Slop: A Strategic Multiple Store Location Model for a Dynamic Environment

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SLOP: A STRATEGIC MULTIPLE STORE LOCATION MODEL
FOR A DYNAMIC ENVIRONMENT

Working Paper 84-110*

by

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Abstract

This paper develops a strategic multiple store location decision model (SLOP) to address the issue of uncertainty in planning the long-term development of an optimal network of stores in a dynamic market environment. In the presence of high uncertainty about the future environment, a multiunit company may find that the optimal network of store locations selected at the time of original planning may be suboptimal in the long term. This complexity in the planning process may arise from the uncertainty in predicting the future market environment. By incorporating a set of alternative future scenarios, the model allows the planner to maintain flexibility by preserving future location options in the development of an optimal network of stores.
Introduction

In recent years, a number of approaches have been proposed to evaluate the location of potential stores. Of the various approaches, the analog method (Applebaum 1968) and multiplicative competitive interactive (MCI) models seem to be the most popular approaches. MULTILOC, (Achabal, Gorr, and Mahajan, 1982) a recent extension of the MCI model, addressed the multiple store location decision faced by many multi-store retailers in optimally penetrating a given market area. However, one of the facets of the retail location decision that is receiving greater attention is the potentially dramatic impact of the changing locational environment (see, for example, Ghosh and McLafferty 1982, Ghosh and Craig 1983).

The market state which exists at the time of the original planning decision may bear little similarity to that which will exist in the future. This uncertainty about the future environment may be caused by a number of factors such as changes in population growth patterns, shifts in demographic profiles, emergence of new competitors, and/or changes in the location strategy of existing competitors. In the presence of high uncertainty about the future environment, a multi-store company may find that the optimal spatial configuration of stores selected at the time of original planning may be suboptimal in the long term.

This complexity in the planning process may arise from the uncertainty in exactly predicting the nature of the future market environment. When forecasting models are applied to medium and long-range planning efforts, where the assumption of constancy is invalid, the result is a most probable future condition based on the expected outcomes of the events forecasted. This approach typically involves the development of a single forecast of the nature of demand at some future time period. This forecast may represent the results of a
consolidation of expert predictions or, possibly, reflect the projection of a single individual or firm. This description of the future is subject to a high degree of variance, and in these situations a multiple store location strategy based on a single "most probable" state may not be desirable. Further, reliance on a single forecast may lead to the development of an inferior configuration of stores in a market area; one that by its very nature is extremely expensive and difficult to alter.

An alternative approach to cope with the uncertainty in predicting the future environment is to integrate several scenarios of the future into the location decision process. A set of alternative futures can be developed simply by combining best-case and worst-case scenarios with the most probable future, or by identifying events within the planning horizon that will alter historical trends (Vanston, et al. 1977; O'Connor 1978; Linneman & Klein 1979). Such scenarios would be conditional forecasts—a future state that is contingent upon the outcome of a specified event.

While there has been a significant stream of research on the dynamic location of facilities (see e.g. Scott 1975; Sheppard 1974), the incorporation of alternative futures has received less attention (Schilling 1976, 1980; Ghosh and McLafferty 1983). When alternative scenarios are defined, the task of picking the correct one as the basis for location planning remains (Schilling 1982). In reality, however, there is a greater likelihood of selecting the correct scenario at some future time than at the present. This is due to the continual reassessment of prior scenario probabilities permitted by the new information about the market environment available to the decision maker over time. If a manager can delay choosing a location for a portion of a multiyear planning horizon, he or she is more likely to select a future location configuration that
will more closely match the future environment than if the selection were required immediately. A closer examination of the problem setting will reveal how this decision can be postponed.

In a typical multi-store operation concerned with penetrating a new market area, or expanding in current markets, not all the stores would be built simultaneously. Instead, their construction would be spread out over the planning period (e.g., five stores a year). The planning period, then, can be defined as covering the time until the entire system is completed. In addition, it can be assumed that, within the planning horizon, each of the stores is considered permanent (i.e., there are no relocations) since firms typically must commit to leases for a minimum of five to ten years. In effect, then, the design of the final configuration of stores is a series of irreversible decisions.

At each decision point, the planner is faced with the problem of siting a store that will become a part of the final locational configuration. Unfortunately, the construction of a store at a given site precludes consideration of all alternative configurations that do not include a store at that location. Every time a decision is made (a store is built), alternate locations are preempted; that is, future alternative configurations are eliminated from consideration (Schilling 1982). In order to maintain flexibility, it would be useful to make decisions that minimize options foreclosed or, equivalently, maximize options available to the location analyst.

"Option" as defined by Schilling (1982) is a future configuration of stores. An option is foreclosed (that option cannot be obtained) when a facility is located somewhere other than at one of the sites dictated by the option. Certainly some options perform worse than others, so that there are some options a location planner would not mind foreclosing. It follows that the
process for identifying options should consider only those final configurations that provide desirable profitability in a specified scenario.

Now consider a pair of options, each providing desirable profitability in a specific (different) scenario, that also have a number of locations in common. A store in the common set can be constructed and both options will remain viable; neither option has been foreclosed. In fact, the decision between these two competing options can be delayed as long as only the common stores are built. In this way, the decision maker can delay selecting an ultimate configuration until more information and better predictions are available on which future will actually occur. Further, if the two options provide the best possible performance in their associated future, then, as long as only common stores are being built, there is no sacrifice in the total system profitability of the final set of stores. The decision maker has not lost the opportunity to construct the optimum location pattern for either future. Additionally, the planner has acquired time to revise and update forecasts, therefore increasing the probability that the final locational configuration will correspond to the actual optimal configuration desired at the end of the planning horizon.

If some reduction in the performance of the final set of store locations is permitted, options could be identified that have an even greater number of common stores and therefore can support an even longer grace period. During this period, the interim level of sales performance should be maintained since the common stores would tend to serve areas of demand common among the scenarios. These areas would, in most situations, correspond to the current state, which forms the core for future growth. Thus, constructing common stores first provides service for current demand. Similarly, the sites that are not shared by the options would tend to serve areas where demand is expected to
arise sometime in the future. The analysis of options, then, is ultimately concerned with identifying a set of locational configurations, where the number of configurations (options) in the set is equal to the number of scenarios under evaluation. Each option in the set would provide a desired level of profitability in its associated scenario and would also have a higher number of store sites in common with the other members of the set. For example if two future scenarios were being evaluated, options would be developed in pairs, with each pair having a designated number of common store locations.

In sum, the planner can decrease the risk associated with relying on a single forecast by considering several future scenarios and identifying good locational configurations for each with as large a similarity in site selection as possible. In essence, the configurations represent contingency plans and the common sites provide the potential for maintaining the viability of those contingency plans. The analysis of options permits the planner to retain much of the flexibility of the present while continuing to analyze and preserve future location options towards the development of a network of stores. The development of this model, termed SLOP (Strategic Location with Options), is presented in the next section. The SLOP model is subsequently applied to the data developed by Huff and Blue (1966) to illustrate its use in multiunit store location decisions in a dynamic environment.

Options Analysis for Multiple Store Location Decisions

In order to develop the model, suppose that 'R' new stores are proposed for a market consisting of 'S' existing stores with 'M' customer originating areas. Given a proposed configuration of new store sites and other attributes of the new
stores, the following MCI model provides predictions of the probability \( P \) of a customer originating in area 'i' shopping at new store 'r' in future 't':

\[
P_{irt} = \frac{\prod_{k=1}^{K} \beta_{kt}}{\sum_{r=1}^{R+S} \prod_{k=1}^{K} \frac{A_{irkt}}{\beta_{kt}}} (1)
\]

where
\( r = 1, \ldots, R \) are new stores and \( R+1, \ldots, R+S \) are existing stores;
\( A_{irkt} = k \)-th attribute describing the new or existing store (r), attracting costumers from area i, \( k=1, \ldots, K \), in future t, \( t=1,2, \ldots, T \).
\( \beta_{kt} = \) estimated parameter associated with the \( k \)-th attribute in future t.

Such probability estimates allow the estimation of expected patronage, sales, and profit from each new store (see e.g., Achabal, Gorr and Mahajan 1982) in each future scenario.

While store size and distance are the attributes utilized later to illustrate options analysis for the multiple store location decision problem, calibration of MCI models in empirical studies should be based on consumer surveys and customer origin studies to determine the most significant attributes in each market in each scenario (see, e.g., Jain and Mahajan 1979; Stanley and Sewall 1976). Furthermore, if consumer research indicates that situation-specific segmentation is a factor (Miller and Ginter 1979), the model should be modified; for example, demand at each customer origin area 'i' could reflect work-based plus home-based shopping trips.

The options analysis of multiple store location and design problems requires the selection of a subset of \( R \) store locations out of \( N \) potential locations as
well as choices on particular values for the attributes, such as store size, for each site. Suppose that for each scenario, attribute $A_{irk}$ can take on $v_k$ values; for example, $k=1$ may signify distance, so that $v_1 = 1$; $k = 2$ may signify store size, with large, medium, and small sizes under consideration, so that $v_2 = 3$; etc. If all combinations of values for the 'K' attributes are possible at a site, then across all scenarios there are $L = (v_1)(v_2)\ldots(v_K)$ distinct store designs. Managerial judgment may serve to limit attention, however, to a more restricted set of designs appropriate for specific sites within a market.

The decision variables are:

$$x_{jlt} = 1,$$ if a store of design $l$ is to be constructed at location $j$ in future scenario $t$, $j=1,\ldots,N$, $t=1,\ldots,T$.

$$= 0,$$ otherwise

$$W_{jlt} = 1,$$ if a store of design $l$ is to be constructed at location $j$ in all scenarios.

$$= 0,$$ otherwise

It is now possible to write the SLOP model:

$$\text{Minimize } Z = \sum_{t=1}^{T} \sum_{i=1}^{M} \sum_{j=1}^{N} \sum_{l=1}^{L} \left( \sum_{j=1}^{N} \sum_{l=1}^{L} \left( C_{jt}E_{it}P_{jlt} - \sum_{j=1}^{N} \sum_{l=1}^{L} F_{jlt}(x_{jlt} + w_{jlt}) \right) \right)$$

subject to

$$\sum_{l=1}^{L} (x_{jlt} + w_{jlt}) \leq 1$$

$$j=1,\ldots,N$$

$$t=1,\ldots,T$$

$$\sum_{j=1}^{N} \sum_{l=1}^{L} (x_{jlt} + w_{jlt}) = R$$

$$t=1,\ldots,T$$
Equation (2) in the model is a scalar representation of a multiple objective function measuring profits in each future scenario (Marglin 1967). The priority weights, \( \lambda_t \), reflects the trade-offs among the scenarios. It can be set equal to one or varied to reflect the relative importance of the scenarios. Establishment of a specific set of weights can be used to reflect a subjective estimate by the decision maker of the likelihood of occurrence of the specific scenarios under evaluation. As is the case in the setting of any parameters in a mathematical model it is, of course, desirable to perform an analysis to evaluate the sensitivity of the solution to these weights. In addition, there are numerous techniques available to the decision maker for establishing appropriate objective weights (see, e.g. Cohon 1978; Zeleny 1982).

Total expenditures by consumers in area 'i' in future scenario 't', \( E_{it} \), are fixed and assumed independent of the network of stores. The sum yields the expected revenue from the \( R \) new stores for each future scenario, while the multiplication by fraction \( C_{jt} \) provides profits before deducting fixed costs. \( F_{jt} \) is the fixed cost of a store of design 'L' at site 'j' in future 't'.

Equation (3) restricts the number of stores at any given site to be no more than one. Equation (4) ensures that exactly \( R \) stores will be located and designed while equation (5) sets the number of common stores (H) across the scenarios.
In equation (6), the subscript \( k \) refers to \( \ell \)-th value of attribute \( k \), \( j = 1, \ldots N \) are potential locations for new stores, and \( j = N+1, \ldots N+S \) are existing locations. The MCI model, equation (1), is extended in equation (6) to include the decision variables \( x_{jlt} \) and \( w_{jl} \). As is evident from equation (6) for each scenario, any change of a site or design alternative has a complex effect on \( P_{ijt} \).

The SLOP model, equations (2)-(6), is a comprehensive statement of the multiple-store location and design problem with options, and represents an extension of the retailing models presently in the literature. Note that if, for example, \( H=0 \) in equation (5), i.e., no common sites, the problem reduces into \( T \) separate statements of the original (single scenario) MULTILOC model. Equation (5), in fact, ties these separate problems together, constraining the solution for each problem to have the required number of common sites. On the other hand, if \( H=R \), that is, all stores are in sites common to all scenarios, the SLOP model reduces to the special case presented by Ghosh and McLafferty (1982).

**Solution Procedure**

Since the objective function of the SLOP model is nonlinear and nonconcave, it is not possible to solve using exact optimization techniques. A complete enumeration of all feasible store configurations often is not practical or even possible because of the extremely large number of alternatives. Consequently, a simple heuristic based on the vector substitution method described by Teitz and Bart (1968) was developed and used in the illustration discussed later in the paper (see, also, Cornuejols, Fisher and Nemhauser 1977; Achabal, Gorr and Mahajan, 1982; Ghosh and McLafferty, 1982).
Beginning with an initial location/configuration, the interchange heuristic proceeds by attempting to improve the current solution. A single pass consists of comparing each location/configuration combination of the current solution in turn with all location/configuration possibilities not in the current solution. Whenever a location/configuration is encountered that improves the current solution, an interchange is made. The now inferior location/configuration in the current solution is removed and the superior location/configuration is substituted. Before an interchange is made, care must be taken that condition (3) of the SLOP model is not violated: interchanges that produce two stores at the same location are not carried out. Passes are made until no (significant) improvement is made in the objective function (2) from one pass to the next.

As discussed earlier, the SLOP model requires evaluation of two types of locations: sites which are common to all scenarios (recall there are H of them), and sites which are unique to each scenario (the remaining (R-H) sites). In order to find the common sites (among scenarios) and the unique sites (for each scenario), the substitution in the interchange heuristic is performed on each of the locations. Briefly, the following steps are needed to implement the heuristic:

a) Given an initial solution, for each store common to all scenarios and for each site available to a common store, interchange the current common store to the test site. Evaluate the profits of the resultant interchange. If the interchange results in improvement, locate the common store at the test site. If not, retain the current common site.

b) Perform (a) for each site and for each store until the required number of common stores have been located with no further improvement in profits.
c) For each store not required to be common among scenarios, and for each site available to a unique store in this scenario, relocate the current unique store to the test site. Evaluate the total profits of the resultant change. If the interchange produces an improvement in the total profits, locate the current unique store at the test site. If not, retain the current unique site.

d) Perform (c) for each unique site in the scenario.

e) Perform (c) and (d) for each scenario.

f) Return to (a) until significant further improvement in total profits is not possible.

Implementation of the interchange heuristic requires specification of a starting location configuration. Since optimality cannot be guaranteed, the starting solution can be expected to influence the quality of finalion. An advisable solution strategy, therefore, is to apply the heuristic to several randomly selected starting location configurations. Our experience, however, is that the solution procedure is relatively robust and that only two or three starting points are required to produce consistent results. This result was also reported by Achabal, Gorr, and Mahajan (1982) in their research in developing the MULTILOC model.

Illustration

To illustrate the SLOP model, the data set developed by Huff and Blue (1966) is employed. Briefly, the retail facilities described in this data set are food stores located in a market area divided into 80 cells (see Figure 1). The problem in this illustration is to determine the optimal location pattern for four stores that a new firm wishes to open in the market area over a multi-year
planning horizon. A major difficulty in making this multi-period location decision could arise from a situation in which, for example, projections provided by two groups of professional market researchers or urban planners do not coincide. That is, the nature of the future environment is uncertain and dichotomous. These inconsistencies could occur in a variety of ways including differing market area, population forecasts, projected income levels, changing zoning regulations, likely future competitive locations, etc.

To illustrate, two alternative futures are developed that focus on differential projections of population growth in the market area. The forecasts are based on the initial data set developed by Huff and Blue (1966) and represent hypothetical population projections. One projection (Future 1) forecasts a major increase in population to occur in the southwest portion of the market area. This growth, depicted in Figure 2, is projected to be concentrated in market area cells 8-10, 12-14, and 27-32. A second projection (Future 2), depicted in Figure 3, indicates that the majority of the growth in the market is anticipated to occur in the "suburbs," i.e. the cells located in the northeast and northwest areas of the market.

Given these two future scenarios, the problem is to determine 1) if the variation in projections will have a major effect on the optimal set of locations for the firm, and 2) what locations appear to be "good" locations in either scenario. If the firm concentrates on constructing facilities at the common locations first, it will be possible to gather additional information in subsequent periods to reduce the uncertainty associated with the future development of the market.

In order to investigate the above problem, calibration of the SLOP model was done using the log-transform procedure developed by Nakanishi and Cooper.
(1974). The values of the parameters $\beta_k$, as reported in Achabal, Gorr and Mahajan (1982), for store size and distance are 2.0059 and -0.3673, respectively, with an associated $r^2$ of 0.63. Using an initial solution for both futures, the SLOP model was then run to identify the best locations in both Future 1 and Future 2 using the interchange heuristic. The model was solved to generate facility configurations from zero to a maximum of four sites in common between the scenarios. For expository purposes, and without loss of generality, both futures were assumed equally likely to occur ($\lambda_t = 1, t = 1, 2$ in equation 2). These results are summarized in Table 1. The following comments are warranted on these results:

a) The data in the last column in Table 1 suggest that irrespective of the two future scenarios, the best strategy for the firm is to locate the first store in cell 36. Since this location is common to the best location mix under both scenarios (see the first row, zero common sites, in Table 1), by locating the store in this cell, the firm is clearly able to preserve its future location options. Note, however, that besides this cell, the solution for Future 1 indicates locating the other three stores in cells 36, 46 and 47. The Future 2 solution, on the other hand, suggests locating the other three stores in cells 37, 43 and 58.

b) After locating the first store in cell 36, if no additional information is available about the actual likelihood of occurrence of either one of the scenarios, future options can be preserved if the firm builds the second facility in cell 37 followed by the third in cell 46. Note that both of these locations are not in the best location configuration of individual scenarios (in the first row in
Table 1, zero common sites, cell 37 is in the best location configuration for Future 2 and cell 46 is in Future 1. However, location of additional stores in these cells collectively provides a hedge against market-related uncertainty by maintaining future options.

In sum, the results in Table 1 suggest a masterplan that the firm can follow to locate the four stores within an uncertain market environment. As the market begins to develop and additional information is available about actual growth patterns, the firm can use Table 1 to assist in selecting the best location mix. For example, after locating two common stores, cells 36 and 37, if the growth patterns suggest the occurrence of scenario 1, the best strategy for the firm then is to locate the two final facilities in cells 35 and 46.

The masterplan, while preserving future options, provides the sequence that the firm can follow to locate stores while maintaining a hedge against uncertainty regarding the marketplace scenarios. This is clearly an advantage that is currently not offered by any of the multiple store location models. To further illustrate this advantage, the MULTILOC model was run to generate the four best locations on the original data developed by Huff and Blue (1966) yielding the best location mix of cells 35, 36, 37 and 46 with a total profit of $88,527. Three of these locations, cells 35, 36 and 46, are also included in the best location mix for Future 1 while two of them, cells 36 and 37, are included in the best location mix for Future 2 (see the first row, zero common sites, in Table 1). However, since the MULTILOC model does not provide the sequence in which these stores should be located, location of the first store in cell 35 could not have provided the firm with a desired hedge against uncertainty. In addition to not appearing in the best location mix for Future 2, this location (cell 35) also does not appear in the best set of four common sites for both futures.
While the above discussion has focused on evaluating the impact on alternative locational configurations of two scenarios dealing with projected population growth in the market area (i.e. alternative demand projections), it is important to note that other scenarios could deal with factors that would actually effect the parameters of the SLOP model. Further, recent projections of the future market environment focusing on emerging trends in retailing (see Sheth 1983) indicates that many consumer shopping patterns will likely change in the decade ahead. For example, the work by Berry (1979) suggests that the "time buying" consumer will become less willing to travel to stores to make purchases of all classes of goods and services. This has the effect of raising the value of the beta in the SLOP model associated with distance. While this represents only one example, such analyses allow the decision maker to evaluate a broad spectrum of future scenarios within the SLOP framework.

Conclusions

This paper proposed an important extension of the MULTILOC model (Achabal, Gorr, and Mahajan 1982), the SLOP model, which represents a model formulation and solution procedure useful in developing an optimal configuration of stores in a changing market environment. Given uncertainty associated with forecasting the dynamic environment, a great deal of flexibility can be achieved in developing a set of store locations by preserving future location options. In this way, location strategies can be formulated that allow decision makers to maintain future financial performance levels while minimizing the impact of uncertain events on their organizations.
When compared to the multiple store location decision models presented to date in the literature, the SLOP model offers a number of additional advantages. By integrating the location decisions with future scenarios of the dynamic market environment, SLOP provides an opportunity to assess the impact of uncertainty on the desirability of specific locations and to estimate the associated profitability. Further, its output aids in the development of a masterplan that a firm can follow in selecting the best location strategy at any stage of market penetration given the available information on the future environment. By preserving future location options, the SLOP model allows the planner to clearly consider his various location alternatives, to hedge his risk, and to maintain flexibility in adapting to a complex and changing environment.
REFERENCES


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Table 1

Summary of SLOP Results

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<tr>
<th>No. of Sites in Common</th>
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<th>Future 2</th>
<th>Total profit ($) (both futures)</th>
<th>Common Locations</th>
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<td>Profit ($)</td>
<td>Cell Locations</td>
<td>Profit ($)</td>
<td>Cell Locations</td>
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<td>0</td>
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<td>35,36,46,47</td>
<td>136,196</td>
<td>36,37,43,58</td>
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<tr>
<td>1</td>
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<tr>
<td>2</td>
<td>120,875</td>
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<td>120,413</td>
<td>36,37,46,56</td>
<td>135,376</td>
<td>36,37,46,56</td>
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Spatial Distribution of Customer Statistical Areas and Existing Food Store Locations

FIGURE 1
FUTURE 2 DEMAND SURFACE

FIGURE 3
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<td>by John W. Slocum, Jr.</td>
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<td>&quot;Managerial Uncertainty and Performance,&quot;</td>
<td>by H. Kirk Downey and John W. Slocum, Jr.</td>
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