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LOCATION DECISIONS AND INFORMATION SEARCH IN UNCERTAIN MULTINATIONAL ENVIRONMENTS: A COMPUTER SIMULATION MODEL

by
Ravi Sarathy

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Business Administration)
in The University of Michigan
1976

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CHAPTER I

INTRODUCTION

Location-allocation systems in multinational firms are concerned with the problem of locating facilities and determining a least cost shipping pattern to meet demand at various sites, all in the context of an international environment, so as to maximize revenue from the investment in facilities. Much work has been done in this vein recently on applying management science techniques to such problems of international logistics -- for example, Rutenberg (1973) and Pomper (1974). Rutenberg's work in general has been directed to applying exact optimization algorithms to a variety of logistics problems in an international environment, while Pomper's model is a small-scale multi-period investment problem solved using dynamic programming after complete enumeration of location possibilities for each period.

A fundamental quality of location problems in multinational firms is uncertainty which affects a wide range of variables in the international environment such as demand-price interactions, exchange rate changes, differential rates of inflation, and tariffs, these variables in turn determining the optimal location solution reached.

A second feature of location problems under uncertainty is the need for flexibility in developing location solutions: that is, the need to develop plans and solutions that are not knife-edge optimal for some single and precise environmental configuration but are near-optimal for a whole range of environmental possibilities that might be encountered. Robustness can be defined as "the relative invulnerability of a statistical estimator or, more generally, a mathematical model to changes in its assumption structure" (Green, 1975). For our purposes, we are interested in developing location solutions that are relatively insensitive to changes in environment; that is, the revenue distribution (under uncertainty) associated with a robust location vector displays less volatility than the revenue distribution for other location solutions, given exactly similar conditions of environmental variation.

Two objectives are established for research: a) the derivation of location choices in a multinational context that will be near-optimal for a wide range of environmental variation, such choices being termed robust; and, b) the development of a method to assess uncertainty in the environment so as to help set priorities for information-seeking in such uncertain international environments.

A multi-stage simulation approach will be used to achieve these objectives.

1. The first step is to develop a formulation of the location-allocation (L-A) problem that will yield optimal location solutions under certainty. A major consideration here will be efficiency in computation and low computer costs since the particular form of the L-A model chosen will be used repeatedly within a simulation model.

2. Next, the optimization method is combined with a simulation model that incorporates the uncertain features of the international environment. This computer simulation model will provide an optimum location solution on each run, given various values for each of the uncertain variables, derived from their corresponding probability distribution. The values of the uncertain environmental variables may change from one run to the next; hence, the optimum location vector might also be different from one run to the next.

3. Next, the results of the simulation study are analyzed to yield location vectors that might possibly be robust for further study. Here, a concept of robustness developed by Gupta and Rosenhead (1968) is applied to yield vectors for further study. These vectors are then introduced into a second set of simulation runs; once again, environment is allowed to vary, though the location solution is held constant. In this manner, revenue distributions are obtained for each location vector that is to be tested for robustness. Environmental variation conditions are duplicated for each location vector tested, and exactly

the same number of simulation runs is conducted for each location vector.

Then, an analysis of the revenue distributions obtained for each location vector is conducted to determine if any one of them is superior to the rest. The statistical tests used here to discriminate between location vectors include:

a) comparison of sample quantiles and the corresponding confidence intervals for population quantiles.

b) comparison of the mean and standard deviation for each sample.

c) a comparison of sample histograms and sample histogram interval percentages

d) a t-test of the difference between mean and standard deviation for the various samples, and

e) the Wilcoxon matched-pair rank-sum statistic for the various samples; this is the non-parametric analogue of the t-tests conducted in (d).

(In the above, sample refers to the revenue distribution obtained for each location vector tested.)

4. Experimental design features are then added to the simulation model, through the choice of fractional factorial sampling plans and the use of randomized blocks. This enables analysis of uncertainty and focuses on the relative impact of various uncertain variables

on the location decision. This information is intended to be used as a guide to making budget allocations when seeking information, and perhaps throw some light on the cost of information in uncertain international environments.

The emphasis of the model is on the operations side. Given global markets, we are interested in determining a logistics system for the multinational firm that will decide where facilities will be located and what the flows of product to supply the various markets should be. The objective is to work out the most profitable combination of flows among countries.

The factors that we exclude from model-building considerations are the existence of differential tax structures among nations and the use of transfer pricing. These affect financial flows and the optimization of financial flows is a different problem from the L-A problem (Rutenberg 1970). Pomper (1974, p. 15) reaches much the same conclusion when he states that the "optimal pattern of sourcing is conditional on choice of transfer prices" and that the other financial variables do not affect the optimality of the logistics solution. He goes on to suggest (ibid., p. 75) that transfer prices can also be excluded if transfer prices are set exactly equal to transfer costs, transfer costs being the total variable cost of manufacturing a unit of the product at a source facility and getting it to the demand destination, this cost

including tariffs and transportation costs. This procedure is followed in the model developed later on and hence the exclusion of financial variables is unexceptional.

The location problem we have been describing can be seen as part of industrial location theory. The question then arises, in what manner are these different from purely domestic location problems? The major difference is that we have to contend with a host of differing national environments, increasing the risk and uncertainty of the system as a whole. Therefore, in addition to the normal components of the logistics system, there are also transfer factors and institutional factors arising out of the international environment that complicate the problem. Figure 1-1 outlines these factors.

Figure 1-1

The Location-Allocation Problem in Multinational Environments

Logistics Factors	Transfer Factors	Institutional Factors
Production:	Exchange Rates	Development-Rebates
Labor	Tariffs	Inflation
Materials		Productivity
Overheads		Local content laws
Markets:		Export requirements
Demand growth trends		Supply interruptions
Prices		Tax differences
Elasticities		
Investment:		
Land		
Equipment		
Working capital		
Transportation costs		

While the three sets in Exhibit 1-1 are not exhaustive, they provide some indication of the complexity introduced by international environments.

In Chapter 2 we take up the formulation of a L-A model to yield optimal location solutions. Chapter 3 builds the simulation model, incorporating the optimizing method discussed in Chapter 2 and features of the international environment. Chapter 4 uses a sample problem and the computer simulation to yield robust location solutions. Chapter 5 uses experimental design and a detailed sampling plan to throw light on the matter of setting priorities for information seeking. Chapter 6 compares robust location solutions with location solutions derived in an ad hoc manner and examines their performance under different starting conditions. Chapter 7 discusses the information requirements of the model and some possible extensions of the model. The Appendix contains a listing of the various computer programs which comprise the model.

CHAPTER II

SOLUTION PROCEDURES FOR THE LOCATION-ALLOCATION PROBLEM

Location-Allocation (L-A) systems are a class of problems characterized by the following general structure:

(a) a set of "n" points distributed in the plane; (demand points, destinations)

(b) a numerical weight attached to each point; (size of demand)

(c) a set of "m" indivisible centroids without pre-determined location. (sources, facilities)

Then, the location-allocation problem is to find locations for the "m" centroids, and allocations of each of the "n" points (or fraction of a point) to some centroid so as to optimize some objective function -- e.g., minimize the total cost of operation of the L-A system.

Further, if none of the "n" points are assigned to more than one centroid, then the problem is equivalent to the optimal m-fold partitioning of a point set. Revelle and Swain (1970) have a linear programming formulation of this problem in discrete space on a network with no fixed costs and no capacity constraints. Their formulation

is such that ordinarily integer solutions would result; if not, integer programming is to be used; they indicate that large problems conforming to their assumptions can be solved easily with their method.

A realistic extension of this model would be the addition of fixed charges associated with the establishment of a facility, with the proviso that the fixed charge for each of the facilities not be equal. (Else, they can be ignored and the Revelle-Swain formulation (ibid) used.) Such a formulation with m sources, n destinations, a fixed charge for each of the m sources if used and linear costs of transporting units from sources to destinations is known as the simple location-allocation problem and Whybark and Khumawala (1972) have surveyed the solution procedures for such problems.

One of the earliest formulations of the simple L-A model was Baumol and Wolfe (1958). It is a heuristic solution approach; some of the complexities it introduces are scale economies and capacitated facilities. Their iterative approach consists of developing marginal facility costs at each iteration, dropping and adding facilities based on these costs and continuing till a (local) minima is reached, which probably depends on the degree of scale economies or concavity in the objective function.

Balinski and Mills (1960) treat the same problem as Baumol and Wolfe except that they assume only one plant. They use a piece-

wise linear approximation for total costs, based on volume shipped, thus developing an average cost per unit based on operating levels. This makes the problem a simple transportation problem once facility locations are fixed; their solution procedure is a heuristic and it is not clear how close their solutions are to the optimum.

Kuehn and Hamburger (1963) developed some heuristics that worked quite efficiently for the discrete space fixed-cost L-A problem. The major heuristic rule was that only major demand centers need be considered as potential locations. They develop near-optimal solutions by considering the addition of only one facility at each iteration and evaluating whether the proposed addition results in lower total costs. They applied their approach to sample problems using 25 potential locations and 50 demand centers; subsequent work showed that their heuristic solutions were fairly close to optimal.

Feldman, Lehrer and Ray (1966) extended the Kuehn and Hamburger heuristic. Their formulation includes economies of scale; this allows cost of meeting demand from facilities to vary over the entire range of possible facility throughput; thus their costs are continuous and concave.

In addition to adding facilities one at a time they also proposed a decision rule for dropping facilities from the solution. The assignment of demand centers to facilities were based on the comparison of

costs with some "reference level" for a given size facility. This reference level is derived with respect to a "local customer set" consisting of those demand centers for which a particular facility is suitable on the basis of transportation costs only. This procedure provides an initial point on the cost curve for each facility and the incremental costs from this point on are then used in the various iterations. The actual throughput for each facility can be used as the "reference level" when considering dropping them. Further, the number of facilities that can serve a demand center are restricted to the fifteen closest facilities. Computational results with this heuristic were favorable.

Yet another heuristic is that of Drysdale and Sandiford (1969). They employ a facility dropping routine similar to that of Feldman, Lehrer and Ray but combine it with a steadily increasing fixed charge for each facility in use after each dropping iteration. Because of the increasing fixed costs the economical set of potential facilities is reduced. This heuristic was used on a practical 35 site problem in Canada and was solved in less than 10 minutes.

One of the first papers to present an exact solution method for the simple Location-Allocation problem is Efroymson and Ray (1966). This method can be used on the fixed-cost discrete space L-A problem, with uncapacitated facilities and economies of scale

being modeled through piece-wise linear approximation. It is a branch and bound technique with certain simplifications introduced that reduce the number of possible branches that need to be investigated and thus reduce the size of the branch and bound tree.

An improvement of the Efroymson and Ray approach is Khumawala (1972), which solved problems with 25 integer variables in 10 seconds (on a CDC 6500). Khumawala developed and tested several branching decision rules and one of these based on the maximum savings from opening a free facility proved markedly superior (the largest Omega decision rule). Khumawala's branch and bound algorithm in the largest Omega decision rule version is the optimization algorithm used in the simulation model developed in Chapter 3.

Both exact and heuristic approaches to L-A problems with capacity restrictions have been developed by Sa (1969). The context is one of expansion of capacity. The computer efficiency of Sa's branch and bound routine is quite low. His heuristic algorithm is more powerful; it first closes facilities in a locally optimal way, then tries to open new facilities. Single exchanges of demand centers between facilities are also used. If no single exchanges are possible further recycling to drop facilities and add new ones is shown to be unnecessary.

Rutenberg (1968) furnishes an exact solution approach for the

discrete space L-A problem (uncapacitated) with continuously concave costs. However, it cannot handle large problems in an efficient manner. A better algorithm was developed by Davis and Ray (1969). It is a branch and bound formulation based on a simple branching rule (the variable closest to 1/2). Computational experience on practical problems with 50 potential sites and 300 demand points is presented with the longest computer running time being 25 minutes (on a Burroughs B . 5500).

Ellwein and Gray (1971) present an exact algorithm for solving large fixed-charge and capacitated problems; additionally, their formulation allows the incorporation of configuration constraints, these being rules about the necessity or infeasibility of specific source combinations. Also, their method may be extended to hierarchical systems with intermediate locations. The presence of configuration constraints reduce the number of feasible solutions and thus significantly reduce the amount of computer time needed to reach an optimal solution.

Soland (1974) presents a branch-and-bound optimizing algorithm for the capacitated L-A problem with concave production and transportation costs. This computer code took nearly 960 seconds on a CDC 6600 for solving a problem with 25 sources, 50 constraints and 24 nonlinear cost functions.

So far we have been considering single-period versions of the location-allocation model. We now consider attempts to extend the model to cover several periods. As we shall see, while exact optimization is possible in theory, such methods become prohibitively expensive to implement on the computer; hence heuristic solution methods are usually applied to practical multi-period problems.

Ballou (1968) presents a dynamic programming approach to solving the multi-period problem. In his approach, optimum solutions from the static location model (for each period) are used as inputs to a multi-period model, with dynamic programming applied to the continuous space static optimal solutions, thus defining an overall optimum or relocation schedule. Lodish (1970) in commenting on Ballou's approach points out that Ballou considering relocating each facility by itself when in practice the profitability of a facility is dependent on where the other facilities are located and the allocations of demand that result. He shows that even a small problem involving, say, ten warehouses and five possible locations for each warehouse, and a planning horizon of five years, would require 5^{21} calculations and lead to computational infeasibility.

Klein and Klimpel (1967) is an attempt to solve a realistically formulated but small dynamic discrete space fixed-cost L-A system with continuous economies of scale and multiple products. The

objective function maximizes net present values for all plant sites, with four minutes being used on a Burroughs B-5500 for a one-shot plant construction, three markets and a three year planning horizon.

Elson (1972) is another example of a practical site location problem; once again it is pointed out that the maximum dimensions of each single period sub-model must be reduced if computer time is to be kept within reasonable bounds. Furthermore, even though each separate single-period optimum does not allow for trends in future periods, the slight inertia of such an approach is useful in the light of uncertainty about the future. The Elson model was applied to logistics management in the Common Market and import-duties were specifically modeled.

Dutton, Hinman and Millham (1974) is another application of L-A techniques. Here the optimal location of nuclear power plants is considered with respect to capital-construction, operating and transmission costs. A complication is the introduction of two products -- peak and energy power. The paper also studies the effect of differing demand estimates on solutions derived and their stability under changed demand conditions.

Bowersox (1972a, 1972b) is a description of a dynamic simulation model for long-range planning of physical distribution systems. While concentrating on physical distribution, it incorporates the rela-

tionship between cost minimization and levels of customer service. The model allows for a hierarchical structure (multi-echeloned warehouses), and multi-products. The model uses a heuristic location solution based on the Kuehn-Hamburger approach.

Rutenberg (1973) is an application of L-A systems to the planning of ocean logistics by multi-national firms. The problem here is to decide whether chartering a ship is profitable and if so, what size charters to put through so as to satisfy flows of goods between a given cluster of ports. The solution decides which clusters of ports should have a chartered vessel and which areas should be serviced by a contract of affreightment. Determining the network of containers routes has implications for plant location too.

Carnoy (1972) studied the question of location of plants for several distinct commodities so as to supply at minimum costs the fixed demands for each of these products in the Latin American Free Trade Association. Explicit attention is paid to economies of scale. Market size in 1975 was estimated for the LAFTA as a whole. Economies of scale are approximated by linear approximations at the relevant ranges. An interesting facet of Carnoy's analysis is the estimation of welfare losses and benefits for each member country yielded by using the model's location solutions rather than producing the goods domestically or importing it from outside the LAFTA. Exchange rates are also considered in deriving comparative costs.

Pomper (1974) is a recent doctoral dissertation dealing with investment planning in multi-national firms. It simultaneously considers both manufacturing and financial policy in a company and is based on an actual small-scale case study. The advantage of the model is its incorporation of uncertainty; this is done by developing an interactive model which prompts a manager for his subjective evaluation of uncertainty faced by the company. Since it is a small-scale study, its approach is based on complete enumeration of feasible location solutions over the time periods of the planning horizon. Once feasible location solutions are established, dynamic programming is used to yield a sequence of capacity expansions. Mention is made of the possibility of using mixed integer programming though it is pointed out that the size of the problem will set limits on the practicability of such an approach. The proposed approach differs from Pomper's approach in that it incorporates an optimizing algorithm, albeit that of the simple L-A model.

Pomper's approach to uncertainty consists of deriving a solution for the most likely "scenario" and then studying the sensitivity of the solution to changes in the most likely scenario. The proposed model handles uncertainty differently in that it attempts to derive robust location solutions whose operating performance would be acceptable whatever the scenario realized. However, Pomper's

model does consider multiple periods and is able to solve for capacity expansions by choosing one out of a limited set of possibilities. Pomper does incorporate several features of the multinational environment and his model may be seen as complementary to the approaches developed in this paper.

In general there is quite a gap between theoretical approaches to L-A systems and models developed for practical use. The practical models are highly simplified; they deal with a few locations, fixed demand and certainty and use linear approximation. The goal of practical models is to yield location solutions that are in some way superior to random choice, and can be implemented. The approach taken in the simulation model also emphasizes the practical, implementation aspects of the model; in particular, this means using an algorithm that costs little to use on the computer and can be used repeatedly without causing storage problems or cost over-runs.

However, in terms of future research, there is no denying that efforts should be made to incorporate the complex L-A models within a simulation context; in particular, a formulation that allows for several periods, joint products with economies of scale, concave costs in production and transportation, as well as the existence of capacity and configuration constraints. The development of computer models of such systems that can be used repeatedly, in a production

mode, would be a boon. However, this remains in the realm of further research. Sheppard (1973) provides a good introduction to the conceptual framework for such approaches, dividing complex Location-Allocation models into the areas of size of facility, location, and timing (of capacity installation and expansion). A series of trade-offs are highlighted including that between one large plant and a series of small plants, this being in turn a trade-off between scale economies and distance costs.

The literature surveyed so far consists of some important research on L-A systems, both at a theoretic and applied level, and has been used in deriving the simulation model described in the next section. There are several bibliographies which may be used as guides to other work in this area.

Perhaps the single best source is the annotated bibliography by Lea (1973). It is a complete survey of the L-A literature up to and including 1971 and reasonably complete up to September 1972. A recent additional source is the bibliography of Francis and Goldstein (1974) which concentrates mostly on normative approaches to solving location problems. An earlier work on location theory that complements Lea's work is an annotated survey of industrial location research: Stevens and Bracket (1967), surveying literature up to end-1965. Finally, a brief introduction to L-A systems may be found in

Revelle, Marks and Liebman (1970) where a distinction is made between private and public sector location models. The difference lies in the nature of the objective function, with private sector models minimizing the costs of production and transportation while public sector models must model and maximize social utility. The two formats would be similar if social utility could be related to dollar value.

In the next section we take up the development of a simulation model of L-A systems in multinational environments.

CHAPTER III

A COMPUTER SIMULATION MODEL OF THE LOCATION-ALLOCATION PROCESS IN MULTINATIONAL FIRMS

A computer simulation model of location decisions in multinational firms is developed in this section. The major reason for resort to computer simulation is the uncertainty surrounding elements of the international environment that affect the location decision. A second reason for the computer simulation model is that it can be used to yield robust location solutions; i.e., location solutions that are relatively impervious to variations in the external environment, this imperviousness being manifest in the lower variability of their revenue outcomes under varying environmental conditions. Finally, a computer simulation model can be used to develop approximate solutions when the data available is scant, and then, by linking an experimental design to the computer model, some guidance can be obtained on the areas into which information seeking effort should be guided.

But before we derive robust location solutions and develop priorities for information seeking in uncertain international environments, we must have a completely developed simulation model to work on. Details of such a model follow.

The computer simulation model provides an optimum location solution on each run, given a value for each of the uncertain variables and for each of the parameters. The actual value for each of the uncertain variables on each run is derived by sampling from the probability distributions described for each of these variables. Naturally, the values that the uncertain variables take on may differ from one run to the next. This means that the optimum location solution suggested by the model may also differ from one run to the next.

The computer model consists of two distinct segments:

1) An input segment where a value is derived for each of the uncertain variables which will determine the location solution.
2) An optimization segment using mixed-integer programming to derive an optimum location solution for a particular configuration of the uncertain variables.

The output from each run of the simulation model consists of the optimum location solution for that run, the allocation of the various demand areas to locations, and the revenue to be derived from that arrangement.

Fig. 3-1 is a macro-flow chart of the simulation model. Table 3-1 shows some sample output.

The two major segments of the model are now described.

Fig. 3-1

Macro-Flow Chart

Computer Simulation of the Location-Allocation Problem in Multinational Firms

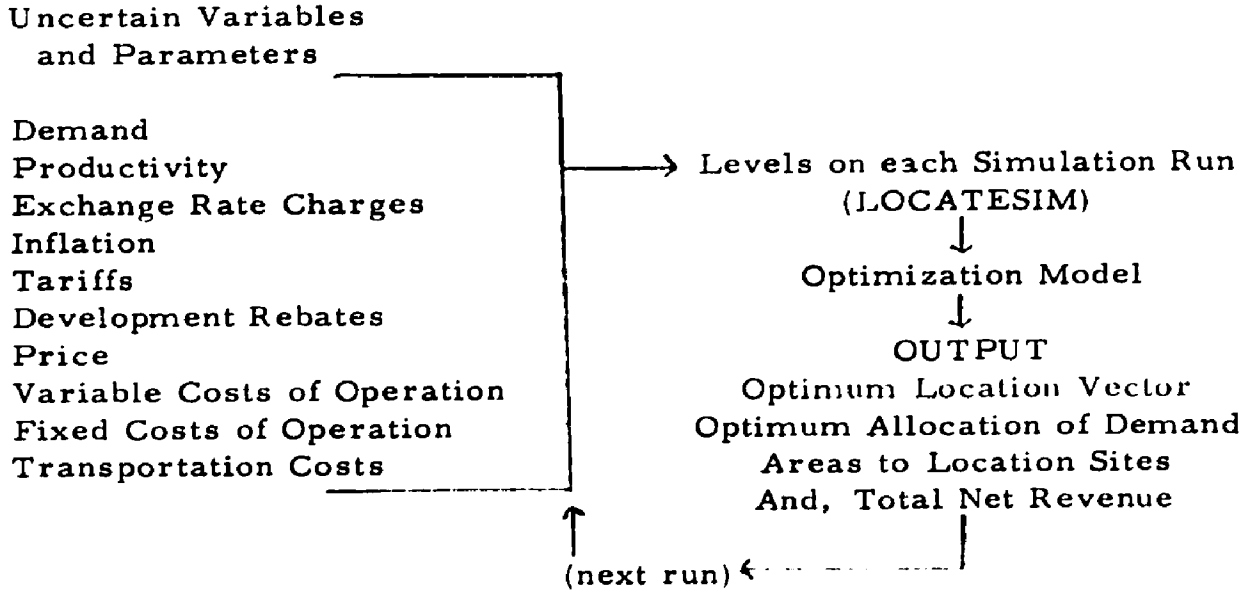

Table 3-1

Sample Output from LOCATESIM

The open Warehouses are # 2, 3, 6

Assign Market to source: 1-3, 2-2, 3-3, 4-3, 5-3, 6-6

Total Variable Cost: 5,692,487
Total Cost: 6,321,179

Net Revenue is = 2,295,604

1) The Input Phase

The uncertain variables included in the model are:

- Demand
- Labor Productivity
- Exchange Rate changes
- Inflation.

In addition, parameters to the model are tariffs, development rebates, transportation costs, fixed costs at each of the location sites, variable costs of operation at each of the locations, price and a price-demand matrix embodying prevailing elasticities of demand at each demand area.

The input phase of the model consists of a series of steps which yield the data necessary for the optimization phase.

(1) Deriving demand levels.

The starting point is the specification of price to be charged at each demand point. This price data is used to derive the base level of demand by reference to the price-demand matrix which sets out the demand (in number of units) that would result from charging a particular price at each demand point. Thus,

$$D_{1_j} = f(\text{Price}_j)$$

where D_{1_j} is the demand (in units) at j and is a function of the price

charged at j. The actual form of the function would be derived from internal company records and industry data for that country. For the sample problem discussed later on we assume that 6 different prices may be charged at each of the demand points and that the demand curve is downward sloping. Since only 6 price points are stated, we have a discontinuous demand curve.

However, D_1 is only the average demand that will arise for a certain price. The uncertainty parameter is therefore added to this base demand. This uncertainty factor is actually a $\pm$% deviation from base demand and the actual amount of percent deviation is specified through a probability distribution. This distribution for demand uncertainty would be based on the company's past performance (errors) in estimation and forecasting. The same probability distribution for demand uncertainty is postulated for every demand destination. Thus

$$D_{2_j} = D_{1_j}(1+u)$$

where D_{2_j} is the actual level of demand realized at point j and u is the percent deviation in demand from the base or average level, for a given price.

Note that this procedure will be carried through for every demand destination specified in the model, and will be repeated for

every run of the computer model. Then, even if the price charged at a destination does not vary over two runs, the uncertainty factor can, and therefore, final demand can be different. And of course, if the price changes, final demand will also change.

(2) Deriving exchange rate changes and total inflation rates.

Various amounts of exchange rate changes are possible at each location site and a probability distribution is derived for each location specifying the different amounts of change with respect to a vehicle currency that might be expected and the probability of occurrence attached to each of these amounts. The probability distribution will of course differ from one location site to the next. Then, on any simulation run, by Monte Carlo sampling we derive a value for the actual amount of change in the exchange rate realized at a site. This sampling will be done for each location site. On the next run this process of sampling will be carried out again and hence the amount of exchange rate changes realized, by site, on the various computer runs may differ.

On any one run, once the amount of exchange rate change at any site is known, it is used to derive the total rate of inflation. That is, a causal relationship is postulated between exchange rate changes and subsequent domestic inflation that results. The exact function used is

$$TINFL_j = DINFL_j - 1/DVAL_j$$

where TINFL is the total inflation rate realized, DINFL is the pre-exchange-rate-change inflation rates (%) and DVAL the amount of exchange rate change realized (%), all at site j. Furthermore, a negative DVAL implies a devaluation and thus tends to raise total inflation rates above the previously obtained domestic inflation rates. In other words, devaluations lead to a degree of imported inflation over and above existing inflation rates. Finally, if the amount of exchange rate change is zero, $TINFL_j = DINFL_j$.

(3) Deriving fixed cost levels at potential location sites.

Initial fixed-cost levels in the vehicle currency are specified for exactly the same size and technology plant at each of the potential location sites. Then, a set of three adjustments are made to this initial fixed cost level; these are for

a) the development rebate (percent of fixed cost) offered at each site,

b) the impact of exchange rate changes at each site, and,

c) the impact of total inflation rates at each site.

Thus,

$$IFC2_j = IFC_j(1-DVREB_j)$$

$$IFC3_j = IFC2_j(1+DVAL_j)$$

$$IFC4_j = IFC3_j(1+TINFL_j)$$

where IFC is the initial fixed cost at site j, $DVREB_j$ is the percent development rebate at site j, $DVAL_j$ is the realized exchange rate change and $TINFL_j$ is the realized inflation rate. Thus, the final realized fixed cost level at site j is

$$IFC_{4_j} = IFC_j(1-DVREB_j)(1+DVAL_j)(1+TINFL_j)$$

(4) Deriving variable costs per unit at the potential location sites.

The procedure at this module is quite similar to that for fixed costs except that variable costs are adjusted for productivity gains or shortfalls rather than for development rebates. The starting point is a variable cost per unit for each location site that is provided. This figure is then adjusted for productivity changes, exchange rate changes and inflation.

Productivity changes are expressed indirectly as $\pm$% deviations from initial variable cost levels. Since uncertainty surrounds the exact variable cost levels that will be achieved, probability distribution are derived for the productivity-related changes in variable costs at each of the location sites. Then, by sampling from the probability distribution on each run, an updated variable cost figure is arrived at. Thus,

$$VC_{2_j} = VC_{1_j}(1+PROD_j)$$

$$VC_{3_j} = VC_{2_j}(1+DVAL_j)$$

$$VC_{4_j} = VC_{3_j}(1+TINFL_j)$$

where VC_{1_j} is the initial variable cost at site j, PROD is the realized change in variable cost obtained by sampling from the probability distribution for productivity changes at site j, with VC_{4_j} being the final realized variable cost level at site j for any one computer run. Thus

$$VC_{4_j} = VC_{1_j}(1+PROD_j)(1+DVAL_j)(1+TINFL_j)$$

where VC_{1_j} is the initial variable cost level and VC_{4_j} the final realized variable cost.

(5) Tariffs and Transportation Costs.

In this model tariffs are specified as a per unit surcharge, being a percent of selling price. Transportation costs are linear, with there being a falt per unit shipped, the actual shipping charge differing from one shipping route to another. Both tariffs and transportation costs can therefore be treated as variable costs. Thus, total variable costs are arrived at by adding together product variable cost after all adjustments, tariffs and transportation costs. Thus,

$$TVC_{jk} = VC_{4_j} + RATE_{jk} + (TR_k)(P_k)$$

where TVC_{jk} is the total variable cost of one unit supplied to destination k from source j, TR_k is the tariff rate at destination k, P_k the

price charged at k, and $RATE_{jk}$ the cost of shipping one unit from j to k.

In all these data modules, costs and prices are stated in one (vehicle) currency and exchange rate changes are also expressed in relation to this vehicle currency.

The financing of operations and its implications for costs and revenues have been left out of the simulation model on the assumption that centralized financing takes place; tax structures are also excluded. As Pomper states, "optimal sourcing patterns are conditional on choice of transfer prices" (1974, p. 15), other financial variables having no effect on the optimality of the logistics solution. Further, Pomper defines transfer cost on any given source-destination route as "the total variable cost of manufacturing at the source plant and getting it to the market" (ibid, p. 75), this cost being adjusted for export incentives and tariffs. Our model follows this very procedure by setting transfer prices exactly equal to transfer costs; hence the exclusion of financial variables is quite justifiable.

(6) The optimization phase.

The optimization phase provides a location vector solution and an allocation of demand areas to location sites. The objective of the optimization phase is to maximize revenue given a certain environmental configuration.

The requirements of our problem conform to what is known in the operations research literature as the location-allocation (L-A) problem. The particular formulation used here is the simple uncapacitated location-allocation problem with linear costs. A computer program based on the algorithm for this problem developed by Khumawala (1970) is therefore embedded into the computer simulation model.

The computer algorithm used has been developed for solving a special class of mixed integer programming problems that have the following structure: Given m potential sources (with unlimited capacity) and n customers or destinations.

$$\text{Minimize } Z = \sum_{ij} C_{ij}X_{ij} + \sum_i F_iY_i$$

subject to

$$\sum_{i \in N_j} X_{ij} = 1, \qquad j = 1, 2 \cdots n,$$

$$0 \leqq \sum_{j \in P_i} X_{ij} \leqq n_iY_i, \qquad i = 1, 2 \cdots m,$$

$$Y_i = 0 \text{ or } 1 \text{ (integer)}, \qquad i = 1, 2 \cdots m,$$

where $C_{ij} = t_{ij}D_j$.

t_{ij} = the total per unit variable cost which includes the FOB cost at the plant (i), the transportation cost from the plant to the customer (j), and the tariff at j,

D_j = the demand at customer j,

X_{ij} = the portion of D_j supplied from plant i,

F_i = the fixed cost associated with plant i,

N_j = set of plants which can supply customer j,

P_i = set of those customers that can be supplied by plant i,

n_i = number of elements in P_i.

Branch and bound methods can be used to solve this essentially combinatorial problem. However, as the number of potential warehouses increases, both solution times and storage requirements become excessive. Khumawala (1970, 1972) was the first to suggest the use of decision rules in deciding which branch of the search tree should be pursued further in order to reach an optimal solution. Of the various decision rules he suggests, we use his "Largest Omega" decision rule. That is, having defined K_0, K_1 and K_2 as the sets of plants that are constrained closed, constrained open and free to be either open or closed at a node. Then,

$$\text{For } i \in K_2, j \in P,$$
$$\omega_{ij} = \text{Min}_{k \in K_2 \cap K_1} [\text{Max } (C_{kj} - C_{ij}, 0)],$$
$$\Omega_i = \sum_{j \in P_i} \omega_{ij} - F_i.$$

And, we choose the location with the largest omega to be fixed open when branching out on the search tree.

This procedure has been integrated into the computer simulation and its structure may be seen by reference to the computer program listing for the simulation model furnished in the Appendix. The difference between Khumawala's procedure and the complete simulation model is that the simulation model seeks to maximize revenues given prices charged at each destination and the cost and environmental configuration of the system. The objective function of the computer simulation is therefore

$$\text{Max } Z = \Sigma_j P_j D_j - (\Sigma_{ij} C_{ij} X_{ij} + \Sigma_i F_i Y_i)$$

with P_j now being price at j, $C_{ij} = (TVC_{ij})(D_j)$ as defined in the input phase of the model and $F_i = IFC_{4i}$, also as defined in the input phase of the computer simulation model.

The model as described thus far can handle up to 30 location sites and up to 60 demand destinations, and can be used to solve location problems, both at the plant level and at a warehouse level (i.e., international logistics). But the model contains several simplifying assumptions and we now comment on the extent to which these assumptions become limitations of the model and how these limitations may be overcome.

(i) The assumption of uncapacitated warehouses.

This implies that capacity restrictions may not be directly modeled. However, capacities may be specified indirectly in the following manner: If, at location "i" two different sized plants are being considered, we first run the model with the smaller-sized plant. Assuming that this particular plant is one of the location sites chosen, we examine the various demand destinations that have been allocated to this plant. The sum of the demand requirements at each such allocated destination yields the present capacity utilization of the plant in question. If this capacity utilized figure exceeds the

implicit capacity of the small plant, we re-run the model, but this time using the larger-sized plant. The fixed costs would probably be higher, with a corresponding reduction in variable costs per unit. If this larger sized plant also figures in the solution, we once again assess its capacity utilization, by reference to the demand destinations and their requirements allocated to this plant. Two possibilities now occur:

(a) the capacity utilization of this larger plant does exceed the capacity of the smaller plant examined in the earlier simulation run. If so, a comparison of the net revenues from the two computer runs decides whether the smaller or larger plant alternative will be implemented. In carrying out this calculation it might be necessary to allocate the excess demand for the smaller sized plant to the next cheapest source of supply. (This is quite easy since the total variable costs of supply, including tariffs and transportation, are available in the computer output for all possible locations).

(b) The larger-sized plant is used but the level of its capacity utilization is not greater than the capacity of the smaller-sized alternative. Once again, total revenues from the two alternatives can be compared and one or the other size plant chosen for implementation. There is also the trivial case where the larger-sized

plant does not figure in the solution, in which case the smaller size is chosen and the excess demand reallocated to the next cheapest source.

(ii) The simultaneous placement of all facilities at once.

This seems to be contrary to real-life situations where a production or logistic network is already in existence. However, the model can be easily made to accommodate an existing framework with the contemplated addition of locations to the existing structure. In selecting locations to be included the optimization framework essentially trades off the addition to fixed costs from adding one more site with the possible lowering in fixed costs arising from supplying destinations more cheaply, because of lower costs of production or lower shipping costs or lower tariffs. Hence, if it is desired that the model be forced to include the existing structure, all that is required is that low (near-zero) or even negative fixed costs be specified for the locations that must be forced. In this manner these locations will always figure in the solution. However, all other costs should be left as they are so that the allocation of demand destinations to locations be optimum. It might also be worthwhile to run the model twice, once using actual fixed costs for all locations, and a second time using the artificially low fixed costs for the forced sites. A comparison of the two solutions will indicate whether the existing structure contains some

less than optimal locations and if so, a comparison of the two revenue figures would provide an indication of the opportunity cost of the forced solution.

(iii) Single-period modeling.

The model as constructed is a single period model. Typically, there is a time lag between the decision to locate a site and its availability. The model uses values for the various uncertain variables and parameters at the start of the period, beginning with the availability of a potential facility and traces the implications for net revenue for one period of a particular location decision.

A question of interest is whether such a model can be applied to multiple periods.

A simple approach that has been used in the literature (Falk and Soland 1974) is to set the single period values equal to the discounted costs and revenues of a T-year time horizon. This implies the acceptance of an agreed-upon discount rate, some known trend of growth in sales and in the various costs. Naturally, the longer the time horizon, the harder it is to come up with values for these variables, with corresponding increases in uncertainty. However, the major flow with this approach is that it provides location solutions in terms of what sites should be chosen at the start of the planning horizon to satisfy demand over the entire planning horizon. Such an

approach rules out the possibility of sequential placement of facilities over time, and the possibility of expanding facilities over time to keep pace with the sales increase.

A better approach to yield the correct sequential expansion of facilities would be as follows: 1) Evaluate each period of the time horizon of planning as a single period model. Then, the computer model as outlined can be used to yield single period solutions. 2) Next, the series of single-period solutions must be examined to determine the proper sequence of capacity expansions. In order to achieve this, additional data must be provided, consisting chiefly of change-over costs and the time lags involved; that is, the cost of dropping a certain facility and utilizing another one, or, simply expanding the capacity of an existing facility. Given such change-over costs, dynamic programming can be used to work out the optimal sequence of expansions, openings, and closings so as to maximize discounted net revenue over the time horizon of planning. This is a complex problem and several recent research studies have been undertaken in this area. For example, the Erlenkotter (1975), Fong and Rao (1975), Wesolowsky and Truscott (1975); Manne (1967) is one of the earliest examinations of this problem, and Ballou (1968) contains a clear example of using the static optimal configurations as input to a dynamic programming problem that provides a solution to the

sequential expansion question. Other location-allocation research that takes cognizance of the time element can be found in Lea (1973), which is an annotated bibliography of location-allocation systems research.

It should be emphasized that the multiple-period location-allocation problem is a distinct problem, and the studies quoted are all deterministic studies. The emphasis of the single period model developed thus far is on uncertainty; the computer model so developed is to be used to derive robust location solutions and aid in directing information-seeking efforts, a purpose quite distinct from that of determining optimal multiple-period solutions in a deterministic environment. However, it would be profitable for future research to attempt to combine the simulation model in a framework of uncertainty with multiple-period location models; this would in turn require considerable progress in algorithmic techniques if practical sized problems are to be solved repeatedly in the context of computer simulation runs without resulting in inordinately high computer costs. For example, a problem consisting of 45 consumption centers and 21 production locations and a 20 year time horizon required 1309 seconds on an IBM 360/91, and this was when using incomplete dynamic programming. (Erlenkotter 1975, pp. 282-3.)

Some other aspects of the model are now considered. It is necessary to specify the potential set of locations from which a choice

is to be made. Thus the model is not a continuous space formulation, but this is in line with location in the real world where a choice is made between predetermined sites, cities, or regions.

The variable costs are assumed to be linear. Hence, economies of scale in production and transportation cannot be handled indirectly but must be specified through piecewise linear approximations.

Configuration constraints cannot be introduced; such as the existence of mutually exclusive relationships between subsets of location sites.

A single product is assumed. Multiple products can be handled by treating each product as a separate instance, but this would be legitimate only if there were no interactions between the multiple products, such as joint costs or joint economies of scale arising from sharing common manufacturing facilities. When the products are interconnected, a more useful expedient might be to set up composite product with several products that have commonalities being given weights in deriving the common product. A suitable method of weighting would have to be worked out.

Summary

A computer simulation model of the location-allocation process in multinational firms has been described. In the input phase,

aspects of the international environment are modeled, either as probability distributions or by parameters value specification. Some of the variables considered are price-demand interactions, exchange rate changes, domestic inflation, tariffs and development rebates, as well as the fixed and variable costs of production and transportation. This data is processed with the help of an optimization routine which is based on the algorithm developed for the simple (uncapacitated) location-allocation problem and described in the operations research literature.

Some of the limitations of the model are discussed and ways suggested to get around them; in particular, problems arising from specifying location capacities, from already existing location systems, and from extending the model to cover several periods are discussed.

In the next section a sample problem is developed and the computer model is used with the sample data to derive robust location solutions.

CHAPTER IV

THE DERIVATION OF ROBUST LOCATION SOLUTIONS

In this section we apply the computer simulation model to a sample problem, develop the concept of robustness and show how robust location solutions may be derived for a data-set at hand.

The sample problem consists of 6 potential location sites which are also demand destinations; the data outlined below include demand and cost data for each of these six sites, parameter values and probability distributions.

Sample Problem Data:

Demand-Price Matrix
'000 units

Demand Site #	1	2	3	4	5	6
Price per unit						
7.0	134	156	197	245	240	245
7.5	127	150	188	235	230	235
8.0	119	142	178	220	220	225
8.5	110	132	165	200	210	200
9.0	100	120	150	180	200	175

Transportation Costs Per Unit

Location Site # \ Demand Site #	1	2	3	4	5	6
1	0.0	.1	.1	.2	.2	.1
2	.1	0.0	.1	.2	.2	.1
3	.1	.1	0.0	.2	.2	.1
4	.2	.2	.2	0.0	.2	.0
5	.2	.2	.2	.2	0.0	.2
6	.1	.1	.1	.2	.1	0.0

Site #	1	2	3	4	5	6
Tariffs (% of Selling Price)	30	40	25	25	20	30
Fixed Costs: ('000 $'s)	200	160	240	300	250	220
Variable Costs Per Unit ($)	3.9	5.0	3.2	3.8	3.2	3.5
Price Charged	7	7	7	7	7	7
Development Rebates (% of Fixed Cost)	7	0	10	18	11	13
Domestic Inflation Rates (%)	30	10	4	7	15	25

Probability of Change in Demand From Base

% Change	Probability
-5	.09
-3.5	.18
-1.5	.18
0	.10
1	.09
1.5	.18
4.5	.18

Productivity Related Changes in Variable Costs (%)

Location # I		II		III		IV		V		VI	
Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change
.3	-10	.6	0	.3	-10	.2	-10	.5	0	.4	-10
.5	0	.2	10	.6	0	.8	0	.3	10	.4	0
.2	10	.2	20	.1	10			.2	20	.2	10

Exchange Rate Changes: Probabilities

Amount of Change*	1	2	3	4	5	6
- .3	.15				.05	.10
- .2	.30				.05	.10
- .1	.40	.2			.20	.35
- .05	.15	.2		.2	.40	.25
0.0		.1	.1	.4	.30	.20
+ .05		.3	.3	.2		
+ .1		.15	.3	.2		
+ .15		.05	.2			
+ .2			.05			
+ .3			.05			

*with respect to some vehicle currency.

Cell values represent probabilities.
Negative amounts represent devaluation.
Positive amounts represent upvaluation.

The simulation model was used on the sample data. A total of 150 simulation runs were made with an optimal location solution provided for each run. Table 4-1 analyzes the 150 runs of the simulation run for each of the 6 potential sites considered in the model.

Table 4-1

Location Site #	No. of occurrences*
1	28
2	38
3	143
4	82
5	36
6	86

*Maximum = 150
(obtained from 150 runs of the model LOCATESIM).

Now, by robust location solutions we are pointing to location solutions that are relatively invulnerable to changes in environmental parameters and the probability distributions of other uncertain environmental variables. In this connection Gupta and Rosenhead (1968) suggest that the "robustness of a decision can be defined simply as the ratio of that number to the number of good end-states considered" (ibid., p. B-21). Following this approach we can use Table 4-1 to estimate the potential robustness of a location site by considering the number of times it appears in the optimum location vector solution over the entire number of simulation runs: i.e., 150.

On the basis of Table 4-1 the following combination of sites were chosen as potentially robust location vectors that should be tested further:

Table 4-2

Vector #	Location Sites
1	3
2	3, 4
3	3, 6
4	3, 4, 6
5	3, 4, 5, 6
6	3, 2, 4, 6.

A disadvantage of the concept of robustness used by Gupta and Rosenhead is that it ignores possible synergies arising out of, say, location #3 in association with location #1. It would be desirable then to also calculate the number of times pairs of location, triples of location, etc. occur in the simulation results. For this example, since the total number of potential locations is only 6, no great harm is done by using a limited definition of robustness. An expanded definition of robustness should however be used when a larger number of potential location sites are being considered.

Another possibility that must be considered when dealing with robustness is the use of second-best solutions. That is, on any one simulation run there may be some location vector, which, though not optimal, is a close second. Then, since we wish to choose robust

vectors, it is possible that the sites that are included in the second-best solution on each simulation run might constitute a potentially robust vector. Of course, from a practical standpoint it would be quite seldom that a particular location site never figures in an optimum location solution, specially if the number of simulation runs is large. Still, this is a theoretical possibility and if the number of potential location sites is large, one should develop second-best solutions on each run, analyze them for occurrences of sites not otherwise figuring in the optimal solutions and perhaps include them when constructing potentially robust location vectors for further testing.

In this connection, the program LOCATESIM does print out a y-matrix that details the location vectors examined in arriving at optimal solution. The only problem then is in deciding whether the second-best solution as derived from this matrix indeed represents globally second-best solutions. Since the optimization algorithm used is a refinement of branch and bound, it is possible that there is some location vector that is globally second-best but is not included in the search path used to derive the optimum solution; then, the globally second-best vector would not be included in the y-matrix and hence one cannot be sure that the globally second-best solution is being considered, when relying on the y-matrix. However, from a practical standpoint this is a minor problem since the purpose here is to

construct combinations of individual sites that may make up a robust location vector after examination of the optimal results (and second-best results as suggested by the y-matrix) for each of several runs of the computer simulation model.

The 6 location vectors chosen for further examination were then set up as input to ROBUST, a simulation program that duplicates the environmental variation for each of the 6 vectors. (Its simulation structure is similar to LOCATESIM). Fifty runs were made for each vector, and revenue distribution obtained for each of the 6 vectors, each distribution containing 50 values.

The Analysis of Revenue Distributions Associated with the 6 Location Vectors Tested

Table 4-3 provides descriptive statistics on the revenue distributions of each of the 6 location vectors tested.

Table 4-3

V	Location Vector Composition	Mean	Std. Dev.	Min.	Max.
1	3	2,194,000	553,330	956,920	3,149,100
2	3,4	2,290,800	449,550	1,248,200	3,131,100
3	3,6	2,340,600	484,490	1,195,700	3,119,800
4	3,4,6	2,419,100	393,730	1,522,000	3,150,400
5	3,4,5,6	2,351,500	329,690	1,493,900	3,080,700
6	2,3,4,6	2,357,400	369,110	1,488,200	3,052,100

Table 4-3 seems to indicate that of the 6 location vectors tested, V4 consisting of Sites #3, 4, and 6 is the most satisfactory, with the highest mean, the third-lowest standard deviation and the highest minimum and maximum values. Further analysis follows, including a test of whether the differences between the samples are indeed significant.

Tables 4-4A and 4-4B reproduce histograms for each of the 6 location vectors tested. The midpoints for each interval are given (Note: .15220 + 7 = 1,522,000) as well as the percentages of the sample in each interval. Also, the interval width does differ for each histogram.

Tables 4-5A through 4-5D provide .1, .25, .75, and .9 quantiles for each of the 6 location vectors, as well as confidence intervals for these quantiles. These tables may be used to establish stochastic dominance, if any, of some of the vectors over others. For example, looking at Table 4-5A, which sets confidence limits for the lowest 10 percent of revenues yielded by the 6 location vectors, vector 4 is stochastically dominant over all other vectors except vector 5. This stochastic dominance of vector 4 over all others except vector 5 persists in Table 4-5B which is for the 1st quartile. In this manner one might proceed through Tables 4-5C and 4-5D and conclude that vectors 3, 4, and 5 are the better ones. At this point,

Table 4-4A

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 1. V1 (EACH X=1)	Location Vector Composition
.95692 +6	6.0	3 +XXX	
.12005 +7	0.	0 +	
.14441 +7	8.0	4 +XXXX	
.16876 +7	14.0	7 +XXXXXXX	
.19312 +7	2.0	1 +X	
.21748 +7	28.0	14 +XXXXXXXXXXXXXX	3
.24184 +7	14.0	7 +XXXXXXX	
.26619 +7	16.0	8 +XXXXXXXX	
.29055 +7	4.0	2 +XX	
.31491 +7	8.0	4 +XXXX	
TOTAL		50 (INTERVAL WIDTH= .24358 +6)	

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 2. V2 (EACH X=1)	
.12482 +7	4.0	2 +XX	
.14574 +7	0.	0 +	
.16666 +7	12.0	6 +XXXXXX	
.18758 +7	6.0	3 +XXX	
.20850 +7	14.0	7 +XXXXXXX	
.22942 +7	20.0	10 +XXXXXXXXXX	3,4
.25034 +7	20.0	10 +XXXXXXXXXX	
.27126 +7	10.0	5 +XXXXX	
.29219 +7	12.0	6 +XXXXXX	
.31311 +7	2.0	1 +X	
TOTAL		50 (INTERVAL WIDTH= .20921 +6)	

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 3. V3 (EACH X=1)	
.11957 +7	2.0	1 +X	
.14095 +7	4.0	2 +XX	
.16233 +7	8.0	4 +XXXX	
.18371 +7	6.0	3 +XXX	
.20509 +7	12.0	6 +XXXXXX	
.22646 +7	22.0	11 +XXXXXXXXXXX	3,6
.24784 +7	8.0	4 +XXXX	
.26922 +7	18.0	9 +XXXXXXXXX	
.29060 +7	12.0	6 +XXXXXX	
.31198 +7	8.0	4 +XXXX	
TOTAL		50 (INTERVAL WIDTH= .21379 +6)	

Table 4-4B

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 4.V4 (EACH X=1)	Location Vector Composition
.15220 +7	2.0	1 +X	
.17030 +7	8.0	4 +XXXX	
.18839 +7	0.	0 +	
.20648 +7	18.0	9 +XXXXXXXXX	
.22458 +7	8.0	4 +XXXX	3, 4, 6
.24267 +7	22.0	11 +XXXXXXXXXXX	
.26076 +7	10.0	5 +XXXXX	
.27885 +7	20.0	10 +XXXXXXXXXX	
.29695 +7	8.0	4 +XXXX	
.31504 +7	4.0	2 +XX	
TOTAL		50 (INTERVAL WIDTH= .18093 +6)	

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 5.V5 (EACH X=1)	
.14939 +7	2.0	1 +X	
.16702 +7	4.0	2 +XX	
.18465 +7	4.0	2 +XX	
.20228 +7	8.0	4 +XXXX	
.21992 +7	22.0	11 +XXXXXXXXXXX	3, 4, 5, 6
.23755 +7	18.0	9 +XXXXXXXXX	
.25518 +7	24.0	12 +XXXXXXXXXXXX	
.27281 +7	14.0	7 +XXXXXXX	
.29044 +7	2.0	1 +X	
.30807 +7	2.0	1 +X	
TOTAL		50 (INTERVAL WIDTH= .17631 +6)	

HISTOGRAM/FREQUENCIES

MIDPOINT	HIST%	COUNT FOR 6.V6 (EACH X=1)	
.14882 +7	2.0	1 +X	
.16620 +7	6.0	3 +XXX	
.18357 +7	6.0	3 +XXX	
.20095 +7	10.0	5 +XXXXX	2, 3, 4, 6
.21833 +7	18.0	9 +XXXXXXXXX	
.23570 +7	10.0	5 +XXXXX	
.25308 +7	26.0	13 +XXXXXXXXXXXXX	
.27046 +7	10.0	5 +XXXXX	
.28783 +7	10.0	5 +XXXXX	
.30521 +7	2.0	1 +X	
TOTAL		50 (INTERVAL WIDTH= .17377 +6)	

Table 4-5A

Prob. = .1

V	Quantile	Confidence Interval*	
1	1,465,800	956,920	1,704,200
2	1,608,100	1,248,200	1,852,400
3	1,577,800	1,195,700	1,932,200
4	1,778,600	1,522,000	2,058,400
5	1,898,600	1,493,900	2,117,600
6	1,826,300	1,488,200	1,974,800

Table 4-5B

Prob. = .25

1	1,779,600	1,469,400	2,099,500
2	2,062,700	1,725,300	2,191,900
3	2,039,800	1,703,600	2,225,000
4	2,145,100	2,035,500	2,342,200
5	2,135,300	2,050,000	2,231,300
6	2,146,100	1,915,700	2,218,100

Table 4-5C

Prob. = .75

1	2,560,600	2,481,000	2,779,200
2	2,589,900	2,479,600	2,857,800
3	2,696,200	2,618,500	2,940,500
4	2,735,600	2,596,400	2,869,000
5	2,583,700	2,507,800	2,647,900
6	2,606,700	2,550,800	2,773,200

*Confidence Interval at 95% level

Table 4-5D

Prob. = .9

V	Quantile	Confidence Interval*	
1	2,787,700	2,749,400	3,149,100
2	2,904,400	2,690,800	3,131,100
3	2,956,100	2,812,600	3,119,800
4	2,879,600	2,793,100	3,150,400
5	2,652,700	2,635,600	3,080,700
6	2,797,700	2,728,400	3,052,100

*Confidence Interval at 95% levels.

referring back to Table 3, one might wish to drop 3 because of its lower mean and high standard deviation and perhaps add back vector 6 because of its favorable mean and variance. That is, at this point we are considering choosing between vectors 4, 5 and 6. Here it would be appropriate to calculate pair-wise t-statistics to check whether there are significant differences between these vectors.

Table 4-6 contains pair-wise t-statistics, which can be used to test the null hypothesis that the mean of the difference between two variables is zero. (Here an assumption is made that the differences have a normal distribution.) On the basis of Table 4-6, it is clear that location vector #4 does differ from vector #5 and 6 at the .01 level. However, there is no basis for assuming that there is a significant difference between vectors 5 and 6. Also, the difference between vectors 3 and 4 is significant at the .05 level though not at the .01 level.

Table 4-6

PAIRWISE T-STATISTICS

VARIABLE	MEAN	MEAN DIFF	STD DEV	T-STAT	SIGNIF
1. V1	.21940 +7	-96788.	.23782 +6	-2.8777	.0059
2. V2	.22908 +7	N= 50			
1. V1	.21940 +7	-.14657 +6	.28297 +6	-3.6626	.0006
3. V3	.23406 +7	N= 50			
1. V1	.21940 +7	-.22507 +6	.35788 +6	-4.4469	.0001
4. V4	.24191 +7	N= 50			
1. V1	.21940 +7	-.15749 +6	.40461 +6	-2.7524	.0083
5. V5	.23515 +7	N= 50			
1. V1	.21940 +7	-.16339 +6	.38354 +6	-3.0124	.0041
6. V6	.23574 +7	N= 50			
2. V2	.22908 +7	-49784.	.33308 +6	-1.0569	.2957
3. V3	.23406 +7	N= 50			
2. V2	.22908 +7	-.12828 +6	.24814 +6	-3.6555	.0006
4. V4	.24191 +7	N= 50			
2. V2	.22908 +7	-60705.	.30163 +6	-1.4231	.1611
5. V5	.23515 +7	N= 50			
2. V2	.22908 +7	-66607.	.27432 +6	-1.7169	.0923
6. V6	.23574 +7	N= 50			
3. V3	.23406 +7	-78494.	.20950 +6	-2.6493	.0108
4. V4	.24191 +7	N= 50			
3. V3	.23406 +7	-10921.	.28467 +6	-.27126	.7873
5. V5	.23515 +7	N= 50			
3. V3	.23406 +7	-16823.	.24502 +6	-.48549	.6295
6. V6	.23574 +7	N= 50			
4. V4	.24191 +7	67573.	.17470 +6	2.7350	.0087
5. V5	.23515 +7	N= 50			
4. V4	.24191 +7	61671.	.10702 +6	4.0748	.0002
6. V6	.23574 +7	N= 50			
5. V5	.23515 +7	-5902.2	.20806 +6	-.20059	.8419
6. V6	.23574 +7	N= 50			

If our assumption about the normality of differences between sample means is not valid, one may use the non-parametric analogue of the t-test, i.e., the Wilcoxon matched-pair rank-sum statistic which tests the null hypothesis that the distribution of the difference between two variables is symmetric about zero; one can also use the median test statistic which tests that the median difference is zero. This data is set out in Table 4-7. Once again, vector 4 is significantly different from 5 and 6, and there is no significant difference between 5 and 6. However, when it comes to distinguishing between vectors 3 and 4, the rank sum of differences test is significant at the .05 level, but not the median test (at the .05 level).

On the basis of the above statistical evidence, it would seem that location vector #4, i.e., locating at sites 3, 4 and 6 is the best robust solution, of the ones tested. There is no guarantee that there is no other solution that would perform better than this solution. But this solution is one reasonably robust location solution.

Since the whole concept of robustness is a satisficing concept, it is not absolutely necessary that the best robust solution derived from those tested be also the best solution. If management feels that some other location vectors need to be tested, this can be then added on and compared with the best solution derived thus far -- a step-wise solution that would also result in computer cost savings.

Table 4-7

PAIRWISE RANK STATISTICS

VARIABLES			
1. V1	N= 50	DIFF<0= 35	DIFF>0= 15	SIGNIF= .0066
2. V2	RANK SUM OF - DIFFERENCES= 923.00			SIGNIF= .0059
1. V1	N= 50	DIFF<0= 35	DIFF>0= 15	SIGNIF= .0066
3. V3	RANK SUM OF - DIFFERENCES= 1000.0			SIGNIF= .0005
1. V1	N= 50	DIFF<0= 36	DIFF>0= 14	SIGNIF= .0026
4. V4	RANK SUM OF - DIFFERENCES= 1048.0			SIGNIF= .0001
1. V1	N= 50	DIFF<0= 32	DIFF>0= 18	SIGNIF= .0649
5. V5	RANK SUM OF - DIFFERENCES= 887.00			SIGNIF= .0160
1. V1	N= 50	DIFF<0= 32	DIFF>0= 18	SIGNIF= .0649
6. V6	RANK SUM OF - DIFFERENCES= 913.00			SIGNIF= .0078
2. V2	N= 50	DIFF<0= 29	DIFF>0= 21	SIGNIF= .3222
3. V3	RANK SUM OF - DIFFERENCES= 747.00			SIGNIF= .2905
2. V2	N= 50	DIFF<0= 33	DIFF>0= 17	SIGNIF= .0328
4. V4	RANK SUM OF - DIFFERENCES= 977.00			SIGNIF= .0010
2. V2	N= 50	DIFF<0= 29	DIFF>0= 21	SIGNIF= .3222
5. V5	RANK SUM OF - DIFFERENCES= 738.00			SIGNIF= .3320
2. V2	N= 50	DIFF<0= 28	DIFF>0= 22	SIGNIF= .4799
6. V6	RANK SUM OF - DIFFERENCES= 774.00			SIGNIF= .1876
3. V3	N= 50	DIFF<0= 32	DIFF>0= 18	SIGNIF= .0649
4. V4	RANK SUM OF - DIFFERENCES= 890.00			SIGNIF= .0148
3. V3	N= 50	DIFF<0= 24	DIFF>0= 26	SIGNIF= .8877
5. V5	RANK SUM OF + DIFFERENCES= 655.00			SIGNIF= .8658
3. V3	N= 50	DIFF<0= 20	DIFF>0= 30	SIGNIF= .2026
6. V6	RANK SUM OF + DIFFERENCES= 645.00			SIGNIF= .9423
4. V4	N= 50	DIFF<0= 14	DIFF>0= 36	SIGNIF= .0026
5. V5	RANK SUM OF + DIFFERENCES= 1005.0			SIGNIF= .0004
4. V4	N= 50	DIFF<0= 16	DIFF>0= 34	SIGNIF= .0153
6. V6	RANK SUM OF + DIFFERENCES= 997.00			SIGNIF= .0005
5. V5	N= 50	DIFF<0= 29	DIFF>0= 21	SIGNIF= .3222
6. V6	RANK SUM OF - DIFFERENCES= 733.00			SIGNIF= .3566

In fact, in a later section the three best robust solutions as derived from the analysis above are compared with (i) location vectors derived by using a rule of thumb: "locate at sites that are also the largest markets," and (ii) with location vectors derived at random. This will help decide whether the elaborate apparatus developed for the analysis of location problems results in any significant improvement in decision-making.

One other flaw with the approach used to develop robust location solutions is the lack of control over starting conditions. For example, the environmental conditions posited in the sample problem are relatively favorable since all six location vectors tested have positive minima (see Table 4-3), ranging from $956,920 to $1,522,000. A question of some importance is, if environmental conditions were relatively unfavorable, how would the potentially robust location vectors perform? This question can be handled by using markedly different starting conditions on the various simulation runs. One way of handling this elegantly is through the use of different blocks in the context of an experimental design. This matter is taken up in the next section.

Summary

A sample problem was developed and the computer simulation model applied to the sample data to yield optimal location solutions.

Optimal solutions were analyzed from the results of 150 computer runs and this led to 6 potentially robust location vectors being formed. The performance of each of these 6 location vectors were then simulated and the resulting revenue distributions analyzed to yield one location vector that was the most robust of the vectors analyzed.

CHAPTER V

EXPERIMENTAL DESIGN AND THE SIMULATION MODEL

A feature of the simulation model that has been developed is its incorporation of a variety of environmental factors that are subject to variation. This variation arises on different runs of the simulation model because of uncertainty surrounding the exact values of each of the parameters. A natural inclination in the face of this uncertainty is to seek further information so as to fix the values of the parameters more firmly. In this connection it would be useful to know the relative influence of each of our uncertain factors on the revenue outcomes so that we may establish priorities in our information-seeking effort; that is, given a limited budget, decide which of the uncertain factors should be first investigated and, if more than one factor or parameter is to be investigated, how much effort, or proportion of our budget, should be expended on each of the factors.

The methodology we have adopted for this purpose is known as experimental design. In particular, we shall be using a methodology known as fractional factorial design. Each run of the simulation model can be termed a <u>treatment</u>, denoting the values used for each of the factors on that particular computer simulation run. If the values attached to the factors change from one run to the next, we

are applying different treatments on each run. The objective of experimental design is to vary the treatments in a systematic fashion so that knowledge is gained both about the dependent variable or outcome, and, about how the different treatments influence the values of the dependent variable.

In factorial experiments the effects of a number of factors are investigated simultaneously. That is, instead of holding all other factors constant and just allowing one factor to vary (sensitivity analysis), we vary all factors at once. The total number of possible treatments would consist of all combinations that can be formed from the different factors. Thus, if we have 2 factors, and each factor can take on one of two values, the total number of treatments would be four.

The usefulness of factorial experiments arises from the fact that with a factorial design one can estimate the effect of a change in a factor on the dependent variable over all environmental arrangements or combinations of other factor values; and, in addition, we can also estimate the impact of two or more factors acting together. (If indeed there is such dependence.) These two kinds of effects are known as main effects and interaction effects (Cochran and Cox, 1968, Ch. 5).

For the purposes of our experiment we plan to use <u>eight</u> factors. Each of these factors will have two levels, a standard level and

an alternative level. One could complain that this is unrealistic in that uncertain factors vary continuously in the real world and can take on a multiplicity of values. But the purpose of the experiment is to determine whether changes in the level of a factor are significant and whether, among the significant factors, some of them have a greater influence on the revenue outcomes than others. Hence, it does no great harm to assume just two levels for each factor.

The 8 factors chosen for the experiment and the two levels set for each of the factors are detailed below.

1. Exchange rate changes

   Standard: no change from starting conditions.

   Alternate: +.1 over starting conditions.

2. Demand uncertainty

   Standard: Starting condition +.05

   Alternate: Starting condition -.05

3. Tariff levels

   Standard: Starting conditions +.1

   Alternate: Starting conditions -.1

4. Fixed cost levels

   Standard: Existing levels + 25000

   Alternate: Existing levels - 25000

5. Variable cost levels

   Standard: Existing levels +. 5

   Alternate: Existing levels -. 5

6. Development rebates

   Standard: No change from starting conditions

   Alternate: Starting condition +. 10

7. Domestic Inflation

   Standard: No change from starting conditions

   Alternate: Starting condition +. 05

8. Price

   Standard: No change from starting conditions

   Alternate: Starting conditions +. 5

As can be seen, factor levels are all defined in relation to some starting condition. Hence, the starting conditions or values for the factors from which base a change may be administered must be defined. In this connection, it is probable that the starting conditions or initial values set for the various factors such as price, demand uncertainty probability distribution, tariffs, development rebates and so forth, could well affect the value of the dependent variable or revenue outcomes. To avoid this, one must also systematically switch around the starting conditions so that one may estimate the impact of the different starting conditions on the revenue outcomes, in addition

to the main and interaction effects of the factors themselves. The different starting conditions are known as blocks and 4 such blocks are provided for in the simulation runs.

The values for each of the 4 blocks are set out below for each of the 8 factors.

In the blocks devised for tariff levels and the remaining factors, Block 1 represents the average level for each factor, Block 2 is a random choice, Block 3 is the mid-point of the upper third of the range. In this fashion, four quite distinct starting conditions are devised for the start of a simulation run, and the effects of changes in each of the factor levels are averaged over this range of starting conditions; the inferences about the impact of changing any factor is thus strengthened since the factor's main effect is considered significant only if its influence is felt over all 4 blocks.

Now that we have established the blocks for each of the factors, we can assess the exact meaning of the standard and alternate factor levels prescribed for the experimental design:

A. Exchange Rate Changes:

The alternate level consists of +. 1 to starting conditions. Then, on block 1, for site #1, there would be a . 15 probability of a -. 2 change in exchange rates (i. e. -. 3, the standard level, +. 1, the alternate level disturbance), a . 3 probability of a -. 1 change in

Exchange Rate Changes: Probability Distribution
(Changes with respect to some vehicle currency;
a negative change represents a depreciation)

Location #

Block 1

1		2		3		4		5		6	
Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.
-.3	.15	-.1	.2	.0	.1	-.05	.2	-.3	.05	-.3	.1
-.2	.3	-.05	.2	.05	.3	.0	.4	-.2	.05	-.2	.1
-.1	.4	.0	.1	.1	.3	.05	.2	-.1	.2	-.1	.35
-.05	.15	.05	.3	.15	.2	.1	.2	-.05	.4	-.05	.25
		.1	.15	.2	.05			.0	.3	.0	.2
		.15	.05	.3	.05						

Block 2

1		2		3		4		5		6	
Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.
-.45	.15	-.09	.2	.1	.1	-.03	.2	-.37	.05	-.5	.1
-.35	.3	-.04	.2	.15	.3	.02	.4	-.27	.05	-.4	.1
-.25	.4	.01	.1	.2	.3	.07	.2	-.17	.2	-.3	.35
-.2	.15	.06	.3	.25	.2	.12	.2	-.12	.4	-.25	.25
		.11	.15	.3	.05			-.07	.3	-.2	.2

Location #

Block 3

1		2		3		4		5		6	
Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.
-.15	.15	-.11	.2	-.1	.1	-.07	.2	-.23	.05	-.1	.1
-.05	.3	-.06	.2	-.05	.3	-.02	.4	-.13	.05	.0	.1
+.05	.4	-.01	.1	.0	.3	.03	.2	-.03	.2	.1	.35
+.1	.15	.04	.3	.05	.2	.08	.2	.02	.4	.15	.25
		.09	.15	.1	.05			.07	.3	.2	.2
		.14	.05	.2	.05						

Block 4

1		2		3		4		5		6	
Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.
-.45	.15	-.15	.2	-.1	.1	-.07	.2	-.37	.05	-.4	.1
-.25	.3	-.1	.2	.1	.3	-.02	.4	-.27	.05	-.3	.1
+.05	.4	.0	.1	.2	.3	.07	.2	-.03	.2	.0	.35
.25	.15	.1	.3	.25	.2	.12	.2	.02	.4	.05	.25
		.15	.15	.3	.05			.07	.3	.1	.2
		.25	.05	.4	.05						

Demand Uncertainty: Probability Distribution
(Change from Average Level established
in Demand-Price Matrix)

Block 1		Block 2		Block 3		Block 4	
Change	Prob.	Change	Prob.	Change	Prob.	Change	Prob.
-.05	.09	-.1	.09	-.2	.09	.0	.09
-.035	.18	-.07	.18	-.15	.18	.03	.18
-.015	.18	-.03	.18	-.12	.18	.06	.18
.0	.10	.0	.10	-.09	.10	.09	.10
.01	.09	.01	.09	-.06	.09	.12	.09
.015	.18	.03	.18	-.03	.18	.15	.18
.045	.18	.09	.18	.0	.18	.20	.18

Tariff Levels
(Proportion of Selling Price)

		Location #					
		1	2	3	4	5	6
Block	1	.3	.4	.25	.25	.2	.3
	2	.35	.41	.29	.20	.20	.31
	3	.367	.467	.283	.283	.267	.367
	4	.233	.333	.217	.217	.133	.233

Fixed Cost Levels ($)

	Location #					
	1	2	3	4	5	6
Block 1	200,000	160,000	240,000	300,000	250,000	220,000
2	250,000	190,000	210,000	290,000	210,000	230,000
3	233,000	187,000	280,000	367,000	283,000	275,000
4	167,000	133,000	200,000	233,000	217,000	175,000

Variable Cost Levels ($ per unit)

		Location #					
		1	2	3	4	5	6
Block	1	3.9	5.0	3.2	3.8	3.2	3.5
	2	3.9	5.8	3.3	3.6	2.6	2.9
	3	4.3	5.7	3.75	4.25	3.75	4.5
	4	3.5	4.3	2.75	3.25	2.75	2.5

Development Rebates (Proportion of Fixed Cost)

		Location #					
		1	2	3	4	5	6
Block	1	.07	.0	.1	.18	.11	.13
	2	.03	.04	.09	.25	.09	.14
	3	.10	.08	.13	.23	.13	.18
	4	.04	.02	.07	.13	.07	.08

Domestic Inflation Rates (%)

		Location #					
		1	2	3	4	5	6
Block	1	30	10	4	7	15	25
	2	31	11	5	10	11	29
	3	37	13	5	9	18	28
	4	23	7	3	5	12	22

Price ($ per unit)

		Location #					
		1	2	3	4	5	6
Block	1	7.	7.	7.	7.	7.	7.
	2	7.	8.5	7.	8.	9.	8.5
	3	7.5	7.0	7.0	8.	7.	7.
	4	8.5	9.0	8.0	9.0	8.0	9.0

exchange rates and so on. For Block 2, again for site #1, there would be a .15 probability of a -.35 change in exchange rates, a .3 probability of a -.25 change in exchange rates. Thus, a new probability distribution is set up for exchange rate changes by site on each block; and, this probability distribution is shifted to the right when the alternate level of the factor is being considered.

B. Demand Uncertainty

Demand Uncertainty is introduced in each block as variations from the average level defined in a price-demand matrix. Thus, there

are differing probability distributions for this demand uncertainty in each block. Then, say for block 1, at the standard level, there would be a .09 probability of no change in the average level of demand (i.e., -.05, the block level +.05, the standard level change), a .18 probability of a .015 change in demand and so on; and, for the alternate level of this factor, there would be a .09 probability of a -.1 change in the average level of demand (i.e. -.05, the block level, +(-.05), the alternate level disturbance, a .18 probability of a -.085 change in demand, and so on.

C. Tariff levels

The standard level consists of a .1 addition to the Block level; then, for Block 1, the site #3, the standard tariff would be .25 + .1 or .35, and the corresponding alternate level would be .25 - .1 or .15.

D. Fixed Costs

The standard level would add $25,000 to the Block fixed cost level. Then, for Block 2, for site #6, the standard fixed cost would be $230,000 + 25,000 or $255,000; while the corresponding alternate level would be $230,000 - 25,000 or $205,000.

E. Variable Costs

The standard level would add .5 or 50 cents to the Block variable cost levels. Then, for Block 3, for site #5, the standard

variable cost would be $3.75 + .5 or $4.25, while the corresponding alternate level would be $3.75 - .5 or $3.25 per unit.

F. Development Rebates

The standard level consists of accepting the Block condition as is. Thus, for Block 4, for site #3, the development rebate would be .07 (of fixed cost); while the corresponding alternate level would be .07 + .10 or .17 (of fixed cost).

G. Domestic Inflation

Once again the standard level consists of the starting Block conditions. Thus, for Block 1, for site #2, the prevailing domestic inflation rate would be 10%, while at the alternate level it would be .10 + .05 or 15%.

H. Price

The standard level consists of the Block conditions; while at the alternate level .5 is added to the price per unit. Thus, for Block 4, for site #1, the alternative price would be 8.5 + .5 or 9.0 per unit.

Since we have 8 factors, each at two levels, the total number of treatments that would yield every possible combination of each of the 8 factors would be 2^8 or 256 computer runs. In addition, the 4 blocks would have to be allocated to the 256 runs. Perhaps 64 to each block. Such an experimental design would yield all main effects, block effects, and all higher-order interaction effects, including the influence of all

8 factors acting together. But this might be somewhat wasteful in that even the lower-order interaction effects may not be significantly different from zero. Hence the approach adopted is to reduce the number of runs required by using a fractional factorial design. This would enable us to estimate the lower-order interaction effects and if they are many and significant an expanded design can be adopted. Thus, we are advocating a step-wise approach which could result in computer cost savings.

The specific sampling plan used is a 1/4 replicate of the full factorial design. The same design has been used by Bonini (1967) and its main advantage is that it estimates all main effects, Block effects and two-factor interaction. It requires 64 runs, with 4 Blocks of 16 treatments each. The details of the sampling plan (Plan 6A. 16 in Cochran and Cox (1968, p. 287) are given below:

SAMPLING PLAN

2^8 factorial in 64 units (1/4 replicate)

Defining contrasts: ABCEG, ABDFH, CDEFGH

Blocks of 16 units

Estimable 2-factors: All

Block:	1	2	3	4
	(1)	eg	ab	acd
	adefh	bcd	cfgh	abeg
	bcdeg	adfgh	acdeg	cefh
	abcfgh	abcefh	bdefh	bdfgh
	adg	fg	cd	cg
	abce	ade	bdg	bde
	efgh	abcg	acdfh	abfh
	bcdfh	bcdefgh	abefgh	acdefgh
	ach	bef	afg	dh
	bfg	abdh	bch	aef
	cdef	cdfg	degh	bcegh
	abdegh	acegh	abcdef	abcdfg
	beh	acf	df	agh
	abdf	bgh	aeh	bcf
	cdgh	cdeh	bcefg	defg
	acefg	abdefg	abcdgh	abcdeh

In the above sampling plan, we have a total of 8 factors, A-H. Then, the presence of a letter in the lower case implies that the factor is used at its alternate level; the absence of a letter implies that it is used at its standard level. Thus, adefh means that factors B, C, and G are used at the standard level and the remaining factors are used at their alternate level. When all factors are used at their standard level, this is signified by the numeral (1).

A computer program, DESIGN, was written to carry out the experimental design simulation. A listing of the program is available in the Appendix.

Sixty-four computer runs were made and the revenue outcomes gathered, each run corresponding to one of the treatments outlined in the sampling plan. Also, the model design was run several times, with a different location vector being used for each experimental design set. That is, the first location vector chosen was sites 3, 4 and 6; 64 computer runs were made by following the sampling plan 1, then, a second vector was chosen -- sites 3, 4, 5 and 6, and the fractional factorial design repeated.

In this fashion, a total of 7 different location vectors were tried. The seven location vectors tested, and the variable number for the associated revenue vector are listed below.

Location Vector	Sites Chosen	Revenue
1	3, 4, 6	V309
2	3, 4, 5, 6	V310
3	2, 3, 4, 6	V311
4	4, 6	V312
5	4, 5, 6	V313
6	1, 4	V314
7	2, 3, 6	V315

The first three location vectors were chosen as being the most robust location choices possible. The revenues associated with each of these 3 choices were stored as vectors 309, 310, and 311, each vector consisting of 64 items. The next two location vectors, 4 and 5, consist of location choices made by following a rule of thumb:

"locate at the largest demand destinations;" and, the last two vectors, 6 and 7, consist of location vectors made up at random.

Analysis of variance techniques were used to examine the experimental design revenue results. For the particular experimental design chosen, we have 3 degrees of freedom (d. f.) for the Block effects, 8 d. f. for the main effects, 28 d. f. for the 2-factor interactions (i. e. 8_{C_2} d. f.) and that left 24 d. f. for higher order interactions, giving a total of 63 d. f. for the analysis of variance.

Table 5-1 and 5-2 provide the results of the analysis of variance. Table 5-1 provides the partial correlation coefficients for Block, Main and Interaction effects if these were found to be significant at the .05 level. Table 5-2 provides the regression equation coefficients, again for independent variables significant at the .05 level. The general form of the regression equation would be

$$\text{Revenue} = \text{constant} + \sum_{i=1}^{4} b_i B_i + \sum_{j=1}^{8} f_j F_j + \sum_{i,j=1}^{4,8} a_{ij} A_{ij} + E$$

where B_i are the Block effects,

F_j are the Main effects,

A_{ij} are the two-factor interactions

E is the experimental error term;

and b_i, f_j and a_{ij} are the associated regression coefficients.

Table 5-1

Analysis of Experimental Design Results

Partial Corr. Coeff. Listed, if sig. at .05 level, else *

		V309 Sites 3, 4, 6	V310 3, 4, 5, 6	V311 2, 3, 4, 6	V312 myopic 4, 6	V313 myopic 4, 5, 6	V314 random 1, 4	V315 random 2, 3, 6
Block:	V201	-.61764	-.75126	-.5918	-.66395	-.78380	-.42538	-.62442
	V202	.74408	.87230	.80937	.84062	.89096	.57937	.82648
	V203	-.95490	-.97207	-.94723	-.96062	-.96744	-.91229	-.94582
Main:	V1 Exch. Rate Ch.	.52470	.64674	*	.40532	.59529	.36391	*
	V2 Dem. Uncert.	.50362	.68926	.56322	*	.59739	*	.55931
	V3 Tariffs	-.79368	-.73235	-.56684	-.79774	-.77273	-.77093	-.71102
	V4 Fixed Costs	*	*	*	*	*	*	*
	V5 Var. Costs	-.90069	-.92485	-.87754	-.86251	-.88373	.77777	-.87598
	V6 Dev. Rebates	*	*	*	*	*	*	*
	V7 Dom. Inflation	*	*	*	*	*	*	*
	V8 Price	.49204	.48226	.45248	.51368	.46842	*	.40652
Interaction:	A 17	.43288	*	.49663	.42242	*	*	.42284
	A 45	.44759	.38954	.38190[X1]	.38416[X2]	*	*	*
x_1 sig. at .0542	A 46	*	.39602	*	*	*	*	*
	A 56	*	*	-.43741	-.45795	*	-.53178	*
x_2 sig. at .0527	A 34	*	*	*	*	*	*	.39548

Table 5-2

Analysis of Experimental Design

Regression Equation Coefficients for indepent variables significant at .05 level

		V309 Sites 3,4,6	V310 3,4,5,6	V311 2,3,4,6	V312 myopic 4,6	V313 myopic 4,5,6	V314 random 1,4	V315 random 2,3,6
Block:	V201	-425310.	-491770.	-481270.	-579420.	-657540.	-393140.	-539460.
	V202	603160.	770730.	903390.	1012800.	1022200.	594550.	990670.
	V203	-1741700.	-1789500.	-1937100.	-2256100.	-1991300.	-1863100.	-1965700.
Constant		2630700.	2615600.	2682900.	2248200.	2634000.	1691500.	2647200.
Main:	V1	192720.	211510.	*	167050.	222840.	188670.	*
	V2	182270.	237300.	257970.	*	224060.	*	262870.
	V3	-407930.	-268280.	-260400.	-498450.	-366170.	-584520.	-393950.
	V4	*	*	*	*	*	*	*
	V5	-648190.	-606540.	-692620.	-642170.	-567980.	-597550.	-707540.
	V6	*	*	*	*	*	*	*
	V7	*	*	*	*	*	*	*
	V8	176720.	137320.	192030.	225570.	159470.	*	173350.
Interaction:	A 17	150150	*	216550.	175590.	*	*	181790.
	A 45	156500	105590.	156390.	156770.	*	*	*
	A 48	*	107560.	*	*	*	*	*
	A 5-	*	*	-184090.	-194090.	*	-303230.	*
	A 34	*	*	*	*	*	*	167760.
	R^2	.95924	.97271	.94820	.95972	.96760	.92121	.94873

Leaving aside the analysis of experimental design for a bit, the various revenue vectors themselves, V309-V315, themselves correspond to the performance of the various location choices under widely varying evnironmental conditions. This data can be used to decide whether analytically robust solutions such as the first three location vectors corresponding to the revenue results variables #s 309, 310, and 311 are indeed superior to location choices made by using rules of thumb, or, randomly derived location solutions. In other words, the revenue results from the experimental design runs can be used to further test the robustness of the analytical solutions and also help decide whether the analytical method does yield superior and statistically significant results over ad hoc methods.

Table 5-3 provides some descriptive measures on each of the 7 revenue vectors corresponding to the various location vector

Table 5-3

Revenue results for various location vectors
over Experimental Design
(Total observations for each vector = 64)

V#	Sites Used	Minimum $	Maximum $	Mean $	St. Deviation $
309	3, 4, 6	-1, 117, 800	5, 736, 000	2, 630, 700	1, 560, 900
310	3, 4, 5, 6	- 649, 530	5, 654, 200	2, 815, 600	1, 521, 800
311	2, 3, 4, 5	-1, 139, 900	6, 294, 200	2, 682, 900	1, 676, 000
312	4, 6	-2, 847, 500	5, 593, 100	2, 248, 200	1, 892, 000
313	4, 5, 6	-1, 044, 300	5, 540, 000	2, 634, 000	1, 684, 200
314	1, 4	-2, 395, 600	5, 424, 500	1, 691, 500	1, 734, 000
315	2, 3, 6	-1, 519, 300	6, 536, 400	2, 647, 200	1, 734, 200

choices, under the conditions of the experimental design. Then, if the revenue results analyzed indeed represent statistically distinct series, the differences in means of the various location solutions can point to the improvement possible; and could represent the maximum one might pay to get better information on the factors involved in the experiment. In reality one would want to pay much less than this for further information; however, whatever the ratio set between the maximum possible improvement in mean revenue and maximum amount payable for further information, the above simulation results provide a guide to what might reasonably be spent. For example, the difference in mean revenues between V313, representing a "myopic" location vector choice based upon proximity to the largest markets and V310 which is an analytically robust solution is ($2,815,600 - $2,634,000) or $181,600. If management is willing to spend half that amount or roughly $90,000 on further information search, this figure becomes the budgeted amount that must now be allocated for further information-seeking among the 8 factors.

This is where Tables 5-1 and 5-2 come in use. In particular, Table 5-2 provides the regression equation coefficients for those factors considered significant; and, it is the relative magnitude of these coefficients that provide a clue to allocating our information budget among these factors.

To begin with, Table 5-1 makes quite clear that the block effects are of considerable importance; this is only to be expected since each block or set of starting conditions has been explicitly defined to be as different as possible from the other blocks. Recall that Block 1 was the average value, Block 2 consisted of values picked at random, while Block 3 and Block 4 deliberately confined themselves to the upper and lower third, respectively, of the range of variation for each of the factors. However, each block merely consists of starting conditions for each of 8 factors; hence, we need to know which of the 8 factors are crucial in their influence on revenue. For this purpose, we turn to the main and interaction effects.

It is clear that regardless of the location vector chosen, the main effects for fixed costs, development rebates and domestic inflation rates are not significantly different from zero. Therefore, in terms of information seeking, the only main effects that we need concern ourselves with are those for exchange rate changes, demand uncertainty, tariff levels, variable cost levels and price. However, whether the main effects for these latter 5 factors are significant or not partly depends on the location vector chosen.

Of the 5 main effects that are significant at least for some location choices, variable costs and tariffs are significant throughout. Of the remainder, price is significant for all but one location choice,

that being a randomly chosen location vector. This is backed by the internal logic of the model, since price choices interact with levels of demand and also with the dollar amount of the tariff; hence, it is only to be expected that price would influence revenue. Furthermore, price is a controllable factor in that management sets the price at each demand destination.

Of the remaining two factors, demand uncertainty is significant for all three analytical robust location vectors; finally, exchange rate changes are significant for two of the three analytically chosen robust location choices; what is even more interesting is that exchange rate changes lose their influence only when location #2 is included as one of the sites chosen for location, location site 2 being, on the basis of the base data, the most inefficient producer with high variable costs and high tariffs.

To summarize, if we wish to set priorities on the basis of correlation coefficients, and the significance of a factor over all location vector choices, the following ranking would result:

a) variable costs and tariffs

b) price

c) demand uncertainty

d) exchange rate changes

However, in addition to the significance of a factor, the size of the correlation coefficient, and, by inference, the value of the

regression coefficients also become important, specially if one is to allocate a budget for search among the various factors. Our task is made somewhat easier in that all factors have only two levels and that the standard level is coded as 1 and the alternate level as 2. Also, since 64 treatments are accorded for each factor, the regression coefficients can be used directly to establish a further ranking of these factors.

Table 5-2 provides the regression equation coefficients for the various significant main effects. As can be seen, Variable Costs levels have the greatest effects on revenues, with the associated sign being, naturally, negative (i. e. the presence of variable costs lowers revenue and an increase in variable costs signified by a move from the standard to the alternate level decreases revenue further). Next in order of effect is tariffs and this is understandable since tariffs are a form of variable cost, and, as the model is constructed, add to costs while not being passed on to the consumer. Of the remaining three significant main effects, a ranking is harder to come by. However, one might tentatively say that demand uncertainty should rank third, followed by exchange rate changes and then price. But it would probably be just as plausible that these three factors are of nearly equal importance.

Next comes the question of the actual weights, so that some criteria may be used to allocate our information-seeking budget of

$90,000. While precise weighting would be difficult to achieve, a rough guide can be obtained by finding the ratio of each significant main effect's regression equation coefficient to the total of all these coefficients. This approach will work here only because the actual values each factor may take are either 1 or 2.

Table 5-4 reproduces the regression equation coefficients obtained from an analysis of variance of V310 corresponding to locations at sites 3, 4, 5 and 6.

Table 5-4

Factor	%	Regression Equation Coefficient
Exchange Rate Changes	14	211,510
Demand Uncertainty	16	237,300
Tariff Levels	18	(-) 268,280
Variable Cost Levels	44	(-) 606,540
Price	8	137,320
Total ignoring sign		1,460,950

Admittedly, Table 5-4 is a crude approximation. But it provides a guideline: namely, about 45% of the information budget allocated to seeking further information on variable costs at the various potential location sites, another 45% allocated roughly equally between information seeking on exchange rate changes, demand uncertainty and tariff

levels, and the remainder of the budget devoted to examining the impact of changing prices: i. e. elasticity considerations.

Next, we can turn to the interactions effects. There is no consistent pattern discernible across the various location vectors. For the three analytically robust location vectors, only the interaction A45 is consistently significant: that is, the interaction of fixed and variable costs. Also somewhat significant is the interaction of exchange rate changes and domestic inflation, but this is only to be expected since the model explicitly introduces a dependent inverse relationship between domestic inflation and realized exchange rate changes.

Other interactions that crop up as being significant for some of the location choices are A48, the interaction of fixed costs and price, A56, the interaction of variable costs and development rebates and A34, the interaction of tariffs and fixed costs. Excluding A48, the other interactions are essentially the interaction of some form of variable cost with fixed cost. Further investigation of these interaction effects can be conducted if desired by using the simulation modeled and varying only the two factors whose interaction is to be studied, holding all other factors constant.

Summary

A fractional factorial experimental design was introduced to control the pattern of variation in the location simulation model. Four Block or starting conditions were set up, these representing an average value for each of the 8 factors tested, a random value, mid-points from the top third of the range of variation and mid-points from the lower third of the range of variation. The 8 factors were tested at two levels, each level representing a certain specified change from block conditions. The 8 factors tested were exchange rate changes, demand uncertainty, tariff levels, fixed costs, variable costs, development rebates, domestic inflation and price. The experimental design chosen was a 1/4 replicate and involved 64 runs. Seven different location vectors were analyzed with the experimental design; of these seven, three were analytically proven robust vectors derived from previous analysis. Two were "myopic" vectors based on choosing those sites that represented the largest markets, and two were location sites made up randomly.

The experimental design results were analyzed, using analysis of variance techniques, and the results showed that variable cost levels were the single most important factor affecting revenues; exchange rate changes, demand uncertainty and tariffs came next, with all three having about the same impact on revenues. Price

changes also had some effect. Among the interaction effects -- which were quite limited -- the interaction of fixed and variable costs was the most important, though of lesser influence than the main or single factor effects.

CHAPTER VI

A SECOND LOOK AT ROBUSTNESS

The experimental design described in the previous chapter was applied within the context of the simulation model to a series of mutually exclusive location solutions. Of these, the first three were obtained by analysis, using the simulation model. These vectors are:

Location Vector #	Sites
1	3, 4, 6
2	3, 4, 5, 6
3	2, 3, 4, 6

Then, two more vectors were derived by applying a rule of thumb: locate at the sites having the largest demand. These vectors may be termed myopic location vectors in that they are short-sighted and concentrate on a subset of the range of variables that affect the optimum location solution; in this case, the decision rule emphasizes demand and low transportation costs. Other myopic decision rules could also be developed: such as, locate where variable costs are lowest; or, locate where tariffs are the highest; and so on. The vectors so developed are:

Location Vector #	Sites
4	4, 6
5	4, 5, 6

Finally, two more location vectors were developed at random. That is, there are 6 location sites; each site may or may not occur in the final location solution. Thus, we are sampling from a binomial distribution, and the two samples that we use are:

Location Vector #	Sites
6	1, 4
7	2, 3, 6

Since the experimental design consisted of 64 treatments, a similar number of revenue outcomes were obtained for each location vector. An analysis of these revenue distributions helps determine whether these vectors are robust under the widely changing environmental conditions embodied in the simulation model, and whether the analytically chosen vectors outperform the myopic and random solutions.

Table 6-1 provides descriptive statistics on the revenue distribution of each of the 7 location vectors tested with the experimental design.

It is clear from Table 6-1 that a traditional risk-averter type manager would choose sites 3, 4, 5 and 6 (i.e., vector #2) with

Table 6-1

Revenue Distribution Analysis

#	Location Vector Composition (Sites)	Mean	Standard Deviation	Minimum	Maximum
1	3, 4, 6	2, 630, 700	1, 560, 900	-1, 117, 800	5, 736, 000
2	3, 4, 5, 6	2, 815, 600	1, 521, 800	- 649, 530	5, 654, 200
3	2, 3, 4, 6	2, 682, 900	1, 676, 000	-1, 139, 900	6, 294, 200
4	4, 6	2, 248, 200	1, 892, 000	-2, 847, 500	5, 593, 100
5	4, 5, 6	2, 634, 000	1, 684, 200	-1, 044, 300	5, 554, 000
6	1, 4	1, 691, 500	1, 734, 000	-2, 395, 600	5, 424, 500
7	2, 3, 6	2, 647, 200	1, 734, 200	-1, 519, 300	6, 536, 400

the highest mean and the lowest standard deviation as the solution to be implemented. It is interesting that the three analytically derived location solutions all have lower standard deviations than the other four vectors; a result that is to be expected since these vectors have been chosen for being robust.

Tables 6-2A through 6-2D provide histograms for each of the location vectors tested. The same scale is used for all seven graphs and the same number of class intervals -- twenty -- is used for each graph. Also, the interval width is the same for each graph: 493, 890 to be exact. These graphs represent revenue outcomes for each vector for exactly the same sequence and range of environmental variation. That is, the uncertainty embodied in the simulation was

Table 6-2A

HISTOGRAM/FREQUENCIES CASES=CASE#:1-64

MIDPOINT	HIST%	COUNT FOR 305.DEPI (EACH X= 1)	
-.23475 +7	0.	0 +	
-.23936 +7	0.	0 +	
-.18597 +7	0.	0 +	
-.13657 +7	0.	0 +	**Sites 3, 4, 6**
-.27154 +6	3.1	2 +XX	
-.37805 +6	1.6	1 +X	
.11534 +6	4.7	3 +XXX	
.60973 +6	3.1	2 +XX	
.11036 +7	4.7	3 +XXX	
.15575 +7	15.6	10 +XXXXXXXXXX	
.20514 +7	10.9	7 +XXXXXXX	
.25253 +7	13.3	10 +XXXXXXXXXX	
.30192 +7	6.3	4 +XXXX	
.35731 +7	10.9	7 +XXXXXXX	
.40670 +7	4.7	3 +XXX	
.45609 +7	12.5	8 +XXXXXXXX	
.50547 +7	3.1	2 +XX	
.55486 +7	3.1	2 +XX	
.60425 +7	0.	0 +	
.65364 +7	0.	0 +	
TOTAL		64 (INTERVAL WIDTH= .49389 +6)	

Tabel 6-2B

HISTOGRAM/FREQUENCIES CASES=CASE#:1-64

MIDPOINT	HIST%	COUNT FOR 310.DEP2 (EACH X= 1)	
-.28475 +7	0.	0 +	
-.23536 +7	0.	0 +	
-.18597 +7	0.	0 +	
-.13653 +7	0.	0 +	
-.87194 +6	1.6	1 +X	3, 4, 5, 6
-.37305 +6	1.6	1 +X	
.11584 +6	4.7	3 +XXX	
.60973 +6	1.6	1 +X	
.11036 +7	7.8	5 +XXXXX	
.15975 +7	12.5	8 +XXXXXXXX	
.20914 +7	6.3	4 +XXXX	
.25853 +7	10.9	7 +XXXXXXX	
.30792 +7	12.5	8 +XXXXXXXX	
.35731 +7	14.1	9 +XXXXXXXXX	
.40670 +7	7.8	5 +XXXXX	
.45608 +7	10.9	7 +XXXXXXX	
.50547 +7	6.3	4 +XXXX	
.55486 +7	1.6	1 +X	
.60425 +7	0.	0 +	
.65364 +7	0.	0 +	

TOTAL 64 (INTERVAL WIDTH= .45608 +6)

HISTOGRAM/FREQUENCIES CASES=CASE#:1-64

MIDPOINT	HIST%	COUNT FOR 311.DEP3 (EACH X= 1)	
-.28475 +7	0.	0 +	
-.23536 +7	0.	0 +	
-.18597 +7	0.	0 +	2, 3, 4, 6
-.13658 +7	1.6	1 +X	
-.87194 +6	1.6	1 +X	
-.37305 +6	4.7	3 +XXX	
.11584 +6	3.1	2 +XX	
.60973 +6	1.6	1 +X	
.11036 +7	7.8	5 +XXXXX	
.15975 +7	10.9	7 +XXXXXXX	
.20914 +7	10.9	7 +XXXXXXX	
.25853 +7	15.6	10 +XXXXXXXXXX	
.30792 +7	3.1	2 +XX	
.35731 +7	9.4	6 +XXXXXX	
.40670 +7	7.8	5 +XXXXX	
.45608 +7	14.1	9 +XXXXXXXXX	
.50547 +7	4.7	3 +XXX	
.55486 +7	1.6	1 +X	
.60425 +7	0.	0 +	
.65364 +7	1.6	1 +X	

TOTAL 64 (INTERVAL WIDTH= .45608 +6)

Table 6-2C

HISTOGRAM/FREQUENCIES CASES=CASE #:1-64

MIDPOINT	HIST %	COUNT FOR 312.DAT4 (EACH X= 1)	
-.23475 +7	0.	0 +	
-.23536 +7	0.	0 +	
-.13597 +7	0.	0 +	
-.13657 +7	4.7	3 +XXX	
-.37194 +6	1.6	1 +X	
-.37305 +6	4.7	3 +XXX	
.11584 +6	1.6	1 +X	4,6
.60973 +6	4.7	3 +XXX	
.11036 +7	14.3	9 +XXXXXXXXX	
.15975 +7	11.1	7 +XXXXXXX	
.20914 +7	4.7	3 +XXX	
.25853 +7	11.1	7 +XXXXXXX	
.30792 +7	7.9	5 +XXXXX	
.35731 +7	9.5	6 +XXXXXX	
.40670 +7	7.9	5 +XXXXX	
.45609 +7	9.5	6 +XXXXXX	
.50547 +7	3.2	2 +XX	
.55486 +7	3.2	2 +XX	
.60425 +7	0.	0 +	
.65364 +7	0.	0 +	

1 < -.23475 +7

TOTAL 64 (INTERVAL WIDTH= .49391 +6)

HISTOGRAM/FREQUENCIES CASES=CASE #:1-64

MIDPOINT	HIST %	COUNT FOR 313.DAT5 (EACH X= 1)	
-.23475 +7	0.	0 +	
-.23536 +7	0.	0 +	
-.13597 +7	0.	0 +	4,5,6
-.13658 +7	0.	0 +	
-.37194 +6	4.7	3 +XXX	
-.37305 +6	3.1	2 +XX	
.11584 +6	1.6	1 +X	
.60973 +6	4.7	3 +XXX	
.11036 +7	12.5	8 +XXXXXXXX	
.15975 +7	7.8	5 +XXXXX	
.20914 +7	7.8	5 +XXXXX	
.25853 +7	6.3	4 +XXXX	
.30792 +7	9.4	6 +XXXXXX	
.35731 +7	14.1	9 +XXXXXXXXX	
.40670 +7	7.8	5 +XXXXX	
.45609 +7	10.9	7 +XXXXXXX	
.50547 +7	4.7	3 +XXX	
.55486 +7	4.7	3 +XXX	
.60425 +7	0.	0 +	
.65364 +7	0.	0 +	

TOTAL 64 (INTERVAL WIDTH= .49391 +6)

Table 6-2D

HISTOGRAM/FREQUENCIES CASES=CASE#:1-64

MIDPOINT	HIST%	COUNT FOR 314.DAT6 (EACH X= 1)	
-.39475 +7	0.	0 +	
-.33536 +7	3.1	2 +XX	
-.11597 +7	0.	0 +	
-.13659 +7	3.1	2 +XX	1,4
-.37194 +6	4.7	3 +XXX	
-.37285 +6	3.1	2 +XX	
.11554 +6	4.7	3 +XXX	
.60973 +6	10.9	7 +XXXXXXX	
.11036 +7	14.1	9 +XXXXXXXXX	
.15975 +7	9.4	6 +XXXXXX	
.20914 +7	12.5	8 +XXXXXXXX	
.25853 +7	4.7	3 +XXX	
.30792 +7	10.9	7 +XXXXXXX	
.35731 +7	7.8	5 +XXXXX	
.40670 +7	7.8	5 +XXXXX	
.45608 +7	0.	0 +	
.50547 +7	1.6	1 +X	
.55486 +7	1.6	1 +X	
.60425 +7	0.	0 +	
.65364 +7	0.	0 +	

TOTAL 64 (INTERVAL WIDTH= .49339 +6)

HISTOGRAM/FREQUENCIES CASES=CASE#:1-64

MIDPOINT	HIST%	COUNT FOR 315.DAT7 (EACH X= 1)	
-.39475 +7	0.	0 +	
-.33536 +7	0.	0 +	
-.13597 +7	0.	0 +	2,3,6
-.13659 +7	1.6	1 +X	
-.37194 +6	3.1	2 +XX	
-.37285 +6	1.6	1 +X	
.11554 +6	3.1	2 +XX	
.60973 +6	7.8	5 +XXXXX	
.11036 +7	6.3	4 +XXXX	
.15975 +7	9.4	6 +XXXXXX	
.20914 +7	9.4	6 +XXXXXX	
.25853 +7	12.5	8 +XXXXXXXX	
.30792 +7	9.4	6 +XXXXXX	
.35731 +7	7.8	5 +XXXXX	
.40670 +7	7.8	5 +XXXXX	
.45608 +7	10.9	7 +XXXXXXX	
.50547 +7	6.3	4 +XXXX	
.55486 +7	1.6	1 +X	
.60425 +7	0.	0 +	
.65364 +7	1.6	1 +X	

TOTAL 64 (INTERVAL WIDTH= .49339 +6)

replicated for each vector; and, the sequence of changes, the progression of uncertainty was also replicated for each vector.

Tables 6-3A - 6-3E provide the first decile, the first quartile, the median, the third quartile and the ninth decile for the 7 location vectors, as well as confidence intervals at the 95% level for these quartiles.

Tables 6-2 and 6-3 combined clearly show that the robust location vectors are fairly similar in this revenue distribution. At the lower end of the scale, where revenues are either low or negative, the robust location vectors outperform the rest, having the higher first decile value and the first quartile value. But, at the higher end of the scale location vector #5, a "myopic" choice, and location vector #7, a random choice and rather similar in composition to the robust vectors have higher values for the median and the ninth decile. (Note, however, that the confidence interval for these estimates have a much larger spread.) This is to be expected since by choosing robust solutions we are choosing solutions that would be relatively impervious to changes in environment; therefore, robust solutions would respond less to favorable environmental conditions, and also less to unfavorable environmental conditions. This is why certain other vectors tested yield higher revenues under favorable conditions. But on the whole, the robust location vectors have the higher means and the lower standard deviations.

Table 6-3A

First Decile of Revenue Distribution

Vector #	1st Decile	Confidence	Interval (95%)
1	454, 170	- 773, 300	1, 423, 500
2	952, 550	- 578, 240	1, 429, 100
3	344, 260	- 792, 540	1, 256, 700
4	-413, 870	-1, 382, 900	442, 950
5	569, 090	- 834, 760	1, 080, 200
6	-703, 050	-2, 322, 000	205, 170
7	480, 840	- 724, 730	858, 200

Table 6-3B

Quartile for Revenue Distributions

Vector #	1st Quartile	Confidence	Intervals (95%)
1	1, 734, 300	882, 730	2, 195, 900
2	1, 675, 800	1, 234, 300	2, 375, 400
3	1, 610, 600	993, 530	2, 200, 600
4	1, 004, 200	380, 310	1, 580, 300
5	1, 292, 400	948, 900	1, 938, 200
6	620, 150	- 77, 189	1, 124, 700
7	1, 533, 200	722, 700	2, 085, 400

Table 6-3C

Median of Revenue Distribution

Vector #	Median	Confidence	Intervals (95%)
1	2,586,700	2,233,300	3,020,500
2	2,865,200	2,384,200	3,557,200
3	2,568,400	2,220,600	3,526,900
4	2,352,000	1,678,500	2,965,500
5	2,882,800	1,988,600	3,361,900
6	1,715,200	1,144,200	2,270,500
7	2,587,800	2,117,700	3,214,500

Table 6-3D

3rd Quartile for Revenue Distribution

Vector #	3rd Quartile	Confidence	Intervals (95%)
1	3,766,700	3,020,500	4,483,600
2	3,933,700	3,557,200	4,577,700
3	3,891,200	3,526,900	4,566,400
4	3,689,500	2,965,500	4,317,600
5	3,861,500	3,361,900	4,524,800
6	2,990,400	2,270,500	3,655,700
7	4,080,400	3,214,500	4,696,800

Table 6-3E

9th Quartile for Revenue Distribution

Vector #	9th Quartile	Confidence	Intervals (95%)
1	4,691,700	4,472,500	5,347,600
2	4,679,700	4,458,500	5,239,600
3	4,736,800	4,483,000	5,761,700
4	4,638,500	4,234,200	5,466,600
5	4,776,600	4,352,500	5,358,600
6	3,890,700	3,464,400	4,991,000
7	4,800,900	4,516,900	5,682,800

It now remains to test whether the variations in revenue distributions are significant or could be due to randomness. For this purpose, we use the t-statistic to test whether the mean of the difference between the revenue outcomes for the various location vectors is zero. For this test two location vectors are compared at a time. We are interested in deciding whether location vector #2 (sites 3, 4, 5, and 6) is significantly different from the other location solutions so as to justify choosing it for implementation. The results of the series of t-tests are given in Table 6-4 (n = 64 for each revenue distribution).

From Table 6-4 it is clear that variable 310, which is the revenue distribution corresponding to location vector #2 is indeed significant from the revenue distributions for each of the other

Table 6-4

Pairwise t-tests of Revenue Distribution

Pair	Mean Difference	Standard Deviation	t-statistic	Significance
309-310	-184,950	408,380	-3.6231	.0006
310-311	132,690	502,830	2.1111	.0387
310-312	567,440	653,380	6.9477	.0000
310-313	181,620	354,510	4.0985	.0001
310-314	1,124,200	729,990	12.32	.0000
310-315	168,420	616,590	2.1851	.0326

vectors, at the .05 level. Hence, if management preferences are inclined to averting risk, specially on the down-side (i.e. avoidance of losses), then location vector #2, being the choice of sites #3, 4, 5, and 6, should be implemented.

Summary

In this section, three robust location vectors were compared with location solutions derived by using a rule of thumb -- e.g. locating at or close to the principal markets -- and with location solutions based on random choice. A wide range of environmental conditions were simulated leading to some situations where losses were reported for each of the vectors tested, as well as large profits. A variety of statistical tests were then used to discriminate between

the resulting revenue distribution. The robust location vectors did outperform the other choices and were shown to be significantly different from these other choices. On the basis of this evidence one of the robust vectors is recommended for implementation.

CHAPTER VII

INFORMATION REQUIREMENTS OF THE SIMULATION MODEL: SUGGESTED EXTENSIONS

In this section we take up the question of gathering data which would enable the simulation model to be used. It must be emphasized that approximate estimates of the various input variables are all that is necessary initially; this is because the model works out the relative influence of each of the independent variables on the location solution. Hence, given initial approximate estimates, the model itself can be used to determine which of the uncertain estimates to refine further.

1. Prices to be charged at each destination.

This is essentially a question of management decision. Policies have to be set such as whether to charge the same price at all destinations. The minimum long-run price, a floor, would be set by total per unit cost plus transfer costs. There is of course a limit to what the market will bear, and competitive prices act as a control or ceiling on the maximum prices that may be charged. A useful facet of the model is that it permits experimentation with different combinations of prices to be charged at the various destinations; hence, within the limits set by costs and competition, the

model may be used to work out a set of prices that yield an acceptable level of profits.

2. A list of potential location sites or sources.

The model furnishes an optimum location solution by choosing from a predetermined list of potential location sites. What is needed is a quick and cheap way of specifying these potential location sites. An obvious factor influencing this list is the level of risk, both economic and political risk. Stobaugh (1969a, 1969b) offers some guidance in this respect. His screening devices are based on both country-related variables and product-related variables. An important measure for potential market size suggested by him is the use of total manufacturing output of a country. Stobaugh also develops a rating scale for determining a country's investment climate (1969b, p. 102) that could be well used as a preliminary screening device.

3. List of potential markets or destinations.

It is conceivable that just about every country in the world would be a potential market for one's product. However, reducing the number of destinations might aid the model in reaching optimum solutions faster and thus result in computer cost savings. Furthermore, management's time is always scarce and it would pay to concentrate on the larger markets. Thus, one obvious criterion in

choosing destinations would be the size of the potential market. If the product in question is already being sold in the particular market we are looking at, past sales offer one indication of the size of the market. In particular, the Yearbook of International Trade Statistics published annually by the U. N. furnishes information on exports and imports of various countries, with goods classified by SITC numbers (U. N., 1975). And, as mentioned earlier, using countries' manufacturing outputs as a measure of relative market size is helpful, specially since this indicator takes into account the effect of relative per-capita incomes. Finally, if the firm in question has a history of sales to various countries, past sales will provide an indication of the size of the market and indicate whether that particular country should be included in the list of destinations.

4. Elasticities of Demand; the Demand-Price Matrix.

This is an area where rough estimates may have to be used because there is not much information available. Past company records by country can point to elasticities, specially if experimentation has been done with different prices. Test marketing is one way of gathering further information on elasticities but it is unlikely that it can be carried out in a number of countries in a short span of time without being prohibitively expensive. One possibility is to use the elasticities encountered in more economically advanced countries

(in the past) to approximate elasticities in countries that are now economically developing. In doing so we are drawing implicitly on the product life-cycle hypothesis, and for this to hold the two countries must be somewhat similar culturally.

The elasticity estimates we are interested in is actually a composite of price-elasticity, income-elasticity and cross-elasticity arising out of the existence of substitutes, usually competitive. Moyer (1968) calculates both cross-section and time-series based income elasticities for a variety of countries for items such as food, clothing, recreation, appliances, light machinery, etc. Other sources of empirical investigations of elasticities may be found in Maizels (1968) which mainly shows how different commodities become important in consumption for countries at different industrialization levels and Gilbert (1958) which is a somehwat outdated series of elasticity calculations for the OECD countries. Chenery (1960) has some data on growth elasticities and imports while Houthakker and Magee (1969) provide a recent and comprehensive account of income and price elasticities in world trade, though mainly for the industrialized nations.

5. Transportation Costs.

This is a highly specialized area with constantly changing rates and routes and the best source of information could be one's

in-house Traffic Department as well as a local freight forwarder's association. They can advise on the various time/cost options available as well as advise on packing requirements to meet classification criteria for tariffs, and other special customs service such as warehousing under bond, duty drawback and others. For the Detroit area one might contact the Detroit Customhouse Brokers and Foreign Freight Forwarders Association, Inc.

6. Exchange Rate Changes.

Two bits of information are required for each potential site: the amount of exchange rate change, and the likelihood of its occurrence. Past exchange rate experience will of course be needed to make estimates of future changes. Such a historic record is easily available in sources such as the International Financial Statistics published by the International Monetary Fund, and the data published by the Federal Reserve (Selected Interest and Exchange Rates, weekly series of charts, Division of International Finance, Financial Markets Section, Board of Governors of the Federal Reserve System). Other factors influencing exchange rate variations are the relative rates of inflation in the two countries whose exchange rates are being studied, the interest rate differentials between the two countries, trends in their respective trade balances, and changes in the level of their reserves.

One other factor influencing the timing of the change in exchange rates is political considerations and these can perhaps best be relayed by local personnel.

7. Productivity.

Changes in productivity can be guaged by comparing output per man-hour with hourly compensation, implicitly imputing all productivity increases to labor. FNCB (1975a, 1975b) contains the results of some research on labor productivity in major industrial countries including the U.S., Belgium, the Netherlands, Switzerland, Canada, Sweden, Japan, Germany, Italy, France and Britain. This study is based on data supplied by the Bureau of Labor Statistics, Office of Productivity and Technology. This study found that total productivity gains for the period 1970-1974 ranged generally from 15-25% with superior performances being registered by Japan (36%) and Belgium and the Netherlands (31-32%). They projected, for 1975, roughly the following increases in manufacturing unit labor costs -- Britain 20%, Canada 12%, Germany 16%, Japan 20%, Netherlands 20% and the U.S. 13%.

Our definition of productivity-related changes in costs also includes higher costs caused by supply interruptions caused by work stoppages and strikes. A recent study by the Conference Board (1973)

contains a specific analysis of work stoppages. The U.S. Department of Labor (1975) routinely gathers data on work stoppages and time cost due to industrial disputes in selected countries (ibid. Table 177) as also data on indexes of output per man-hour, hourly compensation and unit labor costs for selected countries (ibid. Table 171). Most of this data is for the period 1960-1974. Another major source of information is the Yearbook of Labor Statistics published by the ILO (1974). This handbook contains data for the countries of the world on aspects such as labor productivity for the entire economy and for the industrial and the manufacturing sector, wages in manufacturing by major industry sectors, data on industrial disputes -- their number, the number of workers involved in these disputes and the working days lost by country, and data on the hours of work by sector in each country. Also useful in assessing productivity is a study by the ILO (1969).

8. Tariffs.

The major sources for tariffs to be levied on imports are the various government pronouncements. A central source of such information is maintained by the International Customs Bureau (1974). This listing, available on microfiche contains data by country, including a description of the goods, the type of packaging and the legal

tariff. These records are updated as and when changes are made. Freight forwarders are also likely to have the most recent tariff information.

9. Costs of Production: Fixed Costs, Variable Costs and Development Rebates.

Such information will of course be industry-specific and also depend on the technology used. Data on labor costs can be obtained from the ILO (1974) handbook and updates. Materials cost would have to be worked out from engineering estimates and trends of raw materials prices. Overhead will largely be programmed costs and subject to management decision.

On the question of development rebates, once again the best sources of information are the individual governments. Business International puts out a by-country study that is periodically updated titled Investing, Licensing and Trading Conditions Abroad which will be found useful in estimating costs and evaluating the available government incentives. Another somewhat older study is the OECD (1965) study on fiscal incentives for foreign direct investment in the developing countries.

10. Inflation Rates.

There are a variety of sources providing data on inflation

rates in various countries including the U. S. Department of Commerce (1975) publications on International Economic Indicators and Competitive Trends, which has charts on general indicators including real gross national product, industrial production, capacity utilization and capital formation, trade indicators, price indicators including both consumer and wholesale prices, and finance indicators including balance of payments data and an index of effective exchange rates. The U. N. Statistical Yearbook and the IMF's International Financial Statistics are also useful here.

As can be seen, the data requirements of the model are rather extensive. However, most of the data required is readily available from government and international institutional sources. The rest will have to be derived from company legwork, notably information pertaining to production costs but such information would have to be developed even in the absence of this model if the location decision were to be examined rationally by comparing costs at several sites.

We now take up some possible extensions to the model that could make it more realistic and more comprehensive.

(i) Developing a better optimization model.

The optimization model used is the simple location-allocation model, for one product and a single time period. It would be desirable to extend the model so as to allow the explicit modeling of a) capacity

constraints, b) configuration constraints, c) economics of scale in production and transportation, d) multiple products with joint costs, and e) several time periods. Optimization algorithms exist in principle for handling subsets of such an extended model and have been described in Chapter 2. But it would be no easy task to combine these features into a model that can work efficiently in handling large problems. As noted earlier, any optimization algorithm used within a simulation context must be rapid and cheap so as to allow its use in a production (i.e. repeated) mode. This is an advantage that the Khumawala algorithm possesses and hence its use in the simulation model.

(ii) Incorporating regional analysis: gaming the multinational corporation and the nation-states

Given several robust location solutions, the differences between the means and the quartiles, respectively, of the several location vectors indicate the amount of "slack" that can be captured by host-governments through the discerning use of restrictions such as local content requirements: thus, various host countries can study the impact of imposing restrictions of various sorts on the location decisions of the firm.

For example, a nation-state whose site is favored in the optimum solution could guage the extent to which it might raise taxes or

reduce development rebates before the corporation begins to look elsewhere.

A related extension would be to include the influence of competition on the location decision. This should probably be achieved by including a variable for all other competition that would affect size of the market available to a firm, this functional relationship including parameters such as size of profits, amount of capital investment necessary, government tariff barriers and a time-lag for entry of competition.

(iii) The objective function of the model is to maximize revenues accruing to the parent company. Multiple objectives may be formulated to include nation-state objectives such as employment generated and domestic value added as well as other performance variables of interest to the firm including market size and growth, executive turnover and relations with the several host countries.

(iv) Ultimately, if a comprehensive model is developed that includes competition and nation-state interests, its predicted pattern of location expansion over time should approximate the spread of foreign direct investment actually observed for industries in the real world. In other words, it should be possible to develop a location-based theory of foreign direct investment with some predictive power.

Summary

This section reviewed the data requirements of the simulation model and pointed out sources of empirical information for the various data-subsets. Then, some suggestions for extending the model so as to make it more comprehensive were outlined.

APPENDIX

This appendix contains Fortran listings of the three programs described in the text. These are:

1) LOCATESIM: the location simulation model.

2) ROBUST: the testing of potentially robust vectors.

3) DESIGN: the use of experimental design for guidelines on information search in uncertain environments.

```
$LIST LOCATESIM
      1             INTEGER POINT(30)
      2             INTEGER KZ(99,30),K1(99,30),K2(99,30),LN(99,30),IDEL(99,60),
      3            *ILN(30)
      4             REAL PRPOS,IDP,IVC1,TAR,IFCD,IV,PRICE,DVAL1,DVAL2,DVAL3,DVAL4,
      5            *DVAL5,DVAL6
      6               REAL IVC2
      7               DIMENSION IVC2(30,60)
      8             REAL IFC,ID,IVC,MDEL,MDELS,MINC,MEGAS,JD,LLN,MINC1,MINC2,IJD
      9               DIMENSION PRPOS(10),IDP(10,60),IVC1(30,60),TAR(60)
     10               DIMENSION IFCD(30),TINFL(30),DINFL(30)
     11               DIMENSION IV(30),PRICE(30),DVAL(30,100),PROD(30,100)
     12             DIMENSION IFC(30),ID(60),IVC(30,60),MDEL(99,60),MDELS(99,30),
     13            *MEGAS(99,30),JD(99,30),MINC(60),Z(99),Y(99,30),IJD(30),L(30)
     14               DIMENSION IASGN(60,2),DVREB(30),UDEM(100),REVNET(200)
     15               DIMENSION BDVAL(30),BPROD(30)
     16       303   FORMAT(//////45X,'OPEN WAREHSE W. LARGEST OMEGA',//)
     17       257   FORMAT(10X,6F12.2)
     18      2000   FORMAT(/////40X,'ITERATION #',I20)
     19      2006   FORMAT(1H1)
     20      2007   FORMAT(/1X,10F13.2)
     21      2008   FORMAT(F10.0)
     22      2009   FORMAT(//2X,'MIXED WAREHSE COSTS',F15.2)
     23      2015   FORMAT(10X,5F12.0,/)
     24      5833   FORMAT(//5X,'FIRST TERMINAL SOLUTION FOUND WAS',F25.2,
     25            *'IT WAS FOUND AT ITERATION',I15)
     26      5834   FORMAT(/5X,'THE LOWER BOUND AT THE TIME OF THE OPTIMUM WAS',F15.2)
     27      8634    FORMAT(//5X,'SOLUTION AT NODE',I10,5X,'IS',F25.2)
     28      8635   FORMAT(5X,I10,3F20.2,F20.4)
     29     10001 FORMAT(2I10)
     30     10002 FORMAT(8I10)
```

```
10003 FORMAT(///5X,'SOLUTION INFEASIBLE')
10004 FORMAT(///2X,'THE OPTIMUM SOLUTION FOUND AFTER',I7,
     *'      ITERATIONS IS',F15.2,'     IT WAS FOUND AT ITERATION #',
     *I10,/5X,'MAX. # OF DISTINCT NODES USED',I10)
20001 FORMAT(1X,13F9.2)
20002 FORMAT(13F6.2)
20003 FORMAT(//5X,'LOWER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,/,5X,
     *'UPPER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,//)
20004 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED CLOSED',/)
20005 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED OPENED',/)
20010 FORMAT(10F8.2)
20015 FORMAT(8F10.2)
30002 FORMAT(60X,'# OF WAREHSES FIXED OPEN',I10)
30003 FORMAT(60X,'# OF WAREHSES FIXED CLOSED',I8)
30004 FORMAT(5X,'WAREHSE # ',I10,5X,'IS FIXED OPEN - ONLY SUPPLIER')
30005 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED OPEN')
30006 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLOSED NO CUSTOMERS')
30007 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLODED')
97791 FORMAT(//5X,'COMPUTATIONS DISCONTINUED LACK OF STORAGE')
C READ IN DATA
C NO. OF DIFFERENT PRICE OPTIONS OPEN, NO. OF SIMULATION
C RUNS DESIRED
      READ(5,10015)NPRICE,ISIM
10015 FORMAT(I2,I4)
C READ IN VARIOUS PRICES THAT MAY BE CHARGED
      READ(5,20002)(PRPOS(I),I=1,NPRICE)
C NO. OF SOURCES, NO. OF DESTINATIONS
      READ(5,10001)NW,NC
C DEMAND PRICE MATRIX
      DO 2126 IW=1,NPRICE
```

```
      READ(5,10020) (IDP(IW,IC),IC=1,NC)
2126  CONTINUE
10020 FORMAT(6F10.0)
C TRANSPORTATION COST MATRIX
      DO 2125 IW=1,NW
      READ(5,10020) (IVC1(IW,IC),IC=1,NC)
2125  CONTINUE
      MJ=1
C DVAL PROB., CUM. FREQ. BY SOURCES & AMOUNTS
3402  READ(5,3405) MA,MB,CHCUR
      IF(MA.GE.31) GO TO 3406
      DO 3401 IJ=MJ,MB
      DVAL(MA,IJ)=CHCUR
3401  CONTINUE
      MJ=MB+1
      IF(MJ.GE.101) MJ=1
      GO TO 3402
3405  FORMAT(2I5,F10.0)
3406  CONTINUE
C PRODUCTIVITY CHANGES:CUM. FREQ., SOURCE, % CHANGE
3412  READ(5,3405) MA,MB,CHCOS
      IF(MA.GE.31) GO TO 3416
      DO 3411 IJ=MJ,MB
      PROD(MA,IJ)=CHCOS
3411  CONTINUE
      MJ=MB+1
      IF(MJ.GE.101) MJ=1
      GO TO 3412
3416  CONTINUE
C RANDOM DISTURBANCES TO AVG. LEVEL OF DEMAND
```

```
      3422    READ(5,3415)MB,CHDEM
              DO 3421 IJ=MJ,MB
              MDEM(IJ)=CHDEM
      3421     CONTINUE
              MJ=MB+1
              IF(MJ.GE.101) GO TO 3426
              GO TO 3422
      3426    CONTINUE
      3415    FORMAT(I5,F10.0)
      C TARIFFS(% OF SALES PRICE) BY DESTINATION
            READ(5,10020) (TAR(I),I=1,NC)
      C FIXED COSTS BY SOURCES
            READ(5,20015) (IFCD(IW),IW=1,NW)
      C VARIABLE COSTS PER UNIT BY SOURCE
            READ(5,20002) (IV(IC),IC=1,NW)
      C DEV. REBATES(% OF FIXED COSTS) BY SOURCES
            READ(5,20015) (DVREB(IC),IC=1,NW)
      C DOMESTIC INFLATION RATES(%) BY SOURCES
            READ(5,20015) (DINFL(IC),IC=1,NW)
      99    IX1=1303
            DO 100 IJ=1,100
            CALL RANDU(IX1,IY1,FL1)
            IX1=IY1
      100    CONTINUE
      C PRICES CHARGES AT EACH DESTINATION
            READ(5,10020) (PRICE(I),I=1,NC)
            WRITE(6,20006)
            WRITE(6,3111) (PRICE(I),I=1,NC)
      3111   FORMAT(3X,'PRICE CHOICES',3X,6F10.2,/)
            IRUN=1
```

```
      3229    DO 3125 II=1,NW
              CALL RANDU(IX1,IY1,FL1)
              IX1=IY1
              POINT(II)=100.*(FL1)+1.
      3125  CONTINUE
      C DETERMINE ACTUAL DEMAND LEVEL FOR THIS RUN BY DESTINATION
              DO 2148 IF=1,NC
              DO 2128 I=1,NPRICE
              IF(PSPOS(I).EQ.PRICE(IF)) GO TO 2129
              GO TO 2128
      2129    DEMAND=IDP(I,IF)
              CALL RANDU(IX1,IY1,FL1)
              IX1=IY1
              IDND=100.*(FL1)+1.
              DEMAND=DEMAND*(1.+UDEM(IDND))
              ID(IF)=DEMAND
              GO TO 2148
      2128    CONTINUE
      2148    CONTINUE
      C ADJUST FIXED & VARIABLE COSTS FOR DEV. REBATES, EXCHANGE RATE
      C CHANGES, PRODUCTIVITY CHANGES & TOTAL INFLATION RATES
             DO 2121 IW=1,NW
              IFC(IW)=IFCD(IW)*(1.-DVREB(IW))
              IFC(IW)=IFC(IW)*(1.+DVAL(IW,POINT(IW)))
              ADVAL=DVAL(IW,POINT(IW))
              CALL RANDU(IX1,IY1,FL1)
              IX1=IY1
              IDND=100.*(FL1)+1.
              VCOS=IV(IW)*(1.+PROD(IW,IDND))
              APROD=PROD(IW,IDND)
```

```
151             VCOS=VCOS*(1.+ADVAL)
152             IF((ABS(ADVAL)-0.0).LT..04) GO TO 3241
153             TINFL(IW)=DINFL(IW)-(1./ADVAL)
154             GO TO 3251
155       3241  TINFL(IW)=DINFL(IW)
156       3251  IPC(IW)=IPC(IW)*(1.+(TINFL(IW)/100.))
157             VCOS=VCOS*(1.+(TINFL(IW)/100.))
158       3300  BDVAL(IW)=ADVAL
159             BPROD(IW)=APROD
160       C ADD ON TARIFFS & TRANSPORTATION COSTS
161             DO 2131 IP=1,NC
162       2137  TRIF=TAR(IP)*PRICE(IP)
163        2139 RATE=IVC1(IW,IP)
164             IF(IW.EQ.IP)TRIF=0.0
165             IVC2(IW,IP)=VCOS
166             IVC(IW,IP)=(VCOS+TRIF+RATE)*ID(IP)
167       2131  CONTINUE
168       2121  CONTINUE
169             IF(IRUN.GT.1) GO TO 6032
170             WRITE(6,6001)NPRICE,ISIM
171       6001  FORMAT(10X,'# OF PRICE CHOICES',I10,10X,'#OF RUNS AT EACH PRICE
172            *VECTOR',I10,//)
173             WRITE(6,6002)(PRPOS(I),I=1,NPRICE)
174       6002   FORMAT(10X,'POSSIBLE PRICES',6F10.2)
175             WRITE(6,6003)NW,NC
176       6003  FORMAT(30X,'# OF WAREHOUSES =',I5,5X,'# OF CUSTOMERS =',I5)
177             WRITE(6,6014)
178       6014   FORMAT(10X,'DEMAND PRICE MATRIX',//)
179             DO 6005 K=1,NPRICE
180             WRITE(6,6004)(IDP(K,JJ),JJ=1,NC)
```

```
      6004  FORMAT(10X,6F10.0)
      6005   CONTINUE
            WRITE(6,2006)
            WRITE(6,6015)
      6015  FORMAT(10X,'TRANSPORTATION COST MATRIX',//)
            DO 6007 K=1,NW
            WRITE(6,6006) (IVC1(K,JJ),JJ=1,NC)
      6006   FORMAT(10X,6F8.3)
      6007   CONTINUE
            WRITE(6,2006)
            WRITE(6,6008) (TAR(JJ),JJ=1,NC)
      6008   FORMAT(5X,'TARIFF LEVELS',5X,6F8.3)
             WRITE(6,6019)
      6019   FORMAT(10X,'DEV. REBATES(%) BY SITE',/)
             WRITE(6,6013) (DVREB(IC),IC=1,NW)
             WRITE(6,6019)
      6019   FORMAT(//10X,'DOMESTIC PRE-DVAL INFLATION(%) ',/)
             WRITE(6,6013) (DINFL(IC),IC=1,NW)
             WRITE(6,6009) (IFCD(JJ),JJ=1,NW)
      6009   FORMAT(5X,'FIXED COST',5X,10F10.0,/)
            WRITE(6,6011)
      6011   FORMAT(10X,'VARIABLE COST PER UNIT BY LOCATION',//)
            WRITE(6,6010) (IV(JJ),JJ=1,NW)
      6010   FORMAT(10X,F12.3)
      6032  WRITE(6,6012)
      6012   FORMAT(10X,'DEMAND FOR CURRENT PRICE CHOICE',///)
            WRITE(6,6013) (ID(IC),IC=1,NC)
      6013  FORMAT(10X,6F10.0)
             WRITE(6,2006)
             WRITE(6,6041)
```

```
      DO 6022 I=1,NW
       WRITE(6,6036) (IVC2(I,J),J=1,NC)
      WRITE(6,6036) (IVC(I,J),J=1,NC)
 6036 FORMAT(//,10X,6F15.3)
 6041  FORMAT(/9X,'UNIT & TOTAL VARIABLE COST OF MEETING DEMAND')
 6022 CONTINUE
       WRITE(6,6201)
 6201  FORMAT(20X,'EXCHANGE RATE CHANGES REALISED')
       WRITE(6,6110) (BDVAL(IJ),IJ=1,NW)
       WRITE(6,6202)
 6202  FORMAT(//20X,'CHANGES IN PRODUCTIVITY')
       WRITE(6,6110) (BPROD(IJ),IJ=1,NW)
       WRITE(6,6203)
 6203  FORMAT(//20X,'TOTAL INFLATION RATES')
       WRITE(6,6110) (TINFL(IJ),IJ=1,NW)
 6110  FORMAT(//10X,6F15.5)
      METHOD=2
      WRITE(6,2006)
      WRITE(6,297)
  297 FORMAT(10X,'FIXED WAREHOUSE COSTS')
       WRITE(6,257) (IFC(JI),JI=1,NW)
  999 CONTINUE
C OPTIMISATION ALGORITHM BEGINS; KHUMANALA'S LARGEST OMEGA
C DECISION RULE FOR BRANCHING & BOUNDING USED
      METHOD=METHOD+1
      WRITE(6,303)
      NFIRST=0
      NXT=0
      NKTR1=0
      LLN=999999999
```

```
241             XLBD=0.0
242             UBD=LLN
243             MODE=1
244             NODE=1
245             NUBDN=NODE
246             ITER=1
247             KODE=0
248             DO 1000 IW=1,NW
249             JD(NODE,IW)=0
250             K2(NODE,IW)=0
251             K1(NODE,IW)=0
252             K2(NODE,IW)=1
253             LN(NODE,IW)=NC
254             DO 1001 IC=1,NC
255             JD(NODE,IW)=JD(NODE,IW)+ID(IC)
256             IF(IW.GE.2) GO TO 1001
257             IDEL(NODE,IC)=0
258     1001    CONTINUE
259             ILN(IW)=LN(NODE,IW)
260             IJD(IW)=JD(NODE,IW)
261     1000    CONTINUE
262             GO TO 786
263     1       CONTINUE
264             ITER=ITER+1
265             IF(NLBDN.EQ.1)GO TO 4193
266             IF(NKTR.EQ.1.OR.NKTP1.EQ.1)GO TO 4192
267             IF(KODE.NE.0)GO TO 4195
268     4193    NODE=NODE+1
269             MODE=NODE
270             IF(NODE.LT.99)GO TO 9779
```

```
271                GO TO 4196
272          4195  NODE=KODE
273                KODE=0
274          4196  DO 5167 IC=1,NC
275                IDEL(NODE,IC)=IDEL(NLBDN,IC)
276                MDEL(NODE,IC)=MDEL(NLBDN,IC)
277          5167  CONTINUE
278                DO 92 IW=1,NW
279                JD(NODE,IW)=JD(NLBDN,IW)
280                KZ(NODE,IW)=KZ(NLBDN,IW)
281                K1(NODE,IW)=K1(NLBDN,IW)
282                K2(NODE,IW)=K2(NLBDN,IW)
283                LN(NODE,IW)=LN(NLBDN,IW)
284                MDELS(NODE,IW)=MDELS(NLBDN,IW)
285                MDGAS(NODE,IW)=MDGAS(NLBDN,IW)
286          92    CONTINUE
287                GO TO 4194
288          4192  NODE=NLBDN
289          4194  IF(NKTR.EQ.0)GO TO 3786
290                GO TO(3912,3911),NKTR
291          3786  GO TO (911,912),NKTR1
292          3911  NKTR=NKTR-1
293                GO TO 3913
294          911   NKTR1=NKTR1-1
295          3913  KZ(NODE,KKW)=1
296                K2(NODE,KKW)=0
297                GO TO 786
298          3912  NKTR=NKTR-1
299                GO TO 3914
300          912   NKTR1=NKTR1-1
```

```
      3914  K1(NODE,KKW)=1
            K2(NODE,KKW)=0
            GO TO 787
  786       CONTINUE
            DO 20 IC=1,NC
            KKK=0
            KTP=0
            DO 10 IW=1,NW
            IF(KZ(NODE,IW).EQ.1)GO TO 10
            IF(K1(NODE,IW).EQ.1.AND.IDEL(NODE,IC).EQ.IW)GO TO 20
            KTP=KTP+1
            IF(KTP.EQ.1)GO TO 11
            IF(KTP.EQ.2)GO TO 12
            IF(IVC(IW,IC).GE.MINC2)GO TO 10
            GO TO 12
  11        MINC1=IVC(IW,IC)
            MW=IW
            GO TO 10
  12        CONTINUE
            MINC1=AMIN1(MINC1,IVC(IW,IC))
            IF(MINC1.EQ.IVC(IW,IC))GO TO 13
            MINC2=IVC(IW,IC)
            GO TO 10
  13        MINC2=IVC(MW,IC)
             MW=IW
  10        CONTINUE
            IF(KTP.EQ.0)GO TO 19
            IF(KTP.EQ.1)GO TO 14
            IDEL(NODE,IC)=MW
            MDEL(NODE,IC)=MINC2-MINC1
```

```
      GO TO 20
   14 K1(NODE,NW)=1
      K2(NODE,NW)=0
      KKK=KKK+1
      GO TO 20
   10 IF(NODE.NE.1)GO TO 74
      WRITE(6,10003)
      STOP
   20 CONTINUE
      KTR=KKK
      DO 25 IW=1,NW
      IF(K2(NODE,IW).EQ.0)GO TO 25
      MDELS(NODE,IW)=-IFC(IW)
      DO 30 IC=1,NC
      IF(IDEL(NODE,IC).NE.IW)GO TO 30
      MDELS(NODE,IW)=MDELS(NODE,IW)+MDEL(NODE,IC)
   30 CONTINUE
      IF(MDELS(NODE,IW)) 25,26,26
   26 KTR=KTR+1
      K1(NODE,IW)=1
      K2(NODE,IW)=0
   25 CONTINUE
      DO 4386 IW=1,NW
      IF(K2(NODE,IW).EQ.0)GO TO 4386
      GO TO 43861
 4386 CONTINUE
      GO TO 787
43861 IF(KTR.EQ.0)GO TO 787
  787 CONTINUE
      DO 41 IW=1,NW
```

```
361             IF(K2(NODE,IW).EQ.0) GO TO 41
362             LN(NODE,IW)=ILN(IW)
363             JD(NODE,IW)=IJD(IW)
364             DO 41 IC=1,NC
365             MM=IDEL(NODE,IC)
366             IF(K1(NODE,MM).EQ.0)GO TO 41
367             LN(NODE,IW)=LN(NODE,IW)-1
368             JD(NODE,IW)=JD(NODE,IW)-ID(IC)
369       41    CONTINUE
370       788   CONTINUE
371             JW=1
372       43    IF(K1(NODE,JW).EQ.1)GO TO 44
373             JW=JW+1
374             GO TO 43
375        44   DO 45 IC=1,NC
376       45    MINC(IC)=IVC(JW,IC)
377             JW=JW+1
378             IF(JW.GT.NW)GO TO 47
379             DO 46 IW=JW,NW
380             IF(K1(NODE,IW).EQ.1)GO TO 46
381             DO 48 IC=1,NC
382       48    MINC(IC)=AMIN1(MINC(IC),IVC(IW,IC))
383       46    CONTINUE
384       47    KMR=0
385             DO 49 IW=1,NW
386             IF(K2(NODE,IW).EQ.0)GO TO 49
387             MEGAS(NODE,IW)=-IFC(IW)
388             DO 50 IC=1,NC
389             MEGAS(NODE,IW)=MEGAS(NODE,IW)+AMAX1(0.,MINC(IC)-IVC(IW,IC))
390       50    CONTINUE
```

```
      IF(IBGAS(NODE,IW).GT.0.)GO TO 49
      KZ(NODE,IW)=1
      K2(NODE,IW)=0
      KTB=KTB+1
49    CONTINUE
      DO 4329 IW=1,NW
      IF(K2(NODE,IW).EQ.0)GO TO 4329
      GO TO 43291
4329  CONTINUE
      GO TO 789
43291 IF(KTB)789,789,786
789   Z(NODE)=0.
      DO 60 IW=1,NW
      IF(K1(NODE,IW).EQ.1)GO TO 52
      Y(NODE,IW)=0.
      GO TO 60
52    Y(NODE,IW)=1.
60    CONTINUE
      DO 53 IC=1,NC
      KW=IDEL(NODE,IC)
      IF(KZ(NODE,KW).EQ.1)GO TO 538
      IF(K1(NODE,KW).EQ.1)GO TO 54
      XJN=LN(NODE,KW)
      IF(VOL(NODE,IC).GT.IFC(KW)/XJN)GO TO 54
538   JW=1
540    IF(KZ(NODE,JW).EQ.0)GO TO 539
      JW=JW+1
      GO TO 540
539   AA=IVC(JW,IC)
      XLN=LN(NODE,JW)
```

```
421             IF(K2(NODE,JW).EQ.1) AA=AA+IFC(JW)/XLN
422             KW=JW
423             JW=JW+1
424             IF(JW.GT.NW) GO TO 54
425             DO 55 IW=JW,NW
426             IF(K2(NODE,IW).EQ.1) GO TO 55
427             BB=IVC(IW,IC)
428             XLN=LN(NODE,IW)
429             IF(K2(NODE,IW).EQ.1) BB=BB+IFC(IW)/XLN
430             IF(AA.NE.BB) GO TO 56
431             IF(K1(NODE,IW).EQ.1) GO TO 57
432             GO TO 55
433     56      AA=AMIN1(AA,BB)
434             IF(AA.NE.BB) GO TO 55
435     57      KW=IW
436     55      CONTINUE
437     54      XLN=LN(NODE,KW)
438             IF(K1(NODE,KW).EQ.1) GO TO 53
439             Y(NODE,KW)=1./XLN+Y(NODE,KW)
440     53      Z(NODE)=Z(NODE)+IVC(KW,IC)
441             KTR=0
442             DO 4173 IW=1,NW
443             IF(Y(NODE,IW).EQ.0.) GO TO 4174
444             Z(NODE)=Z(NODE)+IFC(IW)*Y(NODE,IW)
445     4174    IF(Y(NODE,IW).EQ.0..OR.Y(NODE,IW).EQ.1.) GO TO 4173
446             KTR=KTR+1
447     4173    CONTINUE
448             IF(KTR) 71,71,72
449     71      CONTINUE
450             IF(NPRINT.EQ.1) GO TO 711
```

```
451             WRITE(6,5833)Z(NODE),ITER
452             NFIRST=1
453       711   IF(NODE.EQ.1)GO TO 6789
454             IF(UBD.GT.Z(NODE))GO TO 790
455             Z(NODE)=LLN
456             KODE=NODE
457             IF(NKTR.NE.0.OR.NKTR1.NE.0)GO TO 1
458             GO TO 1236
459       790   UBD=Z(NODE)
460             IF(NUBDN.NE.1)KODE=NUBDN
461             NUBDN=NODE
462             ITROPT=ITER
463             Z(NODE)=LLN
464             IF(NKTR.NE.0.OR.NKTR1.NE.0)GO TO 1
465       1236   CONTINUE
466             JW=1
467             XLN=NNN
468       7911   JW=JW+1
469             IF(Z(JW).LT.UBD)GO TO 7910
470             IF(Z(JW).LT.LLN)KODE=JW
471             Z(JW)=LLN
472             IF(JW-NODE)7911,7789,7789
473       7910  XLBD=Z(JW)
474             NLBDN=JW
475             IF(JW.EQ.NODE)GO TO 7914
476             JW=JW+1
477             DO 7913 I=JW,NODE
478             IF(Z(I).LT.UBD)GO TO 77913
479             IF(Z(I).LT.LLN)KODE=I
480             Z(I)=LLN
```

```
      GO TO 7913
77913 IF(XLBD.NE.Z(I))GO TO 7913
      XLBD=Z(I)
      NLBDN=I
 7913  CONTINUE
 7914 CONTINUE
      IF(UBD.LE.XLBD)GO TO 7789
      Z(NLBDN)=LLN
      GO TO 2163
   72 IF(NODE.NE.1)GO TO 791
      XLBD=Z(NODE)
      NLBDN=NODE
      Z(NODE)=LLN
      GO TO 2163
   74 Z(NODE)=LLN
      KODE=NODE
      GO TO 7791
  791 IF(Z(NODE).LT.UBD)GO TO 7791
      Z(NODE)=LLN
      KODE=NODE
 7791  IF(NKTR.NE.1.OR.NKTR1.NE.1)GO TO 1
      GO TO 1236
 2163  JW=1
      NODE=NLBDN
 5781 IF(K2(NODE,JW).EQ.1)GO TO 5782
      JW=JW+1
      GO TO 5791
 5782  CONTINUE
      KKW=JW
      JW=JW+1
```

```
      672   DO 6721 I=JW,NW
            IF(K2(NODE,I).EQ.0)GO TO 6721
            IF(MEGAS(NODE,KKW).GE.MEGAS(NODE,I))GO TO 6721
            KKW=I
     6721   CONTINUE
            GO TO 6780
     6780   NKTR1=2
            GO TO 1
     6789   UBD=Z(NODE)
            ITROPT=ITER
            GO TO 7789
     9779   WRITE(6,97791)
            GO TO 97792
     7789   CONTINUE
     97792  CONTINUE
     C LOCATION-ALLOCATION SOLUTION FOR THIS SIMULATION RUN
            WRITE(6,1004)ITER,UBD,ITROPT,NODE
     C Y MATRIX PRINTOUT CONTAINS LOCATION SOLUTIONS TRIED EN ROUTE TO
     C OPTIMUM SOLUTION
             DO 275 JJ=1,NODE
             WRITE(6,271) (Y(JJ,J),J=1,NW)
      271    FORMAT(//,1256.3)
      275    CONTINUE
              WRITE(6,2006)
            WRITE(6,267)

      267   FORMAT(30X,'THE OPEN WAREHOUSES ARE')
             MD=NODE
      529    NUM=0
             IF(MD.LT.1)GO TO 9991
            K=1
```

```
541               DO 521 J=1,NN
542               IF(Y(MD,J).LT..4)GO TO 521
543       511     L(K)=J
544               NUM=NUM+1
545               K=K+1
546       521     CONTINUE
547       268     FORMAT(53X,I10,/)
548               IF(NUM.LT.1)GO TO 9991
549               SUM=0.0
550               DO 531 J=1,NC
551               I=1
552               SMALL=IVC(L(I),J)
553               ISMAL=L(I)
554               IF(NUM.LT.2)GO TO 541
555               DO 541 I=2,NUM
556               IF(IVC(L(I),J).LT.SMALL) GO TO 551
557               GO TO 541
558       551     SMALL=IVC(L(I),J)
559               ISMAL=L(I)
560       541     CONTINUE
561                ICHP=J
562                IASGN(J,1)=ICHP
563                IASGN(J,2)=ISMAL
564               SUM=SUM+SMALL
565       531     CONTINUE
566                TSUM=SUM
567       6042    FORMAT(//9X,'ASSIGN MARKET TO SOURCE',2I10)
568       6043    FORMAT(//10X,'TOTAL VARIABLE COST',F20.2)
569               DO  561 I=1,NUM
570               SUM=SUM+IPC(L(I))
```

```
      561   CONTINUE
             ICHEK=ABS(SUM-UBD)
             IF(ICHEK.LE.50)GO TO 569
             MD=MD-1
             GO TO 529
      569    WRITE(6,268) (L(IK),IK=1,NUM)
             DO 571 J=1,NC
             WRITE(6,6042) IASGN(J,1),IASGN(J,2)
      571    CONTINUE
             WRITE(6,6043)TSUM
      6044    FORMAT(//10X,'TOTAL COST',F24.2)
             WRITE(6,6044)SUM
             TOTREV=0.0
             DO 9791 I=1,NC
            DREV=PRICE(I)*ID(I)
            TOTREV=TOTREV+DREV
      9791  CONTINUE
            REVNET(IRUN)=TOTREV-SUM
            WRITE(6,6049)REVNET(IRUN)
      6049  FORMAT(//10X,'NET REV. IS =',F20.2)
            WRITE(6,2006)
      9891   IRUN=IRUN+1
           IF(IRUN.EQ.ISIM) GO TO 99
           GO TO 3229
      9991 STOP

      596        END
```

```
LIST ROBUST
     1            INTEGER POINT(30)
     2            INTEGER K2(99,30),K1(99,30),K2(99,30),LN(99,30),IDEL(99,60),
     3           *ILN(30)
     4            REAL PRPOS,IDP,IVC1,TAR,IFCD,IV,PRICE,DVAL1,DVAL2,DVAL3,DVAL4,
     5           *DVAL5,DVAL6
     6             REAL IVC2
     7             DIMENSION IVC2(30,60)
     8            REAL IFC,ID,IVC,MDEL,MDELS,MINC,MRGAS,JD,LLN,MINC1,MINC2,IJD
     9            DIMENSION PRPOS(10),IDP(10,60),IVC1(30,60),TAR(60),IFCD(30),
    10           *IV(30),PRICE(30),DVAL1(100),DVAL2(100),DVAL3(100),DVAL4(100),
    11           *DVAL5(100),DVAL6(100)
    12            DIMENSION IFC(30),ID(60),IVC(30,60),MDEL(99,60),MDELS(99,30),
    13           *MRGAS(99,30),JD(99,30),MINC(60),Z(99),Y(99,30),IJD(30),L(30)
    14              DIMENSION IASGN(60,2),DVREB(30),UDEM(100)
    15              DIMENSION REVNET(200,50)
    16              DIMENSION BDVAL(30),BPROD(30)
    17              DIMENSION TINPL(30),DINPL(30),PROD1(100),PROD2(100)
    18               DIMENSION PROD3(100),PROD4(100),PROD5(100),PROD6(100)
    19              DATA UDEM/9*-.05,13*-.035,18*-.015,10*0.0,
    20           *9*.11,18*.015,18*.045/
    21               DATA PROD1/30*-.1,50*0.0,20*.1/
    22               DATA PROD2/60*0.0,20*.1,20*.2/
    23               DATA PROD3/30*-.1,60*0.0,10*.1/
    24               DATA PROD4/20*-.1,80*0.0/
    25               DATA PROD5/50*0.0,30*.1,20*.2/
    26               DATA PROD6/40*-.1,40*0.0,20*.1/
    27             DATA DVAL1/15*-.3,30*-.2,40*-.1,15*-.05/
    28             DATA DVAL2/20*-.1,20*-.05,10*0.0,30*.05,15*.1,5*.15/
    29             DATA DVAL3/10*0.0,30*.05,30*.10,20*.15,5*.2,5*.3/
    30             DATA DVAL4/20*-.05,40*0.0,20*.05,20*.1/
```

```
      DATA DVAL5/5*-.3,5*-.2,20*-.1,40*-.05,30*0.0/
      DATA DVAL6/10*-.3,10*-.2,35*-.1,25*-.05,20*0.0/
  303 FORMAT(//////45X,'OPEN WAREHSE W. LARGEST OMEGA',//)
  257 FORMAT(10X,6F12.2)
 2000 FORMAT(/////40X,'ITERATION #',I20)
 2006 FORMAT(1H1)
 2007 FORMAT(/1X,10F13.2)
 2008 FORMAT(F10.0)
 2009 FORMAT(//2X,'FIXED WAREHSE COSTS',F15.2)
 2015 FORMAT(10X,5F12.0,/).
 5833 FORMAT(//5X,'FIRST TERMINAL SOLUTION FOUND WAS',F25.2,
     *'IT WAS FOUND AT ITERATION',I15)
 5834 FORMAT(/5X,'THE LOWER BOUND AT THE TIME OF THE OPTIMUM WAS',F15.2)
 8634  FORMAT(//5X,'SOLUTION AT NODE',I10,5X,'IS',F25.2)
 8635 FORMAT(5X,I10,3F20.2,F20.4)
10001 FORMAT(2I10)
10002 FORMAT(8I10)
10003 FORMAT(///5X,'SOLUTION INFEASIBLE')
10004 FORMAT(///2X,'THE OPTIMUM SOLUTION FOUND AFTER',I7,
     *'     ITERATIONS IS',F15.2,'     IT WAS FOUND AT ITERATION #',
     *I10,/5X,'MAX. # OF DISTINCT NODES USED',I10)
20001 FORMAT(1X,13F9.2)
20002 FORMAT(13F6.0)
20003 FORMAT(//5X,'LOWER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,/,5X,
     *'UPPER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,//)
20004 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED CLOSED',/)
20005 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED OPENED',/)
20010 FORMAT(10F8.2)
20015 FORMAT(8F10.2)
30002 FORMAT(60X,'# OD WAREHSES FIXED OPEN',I10)
```

```
      30003 FORMAT(0X,'# OF WAREHSES FIXED CLOSED',I8)
      30004 FORMAT(5X,'WAREHSE # ',I10,5X,'IS FIXED OPEN - ONLY SUPPLIER')
      30005 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED OPEN')
      30006 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLOSED NO CUSTOMERS')
      30007 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLODED')
      97771 FORMAT(//5X,'COMPUTATIONS DISCONTINUED LACK OF STORAGE')
            READ(5,10015)NPRICE,ISIM
      10015 FORMAT(I2,I4)
            READ(5,20002) (PRPOS(I),I=1,NPRICE)
            READ(5,10001)NW,NC
             READ(5,10025)MODE
      10025  FORMAT(I2)
             DO 10030 I=1,MODE
             READ(5,10020) (Y(I,J),J=1,NW)
      10030  CONTINUE
            DO 2126 IW=1,NPRICE
            READ(5,10020) (IDP(IW,IC),IC=1,NC)
      2126  CONTINUE
      10020 FORMAT(6F10.0)
            DO 2125 IW=1,NW
            READ(5,10020) (IVC1(IW,IC),IC=1,NC)
      2125  CONTINUE
            READ(5,10020) (TAR(I),I=1,NC)
            READ(5,20015) (IFCD(IW),IW=1,NW)
            READ(5,20002) (IV(IC),IC=1,NW)
             READ(5,20015) (DVREB(IC),IC=1,NW)
             READ(5,20015) (DINFL(IC),IC=1,NW)
             READ(5,10020) (PRICE(I),I=1,NC)
             MD=MODE
      99    IX1=1313
```

```
      DO 100 II=1,100
      CALL RANDU(IX1,IY1,FL1)
      IX1=IY1
100   CONTINUE
      WRITE(6,3111)(PRICE(I),I=1,NC)
3111  FORMAT(3X,'PRICE CHOICES',3X,6F10.0,/)
      IRUN=1
3229  DO 3125 II=1,NW
      CALL RANDU(IX1,IY1,FL1)
      IX1=IY1
      POINT(II)=100.*(FL1)+1.
3125  CONTINUE
      DO 2148 IF=1,NC
      DO 2128 I=1,NPRICE
      IF(PPOS(I).EQ.PRICE(IF)) GO TO 2129
      GO TO 2128
2129  DEMAND=IDP(I,IF)
      CALL RANDU(IX1,IY1,FL1)
      IX1=IY1
      IDND=100.*(FL1)+1.
      DEMAND=DEMAND*(1.+UDEM(IDND))
      ID(IF)=DEMAND
      GO TO 2148
2128  CONTINUE
2148  CONTINUE
      DO 2121 IW=1,NW
      IFC(IW)=IFCO(IW)*(1.-DVRES(IW))
      IF(IW.LE.1)GO TO 3231
      IF(IW.LE.2)GO TO 3232
      IF(IW.LE.3)GO TO 3233
```

```
      IF(IW.LE.4)GO TO 3234
      IF(IW.LE.5)GO TO 3235
      GO TO 3236
3231  IPC(IW)=IPC(IW)*(1.+DVAL1(POINT(IW)))
      ADVAL=DVAL1(POINT(IW))
      CALL RANDU(IX1,IY1,FL1)
      IX1=IY1
      IDND=100.*(FL1)+1.
      VCOS=IV(IW)*(1.+PROD1(IDND))
      APROD=PROD1(IDND)
      VCOS=VCOS*(1.+ADVAL)
      IF((ABS(ADVAL)-0.0).LT..04) GO TO 3241
      TIMFL(IW)=DIMFL(IW)-(1./ADVAL)
      GO TO 3251
3241  TIMFL(IW)=DIMFL(IW)
3251  IPC(IW)=IPC(IW)*(1.+(TIMFL(IW)/100.))
      VCOS=VCOS*(1.+(TIMFL(IW)/100.))
      GO TO 3300
3232  IPC(IW)=IPC(IW)*(1.+DVAL2(POINT(IW)))
      ADVAL=DVAL2(POINT(IW))
      CALL RANDU(IX1,IY1,FL1)
       IX1=IY1
      IDND=100.*(FL1)+1.
      VCOS=IV(IW)*(1.+PROD2(IDND))
      APROD=PROD2(IDND)
      VCOS=VCOS*(1.+ADVAL)
      IF((ABS(ADVAL)-0.0).LT..04) GO TO 3242
      TIMFL(IW)=DIMFL(IW)-(1./ADVAL)
      GO TO 3252
3242  TIMFL(IW)=DIMFL(IW)
```

```
151      3252    IFC(IW)=IFC(IW)*(1.+(TINFL(IW)/100.))
152              VCOS=VCOS*(1.+(TINFL(IW)/100.))
153             GO TO 3300
154      3233    IFC(IW)=IFC(IW)*(1.+DVAL3(POINT(IW)))
155              ADVAL=DVAL3(POINT(IW))
156              CALL RANDU(IX1,IY1,FL1)
157              IX1=IY1
158              IDND=100.*(FL1)+1.
159              VCOS=IV(IW)*(1.+PROD3(IDND))
160              APROD=PROD3(IDND)
161              VCOS=VCOS*(1.+ADVAL)
162              IF((ABS(ADVAL)-0.0).LT..04) GO TO 3243
163              TINFL(IW)=DINFL(IW)-(1./ADVAL)
164              GO TO 3253
165      3243    TINFL(IW)=DINFL(IW)
166      3253    IFC(IW)=IFC(IW)*(1.+(TINFL(IW)/100.))
167              VCOS=VCOS*(1.+(TINFL(IW)/100.))
168             GO TO 3300
169      3234   IFC(IW)=IFC(IW)*(1.+DVAL4(POINT(IW)))
170              ADVAL=DVAL4(POINT(IW))
171              CALL RANDU(IX1,IY1,FL1)
172               IX1=IY1
173              IDND=100.*(FL1)+1.
174              VCOS=IV(IW)*(1.+PROD4(IDND))
175              APROD=PROD4(IDND)
176              VCOS=VCOS*(1.+ADVAL)
177              IF((ABS(ADVAL)-0.0).LT..04) GO TO 3244
178              TINFL(IW)=DINFL(IW)-(1./ADVAL)
179              GO TO 3254
180      3244    TINFL(IW)=DINFL(IW)
```

```
      3254   IFC(IW)=IFC(IW)*(1.+(TINFL(IW)/100.))
             VCOS=VCOS*(1.+(TINFL(IW)/100.))
            GO TO 3300
      3235   IFC(IW)=IFC(IW)*(1.+DVAL5(POINT(IW)))
             ADVAL=DVAL5(POINT(IW))
             CALL RANDU(IX1,IY1,FL1)
             IX1=IY1
             IDMD=100.*(FL1)+1.
             VCOS=IV(IW)*(1.+PROD5(IDMD))
             APROD=PROD5(IDMD)
             VCOS=VCOS*(1.+ADVAL)
             IF((ABS(ADVAL)-0.0).LT..04) GO TO 3245
             TINFL(IW)=DINFL(IW)-(1./ADVAL)
             GO TO 3255
      3245   TINFL(IW)=DINFL(IW)
      3255   IFC(IW)=IFC(IW)*(1.+(TINFL(IW)/100.))
              VCOS=VCOS*(1.+(TINFL(IW)/100.))
            GO TO 3310
      3236   IFC(IW)=IFC(IW)*(1.+DVAL6(POINT(IW)))
             ADVAL=DVAL6(POINT(IW))
             CALL RANDU(IX1,IY1,FL1)
             IX1=IY1
             IDMD=100.*(FL1)+1.
             VCOS=IV(IW)*(1.+PROD6(IDMD))
             APROD=PROD6(IDMD)
             VCOS=VCOS*(1.+ADVAL)
             IF((ABS(ADVAL)-0.0).LT..04) GO TO 3246
             TINFL(IW)=DINFL(IW)-(1./ADVAL)
             GO TO 3256
      3246   TINFL(IW)=DINFL(IW)
```

```
      3256   IFC(IW)=IFC(IW)*(1.+(TINFL(IW)/100.))
             VCOS=VCOS*(1.+(TINFL(IW)/100.))
      3300   BDVAL(IW)=ADVAL
             BPROD(IW)=APROD
             DO 2131 IP=1,NC
      2137  TRIP=CAP(IP)*PRICE(IP)
       2139 RATE=IVC1(IW,IP)
             IF(IW.EQ.IP)TRIP=0.0
             IVC2(IW,IP)=VCOS
             IVC(IW,IP)=(VCOS+TRIP+RATE)*ID(IP)
      2131   CONTINUE
      2121   CONTINUE
             IF(ISUM.GT.1) GO TO 6032
             WRITE(6,6001)NPRICE,ISIM
      6001   FORMAT(10X,'# OF PRICE CHOICES',I10,10X,'#OF RUNS AT EACH PRICE
     *VECTOR',I10,//)
             WRITE(6,6002) (PRPOS(I),I=1,NPRICE)
      6002    FORMAT(10X,'POSSIBLE PRICES',6F10.2)
             WRITE(6,6003)NW,NC
      6003   FORMAT(10X,'# OF WAREHOUSES =',I5,5X,'# OF CUSTOMERS =',I5)
             WRITE(6,6014)
      6014    FORMAT(10X,'DEMAND PRICE MATRIX',//)
             DO 6005 K=1,NPRICE
             WRITE(6,6004) (IDP(K,JJ),JJ=1,NC)
      6004   FORMAT(10X,6F10.0)
      6005    CONTINUE
             WRITE(6,2006)
             WRITE(6,6015)
      6015   FORMAT(10X,'TRANSPORTATION COST MATRIX',//)
             DO 6007 K=1,NW
```

```
241             WRITE(6,6006) (IVC1(K,JJ),JJ=1,NC)
242       6006   FORMAT(10X,6F8.3)
243       6007   CONTINUE
244             WRITE(6,2006)
245             WRITE(6,6008) (TAR(JJ),JJ=1,NC)
246       6008   FORMAT(5X,'TARIFF LEVELS',5X,6F8.3)
247              WRITE(6,6009) (IFCD(JJ),JJ=1,NW)
248       6009   FORMAT(5X,'FIXED COST',5X,10F10.0,/)
249             WRITE(6,6011)
250       6011   FORMAT(10X,'VARIABLE COST PER UNIT BY LOCATION',//)
251             WRITE(6,6010) (IV(JJ),JJ=1,NW)
252       6010   FORMAT(10X,F10.3)
253       6032  WRITE(6,6012)
254       6012   FORMAT(10X,'DEMAND FOR CURRENT PRICE CHOICE',///)
255             WRITE(6,6013) (ID(IC),IC=1,NC)
256       6013  FORMAT(10X,6F10.0)
257              WRITE(6,6041)
258             DO 6022 I=1,NW
259              WRITE(6,6036) (IVC2(I,J),J=1,NC)
260             WRITE(6,6036) (IVC(I,J),J=1,NC)
261       6036  FORMAT(//,10X,6F15.3)
262       6041   FORMAT(/9X,'UNIT & TOTAL VARIABLE COST OF MEETING DEMAND')
263       6022  CONTINUE
264              WRITE(6,6201)
265       6201   FORMAT(20X,'EXCHANGE RATE CHANGES REALISED')
266              WRITE(6,6110) (RDVAL(JJ),JJ=1,NW)
267              WRITE(6,6202)
268       6202   FORMAT(//20X,'CHANGES IN PRODUCTIVITY')
269              WRITE(6,6110) (RPROD(JJ),JJ=1,NW)
270              WRITE(6,6203)
```

```
271      5203   FORMAT(//20X,'TOTAL INFLATION RATES')
272             WRITE(6,6111) (TINFL(IJ),IJ=1,NW)
273      6111   FORMAT(//10X,6F15.5)
274             METHOD=2
275             WRITE(6,2006)
276             WRITE(6,297)
277      297    FORMAT(10X,'FIXED WAREHOUSE COSTS')
278              WRITE(6,257) (IFC(JI),JI=1,NW)
279      999    CONTINUE
280             WRITE(6,267)
281      267    FORMAT(30X,'THE OPEN WAREHOUSES ARE')
282      529     NUM=0
283              IF(MD.LT.1)GO TO 9995
284             K=1
285              DO 521 J=1,NW
286              IF(Y(MD,J).LT..4)GO TO 521
287      511     L(K)=J
288              NUM=NUM+1
289              K=K+1
290      521     CONTINUE
291      268    FORMAT(53X,I10,/)
292              IF(NUM.LT.1)GO TO 9991
293             SUM=0.0
294             DO 531 J=1,NC
295             I=1
296             SMALL=IVC(L(I),J)
297             ISMAL=L(I)
298             IF(NUM.LT.2)GO TO 541
299             DO 541 I=2,NUM
300             IF(IVC(L(I),J).LT.SMALL) GO TO 551
```

```
      GO TO 541
  551 SMALL=IVC(L(I),J)
      ISMAL=L(I)
  541 CONTINUE
       ICUR=J
       IASGN(J,1)=ICUR
       IASGN(J,2)=ISMAL
      SUM=SUM+SMALL
  531 CONTINUE
       TSUM=SUM
 6042  FORMAT(//9X,'ASSIGN MARKET TO SOURCE',2I10)
 6043  FORMAT(//10X,'TOTAL VARIABLE COST',F20.2)
      DO  561 I=1,NUM
      SUM=SUM+IFC(L(I))
  561 CONTINUE
  569  WRITE(6,268) (L(IK),IK=1,NUM)
       DO 571 J=1,NC
       WRITE(6,6042) IASGN(J,1),IASGN(J,2)
  571  CONTINUE
       WRITE(6,6043) TSUM
 6044   FORMAT(//10X,'TOTAL COST',F20.2)
       WRITE(6,6044) SUM
       TOTREV=0.0
       DO 9791 I=1,NC
       DREV=PRICE(I)*ID(I)
       TOTREV=TOTREV+DREV
 9791  CONTINUE
       REVNET(IRUN,MD)=TOTREV-SUM
       WRITE(6,6049) REVNET(IRUN,MD)
 6049  FORMAT(//10X,'NET REV. IS =',F20.2)
```

```
      WRITE(6,2006)
 9891  IRUN=IRUN+1
      IF(IRUN.EQ.ISIM) GO TO 5099
     GO TO 3229
 5099 MD=MD-1
      IF(MD.LT.1)GO TO 9995
      GO TO 99
 9995 IACT=ISIM-1
      DO 9996 I=1,IACT
      PUNCH 5011,(REVNET(I,J),J=1,MODE)
      WRITE(6,5011) (REVNET(I,J),J=1,MODE)
      WRITE(8,5011) (REVNET(I,J),J=1,MODE)
 9996 CONTINUE
 5011 FORMAT(4F20.2)
      WRITE(6,5021)
 5021 FORMAT(10X,'ROBUST LOCATIONS TESTED')
      DO 275 JJ=1,MODE
      WRITE(6,271) (Y(JJ,J),J=1,NW)
 271  FORMAT(//,12F6.0)
 275  CONTINUE
 9991 STOP
      END
```

```
'LIST DESIGN
      1            INTEGER POINT(30)
      2            INTEGER KZ(99,30),K1(99,30),K2(99,30),LN(99,30),IDEL(99,60),
      3           *IL"(30)
      4             INTEGER PLAN(64,9)
      5            REAL PROS,IDP,IVC1,TAR,IFCD,IV,PRICE,DVAL1,DVAL2,DVAL3,DVAL4,
      6           *DVAL5,DVAL6
      7             REAL IVC2
      8             DIMENSION IVC2(30,60)
      9            REAL IFC,ID,IVC,MDEL,MDELS,MINC,MEGAS,JD,LLN,MINC1,MINC2,IJD
     10             DIMENSION PROS(10),IDP(10,60),IVC1(30,60),TAR(60)
     11             DIMENSION IFCD(30),TINFL(30),DINFL(30)
     12             DIMENSION IV(30),PRICE(30),DVAL(30,10),PROD(30,100)
     13            DIMENSION IFC(30),ID(60),IVC(30,60),MDEL(99,60),MDELS(99,30),
     14           *MEGAS(99,30),JD(99,30),MINC(60),Z(99),Y(99,30),IJD(30),L(30)
     15             DIMENSION IASGN(60,2),DVREB(30),"DEM(10)
     16             DIMENSION PRICEF(30),REVNET(200,5)
     17             DIMENSION BDVAL(30),BPROD(30)
     18      203   FORMAT(//////45X,'OPEN WAREHSE W. LARGRST OMEGA',//)
     19      257   FORMAT(10X,6F12.2)
     20      2000  FORMAT(/////50X,'ITERATION #',I20)
     21      2006  FORMAT(1H1)
     22      2007  FORMAT(/1X,10F13.2)
     23      2009  FORMAT(F10.3)
     24      2009  FORMAT(//2X,'FIXED WAREHSE COSTS',F15.2)
     25      2015  FORMAT(10X,5F12.0,/)
     26      5833  FORMAT(//5X,'FIRST TERMINAL SOLUTION FOUND WAS',F25.2,
     27           *'IT WAS FOUND AT ITERATION',I15)
     28      5834  FORMAT(/5X,'THE LOWER BOUND AT THE TIME OF THE OPTIMUM WAS',F15.2)
     29      8634   FORMAT(//5X,'SOLUTION AT NODE',I10,5X,'IS',F25.2)
     30      8635  FORMAT(5X,I10,3F20.2,F20.4)
```

```
10001 FORMAT(2I10)
10002 FORMAT(8I10)
10003 FORMAT(///5X,'SOLUTION INFEASIBLE')
10004 FORMAT(///2X,'THE OPTIMUM SOLUTION FOUND AFTER',I7,
     *'      ITERATIONS IS',F15.2,'     IT WAS FOUND AT ITERATION #',
     *I10,/5X,'MAX. # OF DISTINCT NODES USED',I10)
20001 FORMAT(1X,13F9.2)
20002 FORMAT(13F6.0)
20003 FORMAT(//5X,'LOWER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,/,5X,
     *'UPPER BOUND =',F15.2,5X,'OCCURS AT NODE',I10,//)
20004 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED CLOSED',/)
20005 FORMAT(/10X,'WAREHSE',I10,5X,'IS CONSTRAINED OPENED',/)
20010 FORMAT(10F8.0)
20015 FORMAT(8F10.2)
30002 FORMAT(60X,'# OF WAREHSES FIXED OPEN',I10)
30003 FORMAT(60X,'# OF WAREHSES FIXED CLOSED',I8)
30004 FORMAT(5X,'WAREHSE # ',I10,5X,'IS FIXED OPEN - ONLY SUPPLIER')
30005 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED OPEN')
30006 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLOSED NO CUSTOMERS')
30007 FORMAT(5X,'WAREHSE #',I10,5X,'IS FIXED CLOSED')
97701 FORMAT(//5X,'COMPUTATIONS DISCONTINUED LACK OF STORAGE')
C READ IN DATA
C NO. OF DIFFERENT PRICE OPTIONS OPEN, NO. OF SIMULATION
C RUNS DESIRED
      READ(5,10015)NPRICE,ISIM,IBLOC
10015 FORMAT(I2,I4,I4)
C READ IN VARIOUS PRICES THAT MAY BE CHARGED
      READ(5,20002)(PRPOS(I),I=1,NPRICE)
C NO. OF SOURCES, NO. OF DESTINATIONS
      READ(5,10001)NW,NC
```

```
C DEMAND PRICE MATRIX
      DO 2126 IW=1,NPRICE
      READ(5,10020) (IDP(IW,IC),IC=1,NC)
2126  CONTINUE
10020 FORMAT(6F10.0)
C TRANSPORTATION COST MATRIX
      DO 2125 IW=1,NW
      READ(5,10020) (IVC1(IW,IC),IC=1,NC)
2125  CONTINUE
      MJ=1
      IRUN=1
C READ IN EXPERIMENTAL DESIGN SAMPLING PLAN
      DO 3440 K=1,64
      READ(5,3441) (PLAN(K,KI),KI=1,9)
3440  CONTINUE
3441  FORMAT(9I5)
C LOCATION VECTOR TESTED IN EXPERIMENTAL DESIGN
      READ(5,10020) (Y(1,J),J=1,NW)
C PRODUCTIVITY CHANGES: SITE,CUM. FREQ., % CHANGE
3412  READ(5,3405) MA,MB,CHCOS
      IF(MA.GE.31) GO TO 3416
      DO 3411 IJ=MJ,MB
      PROD(MA,IJ)=CHCOS
3411  CONTINUE
      MJ=MB+1
      IF(MJ.GE.101) MJ=1
      GO TO 3412
3416  CONTINUE
C DVAL PROB., CUM. FREQ. BY SOURCES & AMOUNTS
      READ(5,3405) MA,MB,CHCOS
```

```
      IF(MA.GE.31)GO TO 3426
      DO 3401 IJ=MJ,MB
      DVAL(MA,IJ)=CHCUR
3401  CONTINUE
      MJ=MB+1
      IF(MJ.GE.101)MJ=1
      GO TO 3422
3405  FORMAT(2I5,F10.0)
3406  CONTINUE
C RANDOM DISTURBANCES TO AVG. LEVEL OF DEMAND
3422  READ(5,3415)MB,CHDEM
      DO 3421 IJ=MJ,MB
      UDEM(IJ)=CHDEM
3421   CONTINUE
      MJ=MB+1
      IF(MJ.GE.101) GO TO 3426
      GO TO 3422
3426  CONTINUE
      MJ=1
3415  FORMAT(I5,F10.0)
C TARIFFS(% OF SALES PRICE) BY DESTINATION
      READ(5,10021)(TAR(I),I=1,NC)
C FIXED COSTS BY SOURCES
      READ(5,20015)(IFCD(IW),IW=1,NW)
C VARIABLE COSTS PER UNIT BY SOURCE
      READ(5,20002)(IV(IC),IC=1,NW)
C DEV. REBATES(% OF FIXED COSTS) BY SOURCES
      READ(5,20015)(DVREB(IC),IC=1,NW)
C DOMESTIC INFLATION RATES(%) BY SOURCES
      READ(5,20015)(DINFL(IC),IC=1,NW)
```

```
      99    IX1=1303
            DO 100 IJ=1,100
            CALL RANDU(IX1,IY1,FL1)
            IX1=IY1
      100   CONTINUE
C PRICES CHARGES AT EACH DESTINATION
            READ(5,10020) (PRICE(I),I=1,NC)
            WRITE(6,2006)
            WRITE(6,2005)
      2005  FORMAT(10X,'NEW BLOCK BEGINS'///)
            WRITE(6,3111) (PRICE(I),I=1,NC)
      3111  FORMAT(3X,'PRICE CHOICES, THIS BLOCK',3X,6F10.3,/)
            IBRUN=0
      3229  DO 3125 II=1,NW
            CALL RANDU(IX1,IY1,FL1)
            IX1=IY1
            POINT(II)=100.*(FL1)+1.
      3125  CONTINUE
C READ IN FACTOR LEVELS FOR EACH RUN
C PRICE SETTINGS FOR THIS RUN
      3505  DO 3501 I=1,NC
            IF(PLAN(IRUN,I).EQ.0) GO TO 3502
            PRICEF(I)=PRICE(I)+.5
            GO TO 3503
      3502  PRICEF(I)=PRICE(I)
      3503  CONTINUE
      3501  CONTINUE
C DETERMINE ACTUAL DEMAND LEVEL FOR THIS RUN BY DESTINATION
            DO 2149 IP=1,NC
            DO 2129 I=1,NPRICE
```

```
151             IF(PRPOS(I).EQ.PRICPF(IP))GO TO 2129
152             GO TO 2128
153     2129    DEMAND=IDP(I,IP)
154             CALL RANDM(IX1,IY1,FL1)
155             IX1=IY1
156             IDND=100.*(FL1)+1.
157             IF(PLAN(IRUN,2).EQ.0)GO TO 3511
158             DEMAND=DEMAND*(1.+UDEM(IDND)-.05)
159             GO TO 3512
160     3511    DEMAND=DEMAND*(1.+UDEM(IDND)+.05)
161     3512    ID(IP)=DEMAND
162             GO TO 2148
163     2128    CONTINUE
164     2148    CONTINUE
165     C ADJUST FIXED & VARIABLE COSTS FOR DEV. REBATES, EXCHANGE RATE
166     C CHANGES, PRODUCTIVITY CHANGES & TOTAL INFLATION RATES
167           DO 2121 IW=1,NW
168             IF(PLAN(IRUN,4).EQ.0)GO TO 3521
169             AFC=(IFCD(IW)-25[illegible].)
170             GO TO 3522
171     3521    AFC=(IFCD(IW)+250[illegible].)
172     3522    CONTINUE
173             IF(PLAN(IRUN,6).EQ.0)GO TO 3531
174             IFC(IW)=AFC*(1.-DVREB(IW)-.10)
175             GO TO 3532
176     3531    IFC(IW)=AFC*(1.-DVREB(IW))
177     3532    CONTINUE
178             IF(PLAN(IRUN,1).EQ.0)GO TO 3541
179             ADVAL=DVAL(IW,POINT(IW))+.1
180             GO TO 3542
```

```
      3541    ADVAL=DVAL(IW,POINT(IW))
      3542    CONTINUE
              IPC(IW)=IPC(IW)*(1.+ADVAL)
              CALL RANDU(IX1,IY1,FL1)
              IY1=IY1
              IDND=100.*(FL1)+1.
              IF(PLAN(IRUN,5).EQ.0)GO TO 3551
              VCOS=(IV(IW)-.5)*(1.+PROD(IW,IDND))
              GO TO 3552
      3551    VCOS=(IV(IW)+.5)*(1.+PROD(IW,IDND))
      3552     CONTINUE
              APROD=PROD(IW,IDND)
              VCOS=VCOS*(1.+ADVAL)
              IF(PLAN(IRUN,7).EQ.0)GO TO 3561
              AD=DINFL(IW)+.05
              GO TO 3562
      3561    AD=DINFL(IW)
      3562    CONTINUE
              IF((ABS(ADVAL)-0.2).LT..005)GO TO 3241
              TINFL(IW)=AD-(1./ADVAL)
              GO TO 3251
      3241       TINFL(IW)=AD
      3251    IPC(IW)=IPC(IW)*(1.+(TINFL(IW)/100.))
              VCOS=VCOS*(1.+(TINFL(IW)/100.))
      3300    BDVAL(IW)=ADVAL
              BPROD(IW)=APROD
      C ADD ON TARIFFS & TRANSPORTATION COSTS
              DO 2131 IP=1,NC
              IF(PLAN(IRUN,3).EQ.0)GO TO 3571
              TRIF=(TAR(IP)-.1)*PRICEP(IP)
```

```
211             GO TO 3572
212       3571  TRIP=(TAP(IP)+.1)*PRICEP(IP)
213       3572  CONTINUE
214        2139 RATE=IVC1(IW,IP)
215             IF(IW.EQ.IP)TRIP=0.0
216             IVC2(IW,IP)=VCOS
217             IVC(IW,IP)=(VCOS+TRIP+RATE)*ID(IP)
218       2131  CONTINUE
219       2121  CONTINUE
220             IF(IRRUN.NE.0)GO TO 6032
221            WRITE(6,6001)NPRICE,ISIM
222       6001  FORMAT(10X,'# OF PRICE CHOICES',I5,8X,'# OF RUNS',I5,//)
223            WRITE(6,6002)(PRPOS(I),I=1,NPRICE)
224       6002  FORMAT(10X,'POSSIBLE PRICES',6F10.2)
225            WRITE(6,6003)NW,NC
226       6003  FORMAT(30X,'# OF WAREHOUSES =',I5,5X,'# OF CUSTOMERS =',I5)
227            WRITE(6,6014)
228       6014  FORMAT(10X,'DEMAND PRICE MATRIX',//)
229            DO 6005 K=1,NPRICE
230            WRITE(6,6004)(IDP(K,JJ),JJ=1,NC)
231       6004  FORMAT(10X,6F10.0)
232       6005  CONTINUE
233            WRITE(6,6015)
234       6015  FORMAT(10X,'TRANSPORTATION COST MATRIX',//)
235            DO 6007 K=1,NW
236            WRITE(6,6006)(IVC1(K,JJ),JJ=1,NC)
237       6006  FORMAT(10X,6F9.3)
238       6007  CONTINUE
239            WRITE(6,6008)(TAP(JJ),JJ=1,NC)
240       6008  FORMAT(5X,'TARIFF LEVELS',5X,6F9.3)
```

```
241             WRITE(6,6019)
242     6019    FORMAT(10X,'DEV. REBATES(%) BY SITE',/)
243             WRITE(6,6055) (DVSPB(IC),IC=1,NW)
244     6055    FORMAT(10X,6F10.4)
245             WRITE(6,6019)
246     6019    FORMAT(//10X,'DOMESTIC PRE-DVAL INFLATION(%) ',/)
247             WRITE(6,6013) (DINFL(IC),IC=1,NW)
248             WRITE(6,6009) (IFCD(JJ),JJ=1,NW)
249     6009    FORMAT(5X,'FIXED COST',5X,10F10.0,/)
250            WRITE(6,6011)
251     6011    FORMAT(10X,'VARIABLE COST PER UNIT BY LOCATION',//)
252            WRITE(6,6010) (IV(JJ),JJ=1,NW)
253     6010    FORMAT(10X,F10.3)
254     6032     WRITE(6,6051)
255     6051    FORMAT(10X,'FACTOR SETTINGS:PRICES,THIS RUN')
256             WRITE(6,6052) (PRICEF(I),I=1,NC)
257     6052    FORMAT(10X,6F10.3)
258             WRITE(6,6012)
259     6012    FORMAT(10X,'DEMAND FOR CURRENT PRICE CHOICE',///)
260            WRITE(6,6013) (ID(IC),IC=1,NC)
261     6013    FORMAT(10X,6F10.0)
262             WRITE(6,2006)
263             WRITE(6,6041)
264            DO 6022 I=1,NW
265             WRITE(6,6036) (IVC2(I,J),J=1,NC)
266            WRITE(6,6036) (IVC(I,J),J=1,NC)
267     6036   FORMAT(//,10X,6F15.3)
268     6041    FORMAT(/9X,'UNIT & TOTAL VARIABLE COST OF MEETING DEMAND')
269     6022   CONTINUE
270             WRITE(6,6271)
```

```
      6201  FORMAT(20X,'EXCHANGE RATE CHANGES REALISED')
            WRITE(6,6110) (DOVAL(IJ),IJ=1,NW)
            WRITE(6,6202)
      6202  FORMAT(//20X,'CHANGES IN PRODUCTIVITY')
            WRITE(6,6110) (DPROD(IJ),IJ=1,NW)
            WRITE(6,6203)
      6203  FORMAT(//20X,'TOTAL INFLATION RATES')
            WRITE(6,6110) (TINFL(IJ),IJ=1,NW)
      6110  FORMAT(//10X,6F15.5)
            METHOD=2
            WRITE(6,2206)
            WRITE(6,297)
      297   FORMAT(1HX,'FIXED WAREHOUSE COSTS')
            WRITE(6,257) (IFC(JI),JI=1,NW)
      999   CONTINUE
            WRITE(6,267)
      267   FORMAT(3HX,'THE OPEN WAREHOUSES ARE')
      529   NUM=0
            MODE=1
            MD=1
            K=1
            DO 521 J=1,NW
            IF(Y(MD,J).LT..4)GO TO 521
      511   L(K)=J
            NUM=NUM+1
            K=K+1
      521   CONTINUE
      268   FORMAT(5HX,I10,/)

            IF(NUM.LT.1)GO TO 9991
            SUM=0.0
```

```
      DO 531 J=1,NC
      I=1
      SMALL=IVC(L(I),J)
      ISMAL=L(I)
      IF(NUM.LT.2)GO TO 541
      DO 541 I=2,NUM
      IF(IVC(L(I),J).LT.SMALL) GO TO 551
      GO TO 541
551   SMALL=IVC(L(I),J)
      ISMAL=L(I)
541   CONTINUE
       ICHR=J
       IASGN(J,1)=ICHR
       IASGN(J,2)=ISMAL
      SUM=SUM+SMALL
531   CONTINUE
       TSUM=SUM
6042   FORMAT(//9X,'ASSIGN MARKET TO SOURCE',2I10)
6043   FORMAT(//10X,'TOTAL VARIABLE COST',F20.2)
      DO  561 I=1,NUM
      SUM=SUM+IFC(L(I))
561   CONTINUE
569    WRITE(6,268) (L(IK),IK=1,NUM)
       DO 571 J=1,NC
       WRITE(6,6042)IASGN(J,1),IASGN(J,2)
571    CONTINUE
       WRITE(6,6043)TSUM
6044    FORMAT(//10X,'TOTAL COST',F20.2)
       WRITE(6,6044)SUM
       TOTREV=0.0
```

```
      DO 9791 I=1,NC
      DREV=PRICE(I)*ID(I)
      TOTREV=TOTREV+DREV
9791  CONTINUE
      REVNET(IRUN,MD)=TOTREV-SUM
      WRITE(6,6040)REVNET(IRUN,MD)
6040  FORMAT(//10X,'NET REV. IS =',F20.2)
9891   IRUN=IRUN+1
      IBRUN=IBRUN+1
      IF(IRUN.EQ.ISIM)GO TO 9995
      IF(IBRUN.EQ.IBLOC)GO TO 3402
       WRITE(6,2006)
      GO TO 3229
9995  IACT=ISIM-1
      WRITE(6,2006)
      WRITE(6,5031)
5031  FORMAT(5X,'REVENUE RESULTS OF EXP. DESIGN, BY TREATMENTS',//)
      DO 9996 I=1,IACT
      WRITE(6,5011)(REVNET(I,J),J=1,MODE)
       PUNCH 5011,(REVNET(I,J),J=1,MODE)
      WRITE(9,5011)(REVNET(I,J),J=1,MODE)
9996  CONTINUE
5011  FORMAT(4F20.2)
      WRITE(6,5021)
5021  FORMAT(10X,'LOCATION VECTOR TESTED WITH EXP. DESIGN')
      DO 275 JJ=1,MODE
      WRITE(6,271)(V(JJ,J),J=1,NW)
271   FORMAT(//,12F6.0)
```

```
      275   CONTINUE
            WRITE(6,2006)
            WRITE(6,6061)
 6061       FORMAT(10X,'EXP. DESIGN SAMPLING PLAN FOR 8 FACTORS')
            WRITE(6,6071)
 6071       FORMAT(15X, '0=STANDARD LEVEL, 1=ALTERNATE LEVEL OF FACTOR')
            DO 6065 I=1,64
            WRITE(6,6066)(PLAN(I,J),J=1,8)
 6066       FORMAT('0',8I5)
 6065       CONTINUE
 9901       STOP
            END
```

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