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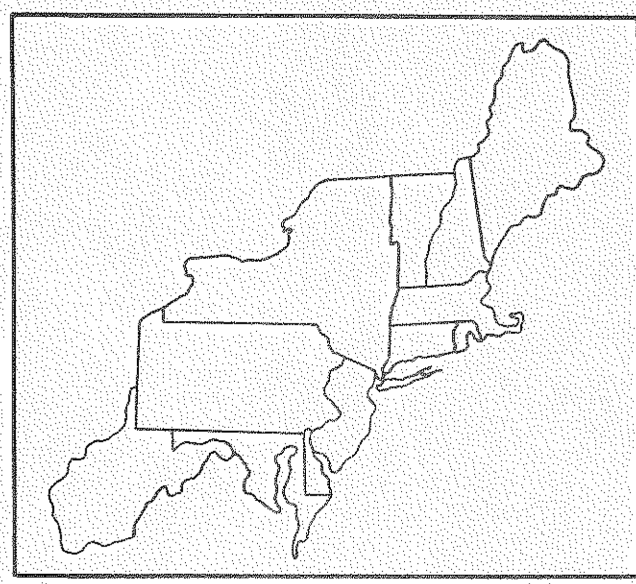

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AN OUTLINE OF THE NORTHEAST DAIRY SECTOR SIMULATOR

by

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One of the principal objectives of the NE-126 regional research project is to study the spatial organization of the Northeast dairy sector. The Northeast Dairy Sector Simulator, or NEDSS, has been constructed to assist in this analysis.

As its name implies, NEDSS is a model of the Northeast dairy sector. It has been designed to be a complete and rather detailed model of the entire Northeast dairy sector. It does not attempt to describe behavior in any other economic sector or geographic region. However, the model could easily be adapted to any geographic region or subregion which had a similarly structured dairy sector. A brief discussion of the model and its distinctive characteristics is provided below.

NEDSS is a transshipment and plant location model that combines network flow and facilities location methodologies. The model concept draws on the plant location formulation described by King and Logan in 1964 and used, in modified forms, in more recent dairy sector analyses (Beck and Gordon, Boehm and Conner, Buccola and Conner, Kloth and Blakley, and Thomas and DeHaven). It also builds on the plant location application discussed by Fuller et al., on the transshipment model discussed by McLean et al., and on the dairy sector networks constructed by Babb et al., and Novakovic et al..

NEDSS differs from its predecessors in the scope of its analysis. This is made possible through the use of recently developed solution techniques. Typically, previous plant location models were forced to seriously restrict the size of the problems which they analyzed. This usually resulted in limiting the numbers of supply or processing points or in independent analyses of each product class. Also, in most of the previous analyses, the movements of processed products from processing to consumption points were ignored.

The dairy sector is viewed at three market levels in NEDSS; these are referred to as supply, processing, and consumption. Raw milk production at the farm level is assumed to be homogeneous and suitable as input for any processed dairy products. At the processing level, milk is assumed to be processed into three dairy product groups: 1) fluid milk products (Class I under Federal Orders), 2) soft manufactured products (Class II under most Federal Orders), and 3) storable manufactured products such as cheese, butter, nonfat dry milk, and miscellaneous hard manufactured products (Class III under most Federal Orders). All three product groups are consumed at the retail level.

NEDSS is capable of simultaneously analyzing the optimal location of processing plants and corresponding optimal milk movements for each of the three

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products previously defined by considering the cost of assembly, processing and distribution between over 1,500 economic units, representing over 280 geographic locations.

Transshipment Formulation

The problem solved by NEDSS can be described as a specially structured transshipment problem. A transshipment problem is a network flow problem in which there are supply, demand, and transshipment nodes having positive, negative, and zero supply, respectively. There are arcs from one node to another which are assigned a non-negative cost and capacity.

Figure 1 depicts the transshipment formulation of a problem in which there are three unique geographic locations--A, B, and C--and production occurs at points A and B, consumption of each of three products exists at points A and C, and processing may occur at any points A, B, and/or C. Product flows move over the arcs from supply points through processing points to demand points in order to satisfy product demands; it is assumed that supply equals demand. A flow is an assignment of non-negative values to each of the arcs. A flow is feasible with respect to the capacities and supplies if the flow on every arc is no larger than the capacity of the arc and the sum of the flows out of a node minus the sum of the flows into the node is equal to the amount of supply at that node. The cost of the network is equal to the sum over all arcs of the flow on each arc times its cost. A transshipment problem is solved when a feasible flow of minimum cost is found.

In NEDSS application raw milk is aggregated at the farm level into geographic centers. These aggregations correspond to the supplies in the transshipment model. As in the case of farms, dairy processing plants are grouped into processing centers. The processing centers fall into three categories according to the type of finished product - fluid, soft, or hard dairy products - into which the raw milk is converted and form a subset of the transshipment nodes. Each center may have a limit on the amount of raw milk which may be processed into each product type. Demands are also grouped geographically into centers with a demand for each of the three product types. The raw milk is shipped from the supply centers to the processing centers and from processing centers to the demand centers subject to the following restrictions:

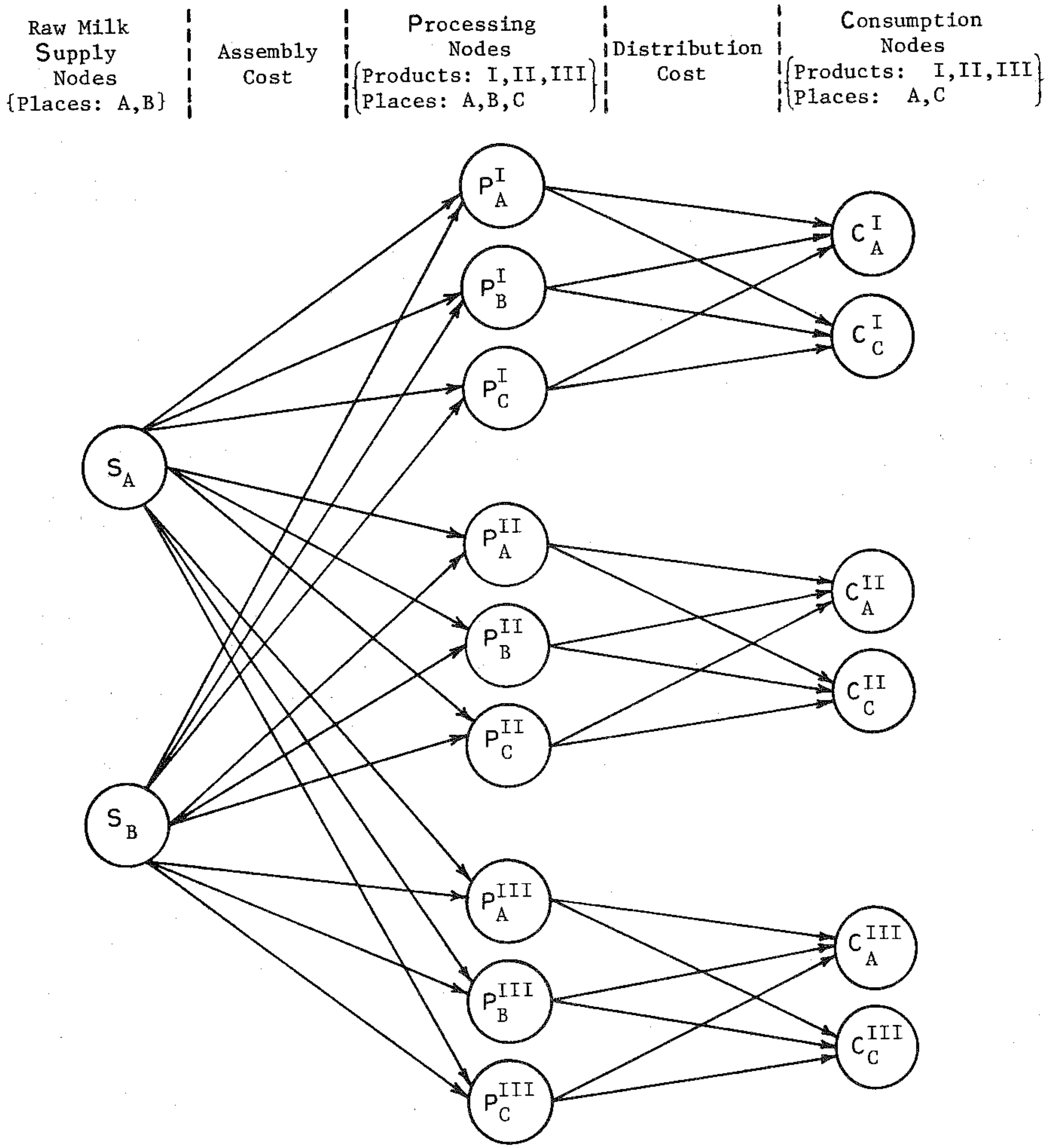
1) The amount of milk shipped from a supply center to the processing centers does not exceed the amount of milk collected at the supply center.

2) No processing center processes more raw milk than its capacity for any product type.

3) The shipments from the processing centers to the demand centers meet the demands for each demand product type at each center.

There are transportation costs associated with shipments of the raw milk to the processors, as well as with shipments of the finished products to the demand centers. There is also a processing cost associated with each processing center and product type. The model is solved when we find a set of shipments satisfying the restrictions above while minimizing transportation plus processing costs.

FIGURE 1. EXAMPLE TRANSSHIPMENT NETWORK



Production

The transshipment formulation of the Northeast dairy sector spatially disaggregates the region into a number of subregions based on the 308 counties included in the study area. Basically, each county which had more than 1,000 head of dairy cows in 1974 defines a production region which is represented by a single point within that county. Counties which had fewer cows are combined with neighboring (larger) counties. This resulted in 236 supply points being delineated (Figure 2).

The supply component of NEDSS, draws from the supply response work of Masud and Elterich and Criner (the latter is reported in this proceedings). Point estimates of milk production are calculated from adaptations of these supply models and alternative assumptions regarding projected exogeneous variables. These point estimates are then used as the production of raw milk entering the transshipment network at production points.

The cost of bulk milk assembly used in NEDSS is based on the work of Hahn (reported in this Proceedings).

Consumption

Consumption regions consist of subregions, comprised of one or more counties, of the 308 counties included in the study area. These subregions were delineated on the basis of county populations and are represented geographically by a single point within each subregion. This resulted in 141 consumption points being delineated (Figure 3).

Milk product consumption for each of the three product categories is treated similarly to milk supply in NEDSS. The demand response work by Morehart (reported elsewhere in this proceedings) has been adapted to the model. Point estimates of consumption are calculated for each consumption area given a set of assumed exogenous variables. These point estimates are then used as the consumption level for final products in the network at each consumption point.

The cost of distributing the three product types from processing to demand centers is based on the work of Metzger.

Processing

Processing of each class of product is allowed to take place at any of the 284 geographic points which are the union of the production points and consumption points, as shown in Figures 2 and 3. The choice of processing locations can be constrained by the user (e.g., existing locations) or selected by the model in a cost-minimizing fashion. Plant capacity estimates used in this study were assembled by Novakovic and Pratt with extensive help from Lynn Sleight, John Rourke (of AMS-USDA), and Homer Metzger (formerly of the University of Maine) as well as other members of the NE126 technical committee (see Hahn, Novakovic, and Pratt).

First, a list of 595 plants operating within the geographic area in 1982 was compiles. Each plant was then categorized with respect to its major product; fluid, soft, or hard dairy products (see Figures 4-6). From these lists, plants were combined into groups of three or more. With the aid of the Dairy

FIGURE 2. SUPPLY POINTS USED IN NEDSS

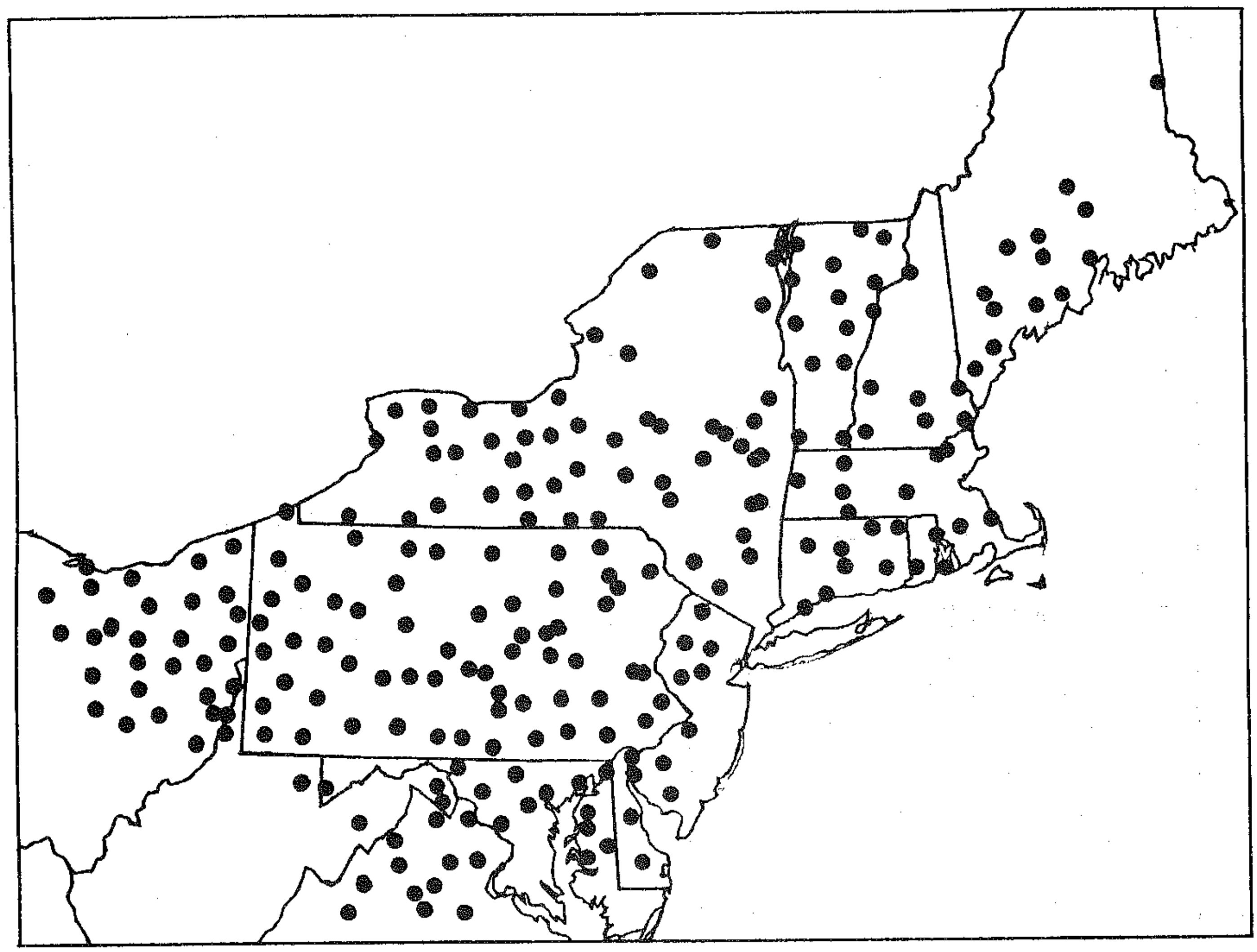


FIGURE 3. CONSUMPTION POINTS USED IN NEDSS.

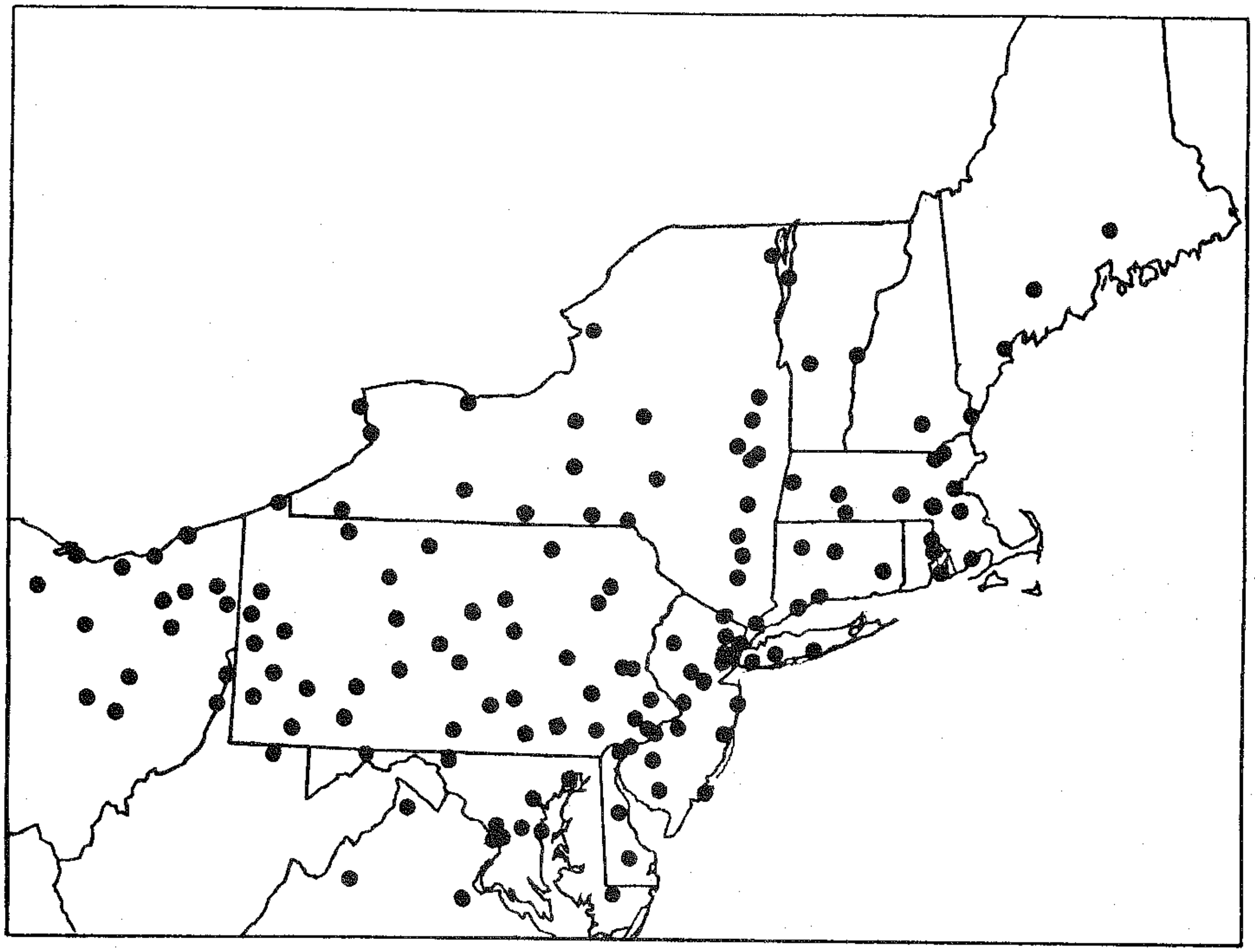


FIGURE 4. ACTUAL LOCATIONS FOR FLUID PRODUCT PROCESSING PLANTS

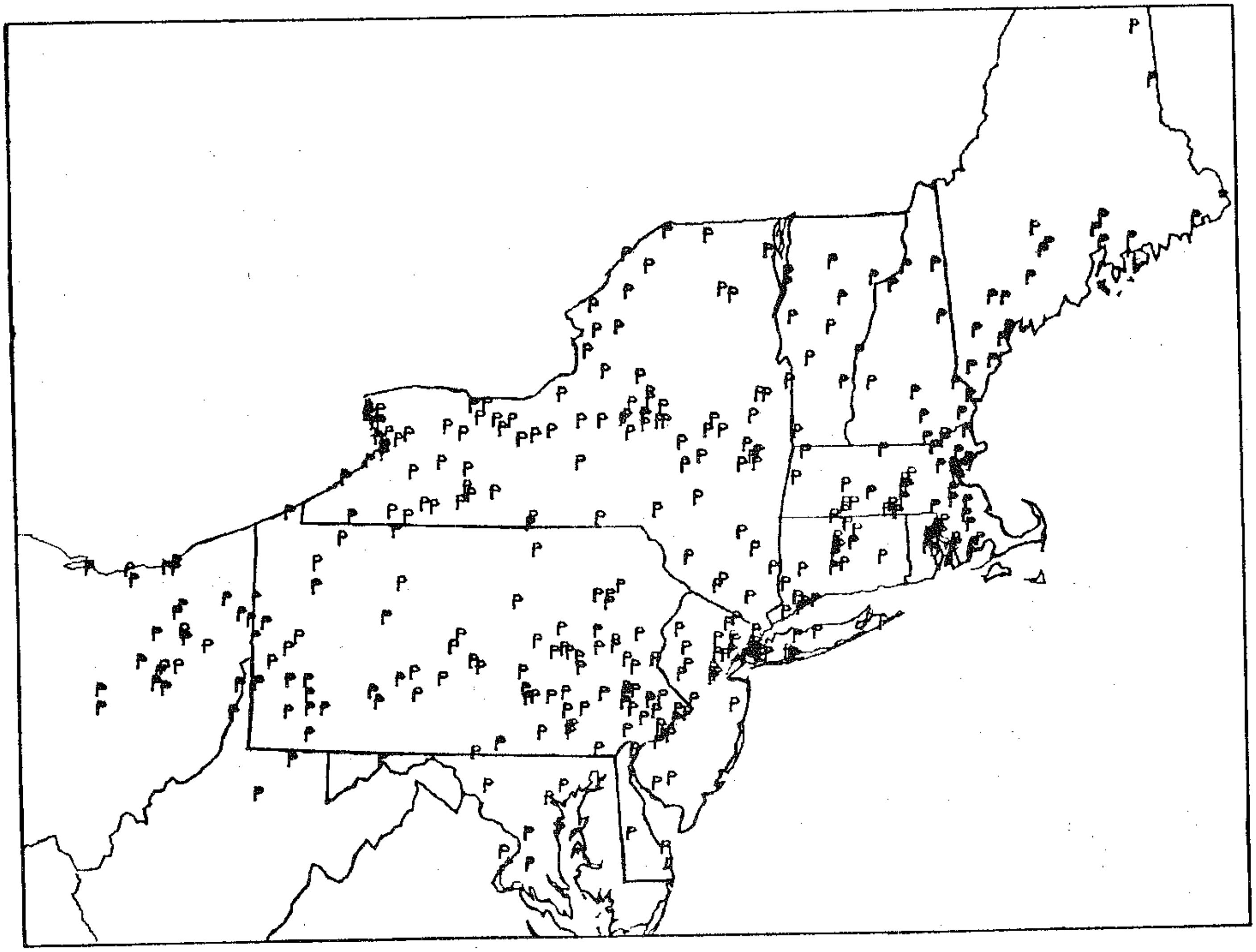


FIGURE 5. ACTUAL LOCATIONS FOR SOFT DAIRY PRODUCT PROCESSING PLANTS

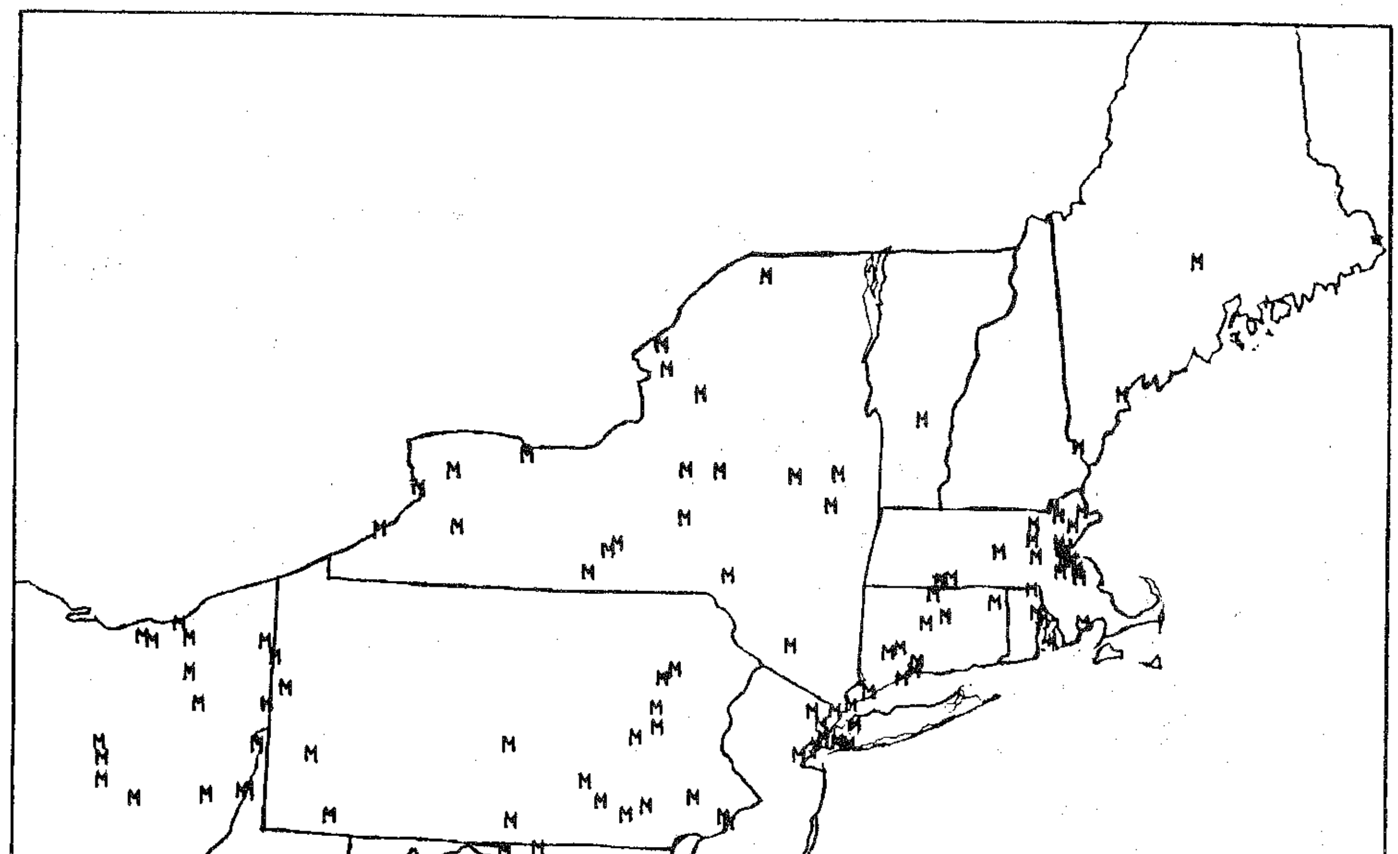
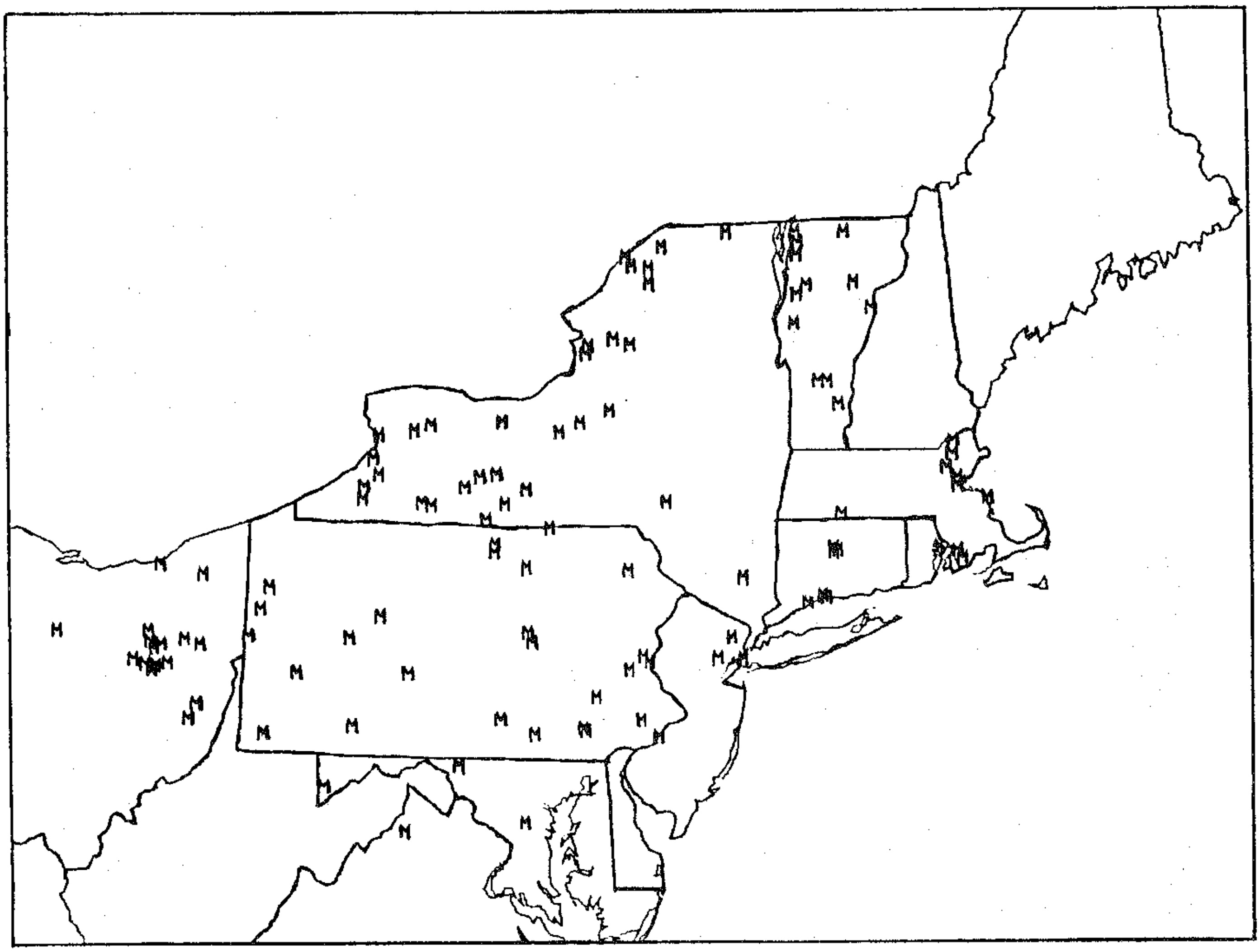


FIGURE 6. ACTUAL LOCATIONS FOR HARD DAIRY PRODUCT PROCESSING PLANTS



Division of AMS-USDA, state milk marketing officials, and University staff, estimates of processing capacity for the resulting 80 fluid plant groups, 10 soft product groups, and 17 hard product groups were made. Figures 7-9 depict the locations of these aggregation points.

The cost of processing raw milk into the three products used in NEDSS is based primarily on the work of Smith (reported in this proceedings).

Geographic Distances

Transportation cost for moving raw milk from production points to processing points and finished products from processing points to consumption points is a function of the distance travelled. Generally, there are $(N^2 - N)/2$ distances which must be derived in some way for N points. For this problem, with 284 points, there are 40,186 such distances to be determined.

To determine all of these distances by hand would be an enormous task susceptible to significant error. Fortunately, a methodology exists whereby this task can be reduced to manageable proportions. 'Shortest Path Algorithms' (Gilson & Witzgall) need only information on the distance between adjacent points in a network in order to find the shortest distance between any two points. Thus, by simply making measurements of the approximately 750 distances between adjacent points in the road network connecting all of the 284 geographic points used in this model, we are able to use a shortest path algorithm to quickly and efficiently determine the 40,186 distances which are needed.

A Model with Positive and Normative Characteristics

NEDSS is an optimizing model. It minimizes the cost of assembling, processing, and distributing milk and milk products. Although NEDSS is, in this sense, a normative model, it is not designed to say what prices ought to be or how milk ought to be produced, processed or consumed. The model is intended to describe the economic performance of the dairy sector assuming that milk is transported and processed efficiently within and across geographic areas. In that sense, it does have positive characteristics.

NEDSS can be operated in several different modes with respect to processing capacities and processing costs; 1) processing capacity at any potential location may be assumed to be unlimited and processing costs per unit can be assumed to be constant with respect to volume processed, 2) processing capacities at each potential processing location may be constrained to some amount and processing costs assumed constant, 3) processing capacities can be unlimited with processing costs per unit assumed to be declining with increased volume, and 4) processing capacities can be constrained and processing costs assumed to decline.

Numerical Implementation

In order to include processing capacities, the typical network formulation of an (uncapacitated) transshipment problem, as represented, in Figure 1 needs to be modified. In Figure 10, a second set of processing nodes is added to the usual array of production, processing and consumption nodes so that the arc from each processor node to the "dummy" processor node could include a capacity, ("cap.= ___"), and a processing cost, (RI, RII, or RIII). The numbers at the

FIGURE 7. LOCATIONS OF AGGREGATED FLUID PRODUCT PROCESSING PLANTS

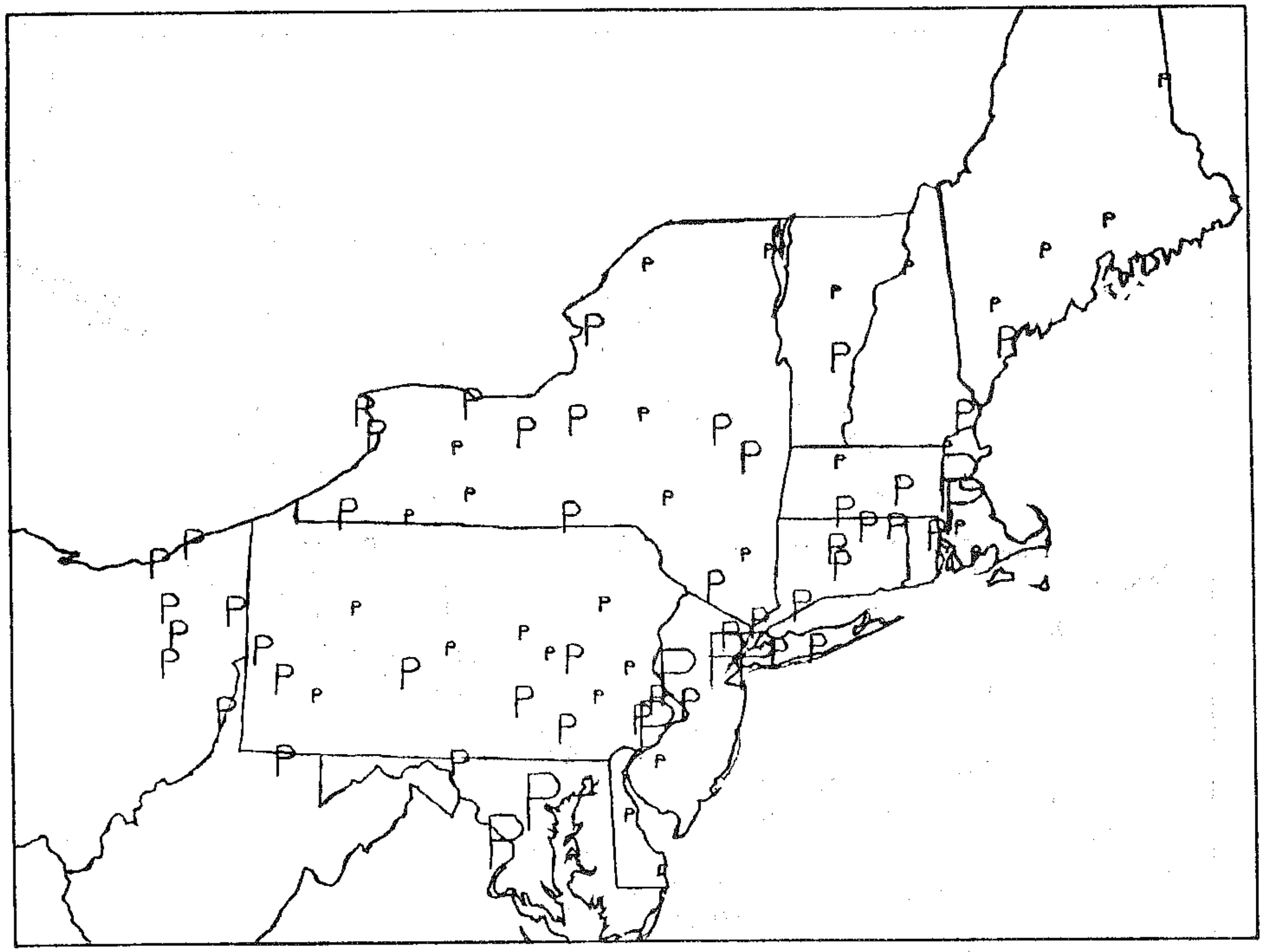


FIGURE 8. LOCATIONS OF AGGREGATED SOFT DAIRY PRODUCT PROCESSING PLANTS

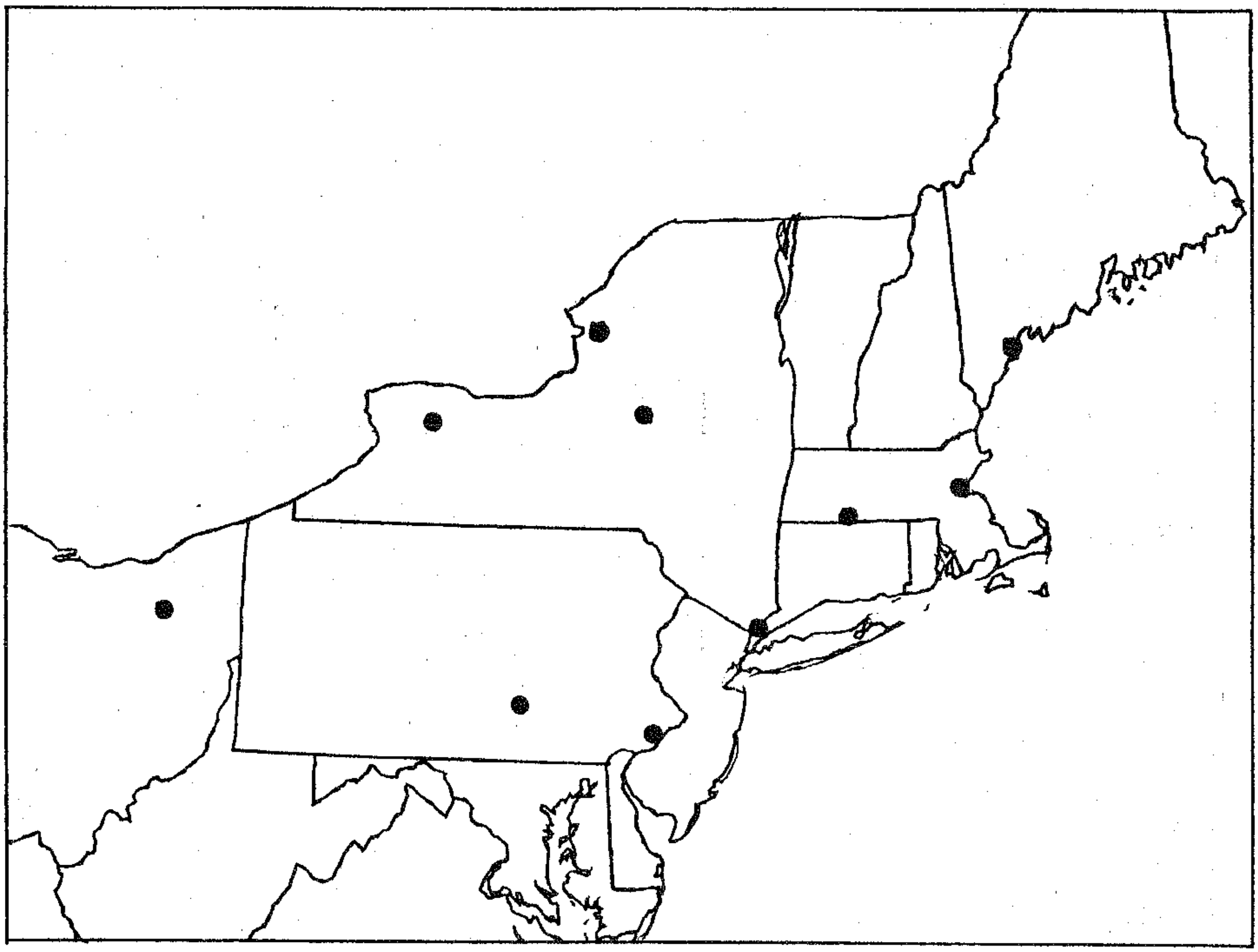


FIGURE 9. LOCATIONS OF AGGREGATED HARD DAIRY PRODUCT PROCESSING PLANTS

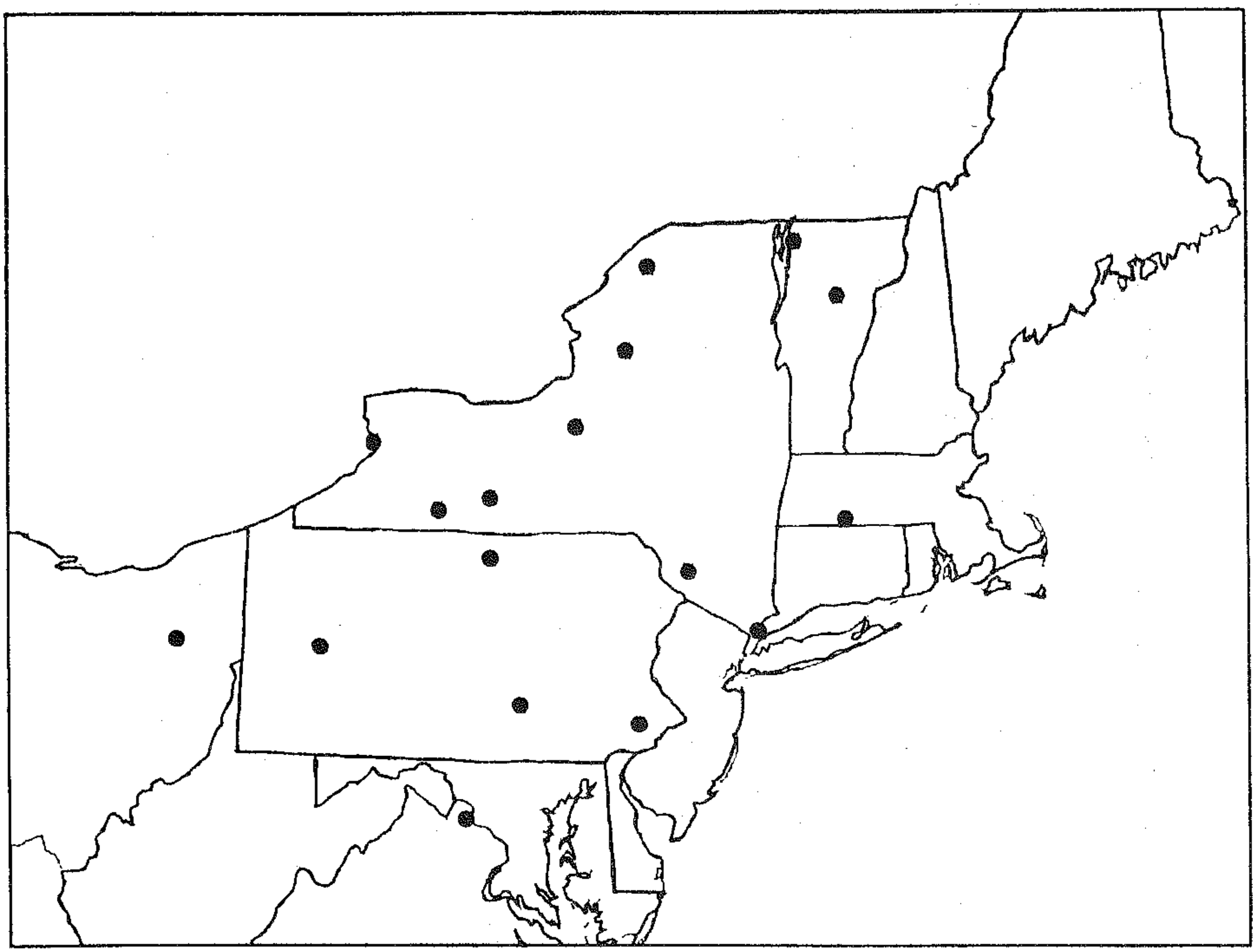
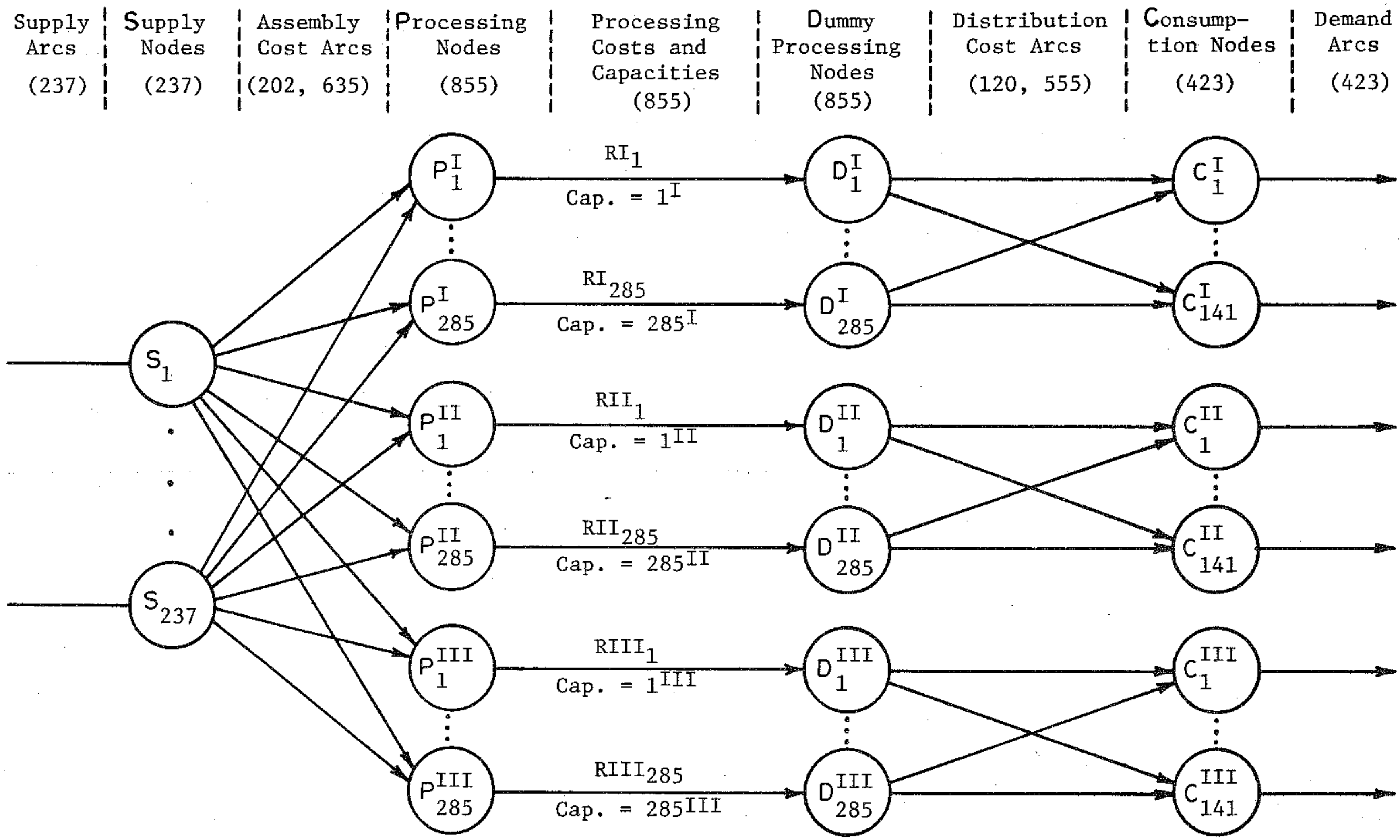


FIGURE 10. NETWORK REPRESENTATION OF NEDSS



top of the figure represent the number of nodes or arcs in each section of the NEDSS network. As can be seen, there are a total of 324,705 arcs and 2,370 nodes. This is a very large problem which requires substantial computing resources simply to generate, as well as to solve.

The network solver used in the NEDSS system is an implementation of the primal simplex method for linear programs. The implementation takes advantage of:

1) the network structure of the linear program. This is accomplished by implementing the revised simplex method and maintaining the basis and its inverse using list structures. The list structures used are those developed by Michael Grigoriadis and Tau Hsu for RNET, a 'minimum cost network flow' computer program written in Fortran at Rutgers University. The significance of using list structures to maintain the basis is that the pivot operations of the simplex method can be performed in a number of steps proportional to the number of nodes in the network. This is much faster than they can be performed by a general purpose simplex code.

2) the unique structure of this particular application. In Figure 10, it can be seen that there are actually 4 separate transportation problems embedded in the network; 1) production to processing, 2) class I processing to class I consumption, 3) class II processing to class II consumption, and 4) class III processing to class III consumption. Each of these sections is "bipartite", i.e. the set of nodes can be partitioned into two subsets so that all arcs begin in one set and end in the other. This information may be used to store the endpoints, (FROM(i) and TO(i)), of an arc, (i), as functions or subroutines with very efficient internal storage requirements that are independent of the size of the problem.

3) the small percentage of arcs which are capacitated. From the problem description we have, the only arcs which are capacitated are the processing arcs. There are fewer of these arcs than there are nodes in the graph. We utilize this observation to store the capacities as a function with internal storage equal to the number of processors plus some amount independent of the problem size.

The exploitation of these special properties (along with the implementation of a program capability for using prior feasible solutions as initial, restart solutions for a subsequent problem) allows for the efficient solution of this very large problem.

A Sample Solution

To demonstrate the general capabilities of NEDSS, a hypothetical, but reasonably representative, example problem was generated and solved. This involved the specification of raw milk production at each production point and final product consumption levels at each consumption point, as well as bulk milk transportation costs and final product distribution costs. This example problem was solved as an uncapacitated problem such that any potential processing point could process as much of any product as needed in order to minimize the total marketing cost (assembly and distribution). No economies of scale in processing costs were allowed, so that for each product type, all potential processing locations faced equal and constant unit processing costs.

Figures 11-13 depict the flows of raw milk from production points, "s", to processing points, "p". Any point which is both a supply and a processing point which is depicted by what appears to be a "B". The lines representing flows provide a quick and concise picture of the solution, which involves hundreds of bulk milk movements. Figures 14-16 depict the flows of final products from processors, "P", to consumption centers, "D". Again, points which are both processing and consumption centers are depicted by what appears to be a "B".

As can be seen from these figures, the general result for this hypothetical example is that milk destined for Class I use moves longer distances as bulk milk while milk destined for Class II and Class III use moves longer distances as final products. Also, since the region is milk deficient, milk moving into the region comes in from the Midwest as Class III final products, destined mainly for the large metropolitan markets on the Atlantic Coast. Class II product demands are entirely satisfied by in-area raw milk and are generally processed outside of the large metropolitan areas and moved to these areas as final products.

Those familiar with dairy markets will find this solution to be quite predictable. As a sample solution, these results are somewhat unexciting by themselves. However, they should demonstrate the range, power and flexibility of the model for comparing the implications of policy and general economic changes that affect milk supply, processing, and/or demand. By altering supply/demand situations as well as the various cost parameters and by using the different solution nodes, the sensitivity of plant locations and product flows to these changes can by systematically investigated.

FIGURE 11. FLOWS OF BULK MILK FROM PRODUCTION POINTS (S) TO FLUID MILK PROCESSING POINTS (P)

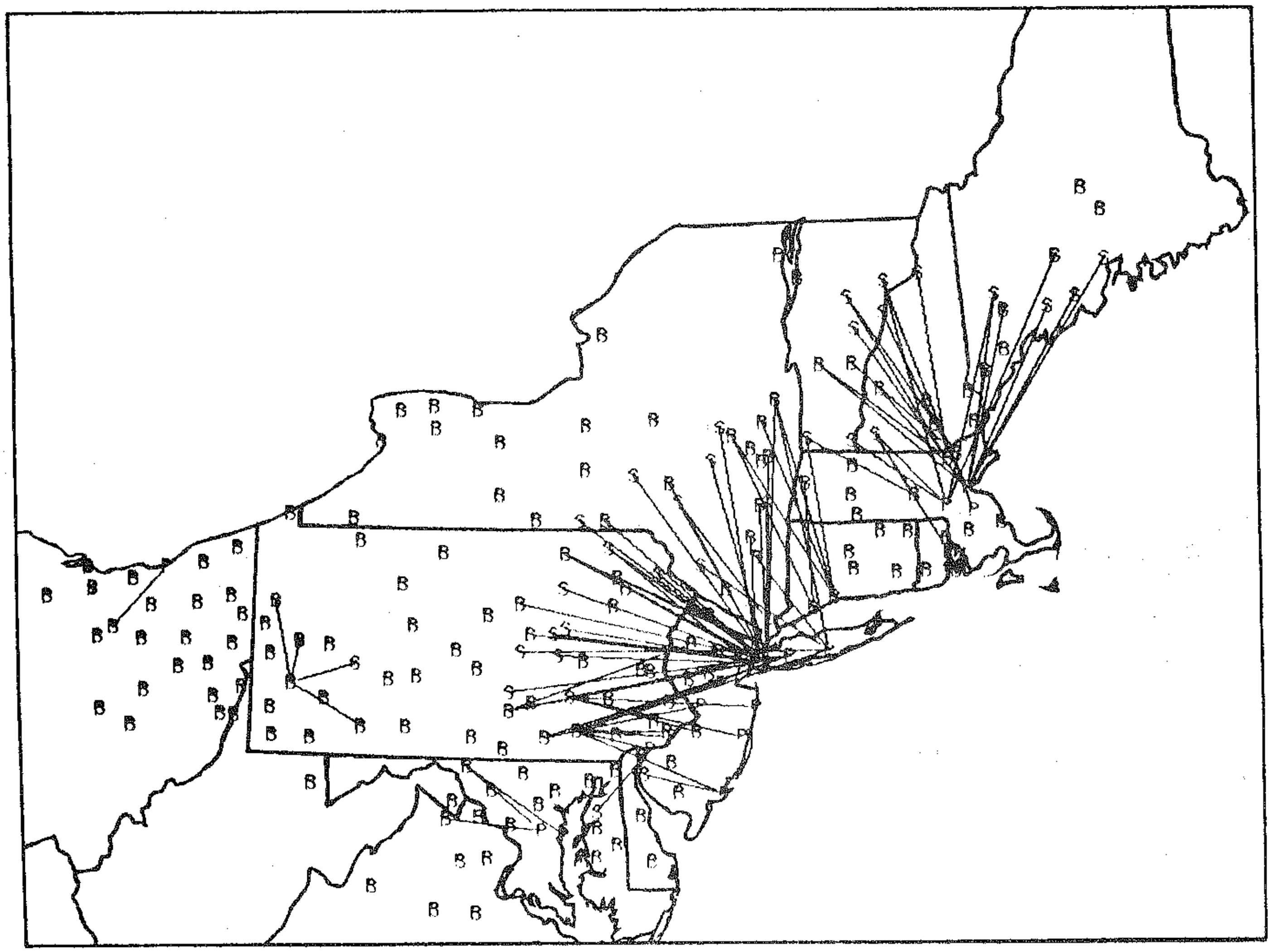


FIGURE 12. FLOWS OF BULK MILK FROM PRODUCTION POINTS (S) TO SOFT DAIRY PRODUCT PROCESSING POINTS (P)

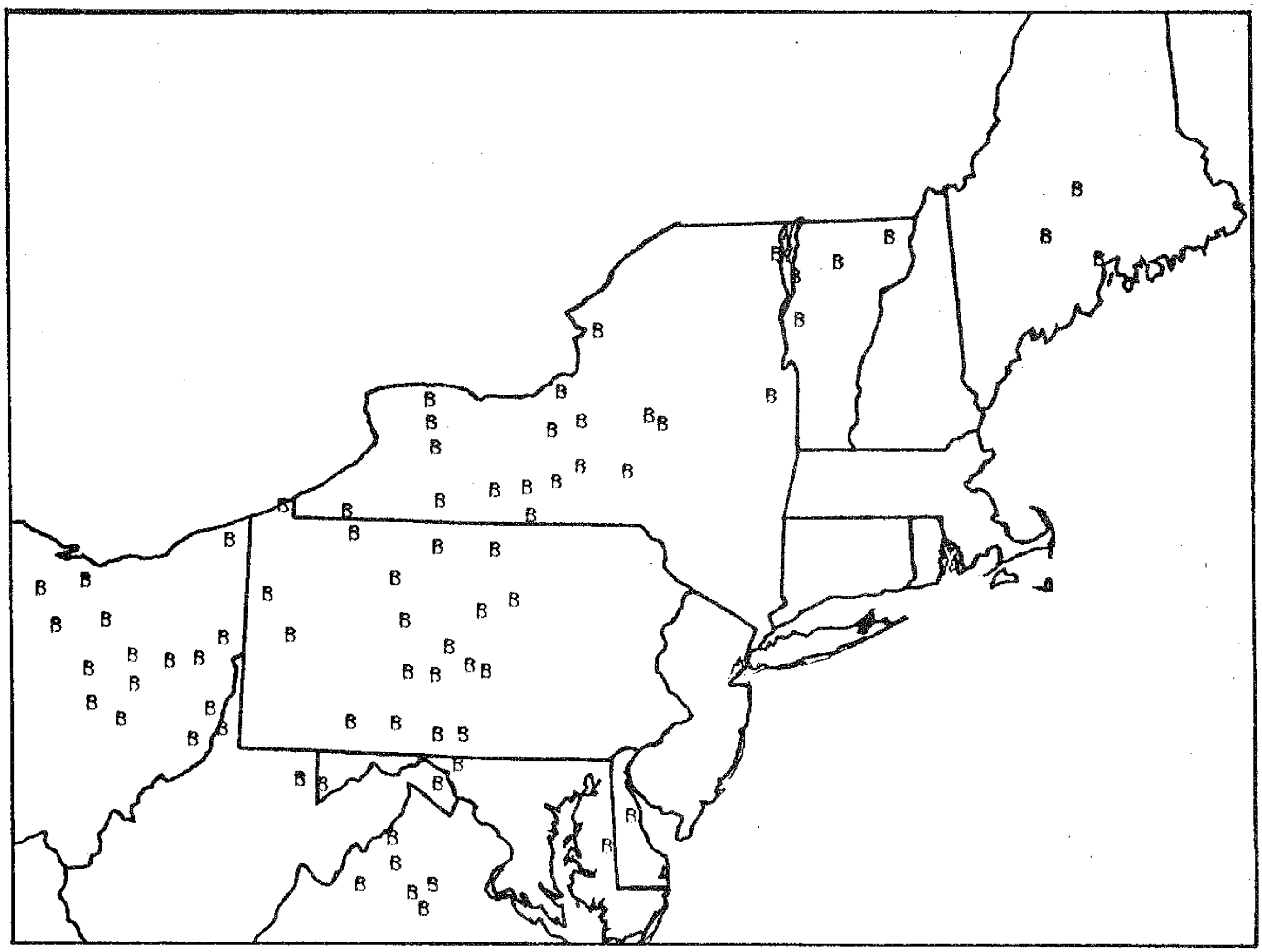


FIGURE 13. FLOWS OF BULK MILK FROM PRODUCTION POINTS (S) TO HARD DAIRY PRODUCT PROCESSING PLANTS

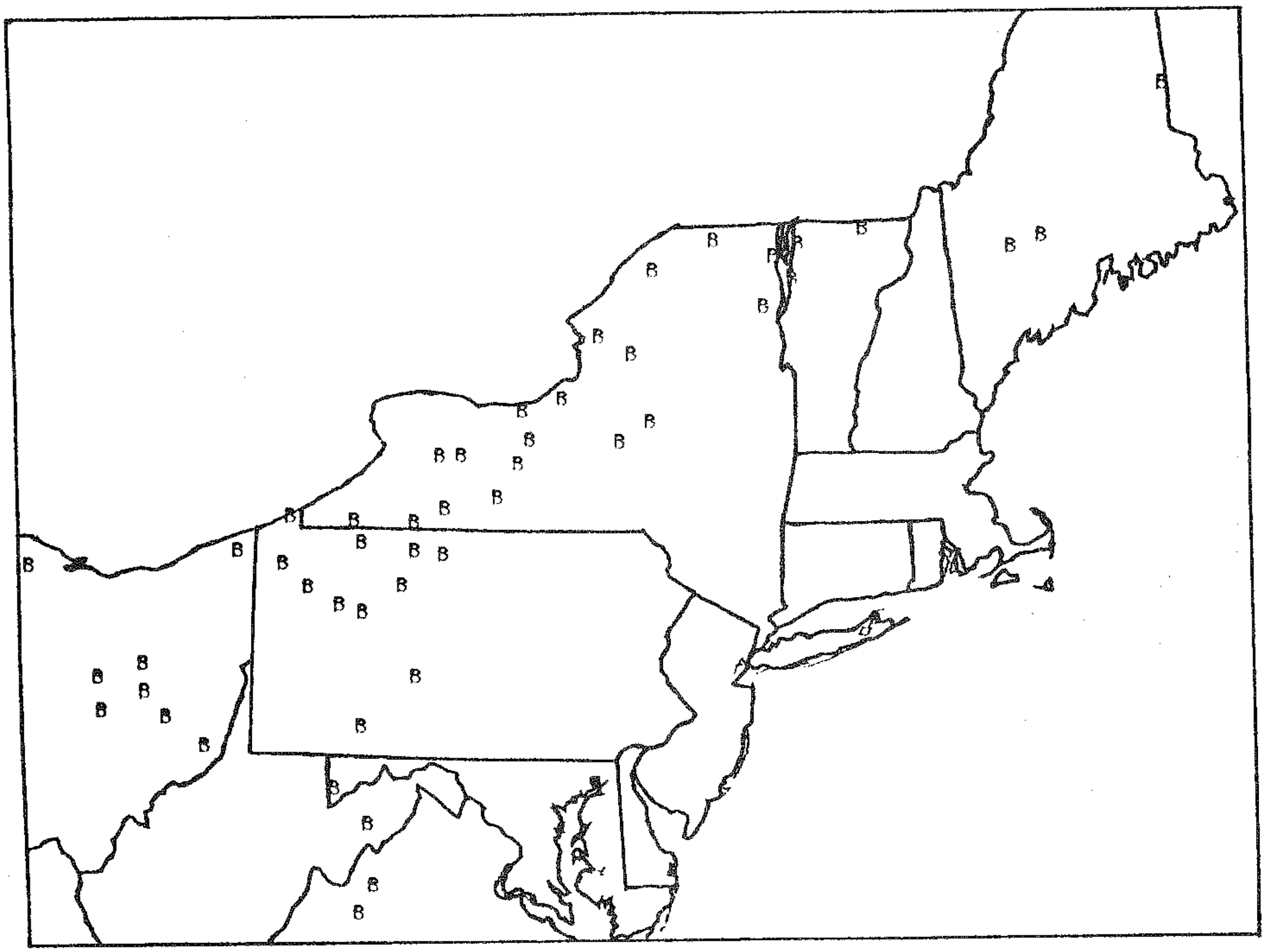


FIGURE 14. FLOWS OF PROCESSED FLUID MILK PRODUCTS FROM PROCESSING POINTS TO CONSUMPTION POINTS

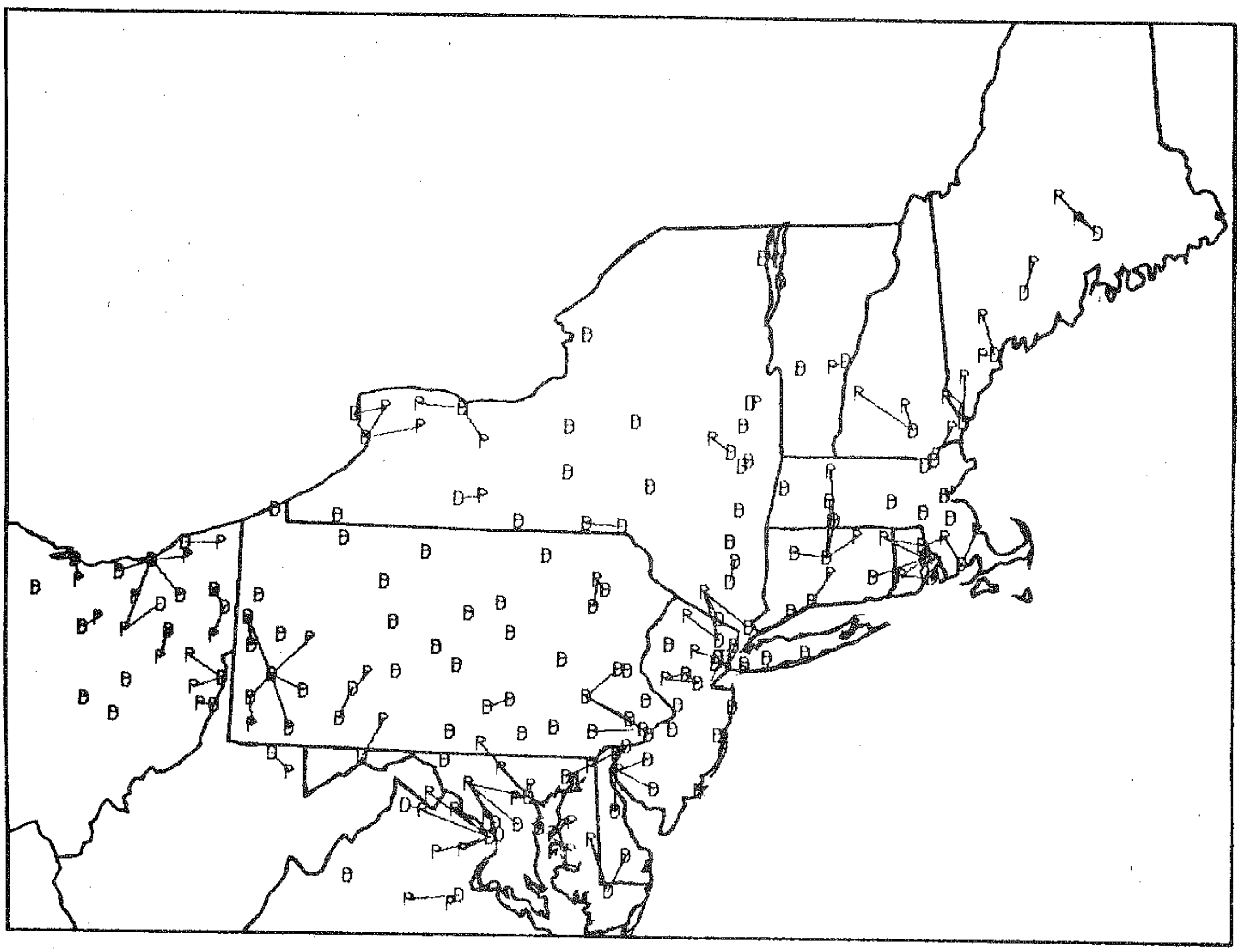


FIGURE 15. FLOWS OF PROCESSED SOFT DAIRY PRODUCTS FROM PROCESSING POINTS (P) TO CONSUMPTION POINTS (D)

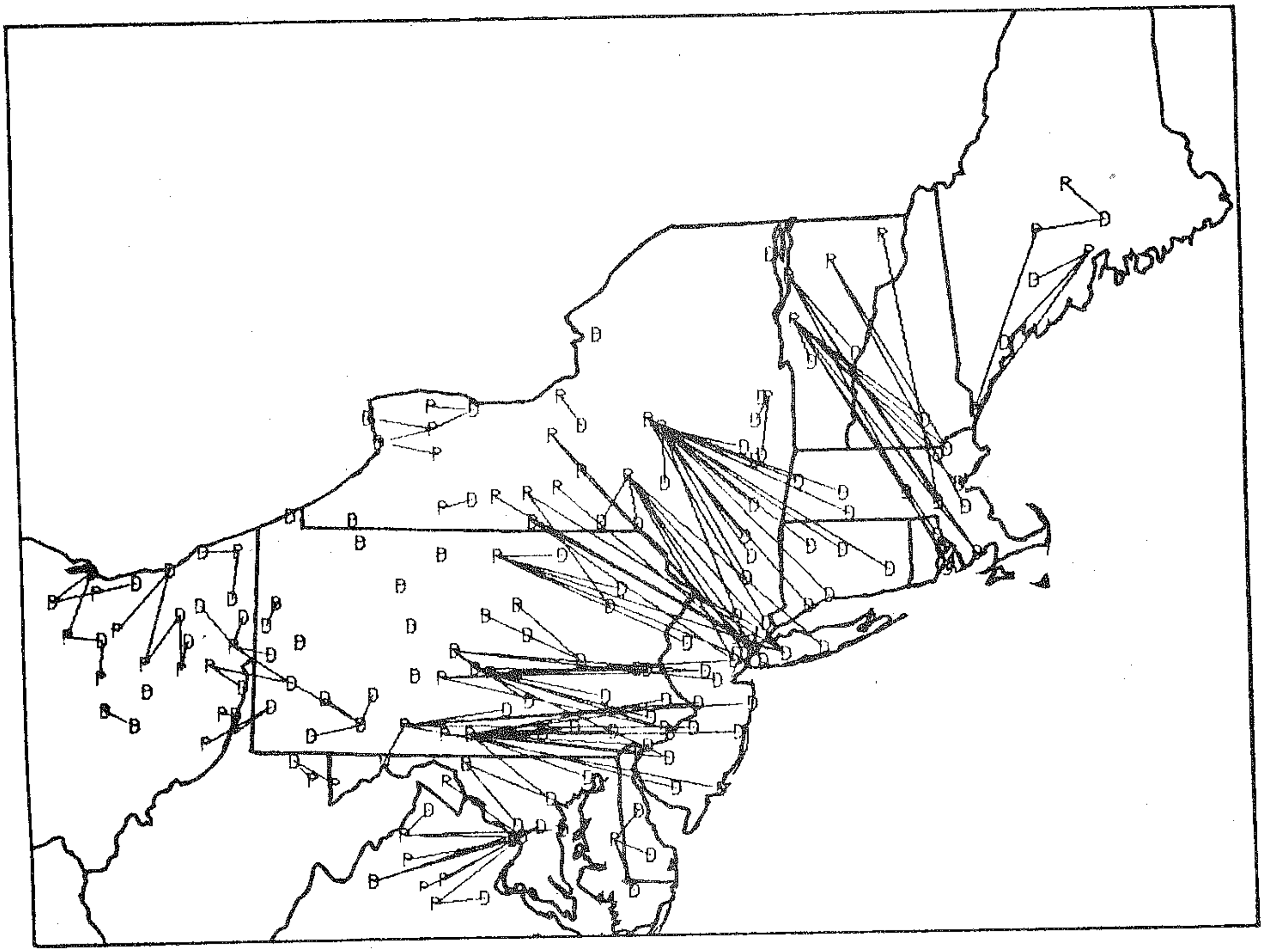
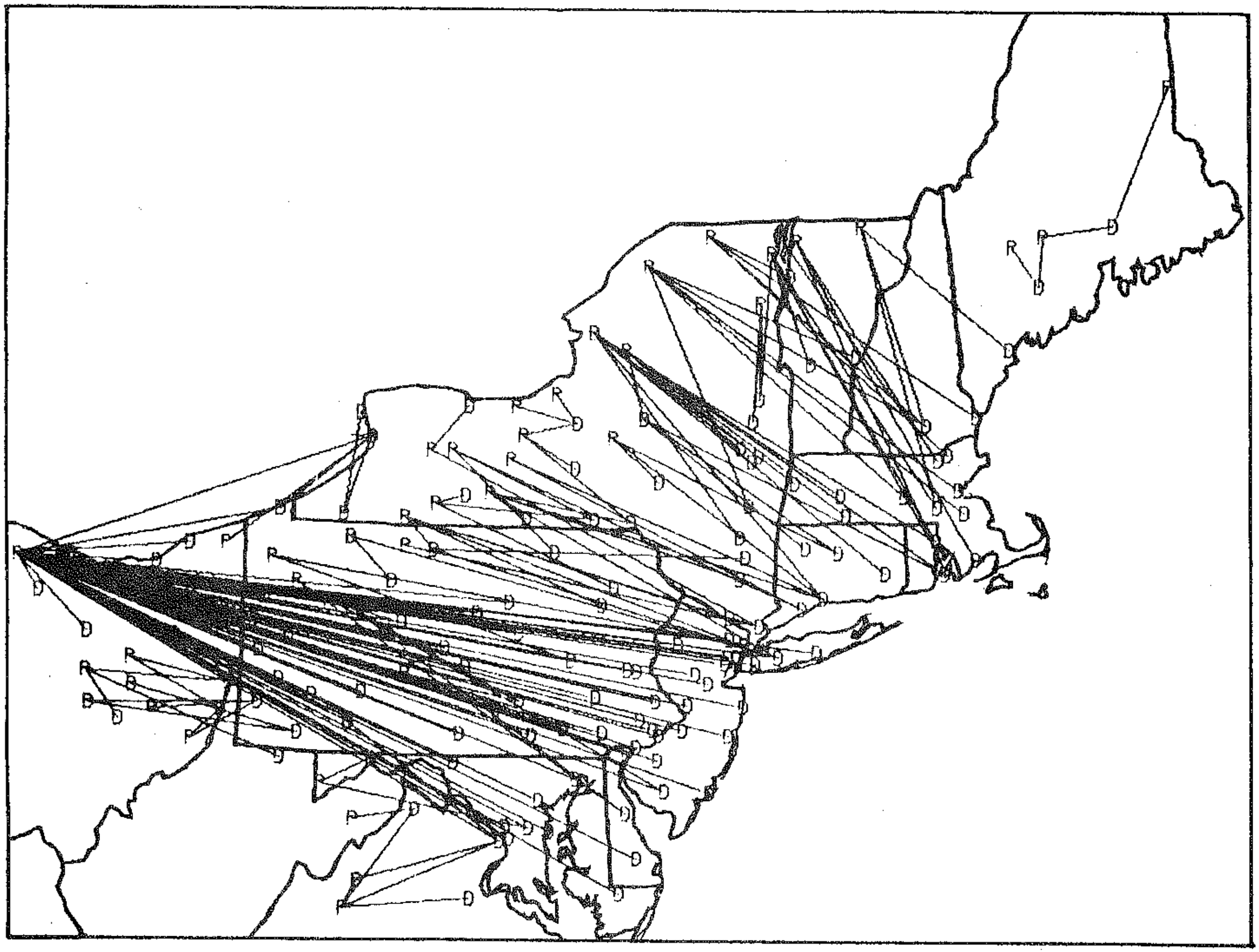


FIGURE 16. FLOWS OF PROCESSED HARD DAIRY PRODUCTS FROM PROCESSING POINTS (P) TO CONSUMPTION POINTS (D)



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