680
      SUBROUTINE THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEETUR02690
     1D3,DSEED6,DSEED9,A,B,NM,NS,IA,IR,IS,TOH,SS,KA,AK,IQQ)             TUR02700
      REAL*8 DSEED3,DSEED6,DSEED9                                       TUR02710
      DIMENSION EVENT(NS),IEVENT(NS),QU3(NS),IG3(NS),Z(50),IA(NS),WK(50)TUR02720
     1,IK3(1),S3(1),R(1),KA(10),AK(10)                                  TUR02730
      IF(IQ.GT.0) GO TO 1                                               TUR02740
      L=L+1                                                             TUR02750
      IP=IP-IF                                                          TUR02760
      IQ=IQ-IF                                                          TUR02770
      IQQ=IQQ-IF                                                        TUR02780
      QU3(L)=TIME                                                       TUR02790
      IG3(L)=IF                                                         TUR02800
      GO TO 3                                                           TUR02810
    1 WW=0.0                                                            TUR02820
      WW=(TIME-SS)*IQ                                                   TUR02830
      TOH=TOH+WW                                                        TUR02840
      IF(IQ.LT.IF) GO TO 2                                              TUR02850
      IQ=IQ-IF                                                          TUR02860
      IQQ=IQQ-IF                                                        TUR02870
      IP=IP-IF                                                          TUR02880
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      GO TO 3                                                           TUR02890
    2 L=L+1                                                             TUR02900
      QU3(L)=TIME                                                       TUR02910
      IG3(L)=IF-IQ                                                      TUR02920
      IQ=IQ-IF                                                          TUR02930
      IP=IP-IF                                                          TUR02940
      IGQ=IQQ-IF                                                        TUR02950
    3 IF(IP.GT.IS) GO TO 6                                              TUR02960
      CALL GGAMS (DSEED6,A,B,1,Z,R)                                     TUR02970
      DO 4 KI=1,NM                                                      TUR02980
      II=KI                                                             TUR02990
      IF(EVENT(II).EQ.99999.) GO TO 5                                   TUR03000
    4 CONTINUE                                                          TUR03010
      WRITE (6,100)                                                     TUR03020
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR03030
    5 EVENT(II)=TIME+R(1)                                               TUR03040
      IEVENT(II)=8                                                      TUR03050
      ML=0                                                              TUR03060
   70 ML=ML+1                                                           TUR03070
      IP=IP+IR                                                          TUR03080
      IF(IP.LT.IS) GO TO 70                                             TUR03090
      IA(II)=ML*IR                                                      TUR03100
      DO 60 KT=1,10                                                     TUR03110
      L5=KT                                                             TUR03120
      IF(AK(L5).EQ.0.0) GO TO 61                                        TUR03130
   60 CONTINUE                                                          TUR03140
   61 KA(L5)=IQQ                                                        TUR03150
      AK(L5)=EVENT(II)                                                  TUR03160
    6 CALL GGEXN (DSEED3,XM3,1,S3)                                      TUR03170
      CALL GGEOT (DSEED9,1,P3,WK,IK3)                                   TUR03180
      IF=1                                                              TUR03190
      DO 7 KI=1,NM                                                      TUR03200
      II=KI                                                             TUR03210
      IF(EVENT(II).EQ.99999.) GO TO 8                                   TUR03220
    7 CONTINUE                                                          TUR03230
      WRITE (6,100)                                                     TUR03240
    8 EVENT(II)=TIME+S3(1)                                              TUR03250
      IEVENT(II)=3                                                      TUR03260
      SS=TIME                                                           TUR03270
      RETURN                                                            TUR03280
      DEBUG SUBCHK                                                      TUR03290
      END                                                               TUR03300
      SUBROUTINE FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IRTUR03310
     1,IR1,IS,IP,A,B,A1,B1,DSEED4,DSEED6,NM,T1,NS,IS1,TOH,SS,KA,AK,IQQ,ITUR03320
     1QQ1,ND11)                                                         TUR03330
      REAL*8 DSEED4,DSEED6                                              TUR03340
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)TUR03350
     1,KA(10),AK(10)                                                    TUR03360
```

```
      ND1=ND11-IQQ1                                                     TUR03370
      ND11=0                                                            TUR03380
      WRITE (6,250) ND1                                                 TUR03390
  250 FORMAT (/,' AMOUNT OF DEMAND IN A PERIOD OF 1=',I10)              TUR03400
      ID1=0                                                             TUR03410
      IF(IP1.GT.IS1) GO TO 1                                            TUR03420
      ID1=IR1-IP1                                                       TUR03430
      IP1=IR1                                                           TUR03440
      CALL NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,IP,A,BTUR03450
     1,A1,B1,DSEED4,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                      TUR03460
    1 DO 2 KI=1,NM                                                      TUR03470
      II=KI                                                             TUR03480
      IF(EVENT(II).EQ.99999.) GO TO 3                                   TUR03490
    2 CONTINUE                                                          TUR03500
      WRITE (6,100)                                                     TUR03510
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR03520
    3 EVENT(II)=TIME+T1                                                 TUR03530
      IEVENT(II)=4                                                      TUR03540
      ND11=IQQ1                                                         TUR03550
      RETURN                                                            TUR03560
      DEBUG SUBCHK                                                      TUR03570
      END                                                               TUR03580
      SUBROUTINE FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IRTUR03590
     1,IR2,IS,IP,A,B,A2,B2,DSEED5,DSEED6,NM,T2,NS,IS2,TOH,SS,KA,AK,IQQ,ITUR03600
     1QQ2,ND22)                                                         TUR03610
      REAL*8 DSEED5,DSEED6                                              TUR03620
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)TUR03630
     1,KA(10),AK(10)                                                    TUR03640
      ND2=ND22-IQQ2                                                     TUR03650
      ND22=0                                                            TUR03660
      WRITE (6,250) ND2                                                 TUR03670
  250 FORMAT (/,' AMOUNT OF DEMAND IN A PERIOD OF SYSTEM 2=',I10)       TUR03680
      ID2=0                                                             TUR03690
      IF(IP2.GT.IS2) GO TO 1                                            TUR03700
      ID2=IR2-IP2                                                       TUR03710
      IP2=IR2                                                           TUR03720
      CALL TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,IP,A,B,TUR03730
     1A2,B2,DSEED5,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                       TUR03740
    1 DO 2 KI=1,NM                                                      TUR03750
      II=KI                                                             TUR03760
      IF(EVENT(II).EQ.99999.) GO TO 3                                   TUR03770
    2 CONTINUE                                                          TUR03780
      WRITE (6,100)                                                     TUR03790
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR03800
    3 EVENT(II)=TIME+T2                                                 TUR03810
      IEVENT(II)=5                                                      TUR03820
      ND22=IQQ2                                                         TUR03830
      RETURN                                                            TUR03840
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      DEBUG SUBCHK                                                      TUR03850
      END                                                               TUR03860
      SUBROUTINE SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,NM,NS)          TUR03870
      DIMENSION IA1(NS),IG1(NS),QU1(NS)                                 TUR03880
      WRITE (6,50) IQ1                                                  TUR03890
   50 FORMAT (/,' EXPECTED NET INVENTORY OF SYSTEM 1 AT THE END OF CYCLETUR03900
     1=',I6)                                                            TUR03910
      IQ1=IQ1+IA1(IJ)                                                   TUR03920
      ITD=0                                                             TUR03930
      IF(I.EQ.0) GO TO 8                                                TUR03940
      DO 1 N=1,I                                                        TUR03950
      ITD=ITD+IG1(N)                                                    TUR03960
    1 CONTINUE                                                          TUR03970
      IF(IA1(IJ).LT.ITD) GO TO 3                                        TUR03980
      DO 2 N=1,I                                                        TUR03990
      W=0.                                                              TUR04000
      W=(TIME-QU1(N))*IG1(N)                                            TUR04010
      QU1(N)=0.                                                         TUR04020
      TW1=TW1+W                                                         TUR04030
      IG1(N)=0                                                          TUR04040
    2 CONTINUE                                                          TUR04050
      IA1(IJ)=0                                                         TUR04060
      I=0                                                               TUR04070
      GO TO 8                                                           TUR04080
    3 DO 5 N=1,I                                                        TUR04090
      W=0.                                                              TUR04100
      IF(IA1(IJ).GE.IG1(N)) GO TO 4                                     TUR04110
      IF(IA1(IJ).EQ.0) GO TO 6                                          TUR04120
      IG1(N)=IG1(N)-IA1(IJ)                                             TUR04130
      W=(TIME-QU1(N))*IA1(IJ)                                           TUR04140
      TW1=TW1+W                                                         TUR04150
      GO TO 6                                                           TUR04160
    4 IA1(IJ)=IA1(IJ)-IG1(N)                                            TUR04170
      W=(TIME-QU1(N))*IG1(N)                                            TUR04180
      TW1=TW1+W                                                         TUR04190
      QU1(N)=0.                                                         TUR04200
      IG1(N)=0                                                          TUR04210
    5 CONTINUE                                                          TUR04220
    6 MM=0                                                              TUR04230
      DO 7 N=1,I                                                        TUR04240
      IF(QU1(N).EQ.0.) GO TO 7                                          TUR04250
      MM=MM+1                                                           TUR04260
      QU1(MM)=QU1(N)                                                    TUR04270
      IG1(MM)=IG1(N)                                                    TUR04280
    7 CONTINUE                                                          TUR04290
      I=MM                                                              TUR04300
    8 RETURN                                                            TUR04310
      DEBUG SUBCHK                                                      TUR04320
```

```
      END
      SUBROUTINE SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,NM,NS)
      DIMENSION IA2(NS),IG2(NS),QU2(NS)
      WRITE (6,50) IQ2
   50 FORMAT (/,' EXPECTED NET INVENTORY OF SYSTEM 2 AT THE END OF CYCLE
     1=',I6)
      IQ2=IQ2+IA2(IJ)
      ITD=0
      IF(J.EQ.0) GO TO 8
      DO 1 N=1,J
      ITD=ITD+IG2(N)
    1 CONTINUE
      IF(IA2(IJ).LT.ITD) GO TO 3
      DO 2 N=1,J
      W=0.
      W=(TIME-QU2(N))*IG2(N)
      QU2(N)=0.
      TW2=TW2+W
      IG2(N)=0
    2 CONTINUE
      IA2(IJ)=0
      J=0
      GO TO 8
    3 DO 5 N=1,J
      W=0.
      IF(IA2(IJ).GE.IG2(N)) GO TO 4
      IF(IA2(IJ).EQ.0) GO TO 6
      IG2(N)=IG2(N)-IA2(IJ)
      W=(TIME-QU2(N))*IA2(IJ)
      TW2=TW2+W
      GO TO 6
    4 IA2(IJ)=IA2(IJ)-IG2(N)
      W=(TIME-QU2(N))*IG2(N)
      TW2=TW2+W
      QU2(N)=0.
      IG2(N)=0
    5 CONTINUE
    6 JJ=0
      DO 7 N=1,J
      IF(QU2(N).EQ.0.) GO TO 7
      JJ=JJ+1
      QU2(JJ)=QU2(N)
      IG2(JJ)=IG2(N)
    7 CONTINUE
      J=JJ
    8 RETURN
      DEBUG SUBCHK
      END
```

```
      SUBROUTINE EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,TUR04810
     1QU3,IG3,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,NM,NS,IP,KA,AK,ITUR04820
     1QQ)                                                               TUR04830
      REAL*8 DSEED4,DSEED5                                              TUR04840
      DIMENSION EVENT(NS),IEVENT(NS),IA(NS),IA1(NS),IA2(NS),IG(NS),QS(NSTUR04850
     1),IM(NS),QU3(NS),IG3(NS),Z1(50),Z2(50),R1(1),R2(1),KA(10),AK(10)  TUR04860
      ITD=0                                                             TUR04870
      JZ=0                                                              TUR04880
      JZ=IQ                                                             TUR04890
      DO 60 KT=1,10                                                     TUR04900
      L5=KT                                                             TUR04910
      IF(AK(L5).EQ.TIME) GO TO 61                                       TUR04920
   60 CONTINUE                                                          TUR04930
   61 ND=KA(L5)-IQQ                                                     TUR04940
      KA(L5)=0                                                          TUR04950
      AK(L5)=0.                                                         TUR04960
      WRITE (6,250) ND,TIME                                             TUR04970
  250 FORMAT (/,' DEMAND DURING LEAD TIME=',I10,' TIME=',F15.5)         TUR04980
      IQ=IQ+IA(IJ)                                                      TUR04990
      WRITE (6,50) JZ,IQ,TIME                                           TUR05000
   50 FORMAT (/,' EXPECTED NET INVENTORY OF MAIN SYSTEM AT THE END OF CYTUR05010
     1CLE=',I6,2X,' IQ=',I6,2X,' TIME=',F10.4)                          TUR05020
      IF(L.EQ.0) GO TO 8                                                TUR05030
      DO 1 N=1,L                                                        TUR05040
      ITD=ITD+IG3(N)                                                    TUR05050
    1 CONTINUE                                                          TUR05060
      IF(IA(IJ).LT.ITD) GO TO 3                                         TUR05070
      DO 2 N=1,L                                                        TUR05080
      W=0.                                                              TUR05090
      W=(TIME-QU3(N))*IG3(N)                                            TUR05100
      QU3(N)=0.                                                         TUR05110
      TW3=TW3+W                                                         TUR05120
      IG3(N)=0                                                          TUR05130
    2 CONTINUE                                                          TUR05140
      IA(IJ)=IA(IJ)-ITD                                                 TUR05150
      L=0                                                               TUR05160
      GO TO 8                                                           TUR05170
    3 DO 5 N=1,L                                                        TUR05180
      W=0.                                                              TUR05190
      IF(IA(IJ).GE.IG3(N)) GO TO 4                                      TUR05200
      IF(IA(IJ).EQ.0) GO TO 6                                           TUR05210
      IG3(N)=IG3(N)-IA(IJ)                                              TUR05220
      W=(TIME-QU3(N))*IA(IJ)                                            TUR05230
      TW3=TW3+W                                                         TUR05240
      GO TO 6                                                           TUR05250
    4 IA(IJ)=IA(IJ)-IG3(N)                                              TUR05260
      W=(TIME-QU3(N))*IG3(N)                                            TUR05270
      TW3=TW3+W                                                         TUR05280
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```
      QU3(N)=0.                                                         TUR05290
      IG3(N)=0                                                          TUR05300
    5 CONTINUE                                                          TUR05310
    6 LL=0                                                              TUR05320
      DO 7 N=1,L                                                        TUR05330
      IF(QU3(N).EQ.0.) GO TO 7                                          TUR05340
      LL=LL+1                                                           TUR05350
      QU3(LL)=QU3(N)                                                    TUR05360
      IG3(LL)=IG3(N)                                                    TUR05370
    7 CONTINUE                                                          TUR05380
      L=LL                                                              TUR05390
      GO TO 31                                                          TUR05400
    8 IF(K.EQ.0) GO TO 31                                               TUR05410
      ITD=0                                                             TUR05420
      DO 9 N=1,K                                                        TUR05430
      ITD=ITD+IG(N)                                                     TUR05440
    9 CONTINUE                                                          TUR05450
      IF(IA(IJ).LT.ITD) GO TO 16                                        TUR05460
      IAA=0                                                             TUR05470
      DO 10 N=1,K                                                       TUR05480
      IF(IM(N).NE.1) GO TO 10                                           TUR05490
      W=0.                                                              TUR05500
      W=(TIME-QS(N))*IG(N)                                              TUR05510
      TW4=TW4+W                                                         TUR05520
      IAA=IAA+IG(N)                                                     TUR05530
      QS(N)=0.                                                          TUR05540
      IG(N)=0                                                           TUR05550
      IM(N)=0                                                           TUR05560
   10 CONTINUE                                                          TUR05570
      IF(IAA.EQ.0) GO TO 32                                             TUR05580
      DO 11 KI=1,NM                                                     TUR05590
      II=KI                                                             TUR05600
      IF(EVENT(II).EQ.99999.) GO TO 12                                  TUR05610
   11 CONTINUE                                                          TUR05620
      WRITE (6,100)                                                     TUR05630
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR05640
   12 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)                                 TUR05650
      EVENT(II)=TIME+R1(1)                                              TUR05660
      IEVENT(II)=6                                                      TUR05670
      IA1(II)=IAA                                                       TUR05680
   32 IAB=0                                                             TUR05690
      DO 13 N=1,K                                                       TUR05700
      IF(IM(N).NE.2) GO TO 13                                           TUR05710
      W=0.                                                              TUR05720
      W=(TIME-QS(N))*IG(N)                                              TUR05730
      TW5=TW5+W                                                         TUR05740
      IAB=IAB+IG(N)                                                     TUR05750
      QS(N)=0.                                                          TUR05760
```

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      IG(N)=0                                                           TUR05770
      IM(N)=0                                                           TUR05780
   13 CONTINUE                                                          TUR05790
      IF(IAB.EQ.0) GO TO 31                                             TUR05800
      DO 14 KI=1,NM                                                     TUR05810
      II=KI                                                             TUR05820
      IF(EVENT(II).EQ.99999.) GO TO 15                                  TUR05830
   14 CONTINUE                                                          TUR05840
      WRITE (6,100)                                                     TUR05850
   15 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                 TUR05860
      EVENT(II)=TIME+R2(1)                                              TUR05870
      IEVENT(II)=7                                                      TUR05880
      IA2(II)=IAB                                                       TUR05890
      GO TO 31                                                          TUR05900
   16 IAA=0                                                             TUR05910
      IAB=0                                                             TUR05920
      DO 20 N=1,K                                                       TUR05930
      IF(IM(N).NE.1) GO TO 17                                           TUR05940
      IF(IA(IJ).GE.IG(N)) GO TO 18                                      TUR05950
      IG(N)=IG(N)-IA(IJ)                                                TUR05960
      W=(TIME-QS(N))*IA(IJ)                                             TUR05970
      TW4=TW4+W                                                         TUR05980
      IAA=IAA+IA(IJ)                                                    TUR05990
      GO TO 21                                                          TUR06000
   17 IF(IM(N).NE.2) GO TO 20                                           TUR06010
      IF(IA(IJ).GE.IG(N)) GO TO 19                                      TUR06020
      IG(N)=IG(N)-IA(IJ)                                                TUR06030
      W=(TIME-QS(N))*IA(IJ)                                             TUR06040
      TW5=TW5+W                                                         TUR06050
      IAB=IAB+IA(IJ)                                                    TUR06060
      GO TO 21                                                          TUR06070
   18 W=0.                                                              TUR06080
      IAA=IAA+IG(N)                                                     TUR06090
      IA(IJ)=IA(IJ)-IG(N)                                               TUR06100
      W=(TIME-QS(N))*IG(N)                                              TUR06110
      TW4=TW4+W                                                         TUR06120
      QS(N)=0.                                                          TUR06130
      IG(N)=0                                                           TUR06140
      IM(N)=0                                                           TUR06150
      GO TO 20                                                          TUR06160
   19 W=0.                                                              TUR06170
      IAB=IAB+IG(N)                                                     TUR06180
      IA(IJ)=IA(IJ)-IG(N)                                               TUR06190
      W=(TIME-QS(N))*IG(N)                                              TUR06200
      TW5=TW5+W                                                         TUR06210
      QS(N)=0.                                                          TUR06220
      IG(N)=0                                                           TUR06230
      IM(N)=0                                                           TUR06240
```

```
20 CONTINUE                                                                    TUR06250
21 IF(IAA.EQ.0) GO TO 24                                                       TUR06260
   DO 22 KI=1,NM                                                               TUR06270
   II=KI                                                                       TUR06280
   IF(EVENT(II).EQ.99999.) GO TO 23                                            TUR06290
22 CONTINUE                                                                    TUR06300
   WRITE (6,100)                                                               TUR06310
23 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)                                           TUR06320
   EVENT(II)=TIME+R1(1)                                                        TUR06330
   IEVENT(II)=6                                                                TUR06340
   IA1(II)=IAA                                                                 TUR06350
24 IF(IAB.EQ.0) GO TO 27                                                       TUR06360
   DO 25 KI=1,NM                                                               TUR06370
   II=KI                                                                       TUR06380
   IF(EVENT(II).EQ.99999.) GO TO 26                                            TUR06390
25 CONTINUE                                                                    TUR06400
   WRITE (6,100)                                                               TUR06410
26 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                           TUR06420
   EVENT(II)=TIME+R2(1)                                                        TUR06430
   IEVENT(II)=7                                                                TUR06440
   IA2(II)=IAB                                                                 TUR06450
27 NN=0                                                                        TUR06460
   DO 30 N=1,K                                                                 TUR06470
   IF(QS(N).EQ.0.) GO TO 30                                                    TUR06480
   NN=NN+1                                                                     TUR06490
   IF(IM(N).NE.1) GO TO 28                                                     TUR06500
   IM(NN)=1                                                                    TUR06510
   GO TO 29                                                                    TUR06520
28 IM(NN)=2                                                                    TUR06530
29 QS(NN)=QS(N)                                                                TUR06540
   IG(NN)=IG(N)                                                                TUR06550
30 CONTINUE                                                                    TUR06560
   K=NN                                                                        TUR06570
31 RETURN                                                                      TUR06580
   DEBUG SUBCHK                                                                TUR06590
   END                                                                         TUR06600
   SUBROUTINE NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,TUR06610
  1IP,A,B,A1,B1,DSEED4,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                          TUR06620
   REAL*8 DSEED4,DSEED6                                                        TUR06630
   DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)TUR06640
  1,Z(50),Z1(50),R(1),R1(1),KA(10),AK(10)                                      TUR06650
   ID=0                                                                        TUR06660
   IF(IQ.LE.0) GO TO 11                                                        TUR06670
   WW=0.0                                                                      TUR06680
   WW=(TIME-SS)*IQ                                                             TUR06690
   TOH=TOH+WW                                                                  TUR06700
   IF(IQ.GE.ID1) GO TO 6                                                       TUR06710
   CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)                                           TUR06720
```

```
      DO 1 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 2
    1 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    2 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IQ
      K=K+1
      QS(K)=TIME
      IG(K)=ID1-IQ
      IM(K)=1
      IQ=IQ-ID1
      IP=IP-ID1
      IQQ=IQQ-ID1
      IF(IP.GT.IS) GO TO 14
      DO 3 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 4
    3 CONTINUE
      WRITE (6,100)
    4 CALL GGAMS (DSEED6,A,B,1,Z,R)
      EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   70 ML=ML+1
      IP=IP+IR
      IF(IP.LT.IS) GO TO 70
      IA(II)=ML*IR
      DO 60 KT=1,10
      L5=KT
      IF(AK(L5).EQ.0.) GO TO 61
   60 CONTINUE
   61 KA(L5)=IQQ
      AK(L5)=EVENT(II)
      GO TO 14
    6 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=ID1
      IQ=IQ-ID1
      IP=IP-ID1
```

```
      IQQ=IQQ-ID1                                                       TUR07210
      IF(IP.GT.IS) GO TO 14                                             TUR07220
      DO 9 KI=1,NM                                                      TUR07230
      II=KI                                                             TUR07240
      IF(EVENT(II).EQ.99999.) GO TO 10                                  TUR07250
    9 CONTINUE                                                          TUR07260
      WRITE (6,100)                                                     TUR07270
   10 CALL GGAMS (DSEED6,A,B,1,Z,R)                                     TUR07280
      EVENT(II)=TIME+R(1)                                               TUR07290
      IEVENT(II)=8                                                      TUR07300
      ML=0                                                              TUR07310
   71 ML=ML+1                                                           TUR07320
      IP=IP+IR                                                          TUR07330
      IF(IP.LT.IS) GO TO 71                                             TUR07340
      IA(II)=ML*IR                                                      TUR07350
      DO 63 KT=1,10                                                     TUR07360
      L5=KT                                                             TUR07370
      IF(AK(L5).EQ.0.0) GO TO 64                                        TUR07380
   63 CONTINUE                                                          TUR07390
   64 KA(L5)=IQQ                                                        TUR07400
      AK(L5)=EVENT(II)                                                  TUR07410
      GO TO 14                                                          TUR07420
   11 K=K+1                                                             TUR07430
      QS(K)=TIME                                                        TUR07440
      IG(K)=ID1                                                         TUR07450
      IM(K)=1                                                           TUR07460
      IQ=IQ-ID1                                                         TUR07470
      IP=IP-ID1                                                         TUR07480
      IQQ=IQQ-ID1                                                       TUR07490
      IF(IP.GT.IS) GO TO 14                                             TUR07500
      DO 12 KI=1,NM                                                     TUR07510
      II=KI                                                             TUR07520
      IF(EVENT(II).EQ.99999.) GO TO 13                                  TUR07530
   12 CONTINUE                                                          TUR07540
      WRITE (6,100)                                                     TUR07550
   13 CALL GGAMS (DSEED6,A,B,1,Z,R)                                     TUR07560
      EVENT(II)=TIME+R(1)                                               TUR07570
      IEVENT(II)=8                                                      TUR07580
      ML=0                                                              TUR07590
   72 ML=ML+1                                                           TUR07600
      IP=IP+IR                                                          TUR07610
      IF(IP.LT.IS) GO TO 72                                             TUR07620
      IA(II)=ML*IR                                                      TUR07630
   14 SS=TIME                                                           TUR07640
      RETURN                                                            TUR07650
      DEBUG SUBCHK                                                      TUR07660
      END                                                               TUR07670
      SUBROUTINE TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,ITUR07680
```

```
     1P,A,B,A2,B2,DSEED5,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                         TUR07690
      REAL*8 DSEED5,DSEED6                                                      TUR07700
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)TUR07710
     1,Z(50),Z2(50),R(1),R2(1),KA(10),AK(10)                                    TUR07720
      ID=0                                                                      TUR07730
      IF(IQ.LE.0) GO TO 11                                                      TUR07740
      WW=0.0                                                                    TUR07750
      WW=(TIME-SS)*IQ                                                           TUR07760
      TOH=TOH+WW                                                                TUR07770
      IF(IQ.GE.ID2) GO TO 6                                                     TUR07780
      CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                         TUR07790
      DO 1 KI=1,NM                                                              TUR07800
      II=KI                                                                     TUR07810
      IF(EVENT(II).EQ.99999.) GO TO 2                                           TUR07820
    1 CONTINUE                                                                  TUR07830
      WRITE (6,100)                                                             TUR07840
  100 FORMAT (' EVENT LIST IS FULL')                                            TUR07850
    2 EVENT(II)=TIME+R2(1)                                                      TUR07860
      IEVENT(II)=7                                                              TUR07870
      IA2(II)=IQ                                                                TUR07880
      K=K+1                                                                     TUR07890
      QS(K)=TIME                                                                TUR07900
      IG(K)=ID2-IQ                                                              TUR07910
      IM(K)=2                                                                   TUR07920
      IQ=IQ-ID2                                                                 TUR07930
      IP=IP-ID2                                                                 TUR07940
      IQQ=IQQ-ID2                                                               TUR07950
      IF(IP.GT.IS) GO TO 14                                                     TUR07960
      DO 3 KI=1,NM                                                              TUR07970
      II=KI                                                                     TUR07980
      IF(EVENT(II).EQ.99999.) GO TO 4                                           TUR07990
    3 CONTINUE                                                                  TUR08000
      WRITE (6,100)                                                             TUR08010
    4 CALL GGAMS (DSEED6,A,B,1,Z,R)                                             TUR08020
      EVENT(II)=TIME+R(1)                                                       TUR08030
      IEVENT(II)=8                                                              TUR08040
      ML=0                                                                      TUR08050
   70 ML=ML+1                                                                   TUR08060
      IP=IP+IR                                                                  TUR08070
      IF(IP.LT.IS) GO TO 70                                                     TUR08080
      IA(II)=ML*IR                                                              TUR08090
      DO 60 KT=1,10                                                             TUR08100
      L5=KT                                                                     TUR08110
      IF (AK(L5).EQ.0.0) GO TO 61                                               TUR08120
   60 CONTINUE                                                                  TUR08130
   61 KA(L5)=IQQ                                                                TUR08140
      AK(L5)=EVENT(II)                                                          TUR08150
      GO TO 14                                                                  TUR08160
```

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    6 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                           TUR08170
      DO 7 KI=1,NM                                                TUR08180
      II=KI                                                       TUR08190
      IF(EVENT(II).EQ.99999.) GO TO 8                             TUR08200
    7 CONTINUE                                                    TUR08210
      WRITE (6,100)                                               TUR08220
    8 EVENT(II)=TIME+R2(1)                                        TUR08230
      IEVENT(II)=7                                                TUR08240
      IA2(II)=ID2                                                 TUR08250
      IQ=IQ-ID2                                                   TUR08260
      IP=IP-ID2                                                   TUR08270
      IQQ=IQQ-ID2                                                 TUR08280
      IF(IP.GT.IS) GO TO 14                                       TUR08290
      DO 9 KI=1,NM                                                TUR08300
      II=KI                                                       TUR08310
      IF(EVENT(II).EQ.99999.) GO TO 10                            TUR08320
    9 CONTINUE                                                    TUR08330
      WRITE (6,100)                                               TUR08340
   10 CALL GGAMS (DSEED6,A,B,1,Z,R)                               TUR08350
      EVENT(II)=TIME+R(1)                                         TUR08360
      IEVENT(II)=8                                                TUR08370
      ML=0                                                        TUR08380
   71 ML=ML+1                                                     TUR08390
      IP=IP+IR                                                    TUR08400
      IF(IP.LT.IS) GO TO 71                                       TUR08410
      IA(II)=ML*IR                                                TUR08420
      DO 63 KT=1,10                                               TUR08430
      L5=KT                                                       TUR08440
      IF(AK(L5).EQ.0.0) GO TO 64                                  TUR08450
   63 CONTINUE                                                    TUR08460
   64 KA(L5)=IQQ                                                  TUR08470
      AK(L5)=EVENT(II)                                            TUR08480
      GO TO 14                                                    TUR08490
   11 K=K+1                                                       TUR08500
      QS(K)=TIME                                                  TUR08510
      IG(K)=ID2                                                   TUR08520
      IM(K)=2                                                     TUR08530
      IQ=IQ-ID2                                                   TUR08540
      IQQ=IQQ-ID2                                                 TUR08550
      IP=IP-ID2                                                   TUR08560
      IF(IP.GT.IS) GO TO 14                                       TUR08570
      DO 12 KI=1,NM                                               TUR08580
      II=KI                                                       TUR08590
      IF(EVENT(II).EQ.99999.) GO TO 13                            TUR08600
   12 CONTINUE                                                    TUR08610
      WRITE (6,100)                                               TUR08620
   13 CALL GGAMS (DSEED6,A,B,1,Z,R)                               TUR08630
      EVENT(II)=TIME+R(1)                                         TUR08640
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      IEVENT(II)=8                                                      TUR08650
      ML=0                                                              TUR08660
   72 ML=ML+1                                                           TUR08670
      IP=IP+IR                                                          TUR08680
      IF(IP.LT.IS) GO TO 72                                             TUR08690
      IA(II)=ML*IR                                                      TUR08700
   14 SS=TIME                                                           TUR08710
      RETURN                                                            TUR08720
      DEBUG SUBCHK                                                      TUR08730
      END                                                               TUR08740
```

APPENDIX E

Early Warning Simulation Program

```
      REAL*8 DSEED1,DSEED2,DSEED3,DSEED4,DSEED5,DSEED6,DSEED7,DSEED8,DSETUR00010
     1ED9                                                               TUR00020
      DIMENSION EVENT(900),IEVENT(900),IM(900),QU1(900),QU2(900),QU3(900TUR00030
     1),QS(900),IG1(900),IG2(900),IG3(900),IG(900),IA1(900),IA2(900),IA(TUR00040
     1900),Z(50),Z1(50),Z2(50),WK(50),WS(50),WZ(50),IK1(1),IK2(1),IK3(1)TUR00050
     1,S1(1),S2(1),S3(1),KA(10),AK(10)                                   TUR00060
      NS=900                                                            TUR00070
      NM=30                                                             TUR00080
      DSEED1=123456.0D0                                                 TUR00090
      DSEED2=247658.0D0                                                 TUR00100
      DSEED3=365274.0D0                                                 TUR00110
      DSEED4=258732.0D0                                                 TUR00120
      DSEED5=541863.0D0                                                 TUR00130
      DSEED6=433215.0D0                                                 TUR00140
      DSEED7=651563.0D0                                                 TUR00150
      DSEED8=265418.0D0                                                 TUR00160
      DSEED9=167519.0D0                                                 TUR00170
      I=0                                                               TUR00180
      J=0                                                               TUR00190
      K=0                                                               TUR00200
      L=0                                                               TUR00210
      SS=0.0                                                            TUR00220
      SS1=0.0                                                           TUR00230
      SS2=0.0                                                           TUR00240
      TW1=0.0                                                           TUR00250
      TW2=0.0                                                           TUR00260
      TW3=0.0                                                           TUR00270
      TW4=0.0                                                           TUR00280
      TW5=0.0                                                           TUR00290
      TOH=0.0                                                           TUR00300
      TOH1=0.0                                                          TUR00310
      TOH2=0.0                                                          TUR00320
      DO 1 N=1,50                                                       TUR00330
      EVENT(N)=99999.                                                   TUR00340
      IEVENT(N)=0                                                       TUR00350
      QU1(N)=0.0                                                        TUR00360
      QU2(N)=0.0                                                        TUR00370
      QU3(N)=0.0                                                        TUR00380
      IG1(N)=0                                                          TUR00390
      IG2(N)=0                                                          TUR00400
      IG3(N)=0                                                          TUR00410
      IA1(N)=0                                                          TUR00420
      IA2(N)=0                                                          TUR00430
      IA(N)=0                                                           TUR00440
    1 CONTINUE                                                          TUR00450
      DO 2 N=1,10                                                       TUR00460
      IM(N)=0                                                           TUR00470
      QS(N)=0.0                                                         TUR00480
```

```
      IG(N)=0                                                           TUR00490
      KA(N)=0                                                           TUR00500
      AK(N)=0.0                                                         TUR00510
    2 CONTINUE                                                          TUR00520
      IF=0                                                              TUR00530
      IF1=0                                                             TUR00540
      IF2=0                                                             TUR00550
      ID=0                                                              TUR00560
      ID1=0                                                             TUR00570
      ID2=0                                                             TUR00580
      READ(5,100) IR,IS                                                 TUR00590
  100 FORMAT( 2I10)                                                     TUR00600
      READ (5,110) IR1,IS1,T1                                           TUR00610
  110 FORMAT(2I10,F10.0)                                                TUR00620
      READ (5,110) IR2,IS2,T2                                           TUR00630
      READ (5,120) YEAR                                                 TUR00640
  120 FORMAT(F10.0)                                                     TUR00650
      READ (5,130) A,B
  130 FORMAT (2F4.0)
      READ (5,130) A1,B1
      READ (5,130) A2,B2
      READ (5,140) XM1
      READ (5,140) XM2
      READ (5,140) XM3
  140 FORMAT(F4.0)
      READ (5,150) P1
      READ (5,150) P2
      READ (5,150) P3
  150 FORMAT(F6.0)
      IQ=IR+IS
      IQ1=IR1                                                           TUR00790
      IQ2=IR2                                                           TUR00800
      IQQ=100000                                                        TUR00810
      IQQ1=100000                                                       TUR00820
      IQQ2=100000                                                       TUR00830
      ND11=100000                                                       TUR00840
      ND22=100000                                                       TUR00850
      XL=(YEAR/365.)*48.                                                TUR00860
      TIME=0.0                                                          TUR00870
      IP=IR+IS
      IPP=IR+IS
      IP1=IR1                                                           TUR00900
      IP2=IR2                                                           TUR00910
      CALL GGEXN (DSEED1,XM1,1,S1)                                      TUR00920
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)                                   TUR00930
      IF1=1                                                             TUR00940
      DO 3 KI=1,NM                                                      TUR00950
      II=KI                                                             TUR00960
```

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      IF(EVENT(II).EQ.99999.) GO TO 4                                   TUR00970
    3 CONTINUE                                                          TUR00980
    4 EVENT(II)=TIME+S1(1)                                              TUR00990
      IEVENT(II)=1                                                      TUR01000
      CALL GGEXN (DSEED2,XM2,1,S2)                                      TUR01010
      CALL GGEOT (DSEED8,1,P2,WS,IK2)                                   TUR01020
      IF2=1                                                             TUR01030
      DO 5 KI=1,NM                                                      TUR01040
      II=KI                                                             TUR01050
      IF(EVENT(II).EQ.99999.) GO TO 6                                   TUR01060
    5 CONTINUE                                                          TUR01070
    6 EVENT(II)=TIME+S2(1)                                              TUR01080
      IEVENT(II)=2                                                      TUR01090
      CALL GGEXN (DSEED3,XM3,1,S3)                                      TUR01100
      CALL GGEOT (DSEED9,1,P3,WK,IK3)                                   TUR01110
      IF=1                                                              TUR01120
      DO 7 KI=1,NM                                                      TUR01130
      II=KI                                                             TUR01140
      IF(EVENT(II).EQ.99999.) GO TO 8                                   TUR01150
    7 CONTINUE                                                          TUR01160
    8 EVENT(II)=TIME+S3(1)                                              TUR01170
      IEVENT(II)=3                                                      TUR01180
      DO 9 KI=1,NM                                                      TUR01190
      II=KI                                                             TUR01200
      IF(EVENT(II).EQ.99999.) GO TO 10                                  TUR01210
    9 CONTINUE                                                          TUR01220
   10 EVENT(II)=TIME+T1                                                 TUR01230
      IEVENT(II)=4                                                      TUR01240
      DO 11 KI=1,NM                                                     TUR01250
      II=KI                                                             TUR01260
      IF(EVENT(II).EQ.99999.) GO TO 12                                  TUR01270
   11 CONTINUE                                                          TUR01280
   12 EVENT(II)=TIME+T2                                                 TUR01290
      IEVENT(II)=5                                                      TUR01300
      DO 13 KI=1,NM                                                     TUR01310
      II=KI                                                             TUR01320
      IF(EVENT(II).EQ.99999.) GO TO 14                                  TUR01330
   13 CONTINUE                                                          TUR01340
   14 EVENT(II)=YEAR                                                    TUR01350
      IEVENT(II)=9                                                      TUR01360
      GO TO 26                                                          TUR01370
   15 EVENT(IN)=99999.                                                  TUR01380
      IEVENT(IN)=0                                                      TUR01390
   26 IN=1                                                              TUR01400
      DO 16 KI=2,NM                                                     TUR01410
      IF(EVENT(IN).GT.EVENT(KI)) IN=KI                                  TUR01420
   16 CONTINUE                                                          TUR01430
      TIME=EVENT(IN)                                                    TUR01440
```

```
      IL=IEVENT(IN)
      IJ=IN
      GO TO (17,18,19,20,21,22,23,24,25),IL
   17 CALL ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSEED1,DS
     1EED7,NM,NS,TOH1,SS1,IQQ1,IPP,IS,A,B,IR,DSEED6,IA,KA,AK,IQQ)
      GO TO 15
   18 CALL TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSEED2,DS
     1EED8,NM,NS,TOH2,SS2,IQQ2,IPP,IS,A,B,IR,DSEED6,IA,KA,AK,IQQ)
      GO TO 15
   19 CALL THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEED3,DS
     1EED6,DSEED9,A,B,NM,NS,IA,IR,IS,TOH,SS,KA,AK,IQQ,IPP)
      GO TO 15
   20 CALL FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IR1,I
     1S,IP,A,B,A1,B1,DSEED4,DSEED6,NM,T1,NS,IS1,TOH,SS,KA,AK,IQQ,IQQ1,ND
     111)
      GO TO 15
   21 CALL FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IR2,I
     1S,IP,A,B,A2,B2,DSEED5,DSEED6,NM,T2,NS,IS2,TOH,SS,KA,AK,IQQ,IQQ2,ND
     122)
      GO TO 15
   22 CALL SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,NM,NS)
      GO TO 15
   23 CALL SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,NM,NS)
      GO TO 15
   24 CALL EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,QU3,IG
     13,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,NM,NS,IP,KA,AK,IQQ)
      GO TO 15
   25 TW1=TW1/YEAR
      TW2=TW2/YEAR
      TW3=TW3/YEAR
      TW4=TW4/YEAR
      TW5=TW5/YEAR
      WRITE (6,200) TW1,TW2,TW3,TW4,TW5
  200 FORMAT (' TW1=',F10.4,' TW2=',F10.4,' TW3=',F10.4,' TW4=',F10.4,'
     1TW5=',F10.4)
      TOH=TOH/YEAR
      TOH1=TOH1/YEAR
      TOH2=TOH2/YEAR
      WRITE (6,201) TOH,TOH1,TOH2
  201 FORMAT (' TOH=',F10.3,' TOH1=',F10.3,' TOH2=',F10.3)
      STOP
      DEBUG SUBCHK
      END
      SUBROUTINE ONE (I,TIME,EVENT,IEVENT,QU1,IG1,IQ1,IP1,IF1,XM1,P1,DSE
     1ED1,DSEED7,NM,NS,TOH1,SS1,IQQ1,IPP,IS,A,B,IR,DSEED6,IA,KA,AK,IQQ)
      REAL*8 DSEED1,DSEED7,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),QU1(NS),IG1(NS),WZ(50),IK1(1),S1(1)
     1,Z(50),R(1),IA(NS),KA(10),AK(10)
```

```
      IPP=IPP-IF1                                                       TUR01930
      IQQ=IQQ-IF1                                                       TUR01940
      IF(IPP.GT.IS) GO TO 6                                             TUR01950
      CALL GGAMS (DSEED6,A,B,1,Z,R)                                     TUR01960
      DO 7 KI=1,NM                                                      TUR01970
      II=KI                                                             TUR01980
      IF(EVENT(II).EQ.99999.) GO TO 8                                   TUR01990
    7 CONTINUE                                                          TUR02000
      WRITE (6,100)                                                     TUR02010
    8 EVENT(II)=TIME+R(1)                                               TUR02020
      IEVENT(II)=8                                                      TUR02030
      ML=0                                                              TUR02040
   70 ML=ML+1                                                           TUR02050
      IPP=IPP+IR                                                        TUR02060
      IF(IPP.LT.IS) GO TO 70                                            TUR02070
      IA(II)=ML*IR                                                      TUR02080
      DO 60 KT=1,10                                                     TUR02090
      L5=KT                                                             TUR02100
      IF(AK(L5).EQ.0.0) GO TO 61                                        TUR02110
   60 CONTINUE                                                          TUR02120
   61 KA(L5)=IQQ                                                        TUR02130
      AK(L5)=EVENT(II)                                                  TUR02140
    6 IF(IQ1.GT.0) GO TO 1                                              TUR02150
      I=I+1                                                             TUR02160
      IQ1=IQ1-IF1                                                       TUR02170
      IP1=IP1-IF1                                                       TUR02180
      IQQ1=IQQ1-IF1                                                     TUR02190
      QU1(I)=TIME                                                       TUR02200
      IG1(I)=IF1                                                        TUR02210
      GO TO 3                                                           TUR02220
    1 WW=0.0                                                            TUR02230
      WW=(TIME-SS1)*IQ1                                                 TUR02240
      TOH1=TOH1+WW                                                      TUR02250
      IF(IQ1.LT.IF1) GO TO 2                                            TUR02260
      IQ1=IQ1-IF1                                                       TUR02270
      IP1=IP1-IF1                                                       TUR02280
      IQQ1=IQQ1-IF1                                                     TUR02290
      GO TO 3                                                           TUR02300
    2 I=I+1                                                             TUR02310
      IQ1=IQ1-IF1                                                       TUR02320
      IP1=IP1-IF1                                                       TUR02330
      IQQ1=IQQ1-IF1                                                     TUR02340
      QU1(I)=TIME                                                       TUR02350
      IG1(I)=IF1-IQ1                                                    TUR02360
    3 CALL GGEXN (DSEED1,XM1,1,S1)                                      TUR02370
      CALL GGEOT (DSEED7,1,P1,WZ,IK1)                                   TUR02380
      IF1=1                                                             TUR02390
      DO 4 KI=1,NM                                                      TUR02400
```

```
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 5
    4 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    5 EVENT(II)=TIME+S1(1)
      IEVENT(II)=1
      SS1=TIME
      RETURN
      DEBUG SUBCHK
      END
      SUBROUTINE TWO (J,TIME,EVENT,IEVENT,QU2,IG2,IQ2,IP2,IF2,XM2,P2,DSE
     1ED2,DSEED8,NM,NS,TOH2,SS2,IQQ2,IPP,IS,A,B,IR,DSEED6,IA,KA,AK,IQQ)
      REAL*8 DSEED2,DSEED8,DSEED6
      DIMENSION EVENT(NS),IEVENT(NS),QU2(NS),IG2(NS),WS(50),IK2(1),S2(1)
     1,Z(50),R(1),IA(NS),KA(10),AK(19)
      IPP=IPP-IF2
      IQQ=IQQ-IF2
      IF(IPP.GT.IS) GO TO 6
      CALL GGAMS (DSEED6,A,B,1,Z,R)
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+R(1)
      IEVENT(II)=8
      ML=0
   70 ML=ML+1
      IPP=IPP+IR
      IF(IPP.LT.IS) GO TO 70
      IA(II)=ML*IR
      DO 60 KT=1,10
      L5=KT
      IF(AK(L5).EQ.0.0) GO TO 61
   60 CONTINUE
   61 KA(L5)=IQQ
      AK(L5)=EVENT(II)
    6 IF(IQ2.GT.0) GO TO 1
      J=J+1
      IG2=IQ2-IF2
      IP2=IP2-IF2
      IQQ2=IQQ2-IF2
      QU2(J)=TIME
      IG2(J)=IF2
      GO TO 3
    1 WW=0.0
      WW=(TIME-SS2)*IQ2
```

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      TOH2=TOH2+WW                                                      TUR02890
      IF(IQ2.LT.IF2) GO TO 2                                            TUR02900
      IQ2=IQ2-IF2                                                       TUR02910
      IP2=IP2-IF2                                                       TUR02920
      IQQ2=IQQ2-IF2                                                     TUR02930
      GO TO 3                                                           TUR02940
    2 J=J+1                                                             TUR02950
      IQ2=IQ2-IF2                                                       TUR02960
      IP2=IP2-IF2                                                       TUR02970
      IQQ2=IQQ2-IF2                                                     TUR02980
      QU2(J)=TIME                                                       TUR02990
      IG2(J)=IF2-IQ2                                                    TUR03000
    3 CALL GGEXN (DSEED2,XM2,1,S2)                                      TUR03010
      CALL GGEOT (DSEED8,1,P2,WS,IK2)                                   TUR03020
      IF2=1                                                             TUR03030
      DO 4 KI=1,NM                                                      TUR03040
      II=KI                                                             TUR03050
      IF(EVENT(II).EQ.99999.) GO TO 5                                   TUR03060
    4 CONTINUE                                                          TUR03070
      WRITE (6,100)                                                     TUR03080
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR03090
    5 EVENT(II)=TIME+S2(1)                                              TUR03100
      IEVENT(II)=2                                                      TUR03110
      SS2=TIME                                                          TUR03120
      RETURN                                                            TUR03130
      DEBUG SUBCHK                                                      TUR03140
      END                                                               TUR03150
      SUBROUTINE THREE (L,TIME,EVENT,IEVENT,QU3,IG3,IQ,IP,IF,XM3,P3,DSEETUR03160
     1D3,DSEED6,DSEED9,A,B,NM,NS,IA,IR,IS,TOH,SS,KA,AK,IQQ,IPP)         TUR03170
      REAL*8 DSEED3,DSEED6,DSEED9                                       TUR03180
      DIMENSION EVENT(NS),IEVENT(NS),QU3(NS),IG3(NS),Z(50),IA(NS),WK(50)TUR03190
     1,IK3(1),S3(1),R(1),KA(10),AK(10)                                  TUR03200
      IPP=IPP-IF                                                        TUR03210
      IF(IQ.GT.0) GO TO 1                                               TUR03220
      L=L+1                                                             TUR03230
      IP=IP-IF                                                          TUR03240
      IQ=IQ-IF                                                          TUR03250
      IQQ=IQQ-IF                                                        TUR03260
      QU3(L)=TIME                                                       TUR03270
      IG3(L)=IF                                                         TUR03280
      GO TO 3                                                           TUR03290
    1 WW=0.0                                                            TUR03300
      WW=(TIME-SS)*IQ                                                   TUR03310
      TOH=TOH+WW                                                        TUR03320
      IF(IQ.LT.IF) GO TO 2                                              TUR03330
      IQ=IQ-IF                                                          TUR03340
      IQQ=IQQ-IF                                                        TUR03350
      IP=IP-IF                                                          TUR03360
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      GO TO 3                                                           TUR03370
    2 L=L+1                                                             TUR03380
      QU3(L)=TIME                                                       TUR03390
      IG3(L)=IF-IQ                                                      TUR03400
      IQ=IQ-IF                                                          TUR03410
      IP=IP-IF                                                          TUR03420
      IQQ=IQQ-IF                                                        TUR03430
    3 IF(IPP.GT.IS) GO TO 6                                             TUR03440
      CALL GGAMS (DSEED6,A,B,1,Z,R)                                     TUR03450
      DO 4 KI=1,NM                                                      TUR03460
      II=KI                                                             TUR03470
      IF(EVENT(II).EQ.99999.) GO TO 5                                   TUR03480
    4 CONTINUE                                                          TUR03490
      WRITE (6,100)                                                     TUR03500
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR03510
    5 EVENT(II)=TIME+R(1)                                               TUR03520
      IEVENT(II)=8                                                      TUR03530
      ML=0                                                              TUR03540
   70 ML=ML+1                                                           TUR03550
      IPP=IPP+IR                                                        TUR03560
      IF(IPP.LT.IS) GO TO 70                                            TUR03570
      IA(II)=ML*IR                                                      TUR03580
      DO 60 KT=1,10                                                     TUR03590
      L5=KT                                                             TUR03600
      IF(AK(L5).EQ.0.0) GO TO 61                                        TUR03610
   60 CONTINUE                                                          TUR03620
   61 KA(L5)=IQQ                                                        TUR03630
      AK(L5)=EVENT(II)                                                  TUR03640
      IPP=IR+IS                                                         TUR03650
    6 CALL GGEXN (DSEED3,XM3,1,S3)                                      TUR03660
      CALL GGEOT (DSEED9,1,P3,WK,IK3)                                   TUR03670
      IF=1                                                              TUR03680
      DO 7 KI=1,NM                                                      TUR03690
      II=KI                                                             TUR03700
      IF(EVENT(II).EQ.99999.) GO TO 8                                   TUR03710
    7 CONTINUE                                                          TUR03720
      WRITE (6,100)                                                     TUR03730
    8 EVENT(II)=TIME+S3(1)                                              TUR03740
      IEVENT(II)=3                                                      TUR03750
      SS=TIME                                                           TUR03760
      RETURN                                                            TUR03770
      DEBUG SUBCHK                                                      TUR03780
      END                                                               TUR03790
      SUBROUTINE FOUR (K,IQ,IQ1,IP1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IRTUR03800
     1,IR1,IS,IP,A,B,A1,B1,DSEED4,DSEED6,NM,T1,NS,IS1,TOH,SS,KA,AK,IQQ,ITUR03810
     1QQ1,ND11)                                                         TUR03820
      REAL*8 DSEED4,DSEED6                                              TUR03830
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)TUR03840
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     1,KA(10),AK(10)                                                    TUR03850
      ND1=ND11-IQQ1                                                     TUR03860
      ND11=0                                                            TUR03870
      WRITE (6,250) ND1                                                 TUR03880
  250 FORMAT (/,' AMOUNT OF DEMAND IN A PERIOD OF 1=',I10)              TUR03890
      ID1=0                                                             TUR03900
      IF(IP1.GT.IS1) GO TO 1                                            TUR03910
      ID1=IR1-IP1                                                       TUR03920
      IP1=IR1                                                           TUR03930
      CALL NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,IP,A,BTUR03940
     1,A1,B1,DSEED4,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                      TUR03950
    1 DO 2 KI=1,NM                                                      TUR03960
      II=KI                                                             TUR03970
      IF(EVENT(II).EQ.99999.) GO TO 3                                   TUR03980
    2 CONTINUE                                                          TUR03990
      WRITE (6,100)                                                     TUR04000
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR04010
    3 EVENT(II)=TIME+T1                                                 TUR04020
      IEVENT(II)=4                                                      TUR04030
      ND11=IQQ1                                                         TUR04040
      RETURN                                                            TUR04050
      DEBUG SUBCHK                                                      TUR04060
      END                                                               TUR04070
      SUBROUTINE FIVE (K,IQ,IQ2,IP2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IRTUR04080
     1,IR2,IS,IP,A,B,A2,B2,DSEED5,DSEED6,NM,T2,NS,IS2,TOH,SS,KA,AK,IQQ,ITUR04090
     1QQ2,ND22)                                                         TUR04100
      REAL*8 DSEED5,DSEED6                                              TUR04110
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)TUR04120
     1,KA(10),AK(10)                                                    TUR04130
      ND2=ND22-IQQ2                                                     TUR04140
      ND22=0                                                            TUR04150
      WRITE (6,250) ND2                                                 TUR04160
  250 FORMAT (/,' AMOUNT OF DEMAND IN A PERIOD OF SYSTEM 2=',I10)       TUR04170
      ID2=0                                                             TUR04180
      IF(IP2.GT.IS2) GO TO 1                                            TUR04190
      ID2=IR2-IP2                                                       TUR04200
      IP2=IR2                                                           TUR04210
      CALL TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,IP,A,B,TUR04220
     1A2,B2,DSEED5,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                       TUR04230
    1 DO 2 KI=1,NM                                                      TUR04240
      II=KI                                                             TUR04250
      IF(EVENT(II).EQ.99999.) GO TO 3                                   TUR04260
    2 CONTINUE                                                          TUR04270
      WRITE (6,100)                                                     TUR04280
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR04290
    3 EVENT(II)=TIME+T2                                                 TUR04300
      IEVENT(II)=5                                                      TUR04310
      ND22=IQQ2                                                         TUR04320
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      RETURN                                                            TUR04330
      DEBUG SUBCHK                                                      TUR04340
      END                                                               TUR04350
      SUBROUTINE SIX (I,IJ,TIME,IA1,IQ1,QU1,IG1,TW1,IP1,NM,NS)          TUR04360
      DIMENSION IA1(NS),IG1(NS),QU1(NS)                                 TUR04370
      WRITE (6,50) IQ1                                                  TUR04380
   50 FORMAT (/,' EXPECTED NET INVENTORY OF SYSTEM 1 AT THE END OF CYCLETUR04390
     1=',I6)                                                            TUR04400
      IQ1=IQ1+IA1(IJ)                                                   TUR04410
      ITD=0                                                             TUR04420
      IF(I.EQ.0) GO TO 8                                                TUR04430
      DO 1 N=1,I                                                        TUR04440
      ITD=ITD+IG1(N)                                                    TUR04450
    1 CONTINUE                                                          TUR04460
      IF(IA1(IJ).LT.ITD) GO TO 3                                        TUR04470
      DO 2 N=1,I                                                        TUR04480
      W=0.                                                              TUR04490
      W=(TIME-QU1(N))*IG1(N)                                            TUR04500
      QU1(N)=0.                                                         TUR04510
      TW1=TW1+W                                                         TUR04520
      IG1(N)=0                                                          TUR04530
    2 CONTINUE                                                          TUR04540
      IA1(IJ)=0                                                         TUR04550
      I=0                                                               TUR04560
      GO TO 8                                                           TUR04570
    3 DO 5 N=1,I                                                        TUR04580
      W=0.                                                              TUR04590
      IF(IA1(IJ).GE.IG1(N)) GO TO 4                                     TUR04600
      IF(IA1( IJ).EQ.0) GO TO 6                                         TUR04610
      IG1(N)=IG1(N)-IA1(IJ)                                             TUR04620
      W=(TIME-QU1(N))*IA1(IJ)                                           TUR04630
      TW1=TW1+W                                                         TUR04640
      GO TO 6                                                           TUR04650
    4 IA1(IJ)=IA1(IJ)-IG1(N)                                            TUR04660
      W=(TIME-QU1(N))*IG1(N)                                            TUR04670
      TW1=TW1+W                                                         TUR04680
      QU1(N)=0.                                                         TUR04690
      IG1(N)=0                                                          TUR04700
    5 CONTINUE                                                          TUR04710
    6 MM=0                                                              TUR04720
      DO 7 N=1,I                                                        TUR04730
      IF(QU1(N).EQ.0.) GO TO 7                                          TUR04740
      MM=MM+1                                                           TUR04750
      QU1(MM)=QU1(N)                                                    TUR04760
      IG1(MM)=IG1(N)                                                    TUR04770
    7 CONTINUE                                                          TUR04780
      I=MM                                                              TUR04790
    8 RETURN                                                            TUR04800
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      DEBUG SUBCHK                                                      TUR04810
      END                                                               TUR04820
      SUBROUTINE SEVEN (J,IJ,TIME,IA2,IQ2,QU2,IG2,TW2,IP2,NM,NS)        TUR04830
      DIMENSION IA2(NS),IG2(NS),QU2(NS)                                 TUR04840
      WRITE (6,50) IQ2                                                  TUR04850
   50 FORMAT (/,' EXPECTED NET INVENTORY OF SYSTEM 2 AT THE END OF CYCLETUR04860
     1=',I6)                                                            TUR04870
      IQ2=IQ2+IA2(IJ)                                                   TUR04880
      ITD=0                                                             TUR04890
      IF(J.EQ.0) GO TO 8                                                TUR04900
      DO 1 N=1,J                                                        TUR04910
      ITD=ITD+IG2(N)                                                    TUR04920
    1 CONTINUE                                                          TUR04930
      IF(IA2(IJ).LT.ITD) GO TO 3                                        TUR04940
      DO 2 N=1,J                                                        TUR04950
      W=0.                                                              TUR04960
      W=(TIME-QU2(N))*IG2(N)                                            TUR04970
      QU2(N)=0.                                                         TUR04980
      TW2=TW2+W                                                         TUR04990
      IG2(N)=0                                                          TUR05000
    2 CONTINUE                                                          TUR05010
      IA2(IJ)=0                                                         TUR05020
      J=0                                                               TUR05030
      GO TO 8                                                           TUR05040
    3 DO 5 N=1,J                                                        TUR05050
      W=0.                                                              TUR05060
      IF(IA2(IJ).GE.IG2(N)) GO TO 4                                     TUR05070
      IF(IA2(IJ).EQ.0) GO TO 6                                          TUR05080
      IG2(N)=IG2(N)-IA2(IJ)                                             TUR05090
      W=(TIME-QU2(N))*IA2(IJ)                                           TUR05100
      TW2=TW2+W                                                         TUR05110
      GO TO 6                                                           TUR05120
    4 IA2(IJ)=IA2(IJ)-IG2(N)                                            TUR05130
      W=(TIME-QU2(N))*IG2(N)                                            TUR05140
      TW2=TW2+W                                                         TUR05150
      QU2(N)=0.                                                         TUR05160
      IG2(N)=0                                                          TUR05170
    5 CONTINUE                                                          TUR05180
    6 JJ=0                                                              TUR05190
      DO 7 N=1,J                                                        TUR05200
      IF(QU2(N).EQ.0.) GO TO 7                                          TUR05210
      JJ=JJ+1                                                           TUR05220
      QU2(JJ)=QU2(N)                                                    TUR05230
      IG2(JJ)=IG2(N)                                                    TUR05240
    7 CONTINUE                                                          TUR05250
      J=JJ                                                              TUR05260
    8 RETURN                                                            TUR05270
      DEBUG SUBCHK                                                      TUR05280
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      END                                                               TUR05290
      SUBROUTINE EIGHT (L,K,IJ,TIME,EVENT,IEVENT,IQ,IA,IA1,IA2,IG,QS,IM,TUR05300
     1QU3,IG3,A,B,A1,B1,A2,B2,TW3,TW4,TW5,DSEED4,DSEED5,NM,NS,IP,KA,AK,ITUR05310
     1QQ)                                                               TUR05320
      REAL*8 DSEED4,DSEED5                                              TUR05330
      DIMENSION EVENT(NS),IEVENT(NS),IA(NS),IA1(NS),IA2(NS),IG(NS),QS(NSTUR05340
     1),IM(NS),QU3(NS),IG3(NS),Z1(50),Z2(50),R1(1),R2(1),KA(10),AK(10)  TUR05350
      ITD=0                                                             TUR05360
      JZ=0                                                              TUR05370
      JZ=IQ                                                             TUR05380
      DO 60 KT=1,10                                                     TUR05390
      L5=KT                                                             TUR05400
      IF(AK(L5).EQ.TIME) GO TO 61                                       TUR05410
   60 CONTINUE                                                          TUR05420
   61 ND=KA(L5)-IQQ                                                     TUR05430
      KA(L5)=0                                                          TUR05440
      AK(L5)=0.                                                         TUR05450
      WRITE (6,250) ND,TIME                                             TUR05460
  250 FORMAT (/,' DEMAND DURING LEAD TIME=',I10,' TIME=',F15.5)         TUR05470
      IQ=IQ+IA(IJ)                                                      TUR05480
      WRITE (6,50) JZ,IQ,TIME                                           TUR05490
   50 FORMAT (/,' EXPECTED NET INVENTORY OF MAIN SYSTEM AT THE END OF CYTUR05500
     1CLE=',I6,2X,' IQ=',I6,2X,' TIME=',F10.4)                          TUR05510
      IF(L.EQ.0) GO TO 8                                                TUR05520
      DO 1 N=1,L                                                        TUR05530
      ITD=ITD+IG3(N)                                                    TUR05540
    1 CONTINUE                                                          TUR05550
      IF(IA(IJ).LT.ITD) GO TO 3                                         TUR05560
      DO 2 N=1,L                                                        TUR05570
      W=0.                                                              TUR05580
      W=(TIME-QU3(N))*IG3(N)                                            TUR05590
      QU3(N)=0.                                                         TUR05600
      TW3=TW3+W                                                         TUR05610
      IG3(N)=0                                                          TUR05620
    2 CONTINUE                                                          TUR05630
      IA(IJ)=IA(IJ)-ITD                                                 TUR05640
      L=0                                                               TUR05650
      GO TO 8                                                           TUR05660
    3 DO 5 N=1,L                                                        TUR05670
      W=0.                                                              TUR05680
      IF(IA(IJ).GE.IG3(N)) GO TO 4                                      TUR05690
      IF(IA(IJ).EQ.0) GO TO 6                                           TUR05700
      IG3(N)=IG3(N)-IA(IJ)                                              TUR05710
      W=(TIME-QU3(N))*IA(IJ)                                            TUR05720
      TW3=TW3+W                                                         TUR05730
      GO TO 6                                                           TUR05740
    4 IA(IJ)=IA(IJ)-IG3(N)                                              TUR05750
      W=(TIME-QU3(N))*IG3(N)                                            TUR05760
```

```
      TW3=TW3+W
      QU3(N)=0.
      IG3(N)=0
    5 CONTINUE
    6 LL=0
      DO 7 N=1,L
      IF(QU3(N).EQ.0.) GO TO 7
      LL=LL+1
      QU3(LL)=QU3(N)
      IG3(LL)=IG3(N)
    7 CONTINUE
      L=LL
      GO TO 31
    8 IF(K.EQ.0) GO TO 31
      ITD=0
      DO 9 N=1,K
      ITD=ITD+IG(N)
    9 CONTINUE
      IF(IA(IJ).LT.ITD) GO TO 16
      IAA=0
      DO 10 N=1,K
      IF(IM(N).NE.1) GO TO 10
      W=0.
      W=(TIME-QS(N))*IG(N)
      TW4=TW4+W
      IAA=IAA+IG(N)
      QS(N)=0.
      IG(N)=0
      IM(N)=0
   10 CONTINUE
      IF(IAA.EQ.0) GO TO 32
      DO 11 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 12
   11 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
   12 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IAA
   32 IAB=0
      DO 13 N=1,K
      IF(IM(N).NE.2) GO TO 13
      W=0.
      W=(TIME-QS(N))*IG(N)
      TW5=TW5+W
      IAB=IAB+IG(N)
```

```
      QS(N)=0.
      IG(N)=0
      IM(N)=0
   13 CONTINUE
      IF(IAB.EQ.0) GO TO 31
      DO 14 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 15
   14 CONTINUE
      WRITE (6,100)
   15 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)
      EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
      IA2(II)=IAB
      GO TO 31
   16 IAA=0
      IAB=0
      DO 20 N=1,K
      IF(IM(N).NE.1) GO TO 17
      IF(IA(IJ).GE.IG(N)) GO TO 18
      IG(N)=IG(N)-IA(IJ)
      W=(TIME-QS(N))*IA(IJ)
      TW4=TW4+W
      IAA=IAA+IA(IJ)
      GO TO 21
   17 IF(IM(N).NE.2) GO TO 20
      IF(IA(IJ).GE.IG(N)) GO TO 19
      IG(N)=IG(N)-IA(IJ)
      W=(TIME-QS(N))*IA(IJ)
      TW5=TW5+W
      IAB=IAB+IA(IJ)
      GO TO 21
   18 W=0.
      IAA=IAA+IG(N)
      IA(IJ)=IA(IJ)-IG(N)
      W=(TIME-QS(N))*IG(N)
      TW4=TW4+W
      QS(N)=0.
      IG(N)=0
      IM(N)=0
      GO TO 20
   19 W=0.
      IAB=IAB+IG(N)
      IA(IJ)=IA(IJ)-IG(N)
      W=(TIME-QS(N))*IG(N)
      TW5=TW5+W
      QS(N)=0.
      IG(N)=0
```

```
      IM(N)=0                                                           TUR06730
   20 CONTINUE                                                          TUR06740
   21 IF(IAA.EQ.0) GO TO 24                                             TUR06750
      DO 22 KI=1,NM                                                     TUR06760
      II=KI                                                             TUR06770
      IF(EVENT(II).EQ.99999.) GO TO 23                                  TUR06780
   22 CONTINUE                                                          TUR06790
      WRITE (6,100)                                                     TUR06800
   23 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)                                 TUR06810
      EVENT(II)=TIME+R1(1)                                              TUR06820
      IEVENT(II)=6                                                      TUR06830
      IA1(II)=IAA                                                       TUR06840
   24 IF(IAB.EQ.0) GO TO 27                                             TUR06850
      DO 25 KI=1,NM                                                     TUR06860
      II=KI                                                             TUR06870
      IF(EVENT(II).EQ.99999.) GO TO 26                                  TUR06880
   25 CONTINUE                                                          TUR06890
      WRITE (6,100)                                                     TUR06900
   26 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                 TUR06910
      EVENT(II)=TIME+R2(1)                                              TUR06920
      IEVENT(II)=7                                                      TUR06930
      IA2(II)=IAB                                                       TUR06940
   27 NN=0                                                              TUR06950
      DO 30 N=1,K                                                       TUR06960
      IF(QS(N).EQ.0.) GO TO 30                                          TUR06970
      NN=NN+1                                                           TUR06980
      IF(IM(N).NE.1) GO TO 28                                           TUR06990
      IM(NN)=1                                                          TUR07000
      GO TO 29                                                          TUR07010
   28 IM(NN)=2                                                          TUR07020
   29 QS(NN)=QS(N)                                                      TUR07030
      IG(NN)=IG(N)                                                      TUR07040
   30 CONTINUE                                                          TUR07050
      K=NN                                                              TUR07060
   31 RETURN                                                            TUR07070
      DEBUG SUBCHK                                                      TUR07080
      END                                                               TUR07090
      SUBROUTINE NINE (K,IQ,ID1,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA1,IR,IS,TUR07100
     1IP,A,B,A1,B1,DSEED4,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                TUR07110
      REAL*8 DSEED4,DSEED6                                              TUR07120
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA1(NS),QS(NS),IG(NS),IA(NS)TUR07130
     1,Z(50),Z1(50),R(1),R1(1),KA(10),AK(10)                            TUR07140
      ID=0                                                              TUR07150
      IF(IQ.LE.0) GO TO 11                                              TUR07160
      WW=0.0                                                            TUR07170
      WW=(TIME-SS)*IQ                                                   TUR07180
      TOH=TOH+WW                                                        TUR07190
      IF(IQ.GE.ID1) GO TO 6                                             TUR07200
```

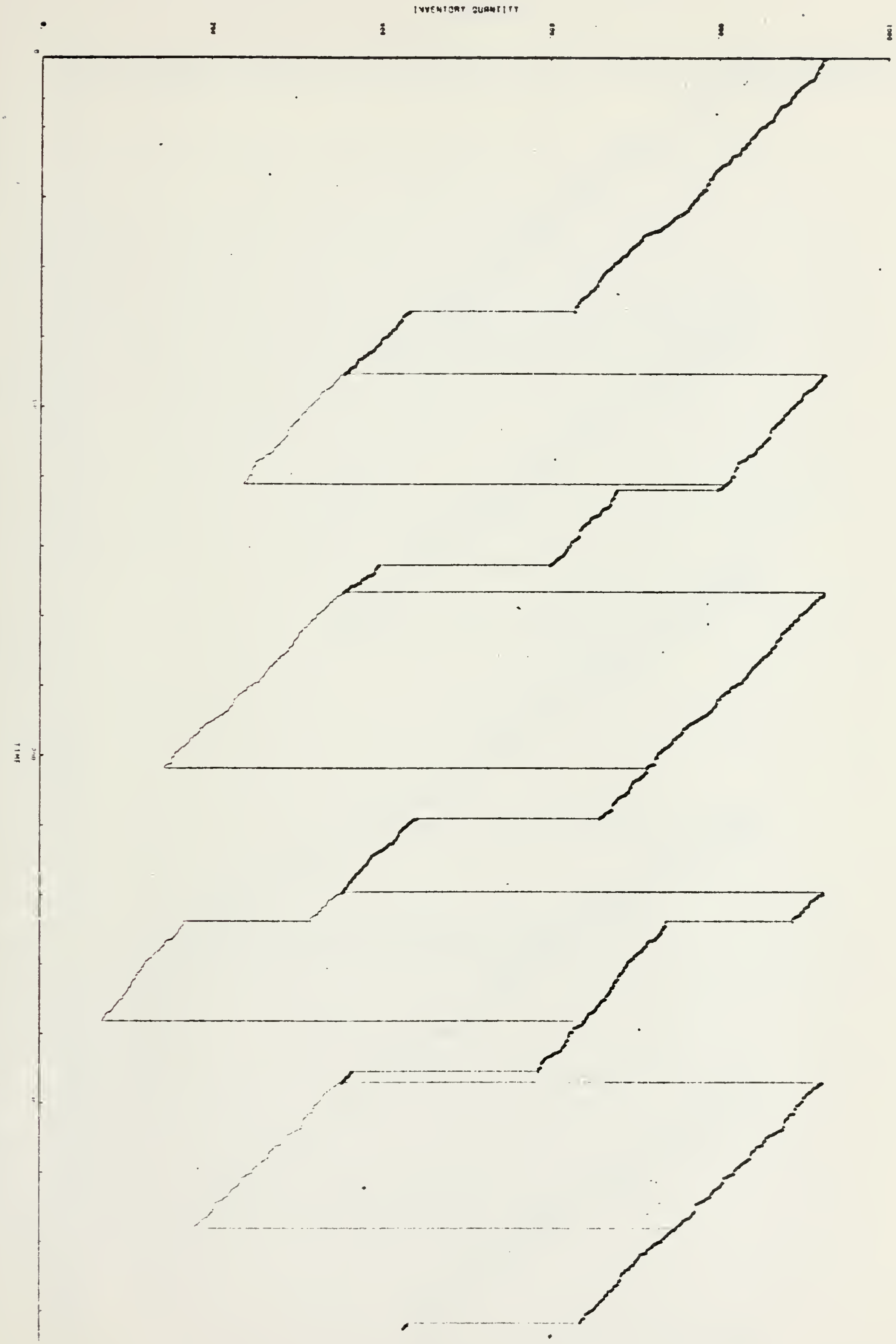
```
      CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      DO 1 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 2
    1 CONTINUE
      WRITE (6,100)
  100 FORMAT (' EVENT LIST IS FULL')
    2 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=IQ
      K=K+1
      QS(K)=TIME
      IG(K)=ID1-IQ
      IM(K)=1
      IQ=IQ-ID1
      IP=IP-ID1
      IF(IP.GT.IS) GO TO 14
      DO 60 KT=1,10
      L5=KT
      IF(AK(L5).EQ.0.) GO TO 61
   60 CONTINUE
   61 KA(L5)=IQQ
      AK(L5)=EVENT(II)
      IP=IR+IS
      GO TO 14
    6 CALL GGAMS (DSEED4,A1,B1,1,Z1,R1)
      DO 7 KI=1,NM
      II=KI
      IF(EVENT(II).EQ.99999.) GO TO 8
    7 CONTINUE
      WRITE (6,100)
    8 EVENT(II)=TIME+R1(1)
      IEVENT(II)=6
      IA1(II)=ID1
      IQ=IQ-ID1
      IP=IP-ID1
      IF(IP.GT.IS) GO TO 14
      DO 63 KT=1,10
      L5=KT
      IF(AK(L5).EQ.0.0) GO TO 64
   63 CONTINUE
   64 KA(L5)=IQQ
      AK(L5)=EVENT(II)
      IP=IR+IS
      GO TO 14
   11 K=K+1
      QS(K)=TIME
      IG(K)=ID1
```

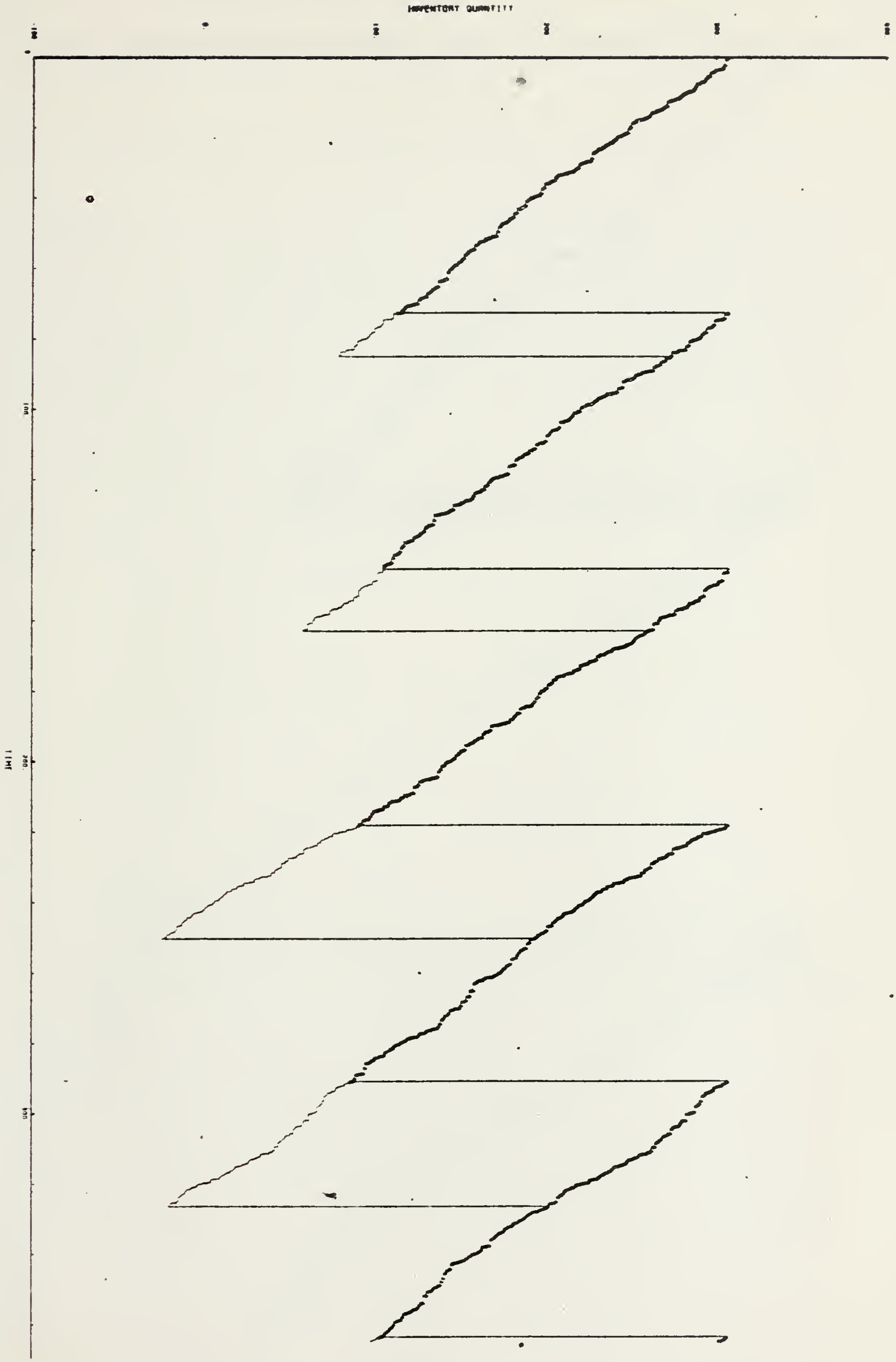
```
      IM(K)=1                                                           TUR07690
      IQ=IQ-ID1                                                         TUR07700
      IP=IP-ID1                                                         TUR07710
   14 SS=TIME                                                           TUR07720
      RETURN                                                            TUR07730
      DEBUG SUBCHK                                                      TUR07740
      END                                                               TUR07750
      SUBROUTINE TEN (K,IQ,ID2,TIME,EVENT,IEVENT,IM,IG,QS,IA,IA2,IR,IS,ITUR07760
     1P,A,B,A2,B2,DSEED5,DSEED6,NM,NS,TOH,SS,KA,AK,IQQ)                 TUR07770
      REAL*8 DSEED5,DSEED6                                              TUR07780
      DIMENSION EVENT(NS),IEVENT(NS),IM(NS),IA2(NS),QS(NS),IG(NS),IA(NS)TUR07790
     1,Z(50),Z2(50),R(1),R2(1),KA(10),AK(10)                            TUR07800
      ID=0                                                              TUR07810
      IF(IQ.LE.0) GO TO 11                                              TUR07820
      WW=0.0                                                            TUR07830
      WW=(TIME-SS)*IQ                                                   TUR07840
      TOH=TOH+WW                                                        TUR07850
      IF(IQ.GE.ID2) GO TO 6                                             TUR07860
      CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                 TUR07870
      DO 1 KI=1,NM                                                      TUR07880
      II=KI                                                             TUR07890
      IF(EVENT(II).EQ.99999.) GO TO 2                                   TUR07900
    1 CONTINUE                                                          TUR07910
      WRITE (6,100)                                                     TUR07920
  100 FORMAT (' EVENT LIST IS FULL')                                    TUR07930
    2 EVENT(II)=TIME+R2(1)                                              TUR07940
      IEVENT(II)=7                                                      TUR07950
      IA2(II)=IQ                                                        TUR07960
      K=K+1                                                             TUR07970
      QS(K)=TIME                                                        TUR07980
      IG(K)=ID2-IQ                                                      TUR07990
      IM(K)=2                                                           TUR08000
      IQ=IQ-ID2                                                         TUR08010
      IP=IP-ID2                                                         TUR08020
      IF(IP.GT.IS) GO TO 14                                             TUR08030
      DO 60 KT=1,10                                                     TUR08040
      L5=KT                                                             TUR08050
      IF (AK(L5).EQ.0.0) GO TO 61                                       TUR08060
   60 CONTINUE                                                          TUR08070
   61 KA(L5)=IQQ                                                        TUR08080
      AK(L5)=EVENT(II)                                                  TUR08090
      IP=IR+IS                                                          TUR08100
      GO TO 14                                                          TUR08110
    6 CALL GGAMS (DSEED5,A2,B2,1,Z2,R2)                                 TUR08120
      DO 7 KI=1,NM                                                      TUR08130
      II=KI                                                             TUR08140
      IF(EVENT(II).EQ.99999.) GO TO 8                                   TUR08150
    7 CONTINUE                                                          TUR08160
```

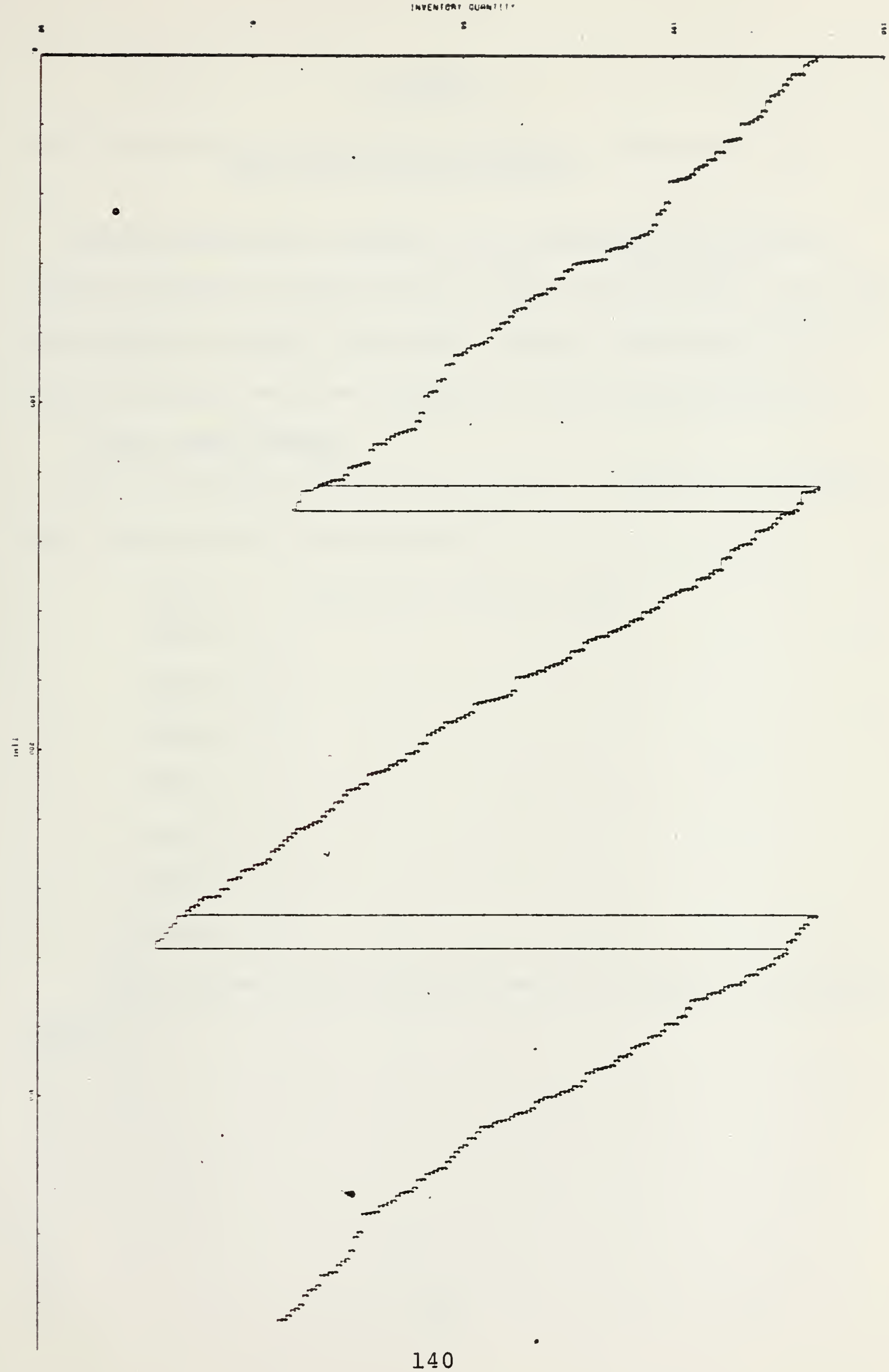
```
      WRITE (6,100)
    8 EVENT(II)=TIME+R2(1)
      IEVENT(II)=7
      IA2(II)=ID2
      IQ=IQ-ID2
      IP=IP-ID2
      IF(IP.GT.IS) GO TO 14
      DO 63 KT=1,10
      L5=KT
      IF(AK(L5).EQ.0.0) GO TO 64
   63 CONTINUE
   64 KA(L5)=IQQ
      AK(L5)=EVENT(II)
      IP=IR+IS
      GO TO 14
   11 K=K+1
      QS(K)=TIME
      IG(K)=ID2
      IM(K)=2
      IQ=IQ-ID2
      IP=IP-ID2
   14 SS=TIME
      RETURN
      DEBUG SUBCHK
      END
```

APPENDIX F

Versatec Output of the Program in Appendix C




INVENTORY QUANTITY
TIME


INVENTORY QUANTITY

APPENDIX G

TI-59 Calculator Program for Analytical Solutions for Periodic Review Systems

This program was written for probabilistic periodic review inventory models having gamma distributed lead times and Poisson arrivals and uses. Normal distribution for demand during lead time instead of Negative Binomial.

Input Requirements

The following variables should be stored in the registers shown before the variables.

STO 01 = λ (arrival rate per day)

STO 02 = C

STO 03 = I

STO 04 = Π

STO 05 = J

STO 06 = A

STO 07 = α-1

STO 08 = β

This program also requires the TI-59 applied statistics module.

Enter	Press	Display
T	A	R
	B	S
	C	η(r)/period
	D	η(r)/year
	E	Annual review and order cost
	A'	Annual inventory carrying cost
	B'	Annual shortage cost
	C'	Total annual variable cost

000	76	LBL
001	11	A
002	55	÷
003	01	1
004	02	2
005	95	=
006	42	STO
007	20	20
008	53	(
009	53	(
010	43	RCL
011	02	02
012	65	×
013	43	RCL
014	03	03
015	65	×
016	43	RCL
017	20	20
018	54	)
019	55	÷
020	43	RCL
021	04	04
022	54	)
023	42	STO
024	21	21
025	53	(
026	43	RCL
027	01	01
028	65	×
029	43	RCL
030	08	08
031	65	×
032	53	(
033	43	RCL
034	07	07
035	85	+
036	01	1
037	54	)
038	54	)
039	42	STO
040	22	22
041	53	(
042	53	(
043	43	RCL
044	01	01
045	65	×
046	43	RCL
047	08	08
048	54	)
049	85	+
050	01	1
051	54	)
052	42	STO
053	23	23
054	53	(
055	03	3
056	06	6
057	05	5
058	65	×
059	43	RCL
060	01	01
061	65	×
062	43	RCL
063	20	20
064	54	)
065	42	STO
066	24	24
067	53	(
068	43	RCL
069	22	22
070	85	+
071	43	RCL
072	24	24
073	54	)
074	42	STO
075	25	25
076	53	(
077	53	(
078	53	(
079	43	RCL
080	22	22
081	65	×
082	43	RCL
083	23	23
084	54	)
085	85	+
086	43	RCL
087	24	24
088	54	)
089	34	√X
090	54	)
091	42	STO
092	26	26
093	53	(
094	01	1
095	55	÷
096	53	(
097	43	RCL
098	21	21
099	33	X²
100	54	)
101	54	)
102	23	LNX
103	34	√X
104	42	STO
105	27	27
106	53	(
107	43	RCL
108	27	27
109	75	−
110	53	(
111	53	(
112	02	2
113	93	.
114	05	5
115	01	1
116	05	5
117	05	5
118	01	1
119	07	7
120	85	+
121	53	(
122	00	0
123	93	.
124	08	8
125	00	0
126	02	2
127	08	8
128	05	5
129	03	3
130	65	×
131	43	RCL
132	27	27
133	54	)
134	85	+
135	53	(
136	43	RCL
137	27	27
138	33	X²
139	65	×
140	93	.
141	00	0
142	01	1
143	00	0
144	03	3
145	02	2
146	08	8
147	54	)
148	54	)
149	55	÷
150	53	(
151	01	1
152	85	+
153	53	(
154	01	1
155	93	.

```
156   04    4
157   03    3
158   02    2
159   07    7
160   08    8
161   08    8
162   65    ×
163   43  RCL
164   27   27
165   54    )
166   85    +
167   53    (
168   43  RCL
169   27   27
170   33  X²
171   65    ×
172   00    0
173   93    .
174   01    1
175   08    8
176   09    9
177   02    2
178   06    6
179   09    9
180   54    )
181   85    +
182   53    (
183   43  RCL
184   27   27
185   33  X²
186   65    ×
187   43  RCL
188   27   27
189   65    ×
190   00    0
191   93    .
192   00    0
193   00    0
194   01    1
195   03    3
196   00    0
197   08    8
198   54    )
199   54    )
200   54    )
201   54    )
202   42  STO
203   28   28
204   53    (
205   53    (
206   43  RCL
207   26   26
208   65    ×
209   43  RCL
210   28   28
211   54    )
212   85    +
213   43  RCL
214   25   25
215   54    )
216   42  STO
217   50   50
218   91  R/S
219   76  LBL
220   12    B
221   53    (
222   43  RCL
223   50   50
224   75    -
225   43  RCL
226   25   25
227   54    )
228   42  STO
229   51   51
230   91  R/S
231   76  LBL
232   13    C
233   53    (
234   53    (
235   43  RCL
236   28   28
237   36  PGM
238   19   19
239   11    A
240   65    ×
241   43  RCL
242   26   26
243   54    )
244   85    +
245   53    (
246   43  RCL
247   21   21
248   65    ×
249   53    (
250   43  RCL
251   25   25
252   75    -
253   43  RCL
254   50   50
255   54    )
256   54    )
257   54    )
258   42  STO
259   52   52
260   91  R/S
261   76  LBL
262   14    D
263   53    (
264   43  RCL
265   52   52
266   55    ÷
267   43  RCL
268   20   20
269   54    )
270   42  STO
271   53   53
272   91  R/S
273   76  LBL
274   15    E
275   53    (
276   53    (
277   43  RCL
278   05   05
279   85    +
280   43  RCL
281   06   06
282   54    )
283   55    ÷
284   43  RCL
285   20   20
286   54    )
287   42  STO
288   54   54
289   91  R/S
290   76  LBL
291   16  A'
292   53    (
293   53    (
294   53    (
295   43  RCL
296   50   50
297   75    -
298   43  RCL
299   22   22
300   54    )
301   75    -
302   53    (
303   00    0
304   93    .
305   05    5
306   65    ×
307   43  RCL
308   24   24
309   54    )
310   54    )
311   65    ×
```

```
312  43 RCL
313  02  02
314  65  x
315  43 RCL
316  03  03
317  54  )
318  42 STO
319  55  55
320  91 R/S
321  76 LBL
322  17 B'
323  53  (
324  43 RCL
325  53  53
326  65  x
327  43 RCL
328  04  04
329  54  )
330  42 STO
331  56  56
332  91 R/S
333  76 LBL
334  18 C'
335  53  (
336  43 RCL
337  54  54
338  85  +
339  43 RCL
340  55  55
341  85  +
342  43 RCL
343  56  56
344  54  )
345  42 STO
346  57  57
347  91 R/S
```

APPENDIX H

Variable Definitions for Simulation Programs

IQ = Net inventory

IP = Inventory position

IPP = Second inventory position for early warning system

IR = Order quantity

IS = Reorder level

ID = Number of items demanded by systems

IF = Number of items demanded per demand by ships

QU = Ship queue

QS = Lower echelon's group demand queue in the main system

IG = Amount of demand for each demand waiting in the queue

IA = Amount of shipment arrived

IM = Index. If it is equal to 1, that means that the demand waiting in the main system queue to be filled belongs to System One.

TW = Total waiting time

TOH = Total average on-hand inventory

T = Length of a period

EVENT = This indicates the subroutines

IEVENT = This indicates time of subroutines scheduled

X = Net inventory variable for Versatec plotter

V = Inventory position variable for Versatec plotter

Y = Time for Versatec plotter

WK = Work space for geometric random variable

WS = Work space for geometric random variable

WZ = Work space for geometric random variable

S = Exponential random number

IK = Geometric random number

WW = Increment

I = Indicates the number of ships waiting in the ship queue at System One

J = Indicates the number of ships waiting in the ship queue at System Two

L = Indicates the number of ships waiting in the ship queue at the main system

K = Indicates the number of demand batches waiting in the group demand queue at the main system

SS = Time indicator

IQQ = Counter for ship arrivals to indicate the number of items demanded per period

ML = Multiplier for the number of batches of demand to be ordered from outside supplier

KA = Indicates the last change on net inventory of the main system in order to get the number of items demanded in a lead time

AK = Time of last change

A = Scale parameter for a gamma distribution

B = Shape parameter for a gamma distribution

XM = Ship arrival rate per day

P = Probability of success for geometric distribution

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