

## 6. BASE CASE STUDY: DETROIT

In order to provide a preliminary comparison of current practice with optimal stocking policies, some representative parts were chosen and optimal stocking policies for these were compared with current stocking levels in the Detroit FDC region. For this comparison, we considered only the no-vanning option as current practice does not involve vanning. In order to account for (what appear to be implicit) response time constraints in practice, optimal policies were computed subject to various response time constraints. The nature of these constraints is discussed in the next section. Thereafter, we present the results of our Detroit region study.

### 6.1. Response Time Constraints

Consider some fixed part. In general, we can represent a response time constraint for the given part for a given region A as follows:

$$(1) \quad \text{Prob} \{ R(A, Y(A)) > T \} \leq B(A)$$

or, in words, the probability that response time  $R(A)$  exceeds  $T$  hours should be less than some prespecified level  $B(A)$ . Here we define response time  $R(A)$  as the (random) time it takes to fill a demand from Region A, given that such a demand occurs. It should be clear that  $R$  depends on the stocking levels  $Y(A)$  of distribution facilities in A and on the spatial distribution of demand in A.

To simplify matters further, we will convert constraints of the above type (1) into direct constraints on the stocking level in region A. This leads to constraints of the form:

$$(2) \quad \text{Prob} \{ D(A) > Y(A) \} \leq B(A)$$

or, in words, the probability that an "excess demand" occurs in Region A should be smaller than  $B(A)$ . An excess demand occurs for Region A when the total demand  $D(A)$  in Region A cannot be covered by stock  $Y(A)$  located at distribution facilities in A. If the maximum time to travel from any distribution facility in A to any demand point in A is  $T$ , then we see that constraint (2) can be considered an approximation to constraint (1).

To be quite specific, we will be considering constraints (2) defined for the following three regions A:

- (1)  $A_2$  = a part station together with its outside locations and all customer locations within its territory.
- (2)  $A_6$  = an FDC and all part stations, outside locations, and customer locations within the FDC's territory.
- (3)  $A_{24}$  = MDC and all reporting territories, i.e., the entire Continental United States.

Thus, for  $A_2$ , constraint (2) amounts to the following: the probability that a demand arising at a customer location in a given part station's territory cannot be filled from the part station or an

outside location within this territory should be less than  $B(A_2)$ . Similar interpretations are attached to  $A_6$  and  $A_{24}$ . The subscripts 2, 6, and 24 refer to current estimates that it takes a maximum of 2, 6 and 24 hours respectively to fill an emergency order from within the defined regions  $A_2$ ,  $A_6$  and  $A_{24}$ .

Clearly, other response time constraints could also be of interest, but we deal here only with the above three. It would also be of interest to consider the impact on response time of the location of distribution facilities (e.g., the location of OLs) within a region. We ignore such locational design issues here.

The next question of interest in defining response time constraints of the form (2) is to relate excess demand to stocking level in a given region. In this regard, we assume:

1. Stock at an OL is only available to that OL.
2. Stock in a Van or a part station is available to all demand points within the territory of the given part station-Van.
3. Stock in the FDC (MDC) is available to all demand points in the FDC(MDC) region.

Thus, suppose there were only two customer locations  $(O_1, O_2)$  in a given part station territory PS and no vanning is allowed. Suppose that one unit of stock is located at  $O_1$ , none at  $O_2$  and none at the part station. If  $p$  is the probability that a demand occurs at (either)  $O_1$  or  $O_2$ , then the probability that excess demand would occur

within the region  $\{PS, O_1, O_2\}$  would be precisely  $p$ , the probability that a demand occurs at  $O_2$ . Note that even if no demand occurs at  $O_1$ , the demand  $O_2$  cannot be filled using the stock at  $O_1$  since no-vanning is assumed here.

Working out the probability calculations for more complicated scenarios than the above is not difficult if one makes a simplifying assumption. The assumption required is that there is a negligible probability that any given part will fail twice in the same physical machine within a replenishment lead time (which may be thought of as being about a week). This being so, if  $p$  is the probability of failure of a given part (over the period in question) in a given machine type in some region A and there are  $N$  machines of the given type in A, then the distribution of failures for the given time period (i.e., the distribution of usage of the given part) can be shown to be approximately Poisson, with mean  $(Np)$ . This well-known distribution is very simple to work with, and from it we can easily derive expressions for  $Y(A)$  in (2), knowing the machine population  $N$  in the region A, and the failure rate  $p$  of the part in question.

For example, suppose the national machine population using a particular part is 7600. Suppose national weekly demand for the part is 1/week. Then the average failure rate of the part is  $p = (1/7600)$ . Now if there are 100 machines of the given type in a region A, then the total demand per week in that region is approximately Poisson with mean  $100p = (100/7600)$ . For  $B(A) = .01$ , constraint (2) would then require that at least one unit of stock  $Y(A)$  be available (and accessible) in region A. If  $p = (20/7600)$ , corresponding to a

national weekly demand of 20, then constraint (2) would require  $Y(A) = 2$  for the same region, if  $B(A) = .01$ .

The reader should note that multiple response time constraints may well be imposed. For example, referring back to the definitions of the regions  $A_2$ ,  $A_6$ ,  $A_{24}$ , the following three constraints might be simultaneously imposed:

$$\begin{aligned} A_2: & \Pr \{ D(A_2) > Y(A_2) \} < .1 ; \\ A_6: & \Pr \{ D(A_6) > Y(A_6) \} < .01 ; \\ A_{24}: & \Pr \{ D(A_{24}) > Y(A_{24}) \} < .0001. \end{aligned}$$

These constraints would be feasibility constraints on stocking levels at part stations ( $A_2$ ), FDCs ( $A_6$ ) and MDC ( $A_{24}$ ) and would be appended to the optimal stocking algorithm described earlier.\* We discuss results of this response-time constrained algorithm for Detroit data below. We simply note here that such constraints have the effect of pushing inventory further down the echelon structure. That is, referring back to Figure 7, the effect of tightening response time constraints is to move the "centralization line" further towards the left-hand corner (i.e., decreasing centralization). We now turn to an analysis of Detroit data to illustrate these matters.

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\* See the Appendix for a detailed flow chart of the part-stocking algorithm with response time constraints.

## 6.2. Data Analysis and Comparisons for the Detroit Region

This section reports on comparisons between current MPLS stocking policies and optimal stocking policies for nine representative parts in the Detroit FDC region. The nine representative parts were obtained as follows. First, we defined three cost classes, consisting of parts with approximate cost of \$2, \$50, and \$1500. We defined also three demand classes, consisting of parts with average national weekly disbursements equal to approximately .3/week, 1/week, and 4/week. For each of the nine resulting aggregate classes, twelve parts were selected at random, and their cost and demand characteristics were averaged. The results of this are displayed in Table 8, where we have labelled the resulting averaged (or "representative") parts as belonging to low, medium, and high cost-demand classes. In addition, we have continued to assume that return rates are correlated with cost class and have taken, for the low, medium, and high cost classes, return rates of .2, .3, and .4, respectively.

For each of the nine representative parts shown in Table 8, we wish to derive optimal stocking policies. The basic structure of our model is that shown in Figure 5 above, except that no specific assumptions are required in this section concerning the number of OLS or customer installations. We do, however, make the assumption discussed in 6.1 above that no installation suffers more than one failure per week within a given part class. Given this assumption, and specific response-time constraints, the algorithm described earlier\* was used to generate optimal solutions. The transportation

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\* See the Appendix for a flow-chart of the model logic.

		<u>DEMAND CLASS</u>		
		LOW	MEDIUM	HIGH
<u>COST</u>	LOW	1.87 .284 .2	1.93 1.213 .2	1.79 3.447 .2
	MEDIUM	57.11 .268 .3	59.58 1.074 .3	49.60 3.587 .3
	HIGH	1629.30 .295 .4	1724.70 1.221 .4	1623.30 3.614 .4

Entries in this table are in the form (x,y,z) where:

x = cost (\$/piece)

y = disbursements (average weekly disb.-nationally)

z = return rate (fraction returned)

Table 8: Data for Representative Parts

cost figures used in deriving the optimal policies were those given previously in Table 5. We continued to use a 2%/month interest rate to reflect the opportunity costs of holding inventory.

The results of these runs are shown in Tables 9 and 10 below. The typical entry in these tables is an abbreviation for the optimal stocking policy (e.g., PS1) and the average weekly cost, nationally, for stocking the part in question using an optimal stocking policy. Two levels of emergency cost were used, low and high, the high being 10 times the low (where low emergency costs are shown in Table 5). Two different response-time constraints were used. In Table 9, stocking policies were required to provide a level of protection such that stock in part stations and associated OLs in the part station territory be sufficient to meet demands 90% of the time. In Table 10, a similar constraint is imposed for region  $A_6$ , which consists of the Detroit FDC and all PSs and OLs within the Detroit region.

What is interesting about these results is that, given the low usage rates for all nine representative parts, the response-time constraint essentially dictates the optimal solution. For example, consider Table 9. For the demand rates given, the minimum stock required to satisfy the response-time constraint indicated for Table 9 is one unit positioned at the PS. Other units might be placed at the PS or at other OLs within the PS territory. But, as it turns out, this single unit placed at the PS is the optimal solution, and this is the case for all levels of emergency cost and for all of the representative parts studied.



Low Emergency Cost

Demand Cost	L	M	H
L	PS1 0.45	PS1 0.66	PS1 1.17
M	PS1 12.05	PS1 12.73	PS1 11.23
H	PS1 342.18	PS1 362.27	PS1 341.30

High Emergency Cost

Demand Cost	L	M	H
L	PS1 0.94	PS1 2.85	PS1 7.92
M	PS1 12.51	PS1 14.66	PS1 18.27
H	PS1 342.70	PS1 364.47	PS1 348.41

Key: PS1: Stock 1 at each PS

Table 9: Stocking Policy & Total Costs

$$\text{Prob} \{ D(A_2) > Y(A_2) \} \leq 0.1$$

## Low Emergency Cost

Demand Cost	L	M	H
L	FDC1 0.25	FDC1 0.43	FDC1 0.87
M	FDC1 6.04	FDC1 6.45	FDC1 5.91
H	FDC1 171.10	FDC1 181.16	FDC1 170.72

## High Emergency Cost

Demand Cost	L	M	H
L	FDC1 0.68	FDC1 2.30	FDC2 6.20
M	FDC1 6.49	FDC1 8.10	FDC1 11.77
H	FDC1 171.54	FDC1 183.88	FDC1 176.64

Key: FDC1: Stock 1 at each FDC  
 FDC2: Stock 2 at each FDC

Table 10: Stocking Policy & Total Costs

$$\text{Prob} \{ D(A_6) > Y(A_6) \} \leq 0.1$$

Similarly, in Table 10, the minimum amount of stock required to meet the indicated response-time constraint is one unit positioned at the FDC. This policy turns out to be optimal in all cases except for the low cost, high demand class, where two units (both positioned at the FDC) are optimal.

Now, of course, it would be unwise to extrapolate the above results to other parts classes without further testing. But what seems to be the case here is that response-time constraints may be determinant of the optimal solution except for low cost-high demand parts. That is, requiring even one unit of a part to be stocked in a given region in order to meet a response-time constraint for that region is so tight a constraint for low demand items that this constraint determines the optimal solution -- namely, put the single required unit at the stocking facility highest up the echelon structure in the given region.

Let us now return to our comparison of current operating procedures in relation to optimal stocking policies. In Table 11 we show the quantity on hand and on order at the indicated locations for the nine representative parts of interest here for October, 1981.\* Several comments are in order in discussing this Table. First, these figures were obtained by taking the total available inventory for each of the twelve actual parts making up a particular representative part.

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\* Data were also gathered for January, 1982, and these were almost identical to those for October, 1981.

This total was then divided by twelve to give the average inventory available for each of the nine representative parts. Next, quantity on hand was also obtained and this was very nearly equal for all parts to quantity on hand and on order, indicating that the replenishment lead time for the FDC and below is sufficiently short relative to usage rates that on order inventory levels are very low. It should be noted that parts costing less than \$30 per unit are not accounted for at the outside locations. This explains the NA entries exhibited in Table 11 for the low cost classes for all outside locations.

Let us now consider how to compare current operating procedures with the optimal stocking policies shown in Tables 9-10. First, consider the policy PS1. This policy is the optimal policy for all cases in Table 9 and it calls for stocking one unit at each PS and none elsewhere. If PS1 were implemented, then one would expect to find the following inventory levels in the system:

CLASS*	LOCATION**						
	MDC	DETFDC	OTFDC	DETPS	OTHPS	DETOL	OTHOL
LL	36.1	0.8	25.1	0.4	23.3	NA***	NA***
LM	116.5	1.8	42.5	0.2	11.8	NA	NA
LH	216.3	3.0	69.8	2.2	75.3	NA	NA
ML	63.1	0.8	27.3	0.8	24.8	1.1	45.5
MM	103.1	1.2	38.5	0.8	33.8	1.3	52.6
MH	356.9	3.1	95.1	2.0	69.9	5.0	185.8
HL	37.3	1.2	15.2	0.3	0.6	0.5	5.5
HM	136.6	1.5	36.5	1.1	23.8	0.7	21.3
HH	347.6	2.2	52.4	1.3	39.8	1.2	33.9

\*Cost-Demand Class, e.g., LH = Low Cost, High Demand

\*\*For Definition of Location Abbreviations, see next page

\*\*\*NA = Not available — see text

Table 11: Average Available Inventory--October, 1981

MDC = Mechanicsburg

DETFDC = Detroit FDC

OTHFDC = All FDCs other than Detroit

DETPS = Detroit Part Stations

OTHPS = All Part Stations outside of the Detroit Region

DETOL = All Detroit Region OLs

OTHOL = All OLs outside of the Detroit Region

Table 11(Cont): Definition of Location Abbreviations

MDC = Replenishment lead time buffer inventory,  
currently set by PIMS to equal three-months  
demand, i.e., 13 times the average weekly  
demand rate shown in Table 8.

DETFDC = 1, since the FDC acts as a parts station  
as well.

OTHFDC = 20, since each of the 20 other FDCs also acts  
as a part station.

DETPS = 4, since there are 4 PSs in the Detroit region.

OTHPs = 72, since there are 72 other PSs outside of  
the Detroit region.

OLs = 0, since PS1 calls for no permanent stock of  
a part at outside locations.

In a similar way, if FDC1 (resp. FDC2) were followed as per  
Table 10, then the following inventory levels would be expected in the  
system:

MDC = 13 x (Average weekly Demand)

DETFDC = 1 (resp., 2)

OTHFDC = 20 (resp., 40)

All other Locations = 0.

Using the above logic, we present in Table 12 the total inventory available in the current system (as obtained from summing all entries in Table 11) as well as the total inventory which would be available if the optimal stocking policy corresponding to the response-time constraints in Tables 9-10 were used. Recall that the response-time constraint for Table 9 was a 2-hour, 90% availability constraint, while for Table 10 it was a 6-hour, 90% availability constraint. From Table 12 it can be noted for the representative parts of interest here that the current system has inventory levels which are generally too high and especially so for high demand parts, when compared with the optimal policy corresponding to a 2-hour, 90% availability constraint. Compared with the 6-hour, 90% availability optimal stocking levels, the current system is significantly overstocked. Note that this comparison has been carried out under the assumption, as per current PIMS practice, of the three-month Mechanicsburg lead-time buffer stock for all policies. If this buffer should be lower, then the quantities in columns 3 and 4 of Table 12, corresponding to optimal solutions, would be even lower. In fact, there is reason to believe that a three-month lead time buffer stock is quite high relative to optimum, at least for high demand items. Such a high buffer stock would imply significant variance in demand and lead time over the replenishment cycle between Mechanicsburg and IBM Manufacturing and vendors. Further analysis of this buffer stock issue needs immediate attention, since reducing Mechanicsburg buffer stock for high usage items may be a high payoff, easily implementable area for improvement.



CLASS*	TOTQTYCUR	TOTQTY2	TOTQTY6
LL	85.7	100.7	24.7
LM	171.8	112.8	36.8
LH	366.6	141.8	86.8
ML	163.3	100.5	24.5
MM	231.5	111.0	36.0
MH	717.8	143.6	67.6
HL	68.4	100.8	24.8
HM	221.4	112.9	36.9
HH	478.3	144.0	68.0

\*CLASS = Cost-Demand Class as in Table 8, with the first and second letter denoting cost and demand class respectively.

TOTQTYCUR = Total available inventory nationally in the current system.

TOTQTY2 = Total available inventory nationally if a 2-hour, 90% availability optimal stocking policy were used (from Table 9, this is PS1).

TOTQTY6 = Total available inventory nationally if a 6-hour, 90% optimal stocking policy were used (from Table 10, this is FDC1 or FDC2).

Table 12: Comparing Current and Optimal Policies

### 6.3. Conclusions from Detroit Study

Several important conclusions result from the above study of the Detroit region. First, response-time constraints can be of critical importance in determining the structure of optimal stocking policies. Second, analysis of data for nine representative parts in the Detroit region and nationally indicates that the current system exhibits higher inventory stocking levels than would be expected in a (2-hour, 90% availability) optimal stocking system. Of course, current operations may be optimal relative to some higher level of service than that studied here, e.g., a 2-hour, 99% availability level might be desired instead of the 2-hour, 90% availability constraint underlying the above comparisons. But this then raises the question of exactly what service level constraints should be used to derive benchmarks for comparing current system performance.

Indeed, the question of which response-time constraints should be used raises another important issue, not studied in this report. This is the question of whether such service level constraints should be imposed at the level of a part or at the level of a product or group of products. If a response-time constraint were imposed at the level of a product, there would be several ways to satisfy this constraint. All parts used in the product could be subject to the same response-time constraint as required for the product. On the other hand, one could achieve the same level of product-level response time by having low cost, high demand parts subject to more stringent response time constraints than high cost, low demand parts. Structuring such tradeoffs across service level constraints for

different parts used in the same product provides an exciting area for future development following this work. Given the above results for the Detroit region, it also appears to be an area of potentially great benefit in reducing inventories in the current system.

## 7. RECOMMENDATIONS AND IMPLEMENTATION STUDIES

The above results provide the basis for our recommendations and for our specification of follow-on studies in key areas of interest. In summary form, our recommendations are as follows:

### Recommendations

1. Performance measurement systems should be reviewed and revised to allow management diagnosis and control of costs and service levels at each echelon in the logistics system;
2. A classification scheme for maintenance parts needs to be devised which will be useful for structuring optimal stocking policies and performance reports;
3. Present forecasting algorithms should be reviewed and updated to reflect state-of-the-art techniques, especially for very low usage items;
4. Stocking algorithms determined or affected by PIMS and RSP must be carefully reviewed and revised in light of the structure of optimal stocking algorithms;
5. The present logistics structure, in terms of number of echelons and location of facilities, is likely not a major problem, but the structure of present transportation modes linking these facilities as well as policies related to which modes are used need careful review and revision;

6. The models developed during the course of this project should be further refined and documented, both in general terms and in providing specific benchmarks for optimal stocking policies and logistics structure.

These recommendations lead to follow-on implementation studies in areas parallel to the above recommendations. In summary form, we recommend the following implementation studies.

#### Areas for Implementation Studies

1. A theoretical and follow-up empirical analysis of demand processes will provide needed information of better forecasting procedures;
2. Given the magnitude of transportation costs in the present system, it is important to perform a transportation systems analysis, concerning both costs and modes, to determine the structure and efficiency of present modal usage patterns;
3. A revised performance measurement system, tracking service levels and various cost and inventory categories, should be implemented on a trial basis to determine design standards for a full-scale implementation of a management control and decision support system for logistics operations;

4. Using the inputs of the demand forecasting, transportation cost, and performance measure studies, the results of the present study should be refined and extended to derive generic, part-specific and machine-type optimal stocking policies and to predict service and cost improvements resulting from their implementation;
5. Based on the results of the above implementation studies, a pilot study for selected parts and machine types should be undertaken to empirically validate the predicted performance of derived optimal stocking policies;
6. Finally, the above steps of model refinement and data analysis should be also undertaken in the logistics structure area in delineating future implementation studies on vaning options, advance diagnostics, and size and location changes of certain major, regional stocking facilities.

In order to provide some initial perspective on these implementation studies, we conclude with a slightly more detailed description of each of these studies as we now see these developing.

1. Demand Analysis and Parts Classification Study

The parts classification used in the initial phase of the analysis was based on two part attributes: mean demand and unit cost. The consideration of other factors, such as transportation cost, criticality, obsolescence risk, salvage cost, and diagnostic value,

may lead to more precise and managerially useful classification schemes. The steps involved in a classification study include:

1. Identification of dependent variables whose variance is to be explained by inter-class differences;
2. Identification of independent variables to define the parts classes;
3. Data collection of appropriate sample of all variables;
4. Statistical Grouping Analyses to determine those classification schemes which give maximal inter-group variance and minimal intra-group variance;
5. Subjective evaluation and refinement of classification scheme.

Similar analyses have been carried out in the health care field for the development of Diagnostic Related Groups (DRGs) which have successfully reduced thousands of disease and condition classes into 183 DRGs. The statistical software to perform such grouping is readily available. The development of part attributes measures related to such matters as criticality, obsolescence risk and diagnostic value will require subjective inputs from Customer Engineering.

Once a statistically valid classification scheme has been established, the next activity to be carried out is the development of accurate forecasting models for each part class. The key issues to be confronted here include: 1) the extremely low rate of part usage, 2) the impact of machine population (number in place, age, intensity of use), and 3) the phenomenon of parts return due to diagnostic use. We recommend a procedure of aggregation of part disbursement data to estimate demand probabilities in a given region based on the machine population in that region using the part in question. This approach needs to be studied in detail. The effort should focus on distribution family identification, parameter estimation, and validation and development of time series based parameter update mechanisms.

## 2. Transportation Costs Study

Our analysis to date has indicated that a key factor for determining optimal stocking rules are the transportation costs associated with various sourcings, priorities and modes. Initial attempts to develop estimates of part specific unit transportation costs indicated that much of the primary data needed is not collected and/or retained in machine readable form. What appears to be needed is an implementation study involving the following steps:



1. Definition of data requirements: (e.g., shipment quantities, source/destination, weight of total shipment and of each part, mode, priority, time, cost of filling order, cost of receiving shipment, cost of carrier);
2. Analysis of mode specific rate structures;
3. Multiple regression analysis to develop a unit transportation cost specific to part class, source, destination, and priority;
4. Estimation of response times.

Such studies are standard in distribution systems analyses and typically require the statistical analysis of a representative sample of transportation transactions.

### 3. Performance Measurement and Monitoring System Development

A key issue confronting the IBM parts maintenance system is the lack of acceptable performance measures and systems to monitor such performance. In developing the analytic models it became clear that the following measures of performance are of vital importance:

1. Inventory Levels and Holding Costs;
2. Normal Transportation Costs;

3. Expedite Transportation Costs;
4. Parts Availability Levels;
5. Response Times.

Indeed, the tradeoff between these measures within a part class and overall parts classes and locations form the basis for our preliminary conclusions on optimal stocking and logistics structure policies. Suggested activity in this area would consist of two major steps:

1. Definition of operationally feasible performance measures for the categories listed above at all levels in the system;
2. Specification of a monitoring system to be integrated with existing software to provide reports on the values of performance measures at all levels and for all parts classes in the system.

The first step will build on the performance measures defined in our analytic models. A number of managerially important issues must be addressed before these measures can become operationally feasible. In particular, the manner(s) of aggregation must be specified. We have noted that measures like response time and PAL are particularly sensitive to these factors. A further issue is that of accountability at the Parts Station, Outside Location and CE levels. Data collection

procedures must be amended across functional boundaries within the FE division. Finally, the relationship of part availability to machine-type availability (or overall product reliability and service level) needs also to be measured and controlled.

#### 4. Development of Optimal Stocking Policies

Upon collection of the data generated by the first three project activities, it becomes possible to repeat the analysis of this report in more detail. As results of model research and development become available, more extensive (less aggregated) model structures can be analyzed. In particular, as the computational requirements of the models decrease, more extensive sensitivity analyses will be carried out.

A major activity of this stage of the project will be the development of generic stocking algorithms for incorporation into PIMS. Our current results are extremely encouraging in that recommended stocking quantities seem to depend on a small number of key part attributes, service requirements and cost factors. Our approach for this activity will be to develop stable relationships (decision rules) between optimal stocking levels (as determined by the analytic models) and the part specific inputs noted above.

In this regard, we envision the following three "models" as providing the basis of further work on optimal stocking policies. First, the parts classification model with related demand and cost estimates. Second, a part-specific optimization model (refining the present model in directions specified in study 7 below) to determine

optimal stocking policies for any given response-time constraints. Third, a product-specific optimization model which would determine and tradeoff the overall costs and benefits of varying service levels across the parts which are used in the product in question.

The issue at stake in the third model is the following. Imposing an average response-time constraint at the product level does not mean that every part used in that product need obey the same response-time constraint. Indeed, providing better service levels for low cost or high demand parts can be traded off against poorer service levels for high cost or low demand parts while still maintaining a given aggregate response time or service level constraint at the product level.

#### 5. Pilot Implementation Study

The major goal of this study would be research is to test the costs and benefits of the recommended changes by implementing the stocking algorithms on a pilot study basis. The boundaries for the pilot study must be defined as a first step in this activity. Issues of performance monitoring and implementability should be considered here. We propose that a suitable sample of parts and machine types be selected for study and that the effects of implmenting model-optimal stocking policies for these parts be carefully studied.

The first step to be employed here should be "parallel simulation." A complete record of all transactions (and related costs) occurring in a given time frame, under current operating policies, should be assembled. Then the implications of what would have

happened for the same demand patterns had optimal stocking policies been in effect can be simulated, possibly under alternative response-time constraints. After this parallel simulation study has been concluded, full-scale implementation for the given sample of parts and machine types could be effected for some FDC region. This pilot study would further validate the expected operation and performance of optimal stocking policies. Conclusions of the pilot study will form the basis for the refinement of our procedures and models to the point where full scale implementation across all parts and machine types is achieved.

#### 6. Logistics Structure Study

The analysis of alternative logistics structure requires two major steps. The first is an extensive management audit of all facility related costs from MDC down through the OL level to ascertain fixed and variable costs. Such an audit will require specification of appropriate cost categories and cost allocation procedures as well as collection of transaction and inventory related data. Once collected for all stocking points in the system, an extended version of the regression analysis carried out in our analysis of structure can be repeated.

The second step in an analysis of logistics structure is the development of the tradeoff model discussed in Section 4 where we described the overall hierarchy of models. The formulation of a preliminary version of such a model has already been carried out. Issues to be investigated include space constraints, inventory budget

limits, the impact of vanning and the consideration of new technologies affecting CE dispatching and advance diagnostics. The key set of inventory related costs will be developed by running optimal stocking models for an extended list of structural design options.

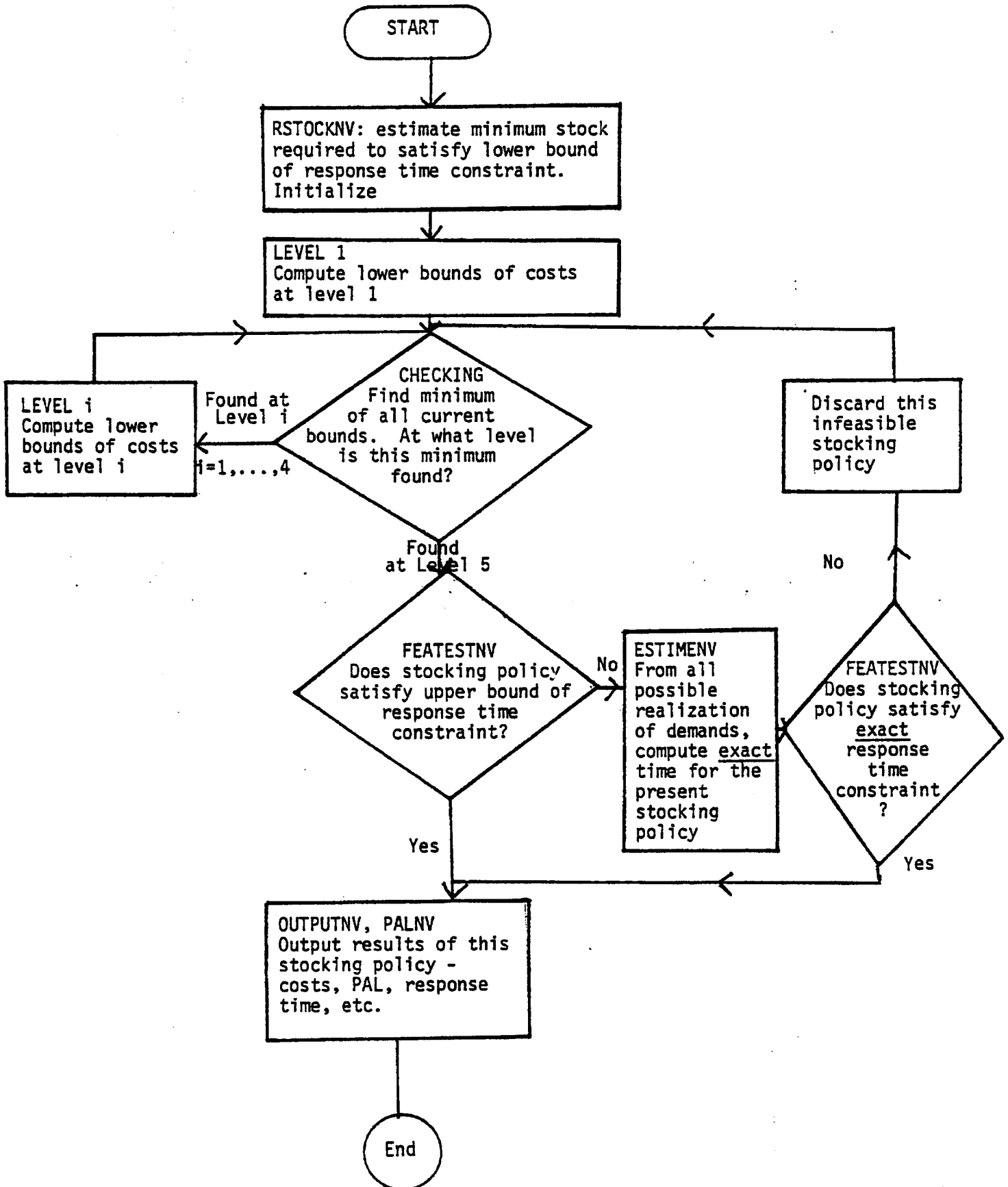
#### 7. Model Development

Throughout the set of activities leading to the pilot implementation study and logistics structure study, we anticipate continued development of the underlying models. Since many of the issues raised here involve research and state-of-the-art algorithm development, we recommend that a research project funded through the Wharton School be set up to handle this activity. Some particular model enhancements on our current research agenda include:

1. Development of the higher demand stocking model;
2. Analysis of the dynamics (product life cycle) of inventory stocking and the incorporation of salvage costs;
3. Development of effective approximations of the overall model;
4. Computational efficiency through use of such approximations and improved bounds and/or algorithms;
5. Expansion of the Aggregated Model Structure developed here to achieve a rational (21 FDC) model.

Theoretical work on most of these issues has already begun. It is to be emphasized, however, that efficient "production" models for incorporation into operational planning and control systems (e.g., in revising or replacing PIMS) will require significant further development effort.

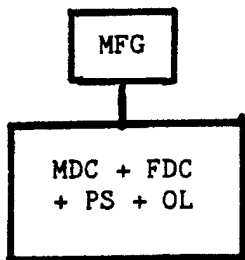
Branch and Bound Algorithm (for No-Van\*): Flowchart and Listings



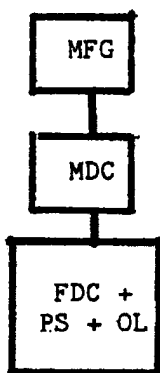
\*Flowchart for Vanning is identical with "NV" functions replaced by corresponding "V" functions.



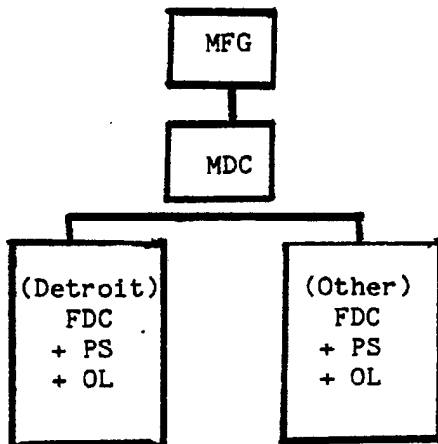
Level 1 :



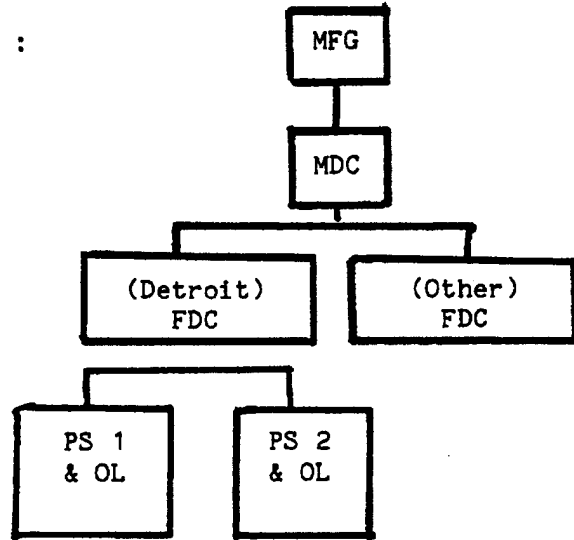
Level 2 :



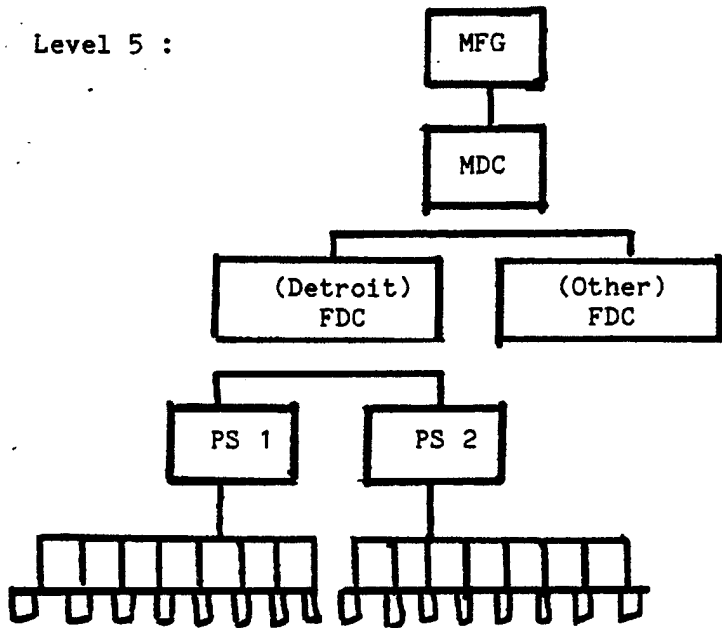
Level 3 :



Level 4 :



Level 5 :



OL

RSTOCKNV : calls INITIAL (initialize)

LEVEL 1 : calls COST1 (cost function at level 1)

LEVEL 2 : calls COST2 (cost function at level 2) which calls  
TRANSPORT & NETFLOW (transportation code)

LEVEL 3 : calls COST3 (cost function at level 3) which calls  
TRANSPORT & NETFLOW (transportation code)  
& HAHA (emergency transshipment bet.  
FDC & MDC & among FDCs)

LEVEL 4 : calls COST4 (cost function at level 4) which calls  
TRANSPORT & NETFLOW (transportation code)  
& HAHA (emergency transshipment bet.  
FDC & MDC & among FDCs)

LEVEL 5 : calls COST5B (cost function at level 5) which calls  
TRANSPORT & NETFLOW (transportation code)  
& HAHA (emergency transshipment bet.  
FDC & MDC & among FDCs)

ESTIMENV : calls SUBEST (calculates expected time for excess  
demands bet. met at OL)

OUTPUTNV : calls PRINT (print out results)

```

V BINOMIAL[ ] V
V Z←X BINOMIAL Y;H
[1] Z←(H!X)×(Y+H)×(1-Y)*X-H←0, X
V

```

```

V BOUND7NV[ ] V
V BOUND7NV;COL;BB;TIME;N2;N3;N4;N5;MINYO;NUM;PROBSUM1;PROBSUM2;
OTIME
[1] TIME←I21
[2] BB←(9 0)ρN2←N3←N4←N5←NUM←0
[3] LEVEL1
[4] CHECK:CHECKING
[5] →(COL[2]= 5 1 2 3)/L1,L2,L3,L4
[6] LEVELS COL[3 4 5 6 7]
[7] →CHECK
[8] L4:LEVEL4 COL[3 4 5]
[9] →CHECK
[10] L2:LEVEL2 COL[3]
[11] →CHECK
[12] L3:LEVEL3 COL[3 4]
[13] →CHECK
[14] L1:OTIME←MTIME[1]+PROBSUM1←PROBSUM2←0
[15] →OUT×12=+/BETA≥PROBSUM1+FEATESTNV 3+COL+2+COL
[16] ESTIMENV COL
[17] →CHECK×12=+/BETA≥PROBSUM2+FEATESTNV 3+COL
[18] OUT:OUTPUTNV COL
V

```

```

V BOUND7V[ ] V
V BOUND7V;DUM;COL;BB;TIME;N2;N3;N4;N5;MINYO;NUM;OTIME;PROBSUM1;
PROBSUM2
[1] TIME←I21
[2] BB←(9 0)ρN2←N3←N4←N5←NUM←0
[3] LEVEL1
[4] CHECK:CHECKING
[5] →(COL[2]= 5 1 2 3)/L1,L2,L3,L4
[6] DUM←COST5A COL[6 7]
[7] BB←BB,(9 1)ρ(DUM+COL[1]),5,COL[3 4 5],MINYO,COL[6 7]-MINYO
[8] N5←N5+1
[9] →CHECK
[10] L4:LEVEL4 COL[3 4 5]
[11] →CHECK
[12] L2:LEVEL2 COL[3]
[13] →CHECK
[14] L3:LEVEL3 COL[3 4]
[15] →CHECK
[16] L1:OTIME←MTIME[1]+PROBSUM1←PROBSUM2←0
[17] →OUT×12=+/BETA≥PROBSUM1+FEATESTV 3+COL+2+COL
[18] ESTIMEV COL
[19] →CHECK×12=+/BETA≥PROBSUM2←FEATESTV 3+COL
[20] OUT:OUTPUTV COL
V

```

```

V CHECKING[ ] V
V CHECKING;L
[1] COL←BB[;L←BB[1;];1|/BB[1;]]
[2] NUM←NUM+1
[3] →DROP×10≠6|NUM
[4] COL
[5] DROP:BB←((9,L-1)+BB),(0,L)+BB
V

```

```

VCONVOL[ ]▽
▽ X←X1 CONVOL X2;I;L;J;H
[1] X←(1+L/(ρX1),ρX2)ρI←0
[2] CON:X[J]+(X1[H[1]]×X2[H[2]])+X[J←1+L/I]
[3] →CON×(1+L)≥I+I+1
▽

VCOST1[ ]▽
▽ X←COST1 Y;I;E1
[1] X←CHOLD×0.5×Y+E1+(AA×MEANP)++/Y+P×Y-I←1+ρP
[2] X←X+((|Y-E1)×|/CC[14])+EE[1]×+/Y+P×I-Y
▽

VCOST2[ ]▽
▽ X←COST2 Y;I;SCH;MINCOST;E1;E2;EX
[1] X←(EE[2]×E1+(+/Y[2]+(+/Y)+P×I-Y[2])+Y[1]×+/(+/Y)+P)+EE[1]×+/(+/Y)
+P×(I←1+ρP)-+/Y
[2] X←X+0.5×CHOLD×(+/Y)+(E1+Y[1]-E1)+E2+(AA×MEANP)++/Y[2]+P×Y[2]-I
[3] →C1×|0≤EX+(+/Y)-E1+E2
[4] SCH←TRANSPORT(3 4)ρCC[1],0,I,E1,(|/CC[2 3 4]),(I+|/CC[5 6 7]),0,
E2,(-EX),Y,0
[5] →ANS
[6] C1: SCH←TRANSPORT(4 3)ρCC[1],(|/CC[2 3 4]),EX,0,I,E1,(I+|/CC[5 6 7]
),0,E2,Y,0
[7] ANS:X←X+MINCOST
▽

VCOST3[ ]▽
▽ X←COST3 Y;T1;T2;TEO;TEM;I;E1;E2;CM;SCH;MINCOST;EX
[1] P1 Haha P2
[2] X←0.5×CHOLD×(+/Y)+(E1+Y[1]-TEO)++/E2+((+/Y[2]+P1×Y[2]-1+ρP1)+(
AA×MEAN1)-T2),(+/Y[3]+P2×Y[3]-1+ρP2)+(AA×MEAN2)-T1
[3] X←X++/EE[1 2 4 5]×TEM,TEO,T1,T2
[4] →C1×|0>EX+(E1++/E2)-+/Y
[5] CM←(4 3)ρCC[1],0,I,(|/CC[2 3 4]),(I+|/CC[5 6 7]),0,CC[3 6 8],EX,Y
[1 2]
[6] SCH←TRANSPORT CM,(4 2)ρCC[6],E1,CC[8],E2[1],0,E2[2],Y[3],0
[7] →ANS
[8] C1:
[9] CM←(5 2)ρCC[1],(|/CC[2 3 4]),0,I,(I+|/CC[5 6 7]),0,CC[6 8],Y[1 2]
[10] SCH←TRANSPORT CM,(5 2)ρCC[3],((+/Y)-E1++/E2),CC[6],E1,CC[8],E2[1]
,0,E2[2],Y[3],0
[11] ANS:X←X+MINCOST
▽

```

```

VCOST4[ ]V
V X+COST4 Y;I;E1;E21;E22;E31;E32;T1;T2;TEM;TEO;PVV;SCH;MINCOST;CM;
EX
[1] PVV+(+/P11[I]),(I+1+Y[4])+P11)CONVOL(+P12[I]),(I+1+Y[5])+P12
[2] PVV HABA P2
[3] X+(E1+Y[1]-TEO)+(E21+(+/Y[2]+PVV*Y[2]-1+1pPVV)-T2)+E22+(+/Y[3]+
P2*Y[3]-1+1pP2)+(AA*MEAN2)-T1
[4] X*CHOLD*0.5*X+(+/Y)+(E31+(+/Y[4]+P11*Y[4]-1+1pP11)+AA*MEAN11)+
E32+(+/Y[5]+P12*Y[5]-1+1pP12)+AA*MEAN12
[5] X+X,+/EE[15]*TEM,TEO,(+/PVV*Y[2][1+1pPVV]),T1,T2
[6] -C1*10≤EX+(+/Y)-E1+E21+E22+E31+E32
[7] CM*(6 3)ρCC[1],0,CC[5 2 5],0,CC[3 6 8 4 7 9 4 7 9],(-EX),Y[1 2]
[8] CM+CM,(6 3)ρCC[6 7 7 8 9 9],0,(3pI),0,CC[10],(I++/CC[8 9]),CC[10]
,0,Y[3 4 5]
[9] SCH+TRANSPORT CM,(6 1)ρE1,E21,E22,E31,E32,0
[10] →ANS
[11] C1:
[12] CM*(4 6)ρCC[(1 4),4],((+/Y)-E1+E21+E22+E31+E32),0,CC[5 6 7 7],E1,
CC[5],0,CC[8 9 9],E21,CC[6 8],0,(2pI++/CC[8 9]),E22
[13] SCH+TRANSPORT CM,[1](3 6)ρCC[7 9],I,0,CC[10],E31,CC[7 9],I,CC[10]
,0,E32,Y,0
[14] ANS:X+X,MINCOST

```

```

VCOST5A[ ]V
V X+COST5A Y;H;YO;PDO;J;I
[1] X+MINYO+2p100000+J+1
[2] HA2:YO+0
[3] HA1:PDO+(H!I)*(DEM[J]*H)*(1-DEM[J])*I-H+0,1I+8-Y[J]-YO
[4] I+(EE[6]*+/PDO*YO[H]+EE[7]*(+/YO+PDO*H-YO)-+/Y[J]+POP[J;]*(-1+1(p
POP)[2])]-Y[J]
[5] →GO*1I≥X[J]
[6] MINYO[J]←YO
[7] X[J]←I
[8] GO:→HA1*1Y[J]≥YO+YO+1
[9] →HA2*12≥J+J+1
[10] X←+/X

```

```

VCOST5B[ ]V
▽ X←COST5B Y;I;I1;I2;POL2;POL2;PDC1;E1;E21;E22;E3;E4;T1;T2;TEO;TEM;
CM;SCH;MINCOST;EX
[1] POL1←(8-Y[6])BINOMIAL DEM[1]
[2] POL2←(8-Y[7])BINOMIAL DEM[2]
[3] PDC1←((+/POL1[I1]),(I+1+Y[4])+POL1)CONVOL(+/POL2[I1]),(I+1+Y[5])+
POL2
[4] PDC1 HABA P2
[5] X←(E1+Y[1]-TEO)+(E21←(+/Y[2]+PDC1×Y[2]--1+1pPDC1)-T2)+E22←(+/Y[3]
+P2×Y[3]--1+1pP2)+(AA×MEAN2)-T1
[6] X←X←(+/Y)++/E3←(+/Y[4]+POL1×Y[4]-I1←-1+1pPOL1),+/Y[5]+POL2×Y[5]-
I2←-1+1pPOL2
[7] X←CHOLD×0.5×X++/E4←(Y[6 7]×1-DEM[1 2])+AA×MEAN11,MEAN12
[8] X←X,+/EE[16]×TEM,TEO,(+/PDC1×Y[2][-1+1pPDC1),T1,T2,(+/POL1×Y[4][
I1)++/POL2×Y[5][I2
[9] →C1×10≤EX←(+/Y)-E1+E21+E22+(+/E3)++/E4
[10] CM←(2 7)pCC[1],0,CC[5 6 7 7],E1,CC[2 5],0,CC[8 9 9],E21
[11] CM←CM,[1](2 7)pCC[3 6 8],0,(2pI),E22,CC[4 7 9],(I←+/CC[8 9]),0,CC
[10],E3[1]+E4[1]
[12] SCH←TRANSPORT CM,[1](2 7)pCC[4 7 9],I,CC[10],0,(E3[2]+E4[2]),(-EX
),Y[13],(+/Y[4 6]),(+/Y[5 7]),0
[13] →ANS
[14] C1:
[15] CM←(4 6)pCC[(14),4],((+/Y)-E1+E21+E22+(+/E3)++/E4),0,CC[5 6 7 7],
E1,CC[5],0,CC[8 9 9],E21,CC[6 8],0,(2pI←+/CC[8 9]),E22
[16] SCH←TRANSPORT CM,[1](3 6)pCC[7 9],I,0,CC[10],(E3[1]+E4[1]),CC[7 9
],I,CC[10],0,(E3[2]+E4[2]),Y[13],(+/Y[4 6]),(+/Y[5 7]),0
[17] ANS:X←X,MINCOST
▽

VESTIMENV[ ]V
▽ ESTIMENV Y;L;X1;X2;X3;I
[1] L←(pX1←(8-Y[6])BINOMIAL DEM[1]),(pX2←(8-Y[7])BINOMIAL DEM[2]),pX3
←(+/(1+RSTOCK[3])+P2),(1+RSTOCK[3])+P2
[2] Y[4]SUBEST Y[5]
▽

VESTIMEV[ ]V
▽ ESTIMEV Y;L;X1;X2;X3
[1] L←(pX1+P11),(pX2+P12),pX3←(+/(1+RSTOCK[3])+P2),(1+RSTOCK[3])+P2
[2] (+/Y[4 6])SUBEST+/Y[5 7]
▽

VEXCHANGE[ ]V
▽ X←EXCHANGE Z
[1] X←((11p0),(10p1),(10p2),10p3)[Z+1]
▽

```

```

VFEATESTNV[ ] ▽
▽ X←FEATESTNV Y;D;H;I;L;J
[1] X←-1+2ρJ+1
[2] →0×1OTIME<2
[3] RE:L←(H,8-H←Y[2+J])+I+1
[4] IN:→INCRE×1D[2]≤Y[J]+(2×(D←L←I)[1])÷OTIME-2
[5] X[J]←X[J]+(D[1]!H)×(D[2]!8-H)×(DEM[J]÷D)×(1-DEM[J])*8÷D
[6] INCRE:→IN×1(-1+×/L)≥I+I+1
[7] X[J]←X[J]÷1-(1-DEM[J])*8
[8] →RE×12≥J←J+1

```

▽

```

VFEATESTV[ ] ▽
▽ X←FEATESTV Y;H;I;L;J;D
[1] X←-1+2ρJ+1
[2] →0×1OTIME<2
[3] RE:L←(H,8-H←Y[2+J])+I+1
[4] IN:→INCRE×1(2×D[1]÷OTIME-2)≥(+/D←L←I)-H+Y[J]
[5] X[J]←X[J]+(D[1]!H)×(D[2]!8-H)×(DEM[J]÷D)×(1-DEM[J])*8÷D
[6] INCRE:→IN×1(-1+×/L)≥I+I+1
[7] X[J]←X[J]÷1-(1-DEM[J])*8
[8] →RE×12≥J←J+1

```

▽

```

VHAHA[ ] ▽
▽ X1 HAHA X2;I;PROB;H;F;Q1;Q2;B1;B2;L
[1] L←(ρX1),ρX2←(+/(1+RSTOCK[3])+X2),(1+RSTOCK[3])+X2
[2] T1←T2←TEO←TEM←I←0
[3] UP:→INCRE×10=PROB×X1[1+H[1]]×X2[1+(H←L←I)[2]]
[4] T1←T1+PROB×Q1←[/(B1+[ /0,H[1]-Y[2]),EXCHANGE 0[Y[3]-H[2]+RSTOCK[3]]
[5] T2←T2+PROB×Q2←[/( /0,Y[2]-H[1]),EXCHANGE B2←0[RSTOCK[3]+H[2]-Y[3]]
[6] TEO←TEO+PROB×[ /Y[1],F←(B1-Q1)+B2-Q2
[7] TEM←TEM+PROB×[ /0,F-Y[1]]
[8] INCRE:→UP×1(-1+×/L)≥I+I+1

```

▽

```

VINITIAL[ ] ▽
▽ INITIAL;I
[1] P11←8 BINOMIAL DEM[1]
[2] P12←8 BINOMIAL DEM[2]
[3] P2←1ρI+1
[4] CH:P2←P2,(-1+P2)×DEM[3]÷I
[5] →CH×1([ /320,RSTOCK[3]+40)≥I+I+1
[6] P2←P2÷P2
[7] POP← 2 9 ρP11,P12
[8] P1←P11 CONVOL P12
[9] P←P1 CONVOL P2
[10] MEANP←MEAN P
[11] MEAN1←MEAN P1
[12] MEAN2←MEAN P2
[13] MEAN11←8×DEM[1]
[14] MEAN12←8×DEM[2]

```

▽



```

VLEVEL1[ ]V
▽ LEVEL1;COL
[1] COL←+/RSTOCK
[2] RE:BB←BB,(9 1)ρ(COST1 COL),1,COL,6ρ0
[3] →RE×1(-1+ρP)≥COL←COL+1
▽

VLEVEL2[ ]V
▽ LEVEL2 Z;I;J
[1] I←+/RSTOCK
[2] IN2:BB←BB,(9 1)ρ(COST2 J,I),2,(J←Z-I),I,5ρ0
[3] N2←N2+1
[4] →IN2×1Z≥I←I+1
▽

VLEVEL3[ ]V
▽ LEVEL3 Z;I;DUM
[1] I←[/(+/RSTOCK[1 2]),Z[2]--1+ρP2
[2] IN3:BB←BB,(9 1)ρ(COST3 DUM),3,(DUM←Z[1],I,Z[2]-I),4ρ0
[3] N3←N3+1
[4] →IN3×1(-1+ρP1),Z[2]-RSTOCK[3])≥I←I+1
▽

VLEVEL4[ ]V
▽ LEVEL4 Z;J1;J2;DUM
[1] J1←RSTOCK[1]
[2] IN4:J2←RSTOCK[2]
[3] IN5:BB←BB,(9 1)ρ(+/COST4 DUM),4,(DUM←Z[1],(Z[2]-J1+J2),Z[3],J1,J2),2ρ0
[4] N4←N4+1
[5] →IN5×1(-1+ρP12),Z[2]-J1)≥J2←J2+1
[6] →IN4×1(-1+ρP11),Z[2]-RSTOCK[2])≥J1←J1+1
▽

VLEVEL5[ ]V
▽ LEVEL5 Z;I;J;DUM;MIN;HI
[1] OTIME←MTIME[1]+I←0
[2] IN10:→IN9×1TEST[1;2;I+1]>Z[4]-I
[3] J←0
[4] IN8:→IN7×1TEST[2;2;J+1]>Z[5]-J
[5] N5←N5+1
[6] DUM←(+/COST5B DUM),5,DUM←Z[13],I,J,Z[4 5]-I,J
[7] →IN11×12≠+/BETA≥FEATESTNV 3+DUM
[8] BB←(BB[1;]<DUM[1])/BB
[9] IN11:BB←BB,(9 1)ρDUM
[10] IN7:→IN8×1Z[5]≥J←J+1
[11] IN9:→IN10×1Z[4]≥I←I+1
▽

VMEAN[ ]V
▽ Z←MEAN X
[1] Z←+/X×-1+1ρX
▽

```

```

VNETFLOW[ ]V
V NETFLOW; GAMMA; STAGE; I; J; K; I1; F; R; FLOW
[1] FLOW←0
[2] DELTA←(↑/↑/G), (↑1+ρGAMMA←Nρ(STAGE←(↑N)≤1)[N])ρ0
[3] I←(ρρR←(STAGE=K←↑/STAGE)/↑N)[1]
[4] →(0=ρJ←((DELTA=0)∧G[I1←R[I]; ]>0)/↑N)/7
[5] DELTA[J]←G[I1; J][DELTA[I1]
[6] GAMMA[J]←I1
[7] →((ρR)≥I←I+1)/4
[8] →((0=ρI←((DELTA>0)∧STAGE=0)/↑N), DELTA[N]>0)/ 0 10
[9] →3, STAGE[I]←K+1
[10] FLOW←FLOW+F←DELTA[J←N]
[11] I←GAMMA[J]
[12] G[I; J]←G[I; J]-F
[13] G[J; I]←G[J; I]+F
[14] → 2 11[1+1<J←I]
V

VOUTPUTNV[ ]V
V OUTPUTNV Y; DUM
[1] DUM←COST5B Y
[2] PRINT
V

VOUTPUTV[ ]V
V OUTPUTV Y; PDO1; PDO2; H1; H2; DUM; I; G1; G2
[1] DUM←COST4 Y[↑3], (+/Y[4 6]), +/Y[5 7]
[2] PDO1←(H1!I)×(DEM[1]*H1)×(1-DEM[1])*I-H1+0, ↑I+8-Y[6]
[3] PDO2←(H2!I)×(DEM[2]*H2)×(1-DEM[2])*I-H2+0, ↑I+8-Y[7]
[4] G1←(+/PDO1×Y[4][H1]++)+/PDO2×Y[5][H2]
[5] G2←(+/PDO1×0[H1-Y[4]])+(+/PDO2×0[H2-Y[5]])-(+/P11×0[(↑1+↑9)-Y[4]+Y[
6])++/P12×0[(↑1+↑9)-Y[5]+Y[7]
[6] DUM[2]←DUM[2]++/EE[6 7]×G1, G2
[7] PRINT
V

```

```

VPALNV[[]]V
V PALNV Y;PROB;I;D;L;H;T1;T2;B1;B2;E1;E2;Q;Q1;POL1S;POL2S;POL1;POL2
;PAL1;PAL21;PAL22;PAL21T;PAL22T;PAL3;ETIME
[1] POL1←(8-Y[6])BINOMIAL DEM[1]
[2] POL2←(8-Y[7])BINOMIAL DEM[2]
[3] POL1S←Y[6]BINOMIAL DEM[1]
[4] POL21←Y[7]BINOMIAL DEM[2]
[5] I←PAL21T+PAL22T+PAL21+PAL22+PAL1+PAL3+ETIME←0
[6] L←(ρPOL1),(ρPOL2),(ρPOL1S),(ρPOL2S),ρP2S←(+/(1+RSTOCK[3])P2),(1+
RSTOCK[3])P2
[7] IN1:D←L-I
[8] PROB←POL1[1+D[1]]×POL2[1+D[2]]×POL1S[1+D[3]]×POL2S[1+D[4]]×P2S[1+
D[5]]
[9] →IN2×10=Q1←+/0[(D[1]-Y[4]),D[2]-Y[6]
[10] T1←[(B1+0[Q1-Y[2]]),EXCHANGE 0[Y[3]-D[3]+RSTOCK[3]
[11] T2←[(0[Y[2]-Q1),EXCHANGE B2←0[RSTOCK[3]+D[3]-Y[3]
[12] PAL22T←PAL22T+PROB×(B2-T2)÷1[D[5]
[13] PAL1←PAL1+PROB×(H←0[(B1+B2-T1+T2)-Y[1])÷1[+/D
[14] PAL21T←PAL21T+PROB×(B1-T1)÷1[+/D[14]
[15] PAL21←PAL21+PROB×B1÷1[+/D[14]
[16] PAL3←PAL3+PROB×Q1÷1[+/D[14]
[17] PAL22←PAL22+PROB×B2÷1[D[5]
[18] ETIME←ETIME+PROB×(+/MTIME[14]×(H×Q),(((H>0)×Y[1]×Q←E1+E2+B2-T2
)+(H=0)×E1+B1-T1),(1/Y[2],Q1),T1)÷1[+/D[14]
[19] IN2:ETIME←ETIME+PROB×MTIME[5]×((D[1]Y[4])+D[2]Y[6])÷1[+/D[14]
[20] →IN1×(1+×/L)≥I+I+1
[21] 'PAL AT MDC OR BELOW: ' ;1-PAL1
[22] 'PAL AT FDC OR BELOW AFTER TRANSHIPMENT: ' ;1-PAL21T,PAL22T
[23] 'PAL AT FDC OR BELOW: ' ;1-PAL21,PAL22
[24] 'PAL AT PS AND OL: ' ;1-PAL3
[25] ''
[26] 'EXPECTED RESPONSE TIME: ' ;ETIME+1-POL1[1]×POL2[1]×POL1S[1]×
POL2S[1]
V
VPRINT[[]]V
V PRINT
[1] 'COMPUTER TIME USED : ' ;((I21)-TIME)+60;' SECONDS'
[2] 'STOCK AT MDC : ' ;Y[1]
[3] 'STOCK AT FDC : ' ;Y[2 3]
[4] 'STOCK AT PS : ' ;Y[4 5]
[5] 'STOCK AT OL : ' ;Y[6 7]
[6] ''
[7] 'NUMBER OF COMPUTATIONS AT LEVEL 1 : ' ;(ρP)-+/RSTOCK
[8] 'NUMBER OF COMPUTATIONS AT LEVEL 2 : ' ;N2
[9] 'NUMBER OF COMPUTATIONS AT LEVEL 3 : ' ;N3
[10] 'NUMBER OF COMPUTATIONS AT LEVEL 4 : ' ;N4
[11] 'NUMBER OF COMPUTATIONS AT LEVEL 5 : ' ;N5
[12] ''
[13] 'HOLDING COST : ' ;DUM[1]
[14] 'EMERGENCY COST : ' ;DUM[2]
[15] 'NORMAL TRANSPORTATION COST : ' ;DUM[3]
[16] 'TOTAL COSTS : ' ;+/DUM
[17] ''
[18] 'UPPER BOUND OF PROB(WEIGHTED RESPONSE TIME > 2) : ' ;PROBSUM1
[19] 'PROBABILITY (WEIGHTED RESPONSE TIME > 2) : ' ;PROBSUM2
V

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VRSTOCKNV[ ]V
V RSTOCKNV Y;YOL;YPS;J;SUMPROB;D;L;I;B
[1] TEST← 3 2 9 ρ0
[2] RSTOCK←3ρJ+1
[3] IN4:B+Y×1-(1-DEM[J])*8+YPS+0
[4] IN3:YOL+0
[5] IN2:L+(YOL,8-YOL)+I+1+SUMPROB+0
[6] IN1:→INCRE×1D[2]≤YPS+(2×(D+L+I)[1])÷MTIME[3]-2
[7] SUMPROB←SUMPROB+(D[1]!YOL)×(D[2]!8-YOL)×(DEM[J]*+/D)×(1-DEM[J])*8
  -+/D
[8] INCRE:→IN1×1(¯1+×/L)≥I+I+1
[9] →OK×1B≥SUMPROB
[10] YOL←YOL+1
[11] →IN2
[12] OK:TEST[J;;YPS+1]←YPS,YOL
[13] →IN3×18≥YPS+YPS+1
[14] RSTOCK[J]←[+/+TEST[J;;]
[15] →IN4×13≥J+J+1
[16] RSTOCK[3]←40×RSTOCK[3]
[17] INITIAL
V

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VRSTOCKV[ ]V
V RSTOCKV Y;J;YPS;SUMPROB;I;L;D;B
[1] RSTOCK←3ρJ+1
[2] IN3:B+Y×1-(1-DEM[J])*8+YPS+0
[3] IN2:L+(YPS,8-YPS)+I+1+SUMPROB+0
[4] IN1:→INCRE×1(2×D[1]÷MTIME[3]-2)≥(+/D+L+I)-YPS
[5] SUMPROB←SUMPROB+(D[1]!YPS)×(D[2]!8-YPS)×(DEM[J]*+/D)×(1-DEM[J])*8
  -+/D
[6] INCRE:→IN1×1(¯1+×/L)≥I+I+1
[7] →OK×1B≥SUMPROB
[8] YPS←YPS+1
[9] →IN2
[10] OK:RSTOCK[J]←YPS
[11] →IN3×13≥J+J+1
[12] RSTOCK[3]←40×RSTOCK[3]
[13] INITIAL
V

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VSUBEST[ ]V
V H1 SUBEST H2;I;OPROB;D;H;T1;T2;B1;B2;Q;Q1;PROB
[1] I←OPROB+OTIME+0
[2] IN1:D+L+I
[3] →IN2×10=Q1++/0[(D[1]-H1),D[2]-H2
[4] T1←[/(B1+0[Q1-Y[2]),EXCHANGE 0[Y[3]-D[3]+RSTOCK[3]
[5] T2←[/(0[Y[2]-Q1),EXCHANGE B2+0[RSTOCK[3]-D[3]-Y[3]
[6] H←0[(B1+B2-T1+T2)
[7] OPROB←OPROB+PROB×X1[D[1]+1]×X2[D[2]+1]×X3[D[3]+1]
[8] OTIME←OTIME+PROB×(MTIME[14]×(H×Q),(((H>0)×Y[1]×Q+E1+E2+B2-T2)+
  (H=0)×E1+B1-T1),(L/Y[2],Q1),T1)+Q1
[9] IN2:→IN1×1(¯1+×/L)≥I+I+1
[10] OTIME←OTIME+OPROB
V

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▽ TRANSPORT[ ]▽
▽ S←TRANSPORT COST;A;B;R;C;U;V;X;H;I;J;K;I1;J1;G;N;DELTA
[1] A←COST[1;R←1+(ρCOST)[1];(ρCOST)[2]]
[2] B←COST[(ρCOST)[1];1;C←1+(ρCOST)[2]]
[3] COST←COST[1;R;1;C]
[4] V←L/[1]COST-φ(φρS+(R,C)ρ0)ρU←L/COST
[5] I←1+L|(X←((0=COST-U0.+V)/1;R×C)-1)÷C
[6] J←(K←1)+C|X
[7] S[I[K];J[K]]←[ /0. L/(A[I[K]]-+/S[I[K];]),B[J[K]]-+/[1]S[;J[K]]
[8] +((ρI)≥K←K+1)/7
[9] G←(2ρN←R+C+2)ρ0
[10] G[1+1;R;1+R+1;C]←(100000×0=COST-U0.+V)-S
[11] G[1+R+1;C;1+1;R]←φS
[12] G[1;1+1;R]←A-+/S
[13] G[1+R+1;C;N]←B-+/[1]S
[14] NETFLOW
[15] →(1.000000000E-8 ≥|+/G[;N])/21
[16] H←L/[L/COST[I1;J1]-U[I1+(DELTA[1+1;R]>0)/1;R]0.+V[J1+(DELTA[R+1+1;C]=
0)/1;C]
[17] U[I1]←U[I1]+H
[18] V[J1]←V[J1+(~(1;C)εJ1)/1;C]-H
[19] G←G×G≠100000
[20] →14,ρG[I1;J1]←G[I1;J1]+100000×(G[I1←1+1;R;J1←1+R+1;C]=0)∧0=COST-U0.
+V
[21] MINCOST←+/,COST×S←(100000×0=COST-U0.+V)-G[1+1;R;1+R+1;C]
▽

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