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Applications of Location Analysis in Agriculture

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Abstract : This article provides a sample of the wide variety of applications of location theory in agriculture. The article includes a classification scheme for location models with early applications for each class of problems followed by a detailed presentation of six more recent applications. Specificities of each of these studies, with respect to the agricultural environment, are discussed. A table containing a summary of the major features of several other studies in agriculture is also provided.

1. Introduction

The theory of spatial equilibrium and optimal location has interested economists as early as early nineteenth century. But the earliest work in agriculture location theory was done by von Thünen. In his famous book "Isolated State With Respect To Agriculture And National Economy" published in 1826, von Thünen investigated the influence of distance from the market on agricultural land use. He considered an uniformly fertile plain having a single population cluster in its center with agricultural products to be cultivated on the surrounding land. He observed that the further a farm product is produced from the market, the higher the transportation costs are. Since the price of a product and its demand are fixed, the revenue from a product decreases with distance from the market. Under these assumptions, the following questions were asked :

(1) What pattern of cultivation will take shape? and

(2) How will the farming of the land be affected by their distance from the market ?

A major conclusion of von Thünen's work is that a farmer will maximize its profits by producing the product that has the maximum net revenue at the distance of his farm from the market. The sequence of areas of cultivation follows an increasing order of transportation cost per acre-product. These areas of cultivation are referred to as von Thünen's rings.

Since the original work of von Thünen, a number of theories of optimal location and spatial equilibrium have appeared. This includes Ohlin (1933), Dunn (1954), Isard (1956), Losch (1962), and Weber (1929). A good survey of these early works is given in Weinschienck et al. (1969), and a bibliography of agricultural location theory is given by Kellerman (1989). Most of the early models, which have roots in economics, are explanatory models. In contrast to this, modern work in agriculture location deals with problems which are optimization problems. The analysis now has expanded the scope of the problem by incorporating the supply and demand functions, capacity limitations, and the number of locations.

The purpose of this article is to provide a sample of the wide variety of *applications* of location theory in agriculture. The article focuses on applications from the second half of this century. This period coincides with significant developments in the field of optimization (operations research) and digital computers that have made solution and analysis of more practical problems possible. Note that applications in forestry are not included in our discussion.

The article is structured as follows : section 2 gives a classification scheme for location models, followed by examples of early applications for each class of problems along with some of their extensions. In section 3, six applications are described in detail. A summary of several other applications is presented in Table 1. A discussion of specificity of these models with respect to the agricultural environment is then provided in section 4.

2. Model Classification and Early Examples

2.1 Classification

The first section of this article presents a classification scheme for location problems based on solution space, as proposed by Chhajed, Francis, and Lowe (1993). In this classification, the problem space is divided into three classes : planar models, network models and discrete models. The main difference between these three classes of models is the manner in which the distance between two points is defined. Note that a problem can be posed on any of the three solution spaces and thus, this classification is a function of the model, and not the problem per se.

In planar models, the distance between two points is often Euclidean, and the number of possible locations for new facilities is infinite, leading to problems that are continuous.

In network models, there exists a transport network on which travel occurs. The transport network, for example, may represent a system of major highways and/or roads. The distance between two points is usually defined as the shortest distance on the network. Distances are often more accurately represented in network models than in planar models, but the need for data is also higher in network models since the length of each segment is needed. For such models, a major advantage of working directly with the network lies in exploiting its properties in developing a solution procedure.

In discrete models, distances may be derived from planar or network distances, or some more general type of transport cost which is proportional to distance. The number of existing facilities and the number of potential new facilities are finite. Discrete problems are often modeled as mixed-integer programs (which include continuous and 0-1 variables) and allow for the incorporation of many realistic assumptions which cannot be included in planar or network models. Unfortunately, they are generally more difficult to solve.

2.2 Early Works

Three early papers which appeared around the same time (between 1959-1963) represent remarkably different approaches to addressing location problems in agriculture. These three papers are examples of models posed on different solution spaces as discussed in the above classification and are described, along with their extensions, in the following section.

• Planar Model : Olson (1959) considered the problem of determining the size of milk processing plants and optimal distance between plants in a cooperative dairy industry. He assumed even supply of milk over the region and uniform transportation cost per unit weight of milk. Thus, posed on a plane, the model is an example of planar model. The milk had to be processed into cheese, butter and powder. The variable part of milk collection cost varied linearly with the weight and the volume of the milk collected. The processing cost was assumed to be a polynomial function of the volume processed. The sizes and the interplant distances were calculated using both circular and hexagonal market areas for each plant. In this analysis, Olson showed how the model could be used to study the impact of density of milk production, cost of transportation, and the ratio of fixed cost to volume on interplant distance.

Extensions of Olson's work were proposed by French (1960) and Henry and Seagraves (1960). French (1960) addressed the general relation between assembly cost and plant volume, when a square grid system of roads and multiple products are considered. Selecting an efficient assembly technique and estimating long-run assembly cost functions were also under investigation in this analysis. Henry and Seagraves (1960) addressed the problem of determining the optimal sizes and locations of processing plants for the broiler industry in the south of the U.S. With the problem formulated as a planar model, they investigated the effects of production density on unit costs for the output of a particular firm.

Many years later, Juarez and Romero (1986), building on Olson's approach, considered the problem of determining the optimal size and location of a food-processing plant in a continuous space. Juarez and Romero assume in their analysis that location and size are not independent, but instead fully interdependent variables. More recently, Heaps, Munro and Wright (1992) explored the relationship between the production of grain and the characteristics of the transportation system in an agricultural space which represents the general features of the grain-growing region of Canadian prairies.

• Discrete Model : Stollsteismer (1963) addressed the problem of simultaneous determination of the number, size and location of plants. Four different models were presented and the most general of these (referred as Case II in the article) considered a situation where economies of scale in plant operations exist and where plant costs vary with location.

This model can be briefly described as follows. Supply of a raw material is available at a number of given sites. This raw material has to be processed at one of a given set of possible processing plant locations. The problem is to determine how many processing plants are needed and where they should be located, and also, to identify where the raw material originating from a given site should be processed. The overall objective is to minimize the sum of transportation and processing costs (including the facility cost) of raw material produced in the region. The problem is known as the Simple Plant Location Problem in Location Theory and has been a subject of extensive research. Several other researchers are also credited for independently "discovering" this problem. For a more extensive discussion of the problem and solution approaches, please see Krarup and Pruzan (1983) and Cornueljols, Nemhauser and Wolsey (1990). Stollsteimer used his model to predict the number, location, and size of pear packaging plants in the Lake County region of California in 1970. The solution method suggested by Stollsteimer was complete enumeration.

Several modifications were proposed to extend the applicability of the Stollsteimer's model to more general settings. Because agricultural production is seasonal in nature, processing plants often handle two or more commodities, thus extending the length of their season and/or increasing plant output. Polopolus (1965) accounted for this aspect of the agricultural production and generalized the Stollsteimer's one product model to permit multiple product processing. The major differences between his and Stollsteimer's model were that, in his model, (1) aggregate assembly costs were affected by different locational patterns as the product dimension was increased and that (2) total processing costs depended on both the number of plants and the combination of products handled at each optimum plant location. An application of his model involved three raw and final products (sweet potatoes, okra, and tomatoes), 25 producing origins, and 10 potential processing locations in Louisiana. Warrack and Fletcher (1970) suggested an algorithm to solve the Stollsteimer's model when a large number of plants are involved. The difficulty of solving such a large-scale problem was handled by using two approaches to suboptimization - the Iterative Elimination Approach and the Iterative Expansion Approach. The solution procedure was applied to the feed industry in Iowa. Note that these heuristics are also known as Drop and Add heuristics and are similar to those proposed by other researchers in location analysis (Francis, McGinnis and White, 1992). Ladd and Halvorson (1970) developed simple procedures to determine the sensitivity of a Stollsteimer's model solution to variations in parameters, such as processing and transport costs, and to investigate the effects of continuous changes on the minimum cost solution. Chern and Polopolus (1970) suggested a discontinuous plant cost function to account for the weakness of the continuity and linearity assumptions. Finally, Kloth and Blakley (1971) proposed an extended Stollsmeister's model that determined the optimal number, size and location of processing plants that minimize assembly, processing and distribution costs and that accounted for the effects of market-share restrictions.

• Network Model : The last work to be described in this section is an example of network location problem in which the structure of the transport network is exploited in obtaining the solution. The problem was that of locating threshing floor for small dispersed wheat fields in Peking suburbs (Hua Lo-Keng and others, 1962). Two cases were considered: (1) routes connecting the fields do not form loops (in graph theory, such a network is referred to as a tree), and (2) routes connecting the fields form loops. The solution procedure was given in the form of a mnemonic rhyme with the first verse providing the solution to case (1) while the remaining two addressed case (2).

When the routes have no loops,
Take all the ends into consideration,
The smallest advances one station.

When the routes do have loops,
A branch is dropped from each one,
Until there are no loops,
Then calculations as before is done.

There are many ways of dropping branches,
The calculation for each must be assessed,
After figuring all, we then compare,
And break the loop in the case which is best.

This problem is known as the 1-median problem and the above poem seems to be the first algorithm to the network version of the 1-median problem. The authors also consider the problem of locating more than one threshing floor, proposing a simple solution procedure to the m-median problem on the tree.

Other important network-structured linear programming problems used in location problems in agriculture are transportation/transshipment problems. A description of these models can be found in Glover, Klingman and Phillips (1992). Note that in these problems, the underlying distances may not be derived from a transport network and, in this respect, may not fit in the network model category of the classification scheme given before. An interesting example of such models in agriculture is the one developed by King and Logan (1964), see also Logan and King (1964). They addressed the problem of finding the optimal location and size of California cattle slaughtering plants given the location and quantity of slaughter animals and the final product demand. Both raw product as well as final product transfer costs are considered. Given that the slaughtering costs for animal varied by region and that economies of scale varied with quantity shipped, the combined cost of assembly of live animals, slaughter and shipment of meat to consuming regions was to be minimized. Even though the model was simplified by taking into consideration only one product, the initial formulation involved many variables and constraints and yielded a large problem, which did not allow for economies of scale in processing cost.

Based on the work of Orden (1956), King and Logan modified the basic transportation model to allow for shipments of the product to go by any sequence of points rather than just from m surplus regions to n deficit regions. Basically the transportation model was modified by specifying each production and consumption area as a possible shipment or transshipment point. The problem was reformulated as follows : should animals be slaughtered at the source and meat shipped or should animals be shipped and slaughtered at one of several possible points, and then meat shipped to the demand areas. This restatement of the problem as a transshipment model provided strong computational advantages and allowed an iterative approach to account for economies of scale in assembly and processing costs as well as in product shipment costs.

Some modifications were suggested by Leath and Martin (1966) to incorporate constraints on demand and supply, as well as restrictions on the quantity of a commodity that can be shipped at a given rate. Alternative formulations of the transshipment problem of King and Logan were also proposed by Hurt and Tramel (1965).

3. A Sample of Applications

Location models have been used in a wide range of applications in agriculture. The following section provides a sample of six applications of location analysis in agriculture. For each of these six applications, a description of the problem context, and of the modeling and solution approach used is included. We conclude each problem with a discussion of some of its interesting aspects. These applications were selected to illustrate the diversity of application areas in agriculture location. A summary of several other papers is provided in Table 1.

3.1 A Cotton Ginning Problem

Klingman, Randolph and Fuller (1976) and Fuller, Randolph and Klingman (1976) explored the possibility of cost reductions in a southwestern valley's cotton ginning industry. The drastic decline in cotton production during the previous decade and innovations in seed cotton storage had greatly reduced processing peaks in the ginning industry and had led to an excessive processing plant capacity. Klingman et al. addressed the problem of least-cost organizational adjustment faced by the cotton ginning industry in an irrigated portion of the Rio Grande Valley that traverses Texas and New Mexico. Fourteen ginning plants, some more recent and some older, with various capacities and costs, were operating throughout this valley. But, the typical seasonal cost function associated with each ginning plant (excluding variable costs) could be captured by a piecewise, linear function with a positive intercept, representing a one-time annual fixed cost of activating a closed plant. Two levels of variable labor costs were also associated with each plant - one for regular shift and another, which was higher, for overtime labor shift. Multiple labor shifts allow the plant to potentially adjust to weekly and seasonal outputs. Thus, the use of overtime could be cost saving if it avoided activating an additional plant. Similarly, choosing the option of seed cotton storage at the field could be preferable.

Accounting for the alternatives of overtime labor shifts and seed cotton storage, the authors developed a large-scale mixed-integer programming model in order to explore the possibility of cost reductions that would result from a decrease in the number of operating plants. This model, which minimized aggregated costs of assembly, storage and processing for the region's ginning industry, identified the gins to be activated for processing cotton during the season, the quantity of seed cotton to be left at field storage, the weekly quantities of seed cotton to be shipped from production areas to ginning plants and finally the weekly quantities to be processed at each activated plant. The large size of the problem (139 production sites, 14 ginning plants and 16 production weeks) ruled out the use of standard mixed-integer programming packages. For this reason, the problem was simplified and reformulated as a minimum-cost flow network problem. In this reformulated problem, the number of variables and constraints was reduced : this minimum-cost flow network problem ignored the fixed charges and only included variable costs, such as seasonal variable costs, leading to an easily solvable network problem. The solution procedure involved considering a specific combination of activated plants and then solving the resulting minimum-cost flow network problem to minimize the seasonal ginning cost. In order to avoid the consideration of all possible combinations of activated plants for which the minimum-cost flow problem needed to be solved, the authors proposed an implicit enumeration procedure. The solution to this problem suggested a ginning process industry of 6 plants instead of the 14 existing plants when the field storage option was included in the analysis. Without the field storage option, the optimal organization involved the operation of 9 plants, 3 in addition to the 6 previously identified.

The originality of Fuller et al.'s study lies in their consideration of seasonality, a major characteristic of production of agricultural commodities, and in the development of a solution procedure which exploits the network structure of the problem allowing for the possibility of obtaining solutions for large-size problems beyond the solution capability of traditional mixed integer programming computer codes.

3.2 The Location of Grain Subterminals

As previously mentioned, location models are encountered in a wide range of applications in agriculture. However, the most popular application area appears to be the grain handling and distribution system.

The analysis done by Hilger, McCarl and Uhrig (1977) was concerned with the identification of an optimal organization of grain subterminals within the highly concentrated grain-producing area of Northwest Indiana. The problem can be described as follows. Corn and soybeans are two major commodities produced in the region. They were shipped monthly from 124 local origins (P) to (1) country elevators (C.E.) which could either store them, ship them to subterminals (S) or ship them to destinations (D) or to (2) subterminals which could either store them or ship them to destinations (Figure 1). There were 13 possible destinations, 105 country elevators and 14 subterminals. Several new grain subterminals had been planned by two major companies; 4 were already under construction, and 2 were about to start. The concern within the grain industry was to find out whether the area was becoming over built.

In order to conduct this analysis, corn and soybeans were combined into an aggregate grain. The problem was then formulated as a large mixed-integer programming problem, resulting from a direct combination of the capacitated transshipment problem and the reservoir storage problem (Ratick et al., 1987). The model minimized total annual cost of grain movement from the local elevator or subterminal to destinations. In addition to the investment costs (fixed costs associated with the opening of a new subterminal), the objective function accounted for transportation and handling costs as well as storage costs. In order to solve such a large problem, the authors used a solution strategy based on the application of Bender's Decomposition (Benders, 1962). This technique, which exploits the particular structure of mixed-integer programming problems, separates the integer variables from the continuous variables and gives two independent problems : (1) the master problem, with the integer-subterminal location variables and (2) a subproblem which consists of the grain shipment and storage problem, given known subterminal locations. The two problems are solved iteratively. The transfer of information from the integer problem to the continuous subproblem is done in the form of fixed value for the location variables and, from the continuous subproblem to the integer problem, in the form of shadow prices. However, in this analysis, the resulting LP subproblem was still so large that additional simplifications were required in order for the subproblem to be solved. This led to a loss of the guarantee of optimality. Finally, because of the importance of export markets, the model was solved under two possible scenarios depending on assumptions on the demand market (high exports and low exports). The results pointed out the need for 5 additional subterminals under the high export assumption and for 3 additional subterminals under the low export assumption.

An interesting feature of this study by Hilger et al. is that it incorporates storage and time. Described by Ratick et al. as an interperiod network storage location-allocation (INSLA) model, the Hilger et al. model allows for 3 alternative options : the total amount of grain transported to a node must be either transshipped, stored or allocated to demand. Furthermore, the model allows for temporary storage where the amount of grain in temporary storage corresponds to the difference between in-facility storage and the storage capacity. The additional per-unit cost associated with the amount of grain in temporary storage insures that the amount of grain in temporary storage will be first released since it is more costly than the amount in in-facility storage. Finally, this study provides a successful illustration of the use of Bender's decomposition technique in solving a large size interperiod network storage location-allocation model.

3.3 The Collection and Processing of Rubber

The third application reported in this section combined a routing problem with a plant location problem and was concerned with the collection and processing of natural rubber in Malaysia. The bulk of the Malaysian rubber was produced on "smallholdings". These "smallholdings" are cultivated lands of an approximate size of less than 2 hectares each and they are mostly unorganized. Because of the social and economic importance of the natural rubber industry to Malaysia, an investigation sponsored by the government was undertaken by Nambiar, Gelders and Van Wassenhove (1981) to explore the potentiality of improvements of the rubber "smallholdings" sector.

Under the assumption that the location of the collection stations (CS) to which the smallholders could deliver their latex and that the set of potential processing factory locations were given, the problem included locating central rubber processing factories, allocating the collection stations to those factories and finally determining the number of vehicles as well as their routing. The perishability of latex required the factories to be within reasonable distance of rubber growing areas and a vehicle tour not to exceed ten hours. Furthermore, the maximum number of overtime hours had to honor labor regulations. This location-allocation and vehicle routing problem was formulated as a mixed-integer programming model which minimized the sum of travel costs, overtime costs and fixed costs of operating the processing facilities as well as the vehicles, and which accounted for truck capacity constraints and time constraints due to the perishability of the latex and labor regulations.

Because of the large size of the problem, two heuristic approaches were proposed :

(1) The first heuristic is based on the subdivision of the rubber growing areas into smaller regions such that all the collection stations within the region can be visited by a truck without violating the capacity and time constraints. One processing facility within each region is to be located. Within each region, the location of the processing facility is determined by finding the least-cost tours from every potential processing plant location, by solving small size traveling salesman problems. Improvement in vehicle routing is considered by applying the savings heuristic of Clarke and Wright (1964). In a subsequent publication (Nambiar et al., 1989), the authors included a comparison of six heuristic methods for the vehicle routing problem and the related traveling salesman problem.

(2) The second heuristic, unlike the first one, does not assume the prior subdivision into smaller areas that allow for tours within the time and capacity requirements. This heuristic addresses the trade-off between lower costs associated with economies-of-scale due to larger quantities processed by a smaller number of facilities and higher savings in vehicle routing costs associated with a larger number of processing facilities. The procedure suggests determining optimal locations for a prespecified number of facilities, based on least-cost tours. Then, Erlenkotter's (1978) DUALOC routine is used to solve the resulting plant location problem with estimated variable costs and iteratively decreasing fixed costs. Starting with a minimum number of processing factories, the procedure is repeated by incrementing the number of factories by one, until the total costs (made of routing costs and fixed costs) start to increase. In a subsequent

publication, the authors take into consideration a forecasted 500% rise in latex supply from now to the year 2000, introducing a dynamic angle to this problem.

The originality of this study lies in the consideration of a routing problem in addition to the original location-allocation problem. But, none of these problems arises in its simplest form : capacity constraints are added to the plant location problem, while multiple depots as well as capacity and time constraints complicate the vehicle routing problem, making the overall problem quite difficult. Note that this analysis accounts for perishability, an important characteristic of agricultural products, through the time window constraints.

3.4 The Fresh Citrus Packing Industry

A review of the different plant location problems in the agricultural environment shows that most of the problems deal with finding the optimal number, location and size of warehouses *at a particular point in time*. These static models do not account for those shifts in demand/supply patterns and/or changes in costs that are likely to occur over a longer planning period. Furthermore, their underlying assumptions are (1) that the optimal configuration obtained from these models for a given time period does not depend on the configuration of the preceding planning periods and (2) that the existing configuration can be immediately redesigned to implement the optimal solution. In many problems, by the time the static solution can be implemented, it is no longer optimal.

The study of the fresh citrus packing industry in Florida, done by Kilmer, Spreen and Tilley (1983) accounted for this limitation. The study focused on the Indian River area, on the East Coast of Florida, which, in the previous fifteen years, had seen the planting of its citrus production shift from areas near the older groves to the southern area. Without an adjustment of the existing configuration, an increase in assembly costs was envisioned as a result of this shift in the location of the production areas. The analysis by Kilmer et al. incorporated these changes in supply patterns from one period to another, and accounted for the possibility of adjustments in the market resulting from the closing of existing facilities or/and the opening of new plants. The authors used the dynamic plant location model, which results from the integration of a standard transshipment model with fixed quantities at supply and demand points with a dynamic programming model. The objective function minimized total costs including assembly, packing and distribution costs, as well as transition costs resulting from plant configuration changes, over a certain number of periods. The solution procedure used in this analysis is based on the work of Sweeney and Tatham (1976). The method places an upper bound on the number of different configurations to be considered in each period in finding the optimal path of adjustments. The solution identified the adjustments required in the number, size and location of citrus packinghouses over time, when changes in quantity produced and in location of production from one period to another are occurring. The results of the study showed a need for only 1 additional packinghouse. The results clearly pointed out the fact that, instead of building new facilities, existing facilities needed to be enlarged to take advantage of economies of scale.

The strength of this analysis lies in the dynamic features of its model which allows for (1) the consideration of the existing plant configuration when studying potential future plant size and location adjustments and for (2) the inclusion of both short- and long-run decisions within the same model.

3.5 The Cattle Slaughtering Industry

Locating cattle slaughtering facilities is another popular application area of location models in agriculture. In order to adapt to the slowdown faced by the Australian meat and processing industry in the early 1980s, many processing firms either closed their abattoirs or operated at low utilization levels. Upon request of the Australian government, Brown and Drynan (1986) undertook the study of the Queensland cattle slaughtering industry. The underlying reason for this project was a series of industry rationalization proposals from the government in order to adjust to the difficulty of the situation.

At the time of the study, the cattle slaughtering industry in Queensland was characterized by (1) delocalized supply centers on the one hand, and concentrated processing and demand centers on the other, which result in large shipping distances and thus, large transportation costs, and by (2) large variations in slaughter cattle supplies with large year-to-year variations due to a variety of physical and market uncertainties and with marked seasonal variations due to feed quality and availability throughout the year. With 4 demand regions, 18 supply regions and 20 potential processing plant sites, the purpose of the study was to identify the optimal locations of abattoirs in Queensland. The problem was formulated as a discrete stochastic plant location model, which combined the discrete stochastic programming method with a traditional plant location model. Because of the dynamic features of the problem, decisions took place in a sequential manner. Locations and sizes of plants were first to be determined, then various scenarios in terms of supply and demand were considered. The objective was to minimize costs. The approach used in the analysis assumed costs to be directly proportional to the mean deviation of plant throughput. A first set of runs considered plant capacities fixed at existing levels and provided short-run solutions for the various scenarios of seasonality. This analysis pointed out the two major effects of variability on short-run plant location analysis : (1) it significantly affects throughputs, capacity utilizations and shipment patterns, and (2) the effect of variability itself is hardly predictable. A second set of runs provided long-run solutions for different scenarios of variability. In this case also, capacity utilizations and throughputs for all plants were highly variable across the various scenarios considered. A comparison of these results with those obtained with a deterministic plant location model revealed a marked improvement in terms of the quantity and quality of information it yields.

This study of the Queensland cattle slaughtering industry points out the limits of traditional deterministic plant location models in investigating problems with major stochastic elements. The strength of this analysis lies in the modeling of variability through a discrete stochastic programming formulation. It allows for specification of detailed adjustment options and costs. The long-run decisions to be made with respect to optimal plant size and location take into consideration various possible states of nature and available adjustment options. It also allows for the detailed specification of long-run costs, which depend, not only on capacity, but also on throughput, accounting for the presence of variability. Finally, the stochastic formulation accounts for multiple objectives associated with variability, through penalties associated with changes in throughput.

3.6 The Bangladesh Grain Model

The last application of location models to be reported in this section also deals with grain handling and distribution. A major difference with the previously reported applications is the environment in which the problem arises. This application was set in a developing country where deciding on the number, size and location of grain storage facility depends, not only on the economic, but also on the health, social, demographic and political characteristics of the environment.

The Bangladesh grain project was a complex, nation-wide logistic project that was initiated upon request of the Bangladesh government and supported by the World Bank. The purpose of the project was (1) to provide a model which described the entire country's grain supply and storage system and (2) to provide recommendations on how to improve the existing system. The situation in Bangladesh at the time of the study, in 1974, was the one of a country which had to overcome serious problems left by a devastating civil war and several major floodings. The country had to increase its level of grain production so as to raise its level of self-sufficiency. It also had to decrease the losses that were occurring during the drying and distribution processes, because of the poor conditions of the transportation and storage systems. Finally, to face considerable price fluctuations and to ensure a minimal level of grain supply to the rapidly growing urban population, the government established a rationing system.

The complexity of this analysis lied in the fact that it had to account for a large number of practical, social, technical, financial and organizational issues and that it integrated parameters such as - demand and supply quantities, production and demographic figures, governmental policies with regard to the rationing and procurement system - which are subject to considerable uncertainties. Because of these difficulties, the goal of the model was not to provide an exact solution but rather a "good starting point" for further analyses that would encompass additional factors. The Bangladesh grain model was formulated by Pruzan (1978) in terms of network flows. The country was divided into 80 local areas or zones, with one vertex for each zone. Each demand point was either a deficit or surplus point and the zone's total yearly deficit or surplus was represented by an equivalent flow into or from the vertex respectively. 58 sites were considered as potential locations for new or rehabilitated major storage facilities (MSFs). The grain originated from production points (i.e., surplus points) and imports is considered to flow through storage facilities to deficit or export points. These flows in the given network were to be determined such that the total costs due to capital, operations and transportation were minimized.

The solution methodology was made of two parts : the first part, by setting the problem in a specific manner (extending the network with a super source and a super sink), provided an initial starting point used as an input to the second part. In the second part, an out-of-kilter algorithm, which took advantage of the network structure, was used to solve the resulting fixed-cost flow problem. The major recommendations, based on the model's outputs, were implemented in spite of a coup d'état which brought many changes in the government.

The interesting feature of this analysis is its attempt to capture a nation-wide grain storage and distribution system. It tries to account for all the implications and not only the economic ones, that are associated with making the decision in such an environment. The model is of a very large size, and it exploits its network structure in the solution process. Finally, unlike in many location studies, the model output is not the solution by itself, but rather a good "starting point" for further analyses.

It is our hope that the detailed presentation of these six studies will provide the reader some insights regarding the wide diversity of applications of location models in agriculture. However, these studies are not assumed to be representative of the work done in agriculture. Table 1 contains the major features of selected applications of location models in agriculture. Although, not meant to be an exhaustive list of applications, this table provides a reasonable idea of the type of studies done in agriculture location. Information regarding the application area, objective of the study, type of model used, solution procedure and sensitivity analysis are included along with an outline of each research project's specificity.

4. Comments and Conclusions

A review of the literature in addition to the survey of various applications summarized in Table 1 point out several characteristics that appear to be important or specific to the agricultural and/or agribusiness environment.

4.1 Large-Scale Problems

Most location problems in agriculture are large-scale problems. Several major reasons could explain this fact.

(1) There are many actors involved in any production process in agriculture. The production of agricultural commodities in most countries is not highly concentrated, and accounting for production implies taking into consideration a large number of producers or farmers. The study by deMol and vanBeek (1991), concerned with the manure problem in the Netherlands, included more than 20,000 farmers while Harrison and Mills' study (1983) of the Irish agribusiness cooperative incorporated approximately 4,500 suppliers. In a mathematical model, this translates into a large number of variables/constraints and leads to large-scale problems.

(2) Location studies in agriculture are of a broad scope. None of these studies did focus on a particular aspect or a particular stage of the process. Rather, studies were interested in the globality of a given industry. In order to have a good representation of the reality and be able to get a better understanding of the situation, analysts incorporate all the various stages of the process in their models. For example, production, storage and distribution stages are included in most studies on grains, while production, processing and distribution stages are incorporated whenever the cattle slaughtering industry was under investigation. In addition, only a few studies were concerned with a specific company or cooperative. In general, studies are concerned with an industry or a sector as a whole. An extreme illustration would be the Bangladesh grain model (Pruzan, 1978) in which the country in its globality was under study. Another example could be the study by D'Souza (1988), which investigated the soybean processing industry in the whole U.S.

(3) Finally, many of the studies considered multiple commodities. For example, many of the applications related to grain handling/distribution considered both corn and soybean (Hilger et al.(1977) or Ladd and Lifferth (1975)). One may also note the study of cooling facilities in Northern Thailand (Chu, 1989) which incorporated more than 50 different types of vegetable products. Finally, Harrison and Wills (1983) included milk, animal feed, chemical fertilizers and cement as products to be handle by the agribusiness cooperative in Ireland.

4.2 Problem Simplification and Solution Procedures

As a direct consequence of large size, solving location problems in agriculture may be very difficult. One approach to face this problem has been to reduce the number of variables to be considered. In order to do so, analysts have widely used input data aggregation. For example, when the number of producers is too large, those producers are aggregated into regions or areas (deMol and VanBeek (1991); Gelders et al.(1987); Jasinska and Wojtych (1984) or Saedt (1981)). Another technique has been to break down the original large-size problem into independent smaller subproblems whenever possible. For example, in his study of the post-harvest handling-chain operation of agricultural products in Northern Thailand, Chu (1989) decomposed the original problem into independent subproblems of smaller sizes based on the access road network. Note that Nambiar et al. (1981, 1989) subdivided the region under study into smaller areas satisfying the capacity and time constraints.

Solving optimally large-scale problems is in most cases either impossible and/or very costly and is therefore an important issue. Because optimal solution procedures can rarely be used, other heuristic techniques, including network solution algorithms, decomposition techniques and dual-ascent procedures, are often reported. Hilger et al. (1977) presented an application of the Bender's decomposition technique to successfully address the grain subterminal problem in Northern Indiana, while Klingman et al. (1976) developed an efficient network-based solution procedure to approach the cotton ginning problem. Erlenkotter's dual ascent-based methods were also reported as a means of solving location models in many agricultural applications (Gelders et al., 1987).

4.3 Economies-of-Scale

Almost half of the articles reviewed in this paper did take into consideration some kind of economies-of-scale. Economies-of-scale appeared in storage, processing, transportation, distribution and/or construction costs. However, one may notice the approach by Jasinska and Wojtych (1984) which does not confirm this tendency. In their study of a sugar-beet distribution system of a Polish enterprise, instead of economies-of-scale, there is diseconomies-of-scale, with the marginal cost for a larger capacity level increased due to the hiring of additional highly expensive reloading machines.

4.4 Importance of Non-Economic Factors

In general, mathematical models only account for economic factors : their objective function focuses either on cost minimization or on profit maximization. The previous section however reported a study where economic considerations, even though they were important, could not be the only criteria on which a decision could be based. For location problems in agriculture, this is not an isolated case and two reasons may explain this fact : (1) many location studies take place in developing areas, and (2) many studies are initiated upon request of a government agency. In many developing countries, the weights of many other factors, such as political and social factors are as important as those of the economic factors, and not accounting for them would lead to unrealistic decisions. Excellent illustrations are provided by the studies of grain systems done by Bornstein and de Castro Villela (1990) in South Brazil and by Pruzan (1978) in Bangladesh. In this last study, instead of considering the results of models as exact solutions, those results are often considered as "good starting point solutions" for further analyses which incorporate various aspects of the background in which the problem arises.

4.5 Seasonality and Uncertainty

An interesting observation about the various models used in agriculture is that most of them are of a static nature. This is quite surprising since one of the main characteristics of any agricultural production is its variability, especially its variability in supply. The supply of agricultural commodities is subject to variations from year-to-year, since the quantities produced are greatly influenced by climatic conditions. It is also subject to seasonal variations due to the nature of the production. Although some authors mention this fact as a limitation of their analysis, most analyses did not account for those changes over time. As a result, many assumptions had to be made regarding levels of demand and supply. Assumptions based on uncertain production and demand forecasts and unclear future policies regarding the system under study may lead to erroneous conclusions. Note however the use of a discrete plant location model by Brown and Drynan (1986) to account for the seasonality with large year-to-year variations and marked seasonal variations which characterized the cattle slaughtering industry in Queensland, Australia. Note also the work by Chu (1989) which incorporates the seasonality of production volumes and access road conditions in his study in Northern Thailand through the use of probabilistic network location methods.

Another consequence of taking into consideration uncertainty and seasonality is that it allows for model characteristics that change over time, for dynamic situations that evolve over time. For agricultural products, since demand is fairly constant over time and supply varies seasonally and geographically, one may want to incorporate the possibility of storage at selected locations in order to satisfy demand at the minimum possible cost. In the case of grain production, grains are harvested at different time and sold at different prices. Models, such as the one developed by Hilger et al. (1977), which incorporate time and allow for the possibility of storage from one period to another, are referred to as interperiod network storage location-allocation (INSLA) models (Ratick et al., 1987).

Finally, another advantage of incorporating the time dimension in location models in agriculture is that it allows for the consideration of time constraints to account for the perishability often associated with agricultural commodities.

4.6 Concluding Remarks

An important aspect of demand for agricultural products in the U.S. and in several other countries is that most products are purchased from the farmer, not by final consumers, but by manufacturers (canners, millers and others) who process the material before selling it to final consumers. For example, wheat is first milled into flour, and then baked into bread before being purchased by the final consumers, most fruit and vegetables are canned or frozen before being available for purchase by the final consumers. Even those to be sold fresh go through a series of operations (transportation, packaging,...) before becoming available to the final consumers (Suits, 1990). Therefore, with the growth of cooperatives, and common storage and distribution facilities, one could have expected more applications in those areas.

Finally, location models in agriculture are descriptive and still not prescriptive. The solutions are difficult to adopt in many cases. Recall that location models in agriculture are large-size problems : they do not focus on a particular actor in the industry, but try to incorporate all different actors involved in the different stages of the production, distribution and/or transformation processes. Implementing the solution of a given model would mean taking steps for optimizing the globality of the system under study. Because multiple parties are involved who may not have the same convergent objectives, the implementation of the model solutions which lead to optimization for a global system may not lead to optimization for each individual actor.

We believe that agriculture provides a fertile ground for applying existing models/tools developed in location analysis and presents an opportunity to develop a new crop of research that incorporates the specific characteristics of agriculture location problems.

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REFERENCES

Banerji, S. and H.B. Fisher, "Hierarchical location analysis for integrated area planning in rural India," *Papers of the Regional Science Association,* 33, (1974), 177-194.

Benders, J.F., "Partitioning procedures for solving mixed variables programming problems," *Numerische Mathematik,* 4, (1962), 238-252.

Borstein, C.T, and Villela, P R de Castro., "Warehouse location in a developing country : Problems in formulating the problem," *European Journal of Operational Research,* 49, (1990), 222-229.

Brown, C.G., and R.G. Drynan, "Plant location analysis using discrete stochastic programming," *Australian Journal of Agricultural Economics,* 30, (Apr. 1986), 1-22.

Cassidy, P.A., W.O. McCarthy and H.I. Toft, "An application of spatial analysis to beef slaughter plant location and size, Queensland," *Australian Journal of Agricultural Economics,* 14, (1970), 1-20.

Chern, W.S., and L. Polopolus, "Discontinuous plant cost function and a modification of the Stollsteimer model," *American Journal of Agricultural Economics,* 52, (1970), 581-586.

Chhajed, D., R.L. Francis, and T.L. Lowe, "Contributions of operations research to location analysis," to appear in *Location Science* , (1993).

Clarke, G. and J.W. Wright, "Scheduling vehicles from a central depot to a number of delivery points," *Operations Research,* 12, (1964), 568-581.

Chu, S.C.K., "A successful implementation of locating passive cooling facilities : the case of Northern Thailand," *European Journal of Operational Research,* 40, (1989), 771-778.

Cornuejols, G., G.L. Nemhauser and L.A. Wolsey, "The uncapacitated plant location problem," in *Discrete Location Theory* edited by R.L. Francis and P. Mirchandani, John Wiley and Sons, New York, 1990.

D'Souza, G.E., " Structure of the U.S. Soybean processing industry in the 1990s," *Agribusiness,* 4, (1988), 11-23.

Dunn, E.S., *The location of agricultural production,* University of Florida Press, Gainesville, Florida, (1954).

Erlenkotter, D., "A dual-based procedure for uncapacitated facility location," *Operations Research,* 26, (1978), 993-1009.

Faminow, M.D., and M.E. Sarhan, "The location of fed cattle slaughtering and processing in the United States : an application of mixed integer programming," *Canadian Journal of Agricultural Economics Rev-Can-Econ-Rurale,* 31, (1983), 425-436.

Francis, R.L., F. McGinnis and J.A. White, *Facility layout and location : an analytical approach,* Prentice Hall, Englewood Cliffs, (1992).

French, B.C., "Some considerations in estimating assembly cost functions for agricultural processing operations," *Journal of Farm Economics,* 42, (1960), 767-778.

Fuller, S.W., P. Randolph, and D. Klingman, "Optimizing subindustry marketing organizations : A network analysis approach," *American Journal of Agricultural Economics,* 58, (1976), 425-436.

Gelders, L.F., L.M. Pintelon, and L.N. Van Wassenhove, "A location-allocation problem in a large Belgian brewery,"*European Journal of Operational Research,* 28, (1987), 196-206.

Glover, F., D. Klingman and N.V. Phillips, *Network models on optimization and their applications in practice,* Wiley-Interscience, New York, (1992).

Harrison, H., and D.R. Wills, "Product assembly and distribution optimization in an agribusiness cooperative," *Interfaces,* 13, (1983), 1-9.

Heaps, T., J.M. Munro, and C.S. Wright, "A location model of grain production and transportation," *The Annals of Regional Science,* 26, 2, (1992), 111-134.

Henry, W.R., and J.A. Seagraves, "Economic aspects of broiler production density," *Journal of Farm Economics,* 42, (1960), 1-17.

Hilger, Donald A., Bruce A. McCarl, and J. William Uhrig, " Facilities location : the case of grain subterminals," *American Journal of Agricultural Economics,* 59, (1977), 674-682.

Hua Lo-Keng and others, "Application of mathematical methods to wheat harvesting," *Chinese Mathematics,* 2, (1962), 77-91.

Hurt, V.R., and T.E. Tramel, "Alternative formulation of the transshipment problem" *Journal of Farm Economics,* 47, (1965), 763-773.

Isard, W., *Location and space economy,* Wiley, New York, (1956).

Jasinska, E., and E. Wojtych, "Location of depots in a sugar-beet distribution system," *European Journal of Operational Research,* 18, (1984), 396-402.

Juarez, F., and C. Romero, "An optimum location and size model for a food-processing plant in continuous space," *Agricultural System,* 22, (1986), 71-76.

Kellerman, A., *Agricultural location theory : a bibliography,* Vance Bibliographies, II, (1989).

Kilmer, R.L, T. Spreen, and D.S. Tilley, "A dynamic plant location model : the east Florida fresh citrus packing industry," *American Journal of Agricultural Economics,* 65,(1983), 730-737.

King, G.A., and S.H., Logan., "Optimal location, number and size of processing plants with raw product shipments," *Journal of Farm Economics,* 46, (1964), 730-737.

Klingman, D., P.H. Randolph, and S.W. Fuller, "A cotton ginning problem," *Operations Research,* 24, (1976), 700-717.

Kloth, D.W., and L.V. Blakely., "Optimum dairy plant location with economies of size and market share restrictions," *American Journal of Agricultural Economics,* 53, (1971), 461-466.

Krarup, J. and P.M. Pruzan, "The single plant location problem : Survey and synthesis," *European Journal of Operational Research*, 12, (1983), 36-81.

Ladd, G.W., and M.P. Halvorson, "Parametric solutions to the Stollsteimer model," *American Journal of Agricultural Economics*, 52, (1970), 578-580.

Ladd, G.W., and D.R. Lifferth, "An analysis of alternative grain distribution systems," *American Journal of Agricultural Economics*, 57, (1975), 420-430.

Langemeier, L.N., and R.M. Finley, "Effects of split-demand and slaughter-capacity assumptions on optimal locations of cattle feeding," *American Journal of Agricultural Economics*, 53, (1971), 228-234.

Leath, M.N., and J.E. Martin, "The transshipment problem with inequality restraints," *Journal of Farm Economics*, 48, (1966), 894-908.

Logan, S.H., and G.A. King, "Size and location factors affecting California's beef slaughtering plants," *Hilgardia*, 36, (1964), 139-188.

Losch, A., *The location of economic activity*, Stuttgart, Fischer, (1962).

de Mol, R.M. and P. van Beek, "An OR contribution to the solution of the environmental problems in the Netherlands caused by manure," *European Journal of Operational Research*, 52, (1991), 16-27.

Monteroso, C.D.B., C.L. Wright, and M.C.S. Lacerda, "Grain storage in developing areas : location and size of facilities (Brazil)," *American Journal of Agricultural Economics*,, 67, (1985), 101-111.

Nambiar, J.M., L.F. Gelders, and L.N. VanWassenhove, "Plant location and vehicle routing in the Malaysian rubber smallholder sector : a case study," *European Journal of Operational Research*, 38, (1989), 14-26.

Nambiar, J.M., L.F. Gelders, and L.N. VanWassenhove, "A large-scale location-allocation problem in the natural rubber industry," *European Journal of Operational Research*, 6, (1981), 183-189.

Ohlin, B., *Interregional and international trade*, Harvard University Press, Cambridge, (1933).

Olson, F.D., "Location theory as applied to milk processing plants," *Journal of Farm Economics*, 41, (1959), 1546-56.

von Oppen, M., and J.T. Scott, "A spatial equilibrium model for plant location and interregional trade," *American Journal of Agricultural Economics*, 58, (1976), 437-445.

Orden, A., "The transshipment problem," *Management Science*, 2, (1956), 277-285.

Polopolus, L., "Optimum plant numbers and locations for multiple product processing," *Journal of Farm Economics*, 47, (1965), 287-295.

Pruzan, P.M., "The Bangladesh grain model," *European Journal of Operational Research*, 3, (1978), 110-121.

Ratick, S.M., J.P. Osleeb, M. Kuby, and K. Lee, "Interperiod network storage location-allocation (INSLA) models ," in *Spatial Analysis and Location-Allocation Models*, A.Ghosh and G.Rushton, editors, Nostrand Reinhold, (1987), 269-301.

Saedt, A.P.H., "The siting of green forage drying plants for use by a large number of farms - a location-allocation case study," *European Journal of Operational Research,* 6, (1981), 190-194.

Stollsteimer, J.F., "A working model for plant numbers and locations," *Journal of Farm Economics,* 45, (1963), 631-45.

Suits, D.B., "Agriculture" in *The structure of American industry,* edited by W. Adams, Macmillan Publishing Company, 8th edition, (1990), 1-40.

Sweeney, D.J., and R.L. Tatham, "An improved long-run model for multiple warehouse location," *Management Science,* 22, (1976), 748-758.

von Thunen, J.H., "*Der Isolierte Staat in Beziechung auf Landwirtschaft und Nationalokonomie,*" 3rd ed., Schumacher-Zarchlin, Berlin, (1875).

Tyrchniewicz, E.W., and R.J. Tosterud, "A model for rationalizing the Canadian grain transportation and handling system on a regional basis," *American Journal of Agricultural Economics,* 55,(1973), 805-813.

Warrack, A.A., and L.B. Fletcher, "Plant-location model suboptimization for large problems," *American Journal of Agricultural Economics,* 52,(1970), 587-90.

Weber, A., *The theory of the location of industries,* University of Chicago Press, Chicago, (1929).

Weinschenk, G., W. Henrichsmeyer and F. Aldinger, "The theory of spatial equilibrium and optimal location in agriculture : a survey," *Review of Marketing and Agricultural Economics,* 37, (1969), 3-70.

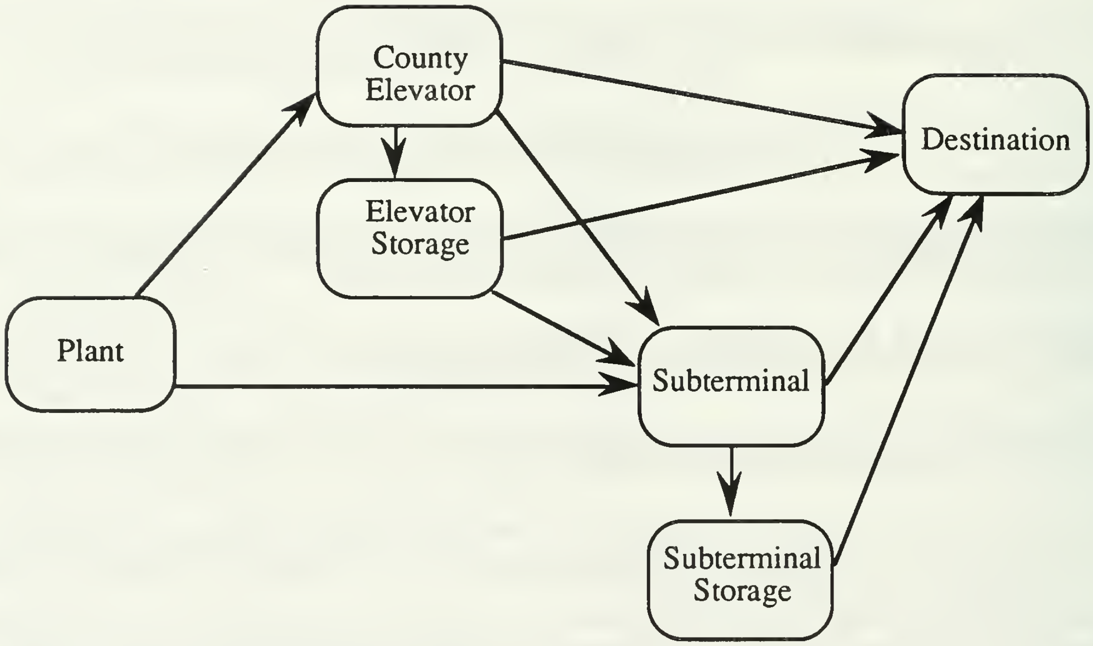

Figure 1: Possible Grain Movement

Table 1 : Selected Location Problems in Agriculture

Authors	Application Area	Description of the Study	Model Type	Solution Procedure	Sensitivity Analysis	Special Features
deMol and vanBeek (1991)	OR solution to manure problems in the Netherlands	Identification of acceptable destinations (application or processing) for the manure produced	• LP for processing network • MIP model for the location-allocation model	• Commercial packages : MGG and SCINONIC/VM	No	• Economies-of-scale included • Large-size problem with 21549 farms • Aggregation of those farms into 74 areas • Initiated by the Institute of Agric. Engineering and the Agricultural University
Bomstein and de Castro Villela (1990)	Warehouse location for grain storage in South Brazil	Initially, determination of the optimal location and dimension of warehouses for grain storage, then location of service stations for technical assistance	• initial model : warehouse location model • revised model : 0-1 knapsack problem	None	No	• Economies-of-scale • Political, economic and social aspects included • Totally revised problem and model as a direct implications of including the previous factors • Partially funded by State Agency
Chu (1989)	Post-harvest handling-chain operation of agricultural products in Northern Thailand	Determination of the optimal number and location of cooling facilities and the assignment of sites to those facilities	• Location-Allocation problem on a network with MIP formulation	• Direct Methods : enumeration and branch-and-bound approach • Heuristic Approaches : a node-partioning heuristic, a node substitution heuristic, and a combination of both heuristics	Yes, with three possible node weight measures investigated	• Large size problem with 30 villages and 50 different kinds of vegetable products • Access road network and locations of various extension stations at the basis of the decomposition of the problem into independent sub-problems of smaller sizes • Seasonality of production volumes and access road conditions handled by probabilistic network-location methods • Project supported by the Govemment
Nambiar, Gelders & VanWassenhove (1989) Nambiar, Gelders & VanWassenhove (1981)	Plant location and Vehicle routing in the rubber industry in Malaysia	Location of rubber factories (RF), the allocation of given collection stations (CS) to rubber factories, and the vehicle routing problem of transporting latex from RF to CS	• Location-Allocation and Routing problem formulated as IP model	• For Location-Allocation problem, Dual Ascent procedures with in Static case : DUALOC, and in Dynamic case : DYNALOC • For VRP : 6 heuristic methods investigated	Yes, Effects of changes in costs under various scenarios (smaller vs. larger number of open locations, shorter vs. longer planning horizon,..)	• Time and Capacity constraints • Large size and complex problem • Decomposition into smaller problems • Project supported by the Malaysian Government
D'Souza (1988)	Soybean Processing Industry in the United States	Determination of the number, size and location of soybean processing plants in the U.S.	• 3-stage transshipment model formulated using LP	• Commercial LP packages : MPSX	No	• Large size problem, applied to the whole U.S. (partitioned into 57 regions) • Economies-of-scale • Multicommodity (soybeans as raw materials, and meal and oil as joint end-products) • Attempt to illustrate how the soybean processing industry should enhance efficiency • Consideration of two base periods 1977 and 1981, then predictions for 1990 and 2000
Gelders, Pintelon & VanWassenhove (1987)	Brewing Industry in Belgium	Location and number of depots, and allocation of customers to depots	• Location-Allocation problem in both continuous and discrete approaches	• Dual-Ascent solution procedures : Discrete model with DUALOC and continuous model with GRAVLOC	Yes, Effects of changes in fixed and transportation costs, and in the number of depots to be opened	• Large Size problem with 24000 depot customers • Aggregation of customers into 650 regions • Comparison of results under both approaches
Brown and Drynan (1986)	Cattle Slaughtering Industry in Queensland, Australia	Selection of plant sites, sizes, throughputs and product flows subject to supply and demand	• Discrete Stochastic Plant Location Model as a MIP model	• Conventional MIP packages (APEX III)	Yes, various levels of seasonality are investigated	• Economies-of-scale •Seasonality with large year-to-year variations and marked seasonal variations • Detailed specification of long-run costs • Multiple objectives • Comparison of results obtained from static and dynamic models

Monteroso, Wright, Lacerda and Ofugi (1985)	Grain Storage in Brazil	Effect of location and size of collector storage facilities on the total cost of grain transport and storage in a developing country	• Dynamic problem formulated as a Capacitated Network Flow Model	• Drop/Add heuristics to generate different choices of sizes and locational configurations • then, Out-of-Kilter method to solve the resulting network model	Yes, Changes in level of production, in ratio transport to storage costs, changes in fuel prices investigated	• Economies-of-scale in storage construction, but storage costs are linear • Spatial, temporal, capacity and economic features of storage included • Research project undertaken by the Brazilian Transportation Planning Agency, funded by the Institute of Economics and Social Planning
Jasinska and Wojtych (1984)	Sugar-Beet Distribution System in Silesia, Poland	A minimum-transportation plan detemining the number, location and sizes of depots to be opened and the amount of sugar-beet flows	• Large-Scale Mixed Integer Linear Programming (MIP) model	• Conventional LP and MIP packages • Heuristic Procedures with 1/ Constrained Continuous Knapsack Problem and 2/ Capacitated Depot Location Problem	No	Large size and capacitated problem • Aggregation of 1588 farms into 128 zones • Instead of economies-of-scale, the marginal cost for a larger capacity level is increased • Depot cost function is approximated by a piecewise linear function with one jump discontinuity
Harrison and Wills (1983)	Product Assembly and Distribution Optimization in an Agribusiness Cooperative in Ireland	Rationalization of the milk collection and fertilizer and animal food distribution and warehousing of an agribusiness cooperative	• Milk Processing and Distribution Model formulated as a traveling salesman-type model • Stores Trading Model formulated as a modified transshipment model (network structure)	• Traveling Salesman Type Solution Procedures • for the Stores Trading model, development of a six-step iterative procedure	Yes, various management scenarios were investigated	• Economies-of-scale for assembly, but no economies-of-scale for processing and distribution • Large size problem with 4674 suppliers and 74 platforms in the platform milk system and 1729 suppliers in the bulk milk system • Multicommodity problem (milk, animal foods, chemical fertilizer, cement,...)
Kilmer, Spreen and Tilley (1983)	Citrus Packing Industry in East Florida	Determination of the dynamic adjustments required in number, size and location of citrus packinghouses over time	A standard transshipment model is integrated with a dynamic programming model : • Static Plant Location Model formulated as a MIP model, • Dynamic Plant Location Model based on estimated discounted transition costs and static solutions	• MIP-MPSX search procedure for IBM for Static Model • Sweeney and Tatham's (1976) procedure for Dynamic Model	No	• Dynamic features of the model, allowing for short-term and long-term adjustments • Economies-of-scale • Multicommodity problem with oranges and grapefruits
Faminow and Sarhan (1983)	Fed Cattle Slaughtering and Processing Industry in the United States	Determination of the optimal number, size and location of large-scale fed cattle slaughtering and processing plants given spatially dispersed patterns of fed cattle supply and fed beef demand	• Fixed-Charge Facilities Location Problem, formulated as a Mixed Integer Plant Location Model	• Conventional MIP Packages : APEX III	Yes, four models based on different plant capacity scenarios	• Large size problem, thus only large scale plants were considered in the analysis • Impact of the relocation of U.S. beef slaughtering and processing industry on export markets of Canadian beef
Saedt (1981)	Siting of Green Forage Drying Plants in the Netherlands	Determination of the optimal number, locations and sizes of green forage drying plants in Friesland (Netherlands), as well as the optimal allocation of farms to dryers	• Location-Allocation Model under : 1/ an unrestricted set of possible solutions (planar model), and 2/ a finite-set approach (MIP model)	• for unrestricted set : use of the heuristic adaptative location-allocation algorithm of Eilon et al. • for restricted set : complete enumeration	Yes, different number of dryers considered in the analysis	• Large size problem with 4995 farms considered • Aggregation of those farms into 1825 delivery points
Pruzan (1978)	Grain Model in Bangladesh	Identification of the best solution - both technically and economically - to the country's grain supply and storage problems	• Fixed-cost flow problem formulated as a large-scale MIP model	To solve the network model for different choices of sizes and locational configurations : • Drop/Add heuristic to generate those configurations • then, Out-of-Kilter method to solve the resulting network model	Yes, effect of changes in storage facility types, in production level, and in transportation costs	• Solution of model considered as "good starting points" for future manual evaluation • Health, social, political, demographic, economic and financial features included • Large-size problem since nation-wide logistics problem (network with appr. 600 vertices and 6000 arcs) • Project initiated by the Bangladesh Ministry of Food and Civil Supplies and supported by the World Bank

Hilger, McCarl and Uhrig (1977)	Grain Subterminal Location in Northern Indiana	Optimal organization of grain (corn and soybean) subterminals within the region under different assumptions	Formulated as a MIP with some quadratic constraints	Solution strategy based upon the technique of Benders decomposition leading to 2 subproblems : • a master Problem (IP model) • a network LP subproblem	Yes, two different levels of export (low and high)	• Large size problem with 19 potential subterminals, 105 country elevators and 13 final destinations • Aggregation of corn and soybean into one unit • Temporal characteristics (12 months) with possibility of permanent and temporary storage
Fuller, Randolph and Klingman (1976) Klingman, Randolph and Fuller (1976)	Cotton Ginning Industry in two southwestern valleys of the U.S.	Determination of plants to be activated for processing cotton and the spatial and temporal flow of raw material each week	Plant Location Model formulated as • a transportation problem for the weekly problem • then, a minimum cost-flow network problem without fixed costs for the seasonal problem	• Implicit enumeration Procedure followed by • Network Solution Procedure	Yes, Effects of considering storage or not	• Large size problem (139 production locations, 14 processing plants and 16 production weeks) • Seasonal cost function (with piecewise linear variable cost function with positive intercept, 2 levels of variable labor costs for regular and overtime shifts) • Storage possibility
von Oppen and Scott (1976)	Soybean Industry in India	Determination of regionally optimal numbers and sizes of processing plants and optimal interregional trading and pricing	• Spatial equilibrium model for plant location and interregional trade • Single equation model for plant location • Quadratic programming model for inter-regional trade	• Interative method between plant location and the inter-regional model	No	• Combination of a planar model with quadratic programming model • Results of the model compared with actual development over a 4 year period of Indian Soybean industry
Ladd and Litfferth (1975)	Grain Distribution Systems in Iowa	Examination of alternative rail-based grain distribution system with detemination of number, sizes, locations and storage capacity of subterminals	• Two-stage hierarchical, multi-period transshipment problem formulated as LP	Solution method into 2 parts • Part 1 : spatial and temporal flows of grain • Part II : locational patterns of rail lines and elevators	Yes, Effects of different rail abandonment plans, different rate structures and different prices	• Economies-of-scale in rail transportation • Two-commodity (corn and soybean) • Multi-period model with storage • Maximization of revenues
Banerji and Fisher (1974)	Integrated Area Planning in Rural India	Development of an initial and general framework for the efficient and equitable spatial organization of the micro-region	• Integration of the Set-Covering and P-Median Problems	• For the Set-Covering Problem, use of a two-step procedure • For the M-Median problem, use of Tietz and Bart (1968) heuristic	Yes, Various maximum travel distance standards considered	• Optimal spatial location modified to account for the existing social and economic infrastructure and other realities • Only the first of a 3-step project • Funded by the Government of India with assistance of Ford Corporation
Tyrchniewicz and Tosterud (1973)	Grain Handling and Transportation in Canada	Impact of rationalization and identification of corresponding country grain elevators located on these branch lines to be abandoned	• a Discrete Collection, Handling and Distribution (CHAD) model	• The model evaluates the system costs, given the parameters	Yes, Effects of two criteria (farmer's preferred delivery point criteria and minimum distance criteria) investigated	• Results are useful for negotiation process • Several institutional and regulatory constraints involved in the model
Kloth and Blakley (1971)	Dairy Industry in the U.S.	Determination of optimal location and size of milk processing plants	• Extension of Stollsteimer's model	• Commercial Packages : IBM Linear and Separable Programming Routine	Yes, Effects of total costs and interregional flows of milk under 3 alternative degrees of market concentration	• Economies-of-Scale • Inclusion of market-share restrictions • Large size problem (105 consuming markets and 92 areas of production) • Imposition of plant size restrictions
Langemeier and Finley (1971)	Cattle Feeding Industry	Determination of optimal location of cattle feeding	• Spatial equilibrium model	• An iterative procedure	Yes, Effect of split demand and slaughter capacity assumptions	• Incorporation of split demand and slaughter capacity assumptions
Warrack and Fletcher (1970)	Feed Industry in Iowa	Determination of optimal location and size of plants	• Extension of Stollsteimer's model	2 suboptimization methods : • Iterative Elimination Approach (IELMA) and • Iterative Expansion Approach (IEXPA) related to the SAOPMA sub-optimization method	Yes, double shift vs. single shift in manufacturing operations	• Large size problem with 40 potential plant locations and 99 demand points • economies-of-scale reflected in linear non-homogeneous total cost function for feed manufacturing plants

Chern and Polopolus (1970)	Orange Industry in Florida	Determination of location of fresh orange packing and processing plant	• Modification of Stollsteimer's model	• use of a 2-step solution procedure	Yes, 3 cases on the basis of the form of the total operating costs of processing functions	• Discontinuous Plant Cost Function • Economies-of-Scale • Two commodity model with canning and eliminated oranges
Cassidy, McCarthy and Toft (1970)	Beef Slaughtering Industry in Queensland, Australia	Determination of the optimal size, number and location of beef slaughtering plants	• Modified Transshipment Problem formulated as a MIP model • Plant location with a single equation optimization model • Interregional trade of inputs and products with quadratic programming model	• King and Logan's heuristic programming technique, involves a "Drop" technique	Yes, in the long-run unlimited capacity case, changes in processing costs	• Economies-of-Scale, with the inclusion of non-linear processing costs • Seasonality of supply in estimation of cost curves • Project supported by the State Government Committee of Inquiry
King and Logan (1964) Logan and King (1964)	Cattle Slaughtering Industry in California	Determination of the optimal location and size of cattle slaughtering plants	• Transshipment model formulated as a LP model	• Iterative use of the transshipment model - combined iterative and budgeting approach	Yes, Effects of constant processing costs vs. economies-of-scale investigated	• First Transshipment model use in Agriculture • Economies-of-Scale • Large-Scale model
Polopolus (1965)	Vegetable Canning Industry in South Central Louisiana	Determination of the optimal number, size and location of multiproduct vegetable canning plants	• Extension of Stollsteimer's one product model	• Combined iterative and budgeting approach	No	• Multi-commodity with sweet potato, okra and tomato • Economies-of-large-sized truck operations
Stollsteimer (1963)	Deciduous Fruit Industry in California	Determination of the optimal number, size and location of pear packing facilities	• Plant Location Problem formulated as an extension of the basic LP transportation model	• Complete enumeration	Yes, 4 cases investigated : Presence or absence of economies-of-scale and whether or not plant costs dependent on plant location	• First inclusion of preselected potential plant locations and discrete supply or demand locations • First formulation of Simple Plant Location Problem (SPLP)
Henry and Seagraves (1960)	Broiler Industry in the south of the U.S.	Determination of optimal size and location of processing plants	• Formulated as a planar model	• Graphical solution procedure	Yes, Effects of production density on unit costs for the outputs of particular firms	• Circular supply area
Olson (1959)	Dairy Processing Industry in Minnesota	Determination of the optimal location and size of milk processing plants in a dairy cooperative	• Plant Location Problem formulated as a Planar Model	• Calculus	Yes, Effects of various densities of milking production and hauling costs, of various types of plants, of seasonal patterns vs. constant supply	• Assembly costs varied linearly with volume and weight of milk • Processing costs expressed as a polynomial function of volume processed • Hexagonal vs. circular market areas for each plant