Cotton Ginning

1975

Abstract

The paper relates a subindustry's optimum organizational adjustment to decreased raw product output and new storage technology. The research product specifies existing processing plants to be activated and associated spatial and temporal raw product flows from production locations to activated plants, at alternative sites. A solution was obtained by employing an out-of-kilter algorithm and implicit enumeration.

Key words: cotton gins, operational efficiency, plant location methodology

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Optimizing Subindustry Short-run Marketing Organization: A Large Scale Mathematical Programming Problem

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The problem of estimating efficient market areas or marketing subindustry organization has received extensive treatment in the *Journal*. Early models developed and applied by French, Henry and Seagraves, Olson, and Williamson treated space as continuous and assumed that a region had uniform average density of supply or demand. The solution specified most efficient plant size and corresponding demand or supply market area. A later model development by Stollsteimer was capable of including preselected potential plant locations and discrete supply or demand locations. The obtained solution communicated least cost number, size and location of marketing facilities. Recent extensions of the basic Stollsteimer model by Polopolus, Chern and Polopolus, Ladd and Halvorson, and Warrack and Fletcher have enabled the applied researcher to incorporate additional realism, test sensitivity of solution and increase size of plant location problem. King and Logan applied a transshipment model to a plant location problem where materials move from a supply point through another intermediate supply point and on to the demand point or even through an intermediate demand point. The basic transshipment model has been further developed by Hurt and Tramel, and Leath and Martin. Kloth and Blakely and Candler, Snyder and Faught have used separable programming and concave programming, respectively, to accomodate those situations where nonlinear long-run total processing costs exist.

This paper reports a problem and solution procedure which partially parallels previous plant location analysis; however, several unique elements exist. The encountered location problem involved a determination of a processing industry's optimal short-run organizational adjustment to a region's decreased raw product output and new storage technology. The objective was to specify existing processing facilities to be activated or deactivated and spatial and temporal flows of raw product to plants and/or storage to minimize total cost of assembly, storage and processing. Generally, the plant location models employed by applied economists resolve optimal long-run industry solutions which focus on trade-offs between regional transportation cost and plant cost that is associated with increasing subindustry plant numbers. However, this problem required consideration of these additional complications: 1) short-run plant costs which were unique to each plant, 2) availability of increasing plant output through use of higher cost overtime labor, 3) opportunity to activate or deactivate a plant on a weekly rather than a seasonal basis and 4) availability of storing raw product to extend the processing season.

Most plant location solution procedures were unable to [redacted] incorporate necessary realism [redacted] but, if appropriate, generally required extensive computer time to obtain a solution. Therefore, the problem was formulated as a network problem and solved with the use of an out-of-kilter algorithm and implicit enumeration. The problem and solution procedure should be of general interest to applied economists involved in locational analysis.

split infinitive

Problem Situation

Cotton production in several Southwestern irrigated valleys has decreased by 50 percent during the past decade, while regional processing (ginning) capacity has remained relatively unchanged. Innovations in seed cotton storage have provided the opportunity to extend assembly and processing activities beyond the harvesting period. Because of the nature of variable plant costs and the feasibility of seed cotton storage, it was hypothesized that total system costs could be decreased by reducing the number of existing plants which operate.

Each plant has a unique, convex, piecewise linear variable cost function with a positive intercept (Figure 1). The positive intercept value represents a one-time annual fixed charge for activating and operating a plant and includes costs of salaried management personnel and an electrical connection charge. The electrical connection charge purchases enough electricity to process that volume associated with the juncture of the linear segments constituting the plant cost function, i.e., V_j. Consequently, marginal costs up to V_j are less than those beyond V_j.

Plants have the opportunity to increase weekly and/or seasonal output by employing crews on an overtime shift. Thus, there are two levels of variable labor cost associated with each plant -- one for the regular and another for overtime. If the capacity of the regular shift is exceeded, all of the additional cotton must be processed at the more expensive overtime rate. However, prudent use of overtime may be cost saving if it avoids the necessity of activating an additional plant.

Additional cost trade-offs exist between number of operating plants and assembly cost, that is, as plants are activated, average assembly distance

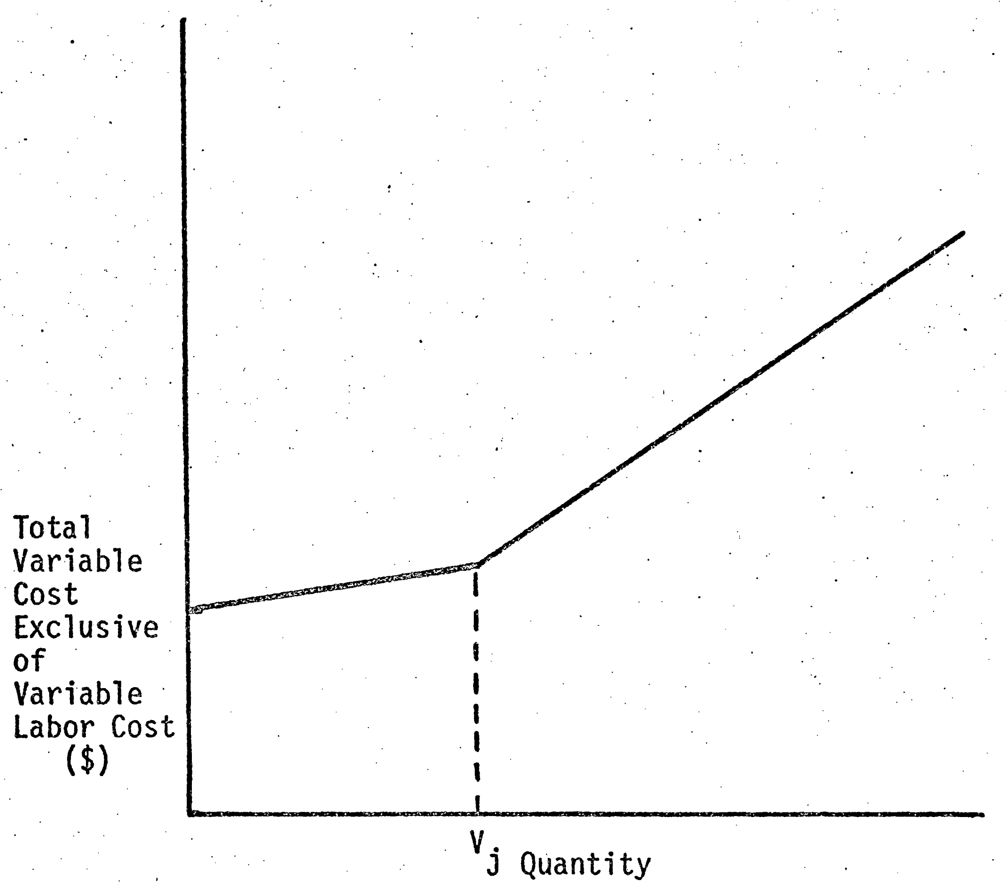

Figure 1. Total Variable Plant Cost Exclusive of Variable Labor Cost

and assembly cost decrease. In addition, reducing regional processing capacity below peak week demands necessitates the storage of seed cotton and this adds an additional cost to the system. However, seed cotton storage may be preferable to activating an additional plant.

The solution to the problem must specify regional ginning industry organization which minimizes aggregated costs of assembly, storage and processing. In particular, the solution must designate existing plants to be activated each week, quantity of seed cotton to be field stored and the quantity of seed cotton to be shipped from specific production locations to activated plants.

Principal factors bearing on the optimal solution are:

1) shipping cost between production locations and activated plants
2) seed cotton storage cost
3) maximum seed cotton storage period
4) kurtosis of distribution relating harvested production per time period
5) plant cost structure
6) overtime labor cost
7) regular and overtime plant processing capacity

Mathematical Representation of the Problem

Consider m production locations and n existing plants at alternative sites. The weekly quantities of raw product at each origin are known and are denoted as $P_{1k}, \ldots, P_{mk}$, where $k = 1, \ldots, W$ denotes the week. Also, the weekly capacities of each of the existing plants are known and are denoted as $K_1', \ldots, K_n'$ for output processed during regular hours and $K_1'', \ldots, K_n''$ for output processed during overtime hours. Thus, marginal labor cost at each plant are given by,

r'_j = marginal labor cost incurred during regular hours, and

r''_j = marginal labor cost incurred during overtime hours.

Additional plant costs are given by,

F_j = annual fixed charge associated with activating plant j,

c'_j = marginal cost exclusive of labor associated with plant j's initial linear cost segment,

c''_j = marginal cost exclusive of labor associated with plant j's second linear cost segment.

where, the juncture point between the two segments is at V_j for plant j and $c'_j < c''_j$.

The cost of placing the raw product into storage and then later removing it represents a one-time cost which is independent of the production origin, the existing plant and the time period. This unit storage cost is represented by S. Assembly cost between each pair of origins and existing plant sites is proportional to the quantity shipped and the distance between the origin and plant site. The unit assembly cost from origin i to plant site j is given by t_{ij}. The objective of the problem is to select a configuration R of the n existing plants such that the aggregated cost of assembly, storage and processing is minimized, all raw material is processed and existing plant capacities are not exceeded.

To obtain a mathematical model of this process, the following decision variables are defined:

y_j = a binary variable where y_j = 1 when plant j is activated and y_j = 0 when plant j remains closed.

X'_{ijk} = quantity of raw product available at production origin i and processed at plant j in week k during regular hours.

X''_{ijk} = quantity of raw product available at production origin i and processed at plant j in week k during overtime hours.

$S'_{ijk\ell}$ = quantity of raw product stored at production origin i in week k and then processed at plant j during regular hours in week ℓ.

$S''_{ijk\ell}$ = quantity of raw product stored at production origin i in week k and then processed at plant j during overtime hours in week ℓ.

From these decision variables it is possible to determine,

X_j = quantity of raw product processed at plant j.

In addition, it is useful to include the following function,

I_n = a standard indicator or characteristic function where I_n(statement) = 1 if the statement is true and I_n(statement) = 0 if the statement is false.

Then, the mathematical ~~statement~~ model of the problem is as follows:

Determine the values of the decision variables such that,

$$Z = \sum_{j=1}^{n} y_j \Bigg[F_j + c'_j X_j I_N \left(X_j < V_j\right) + \left(c'_j V_j + c''_j \left(X_j - V_j\right)\right) I_N \left(X_j > V_j\right)$$

$$+ r'_j \left(\sum_{i=1}^{m} \left(\sum_{k=1}^{W} X'_{ijk} + \sum_{\ell=1}^{W} \sum_{k=1}^{\ell} S'_{ijk\ell} \right)\right) + r''_j \left(\sum_{i=1}^{m} \left(\sum_{k=1}^{W} X''_{ijk} + \sum_{\ell=1}^{W} \sum_{k=1}^{\ell} S''_{ijk\ell} \right)\right)$$

$$+ s \sum_{i=1}^{m} \sum_{\ell=1}^{W} \sum_{k=1}^{\ell} \left(S'_{ijk\ell} + S''_{ijk\ell} \right)$$

$$+ \sum_{i=1}^{m} \left(t_{ij} \left(\sum_{k=1}^{W} \left(X'_{ijk} + X''_{ijk} \right) + \sum_{\ell=1}^{W} \sum_{k=1}^{\ell} \left(S'_{ijk\ell} + S''_{ijk\ell} \right)\right)\right) \Bigg]$$

is minimized subject to the conditions:

1. All raw product which is available at production location i in week k is either processed or stored.

$$\sum_{j=1}^{n} y_j \left(X'_{ijk} + X''_{ijk} + S'_{ijk\ell} + S''_{ijk\ell} \right) = P_{ik}, \quad \begin{array}{l} i = 1, \ldots, m \\ k = 1, \ldots, W \\ \ell = k+1, \ldots, W \end{array}$$

2a. Plant's weekly processing capacity associated with regular processing hours is not exceeded. For plant j in week ℓ, this is

$$\sum_{i=1}^{m} \left(X'_{ij\ell} + \sum_{k=1}^{\ell-1} S'_{ijk\ell} \right) \leq K'_j \qquad \begin{array}{l} j = 1, \ldots, N \\ \ell = 1, \ldots, W \end{array}$$

2b. Plant's weekly processing capacity associated with overtime processing hours is not exceeded. For plant j in week ℓ, this is

$$\sum_{i=1}^{m} \left(X''_{ij\ell} + \sum_{k=1}^{\ell-1} S''_{ijk\ell} \right) \leq K''_j \qquad \begin{array}{l} j = 1, \ldots, N \\ \ell = 1, \ldots, W \end{array}$$

3. To determine total seasonal output for plant j, X_j, the following is specified.

$$\sum_{i=1}^{m} \left(\sum_{k=1}^{W} \left(X'_{ijk} + X''_{ijk} \right) + \sum_{\ell=1}^{W} \sum_{k=1}^{\ell} \left(S'_{ijk\ell} + S''_{ijk\ell} \right) \right) = X_j \qquad j = 1, \ldots, n$$

4. Restrictions on the decision variables are

$$X'_{ijk} \geq 0, \; X''_{ijk} \geq 0, \; S'_{ijk\ell} \geq 0, \; S''_{ijk\ell} \geq 0 \text{ and } y_j = 0 \text{ or } 1$$

The mathematical model is, of course, nonlinear. However, it can be made linear by choosing an arbitrary subset, R, of the plants. Then by assigning the values $y_j = 1$ if $j \in R$ and $y_j = 0$ if $j \notin R$, and by using separable convex prog the problem becomes one of linear programming for each possible subset of the plants.

Although the problem may ~~be~~ now be formulated as one of linear programming, ~~several~~ two difficulties exist: (1) For the problem under consideration, the

break-out

Because of the variables y_j and the indicator fns the mathematical is not linear. However, the model linear programming model is so large that no available simplex code can be used to find a solution directly. It would be possible to apply a double decomposition procedure, but the computational convergence of decomposition is known to be slow and in this case appeared impossible. (2) Even if there were a simplex code that could solve the problem, the solution would be for only a given subset of plants. This implies that for every possible subset of plants, a linear programming problem would be solved and then finally that subset whose linear programming solution is a minimum over all subsets, will be the optimal configuration. Unfortunately, the total number of possible configurations can be large, namely 2^N-1. For $N = 20$ there is a total of 1,048,575 linear programming problems to be solved. If it were optimistically assumed that the linear programming solution would require one minute per subset, then a total of three years would be required to examine all possible subsets, assuming the computer operated 24 hours per day. Fortunately, these difficulties are independent. After careful examination of the problem structure, it was formulated as a network flow problem, so that a network algorithm could be used to find the best solution for any subset of plants. Then, using implicit enumeration, the number of subsets that are actually examined is reduced from the 2^N-1 value.

Network Formulation

A network consists of a number of nodes or junction points, each joined to some or all of the others by arcs. Nodes are diagrammed as circles while arcs are indicated by lines or line segments. The crossing of arcs does not indicate intersection of corresponding arcs except at nodes. The unidirectional flow of raw product is represented by an arrow placed on an arc. To exhibit the structure of the cost flow network, a prototype of the original problem is formulated in Fig. 2 and 3. The enclosed area in Fig. 2 is enlarged in Fig. 3.

The prototype problem involves four production origins, which produces raw product for three consecutive weeks and four existing plants which may operate these three weeks plus an additional three weeks. Level iAk nodes represent raw product origin i in week k, while P_{ik} depicts raw product produced at origin i in week k. In the example problem, a total of 12 production nodes are represented. In addition, associated with each production origin node are arcs which connect it with the jBℓ nodes, where jBℓ represents available processing at plant j during week ℓ. Arcs connecting the iAk level nodes with the jBℓ level nodes represents unit transportation cost between origin and existing plant location (t_{ij}) and a one-time unit storage cost (S), if the value of ℓ associated with the jBℓ level node is greater than the value of k associated with the iAk level node. All raw product processed in each plant during the six weeks is then channeled through a single node, called the weekly master node for that plant. The jC level node corresponds to the weekly master node for plant j. Two arcs connect each jBℓ level node with the jC level node. One arc represents plant j's regular weekly capacity (K_j') and associated marginal labor cost (r_j') while the second arc depicts overtime weekly capacity (K_j'') and its associated higher marginal labor cost (r_j''). To accomodate the two levels of marginal cost associated with the two linear segments comprising each plant's cost function, D level nodes are introduced. Two arcs connect each C and D level node. One arc represents marginal cost (ε_j') and volume (V_j) associated with the jth plant's first linear cost segment, while the second arc represents

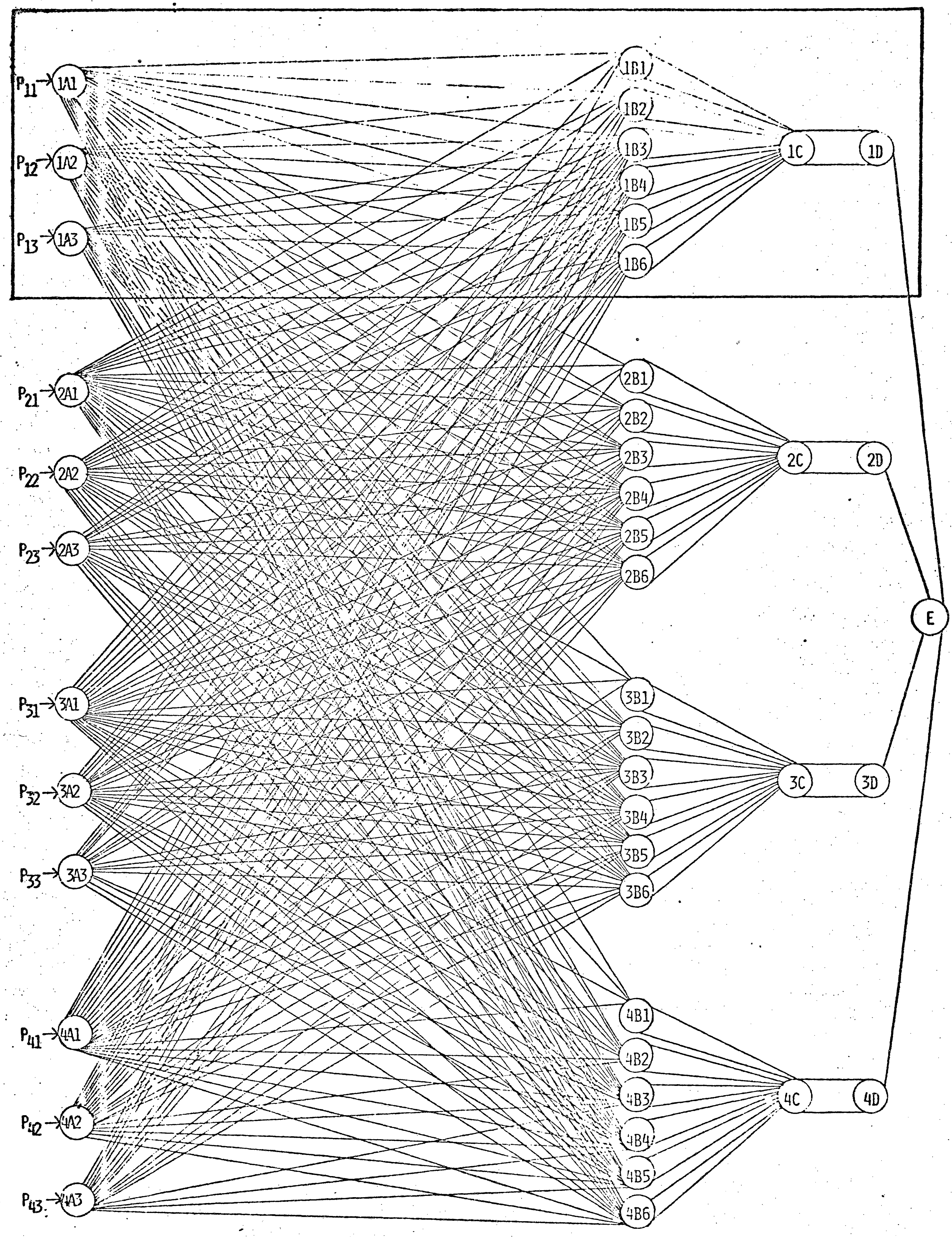

Figure 2. Network Diagram of Prototype Problem

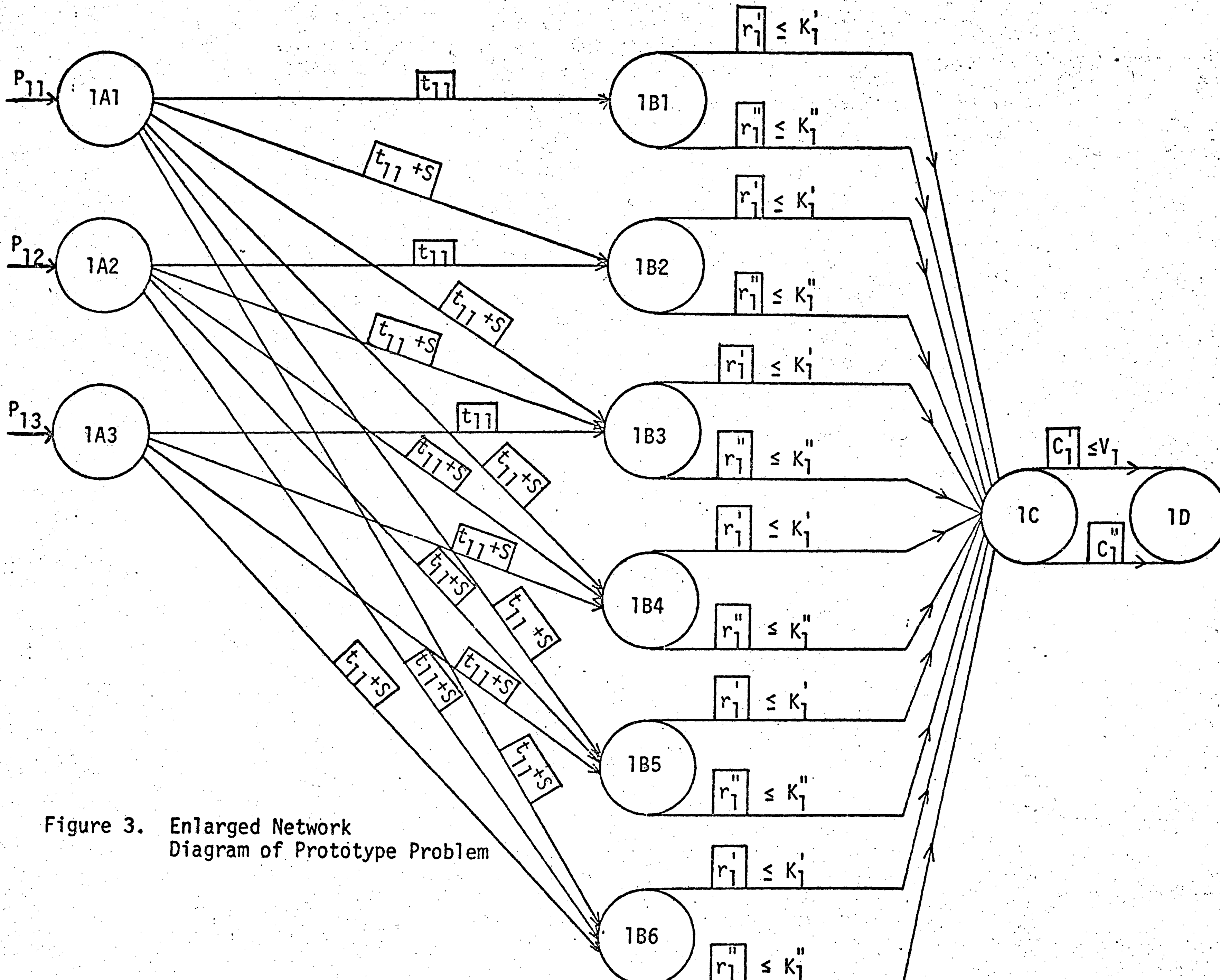

Figure 3. Enlarged Network Diagram of Prototype Problem

marginal cost (C''_j) associated with the second linear cost segment. Finally, all flow is channeled through a single node, node E, which acts as a sink for the entire raw product production.

Each arc in Fig. 3 has marginal cost enclosed in a box (unless there is no cost), and a lower and upper bound. On some arcs only an upper bound is given, implying a lower bound of zero. Other arcs have no bounds as stated, implying only that the flow should be nonnegative and, thus, could be infinite. Finally, some arcs have a single number without an inequality. For these arcs the lower and upper bounds are both equal to that number. The network problem then can be stated as follows: For a given set of plants find the least cost flow of goods through the network such that the flow does not violate the flow bounds on each arc.

Network Algorithm

In general, a network can be considered as a set of nodes connected by a set of arcs. Let X denote the set of nodes and E the set of arcs. If i and j are nodes in X that are connected by an arc from i to j, then the arc can be represented by the ordered pair (i,j) which is in E.

The most general network flow problem may be stated as follows: Suppose that for each arc (i,j) in E there are two ~~members~~ numbers that limit flow -- a lower bound denoted by $L_{ij} \geq 0$ and an upperbound or capacity denoted by K_{ij}, where $L_{ij} \leq K_{ij}$. Also suppose on each arc there is defined a unit flow cost denoted by C_{ij}. The objective of the network flow problem is to find a least cost flow that satisfies the upper and lower bounds. This is referred to as the circulation problem.

Note that for each arc (i,j) the triplet $[L_{ij}, K_{ij}, C_{ij}]$ is defined. The flow in each arc is denoted X_{ij}. Obviously,

$$L_{ij} \le X_{ij} \le K_{ij}$$

for all $(i,j)\epsilon E$. At each node there must exist a flow balance, that is, the flow into the node must equal the flow out. For each node $i\epsilon X$ this flow balance is represented by

$$\sum_j X_{ji} - \sum X_{ij} = 0$$

The objective is to find a set of flows, X_{ij}, which satisfies the flow bounds and the flow balance and which minimizes total flow cost.

$$\sum_i \sum_j C_{ij} X_{ij} = Z \text{ (min.)}$$

Thus, the problem is essentially one of linear programming. Because of the structure of this linear programming problem it is possible to construct a special computational algorithm that is much more efficient than the simplex. The appropriate algorithm for this problem is called the out-of-kilter algorithm (Ford and Fulkerson).

For each node equation define the dual variables U_i, $i\epsilon X$. Then multiply each node equation by this dual variable, add over all the equations and subtract this total from the cost function. This gives what Dantzig calls the relative cost function. The coefficients of the relative cost function are easily seen to be:

$$C^*_{ij} = C_{ij} + U_i - U_j$$

If the flow X_{ij} is feasible and optimal, then $C^*_{ij} = 0$ implies $L_{ij} \le X_{ij} \le K_{ij}$, $C^*_{ij} < 0$ implies $X_{ij} = K_{ij}$ and $C^*_{ij} > 0$ implies $X_{ij} = L_{ij}$. For non-optimal but feasible flow, each arc can be classified in one of the following classes.

a. $C^*_{ij} > 0$ and $X_{ij} = L_{ij}$

b. $C^*_{ij} < 0$ and $X_{ij} = K_{ij}$

c. $C^*_{ij} = 0$ and $L_{ij} \leq X_{ij} \leq K_{ij}$

a.* $C^*_{ij} > 0$ and $X_{ij} > L_{ij}$

b.* $C^*_{ij} < 0$ and $X_{ij} < K_{ij}$

These five classes may be illustrated by Fig. 4. The arcs that are in classes a, b or c satisfy the criterion for optimality and are thus "in-kilter." If all arcs are in-kilter, the solution is optimal.

But if the solution is not optimal, then there are some arcs in class a* or b.* These arcs are "out-of-kilter." The objective is to bring all out-of-kilter arcs into kilter. This may be accomplished in two ways: 1) change the flow so that an a*-arc becomes an a arc or a b*-arc becomes a b-arc, or 2) change the dual variables so that an a*-arc or a b*-arc becomes a c-arc. The details of this procedure are given in Ford and Fulkerson and need not be repeated here, especially since there are available several out-of-kilter computer codes.

The network formulation solves the same problem as the linear programming model using the separable convex procedure, namely, given a subset of plants what is the least cost flow of goods from production origins to the plant sites? After the solution is obtained the total of the fixed charges for the plants in the subset must be added to the total cost flow to obtain the final subset cost. However, this still leaves the problem of finding which of the many subsets to be used. For this a process of implicit enumeration was employed.

Selection of the Subsets

Although the network formulation will yield an optimal solution for a given subset of plants, it does not indicate which subset is best. The

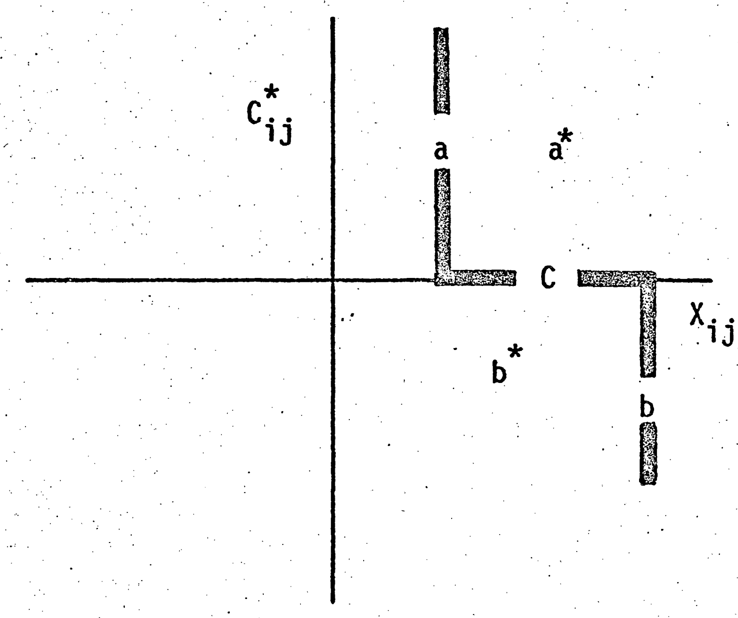

Figure 4. Out-of-kilter Solution Procedure

problem of finding which of the many plant combinations will be least cost is a problem of combinatorial mathematics. Numerous problems have been classed as combinatorial mathematics problems, but few have a closed form solution method. Instead, an enumeration procedure is often used. But as noted earlier, a complete enumeration of all combinations is not possible. However, to find an optimal combination in a reasonable time, it may be possible to organize the computations in such a way that only a fraction of the combinations need be examined. If the problem lends itself to development of binary variables, i.e., if a plant is either turned-on or turned-off, then, a technique referred to as implicit enumeration is applicable. The procedure does not deal with a specific mathematical framework nor does it follow the conventional iterative idea of an optimization process. Implicit enumeration is nothing more than an organized method of complete enumeration in which only a fraction of the total number of combinations are examined.

The basic idea of implicit enumeration is to picture the construction of a solution to an optimization problem as a search over a logic tree composed of branches and nodes. The computation then proceeds along a branch until it becomes obvious that continued progress along a given branch is unnecessary because the best possible payoff on that branch can be shown to be inferior to payoffs already observed on other branches. In this way, only partial examination of most branches need be considered, thus, significantly reducing number of combinations considered. Techniques for implicit enumeration vary widely from problem to problem; however, some of the basic principles are indicated by Garfinkel and Nemhauser.

Empirical Analysis

An extensive resource commitment was necessary to develop data inputs to carry-out the locational analysis. A 139 X 14 matrix relating production, production locations and distance to existing gin sites was developed from aerial photos and Agricultural Stabilization and Conservation Service data. The most expensive data gathering activity was that associated with estimating individual plant cost functions. Work measurement data was collected on each plant by use of the work sampling technique. Input-output parameters for energy, plant downtime and capacity utilization characteristics and other technical aspects of production effecting variable cost was obtained by monitoring plants throughout the 1973 season (Fuller and Washburn). Storage system input-output parameters were determined by monitoring an area which had adopted this technology. Once production functions had been specified, the cost functions were determined by applying factor prices.

The considered ginning subindustry is located along an irrigated segment of the Rio Grande Valley which extends for approximately 90 miles and varies from .25 to 7 miles in width. Currently fourteen gins operate in this area and annually process an average of 3071 bales per plant. Typically, harvest extends over a 16 week period with approximately 50 percent of the area output being collected in four consecutive peak harvesting weeks.

The optimum solution involved activation of six plants each processing a seasonal average of 7167 bales, during a sixteen week period. The selected plants were evenly dispersed throughout the production region with some modification for locational pulls associated with more intensive production areas. Approximately seven percent of the region's cotton production was processed during overtime shifts, whereas, slightly over ten percent of the production entered storage. Utilization of overtime shifts and storage occurred during peak harvesting weeks, when harvested output exceeded processing capacity.

As previously noted, cost trade-offs exist between plant costs and shipping, storage and overtime labor costs. That is, as additional plants are activated, system plant cost increases because of each plants' fixed charge, while shipping, storage and overtime labor cost decrease. Conceptionally, the least cost solution is characterized by a point where marginal savings in shipping, storage and overtime labor cost is equal to the marginal loss in plant cost (with respect to activating additional plants at their associated locations). The least cost solution involved deactivation of numerous plants, utilization of overtime and storage to increase the selected plants annual volume and a tendency to select a plant locational pattern which minimized shipping cost. One of the principal factors effecting plant selection was the substantial variable cost differences among plants. The selected plants experienced variable costs which were 13 percent less than the non-selected plant group and accordingly per hour processing capacity averaged 18 percent greater than the other plant group. Because of the inverse relationship between plant capacity and variable cost, storage cost was also favorably effected by selecting larger than average plant sizes. Even though plants fixed charges must have strongly influenced optimal plant numbers, it varied little between plants and accordingly had an insignificant effect on plant selection. The solution revealed that use of some storage and labor overtime was cost preferable to opening additional plants; however, the storage constraint was not reached. With additional storage, several more plants could have been deactivated since 22 processing weeks were available and no plant operated in excess of 16 weeks. Clearly, cost saving (fixed charges) associated with further reductions in plant numbers failed to offset increases in storage, shipping and overtime labor costs. The effect of shipping costs on the optimal solution evidenced itself in the following manner: 1) A locational configuration which closely approximates one predicted by a priori reasoning; that is, plants situated so as to minimize shipping cost. 2) With the optimal solution, excess plant capacity exists during a portion of the season, thus the opportunity to route cotton to the more efficient plants. Since this never occurred, it implies that these processing cost savings failed to offset shipping costs associated with the additional shipping distances.

Because of the ginning industry's excess plant capacity it was not necessary to operate all area plants to meet peak harvest demands. Therefore, some reduction in operating plant numbers and associated plant cost was available without introduction of storage. Thus, to identify system cost savings directly attributable to new storage technology, a solution was obtained which disallowed this activity. This was accomplished by removing the storage arcs between A and B level nodes (Figure 2,3).

The least cost solution, disallowing storage, involved the operation of nine plants each processing a seasonal average of 4778 bales. Approximately, seven percent of the regions cotton production was processed during overtime shifts and was activated in those weeks when harvested output exceeded processing capacity. Characteristics of the non-storage optimal solution was similar to the optimal solution permitting storage. All six of the plants included in the optimal solution involving storage also appeared in the optimal non-storage solution, thus the tendency to select the higher capacity plants which experienced lower variable cost. As exhibited by the least cost solution which included storage, principal system cost savings are available through reducing plant numbers (fixed charges) and maximizing volume per plant.

Closing unneeded plants was predicted to reduce system cost by 13.5 percent, while the introduction of storage decreased costs an additional 2.5 percent (Table 1). Based on savings attributable to storage, 6.5 years would be required to capture capital investment necessary for implementation of the new storage technology.

Summary

As applied economists endeavor to include additional realism into their locational analysis, conventional solution techniques become limiting and unaccomodating. The encountered plant location problem involved consideration of several dimensions not conveniently incorporated into existing location models. The problem required consideration of 1) short-run costs unique to each plant but whose general form was non-linear with an annual fixed charge, 2) two levels of variable labor cost associated with regular and overtime work shifts and each shifts weekly output constraint, 3) storage cost and 4) shipping cost between each pair of production locations and plant sites. The least cost solution identified 1) plants to be activated at alternative sites and associated quantity processed per week, 2) quantity processed at each plant in regular and overtime labor shifts per week and 3) quantity to be stored per week.

To attain the desired degree of realism, the problem was formulated as a network problem and solved with a network code. The network formulation permits

Table 1. Contrasted Characteristics of Conventional and Optimum Short-run Industry Organization

Organization	Number of Operated Plants	Plant Cost[1]	Storage Cost	Assembly Cost	Total System Cost
		($)	($)	($)	($)
Conventional	14	528122	0	69167	597289
Optimum without storage	9	445065	0	71326	516391
Optimum with Storage	6	393018	26786	80970	500775

[1] Does not include plant fixed cost, bagging and ties, office supplies and utilities, advertising and travel.

the applied economist to incorporate additional realism into his analysis and recent developments in network code algorithms allow investigation of larger problems.

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Footnotes

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