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FACILITY LOCATION ANALYSIS IS JUST THE BEGINNING (IF YOU DO IT RIGHT)

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ABSTRACT. The question *How many warehouses should we have?* is deceptively simple because a proper answer requires answering, at the same time, a host of interdependent questions. We think that this calls for a comprehensive distribution planning model with optimization capability. Such a managerial tool can be used to deal not only with warehouse location questions, but also with a variety of additional management questions. With this approach, the seed provided by the facility location issue can bear fruit of added utility far beyond original expectations.

The authors' experience is that this full potential is seldom achieved in practice without deliberate efforts to remove the block caused by the usual narrow focus on "just" locating facilities.

"How many warehouses should we have?" This question arises periodically at virtually every company offering goods in the marketplace. It has led to numerous methods for facility location and has given rise to innumerable computer programs for dealing with this question at individual companies. We believe that, to date, this literature and these computer programs have not begun to yield more than a small fraction of their potential value to management.

There are at least three reasons for this unfortunate state of affairs: *One*: Facility location models have not always been sufficiently comprehensive. *Two*: Computer programs for facility location often lacked the requisite capability for optimization. *Three*: Even if the model is sufficiently comprehensive and optimization capability is available, preoccupation with just locating facilities tends to distract from the wider range of issues which *should* be considered.

This paper addresses all three points, with particular emphasis on the third. We hope this will place facility location modeling in a more profitable perspective for management.

THE NEED FOR COMPREHENSIVENESS

The issue of how many warehouses a firm should have is bound up with such issues as:

(1) warehouse mission,
(2) warehouse design,
(3) warehouse location,
(4) operational utilization.

FACILITIES/EQUIPMENT—LOCATION; PLANNING

Issue (1) involves such decisions as which products should be inventoried at a warehouse and how the warehouse fits into overall customer service, inventory, and transportation strategies of the company. Issue (2) raises questions about ownership alternatives (public? leased? owned?), about the degree of material handling mechanization to be employed, about the size of the facility, and so on. Issue (3) raises questions about balancing the advantages of nearness to customers against nearness to plants from a transportation viewpoint, with due consideration of regional labor and tax differentials and of less tangible ''market presence'' considerations. Issue (4) raises such questions as the proper assignment of customers to warehouses, the proper use of cross-docking and plant direct supply, and the proper pattern of inbound supply.

These questions in turn raise still other questions. For instance, in a situation where there are multiple sources for some products, how much of each product should be produced by each plant or vendor (different sources have different landed costs at customers and warehouses)?

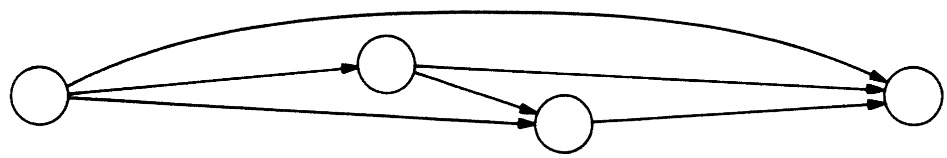
As these issues are clearly interdependent they should be dealt with simultaneously, if possible. Ignoring some of the interactions or dealing with issues sequentially instead of simultaneously can yield misleading conclusions and result in poor managerial decisions.

It follows that a *comprehensive* distribution planning system along the lines sketched in Figure 1 is required. The three fundamental entities involved in dealing with commodities (aggregations of individual products) are: ''sources'' (plants, copackers, vendors), existing and candidate ''distribution centers'' or ''DC's'' (master distribution centers, regional distribution centers, branch warehouses), and ''customers'' (aggregations of individual customers). Sources may have supply costs and lower and upper limits on supply. Each candidate distribution center has a specific mission specifying which commodities can be carried, ownership option and type of design, possible lower and upper throughput limits, and a cost structure composed of fixed and variable costs (covering storage, handling, inventory carrying, taxes, etc.). The customers have forecasted demands to be met for each commodity, normally by delivery from some distribution center but possibly also by direct shipment. Company policy must be observed with regard to split shipments to customers (e.g., certain commodities must be all supplied from a single distribution center). Transportation links can be included or excluded as desired (e.g., based on customer service considerations), and every link has a commodity-specific freight rate which reflects the appropriate mix of modes and weight breaks.

Such a model would enable calculation of performance measures covering cost and customer service for any consistent set of assumptions, data, and design for the distribution system. Also shown in Figure 1 is the function of the solver needed to find the best design for the distribution system for any consistent set of assumptions and data. (''Best'' here means cost minimizing, although this is equivalent to profit maximizing under the assumption of known demands to be met exactly. Other assumptions concerning demand or customer service may call for a modified statement of solver function.)

Distribution planning systems of the type indicated are now practical for most firms.

FIGURE 1. SKETCH OF A COMPREHENSIVE DISTRIBUTION PLANNING SYSTEM.



SOURCES	EXISTING & CANDIDATE DISTRIBUTION CENTERS	CUSTOMERS
• List of Commodities • Supply Limits (for multisource commodities) • Supply Costs (for multisource commodities)	• Eligible Commodities for each Candidate DC • Min and Max Allowable Annual Throughput Volume for each Candidate DC • Distribution Center Costs Fixed, Variable	• Customer Demands • Split Delivery Policy

• Freight Rates: Inbound, Direct, Interwarehouse Transfer, Outbound

MAIN FUNCTION OF THE SOLVER

Determine
- how many DC's, where, and what size
- DC territories
- all transportation flows
- source loadings

so as to minimize total costs
- supply (e.g., manufacturing)
- transportation
- warehousing
- inventory
- system reconfiguration

subject to all appropriate constraints
- supply capacity
- DC throughput capacity
- demands to be met
- single-sourcing of customers
- customer service

THE NEED FOR OPTIMIZATION CAPABILITY

Models of the type sketched in Figure 1 are today most commonly run with nonoptimizing solvers (heuristics of one type or another). The reason is simply that true optimization has until recently been technically difficult to achieve owing to the highly combinatorial nature of the problem. Consequently, numerous suboptimal methods have come into use.

We feel that the consequences of this situation are more unfortunate than is generally appreciated. The problem is not that optimization capability is needed to cope with the staggering number of alternatives for distribution system design, although this is important. It is not that optimization capability is needed to resolve the cost trade-offs inherent in distribution planning, although this too is important. It is not even that managers would rather have the best answers possible from their planning support systems, although certainly this is compelling. Rather, the crux of the matter is that *optimization capability is needed to permit reliable comparisons between different runs of the model*.

If the solver is heuristic in character, such comparisons will be very unreliable because comparing two error-prone solutions greatly magnifies the relative error. Erroneous conclusions are likely to result. (An exception would occur in the rare case where the error distribution of the heuristic is known, and the comparison error is demonstrably small relative to the true difference being measured.)

The importance of inter-run comparisons should not be underestimated. They are needed to justify conclusions reached with the help of the model by (a) exploring uncertain assumptions, (b) studying the impact of alternative futures, and (c) measuring the performance differences between the leading alternatives. Inter-run comparisons are essential in ferreting out the reasons *why* the distribution system has the cost and customer service behavior that it does as factors change. And, as will be brought out in detail in the next section, they permit a greatly expanded repertoire of uses for the model.

It is our repeated observation that these motives for making inter-run comparisons are so overwhelming that, in practice, comparisons nevertheless are made and conclusions drawn even when a heuristic rather than optimizing procedure is used. The severe qualifications which should accompany the presentation of such conclusions to management are, lamentably, seldom as visible as they should be and sometimes entirely absent.

See Geoffrion and Van Roy [1979] for an in-depth discussion on the risks of using heuristics in distribution planning.

VARIETY OF USES OF A COMPREHENSIVE OPTIMIZING "FACILITY LOCATION" SYSTEM

A comprehensive optimizing distribution planning system along the lines of Figure 1 has a surprisingly wide variety of potential uses. These may be conveniently grouped as follows:

I. Network Rationalization Issues

II. Adaptive "What If ...?" Questions

  A. Environmental Changes

  B. Business Decisions and Policies

III. Parametric Studies

Each category will be discussed in turn.

I. Network Rationalization Issues

The basic question to be answered is: Given a certain required level of customer service, what is the most appropriate structure for the distribution system, and how should products flow through that structure to minimize total system operating costs? This general question includes the following specific ones.

1. *How many DC's should there be, and where?*

2. *Proper ownership and design option for each DC?*

Whenever it is desired to select among ownership options (public, lease, purchase) or design options, these options must all be represented either implicitly or explicitly on the list of candidate DC's (for each city where a choice is to be made, there can be more than one version of the facility on the list).

3. *Proper size of each DC?*

DC "size" is measured in terms of annual throughput volume, which usually can be converted without difficulty into average and peak requirements for physical space.

4. *Source direct versus warehousing versus crossdocking choices for serving individual customers?*

The model must be set up with all possible alternatives explicitly available in order to get at the crossdock vs warehouse issue. This typically involves replicating the candidate DC's to reflect differing missions.

5. *Inbound transportation flows: allocation of supplies to DC's and customers?*

6. *How much of each commodity should come from each source?*

7. *Outbound transportation flows: which customer groups get which commodities from which DC's?*

8. *How should inventory be deployed?*

Proper inventory deployment can be inferred from the annual throughput of each of the commodities carried at each of the DC's, and also by the model's choice among any stocking mission options provided on the list of candidate DC's.

9. *Relative profitability of customers and products?*

These questions differ from the preceding ones in that they do not represent distribution system design issues to be answered optimally. Rather, they are questions concerning the optimal design once it has been found. The ability to answer such questions is one of the benefits of having a truly comprehensive model of the distribution system. The answers have implications for pricing policy, promotion planning, sales allocation in times of short supply, and perhaps also for dropping unprofitable product/customer combinations.

All of the above questions can, in principle, be addressed simultaneously and answered by a single optimization run. Of course, in practice several alternative scenarios (each requiring its own computer run) may be necessary to take account of the alternative futures which need to be considered.

II. Adaptive "What if ...?" Questions

The usefulness of a distribution planning system along the lines of Figure 1 can be extended greatly by using it in a "casewise" manner. By this we mean that model assumptions or data are changed and reoptimization carried out in order to observe the change by comparison with a "base case" or "reference" run. This is commonly known as asking "What if ...?" questions.

It is very important to draw a distinction between adaptive and nonadaptive answers to such questions. Suppose, for the sake of illustration, that we wish to evaluate the impact of distribution center labor cost inflation over the next few years. A *nonadaptive* evaluation of the impact could be obtained by revising the labor component of distribution center costs and recalculating the total labor bill using the base case solution with no reoptimization. The resulting evaluation is of limited managerial interest because it presupposes that the distribution system will not adapt in any way to increased labor costs. It would be of considerably greater managerial interest to reoptimize using the higher labor costs. The resulting *adaptive* evaluation would take account of the fact that some of the increased labor costs can be avoided by such measures as (a) shifting volume to DC's in regions with lower labor rates, (b) substituting transportation for warehousing, and (c) installing labor-saving equipment. The user could preclude certain types of adaption (e.g., relocation of warehouses) if desired by fixing certain decision variables prior to performing the reoptimization.

Adaptive answers to "What if ...?" questions require optimization capability. Heuristic solvers are risky because of the previously mentioned dangers associated with inter-run comparisons. Such comparisons are, however, at the very heart of "What if ...?" questions. At least two runs are necessary for each "What if ...?" and sometimes, as in plant location studies, the number of cases to be compared may be considerably more than two.

Cited below are a number of "What if ...?" situations where adaptive evaluations are usually desirable. The list is far from exhaustive. For instance, a variety of other "What if ...?" questions arise in the course of trying to understand the influence of various modeling assumptions on results. For this purpose one must make changes to such estimated factors as unit costs, facility capacities, demand forecasts, and so on, and observe the resulting effect on distribution system structure and performance.

II. A. *ENVIRONMENTAL CHANGES*

Changes in the environment are not subject to managerial control, but management should try to understand the possible impact of such changes on the firm and be prepared to adapt promptly as changes occur. The following examples are illustrative.

1. *Impact of possible changes in demand structure*

How should the distribution system adapt to continuing demographic shifts? To a slowdown in the economy? To an anticipated gain in market share in the Southeast? Just revise the demand segment of the model and reoptimize.

2. *Impact of higher fuel costs for transportation*

Higher fuel costs influence different modes of transportation differently. To determine the impact of higher fuel costs, express these higher costs in terms of higher freight rates by mode/weight break over all commodity/lanes, and redo the optimization.

The distribution system will be rebalanced so as to absorb the increased fuel costs with the smallest possible increase in total system costs (by such means as using lanes which are more fuel efficient in preference to lanes that are less so).

Another approach is to consider a revised mode selection policy which is more fuel efficient than the present one; regenerate the freight rates using the new policy and reoptimize.

3. *Impact on a plant or DC of transportation strike, natural disaster, weather closure, energy shortage, etc.*

Simply rerun the reference case with suitably reduced plant or DC capacities or with certain transportation lanes omitted. Such results can be worked out *during* a crisis to help cope with it, or *before* the fact if a specific risk is identifiable and contingency planning or vulnerability analysis is desired.

II. B. *BUSINESS DECISIONS AND POLICIES*

Alternative business decisions and policies need to be evaluated carefully before committing the organization's resources. Here we successively focus on several functional areas to indicate some of the issues which can be evaluated in a fully adaptive manner.

PRODUCTION

1. *Evaluation of plant capacity expansion proposals*

It takes one run to evaluate each plant capacity expansion, plus (usually) a base or reference run where no expansion is allowed. Just increase the upper limit on plant capacity, change the production costs, reoptimize, and compare total system costs. The best use of the new capacity will be revealed.

2. *Plant location studies*

Plant location decisions are usually taken very seriously by top management, far more seriously in terms of noncost criteria than DC locations. Hence it is usually advisable to examine the candidate plant locations individually on a case-by-case basis. Each case requires a run to rebalance the distribution system for the location alternative being evaluated.

3. *Impact of introducing a new product line or discontinuing one*

Add or delete all of the appropriate problem data for a commodity or group of commodities, reoptimize, and compare the results.

MARKETING

4. *Pricing policy analysis*

Changing prices generally changes market share. Suppose that specific consequent market share changes are projected by customer group. Total revenues before and after the price change are easily computed from price and demand information. The minimum total distribution costs before and after can be computed. Subtracting one from the other yields total profit before and after the price change, which is the desired evaluation of the new pricing policy given the projected effect on market share.

5. *Split delivery policy analysis*

What would happen if a change of policy were to allow certain products to be supplied to a customer from different warehouses, instead of having to come from a single warehouse as at present? What about the opposite situation?

It is straightforward to alter the split delivery rules, reoptimize, and then observe the effect on minimal total cost.

6. *Expanding into new market regions*

Demand data can be revised to reflect the possible opening of new market regions for certain products. Reoptimization thoroughly assesses the effects of such marketing actions on distribution system structure and cost.

TRANSPORTATION

7. *Transportation policy analysis (e.g., common carrier vs private fleet, freight consolidation)*

To evaluate a proposed new transportation policy, work out the influence of the new policy on average freight rates (taking into account changes in mode choice and the relative frequency of different shipment sizes), change the rates and reoptimize. Compare the new results with the corresponding run for the current transportation policy. As always, the entire distribution system will adapt to make the most of a revised policy.

8. *Evaluation of DC capacity expansion or mechanization proposals*

Revise DC capacity and cost data, and reoptimize. Additionally, there is the option of automatically selecting the best of all design proposals for every DC location *in a single run* if one includes all of these choices as explicit alternative DC's in the model (each with its own capacity limits and cost structure). Thus proposals for DC expansion and mechanization can be examined either case-by-case or all at once.

9. *Inventory policy comparisons*

Every inventory policy has associated with it an implied relationship between average annual inventory levels and annual demand, for each commodity at each DC. Change any parameter of the inventory policy — for example, reduce the target stockout rate — and the implied relationship changes. This relationship is, of course, one of the components of each DC cost versus throughput function, which in turn determines the fixed and variable (by commodity) DC cost data elements. Consequently, to compare two alternative inventory policies:

(a) work out the effect on the relationship between average annual inventory level and annual demand,
(b) feed this change into the problem data via the fixed and variable DC cost data elements,
(c) carry out the optimization with the revised data, and
(d) compare the results.

GENERAL

10. *Impact of combining autonomous divisional distribution systems*

Many large firms presently run several autonomous distribution systems, whether by design or as a historical accident of growth. How much is it worth to combine them? Separate runs can optimize the autonomous systems separately. A combined run can be carried out to optimize under the assumption of shared facilities. This puts a price tag on the value of combination, and also indicates *how* the systems should be combined.

11. *Evaluation of alternative distribution echelon structures*

Various techniques are available to deal with a variety of echelon structures. The best of each type of echelon structure usually can be found in a single run — so with several runs one can evaluate several types.

12. *Implementation priority analysis*

Implementation priority analysis runs identify the specific changes in the distribution system (especially the opening or closing of distribution centers) which account for the largest potential savings. This helps management to decide which changes to implement first, which to do later, and which are too marginal in benefit to be worth the organizational upset of doing at all.

III. Parametric Studies

A parametric study involves the systematic variation of a single factor, with optimization performed for several different values. The aim is usually to obtain results in the form of a curve representing the essence of the influence of the factor being varied. Whereas the comparison of two runs is always meaningful for "What If" uses, this is not so for parametric studies like those listed below. A carefully matched series of at least three runs is needed: you can't tell the shape of a curve from only two points.

1. *Quantify the trade-off between least distribution cost and customer service*

The trade-off between distribution cost and customer service is one of the most important relationships which the distribution planner can study. It is obtained by finding, for each of several different levels of customer service bracketing the current level, the least cost distribution system.

2. *Quantify the variation of least distribution cost with the number of DC's*

For a given level of customer service, what is the least cost distribution system for each of several different numbers of distribution centers? This relationship is of vital interest to management for a variety of reasons.

3. *System sensitivity analysis with respect to any factor (e.g., inflation by cost category)*

4. *Influence of demand change over time*

If demand is presumed to change for several years with known regional change factors by commodity, one can do a series of runs which traces the evolution of the least cost distribution system over time. Note that this is not the same as solving the dynamic multiperiod extension of the problem sketched in Figure 1.

The first three types of parametric studies are discussed in some detail in Geoffrion [1979].

CONCLUSION

The major points made in this article can be recapitulated briefly as follows.

1. The very concept of a pure "facility location analyzer" is obsolete: facility location decisions require a *comprehensive* distribution model that deals simultaneously with interdependent decisions.

2. Only distribution planning systems which truly *optimize* permit reliable comparisons of the results of different computer runs. One consequence of optimization capability is that "What if ...?" questions can be answered in a *fully adaptive* fashion; that is, the entire distribution system can be rebalanced optimally to accommodate the implied change(s).

3. A comprehensive optimizing distribution planning system has a surprisingly *rich variety of uses* beyond facility location and its interdependent decisions. These extend beyond network rationalization to the study of many possible environmental changes and alternative business decisions and policies. And parametric studies can illuminate important relationships of managerial interest. Much depends on the imagination of the user to recognize the many opportunities for profitable use of the planning system.

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