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MODELING THE SPATIAL ORGANIZATION OF THE NORTHEAST DAIRY INDUSTRY

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Maine. Milk supply is spatially represented by 236 supply points. There are 141 demand points. Up to 284 locations can be chosen as processing centers. As currently implemented, NEDSS is a single time period model. The length of time is user determined. Annual data are used for the analysis presented in this publication.

Given estimated milk marketings, dairy product consumptions, and assembly, processing, and distribution costs for 1980, results of two scenarios are presented here.[1] In BASE1980, optimal milk and product flows and plant utilizations are calculated given estimated 1980 costs and conditions. Plant locations are restricted to areas where plants currently exist and plant throughput is limited to no more than the estimated capacity at each location. Plant locations and capacities are unrestricted in LOCATE1980, which is otherwise also based on estimated 1980 costs and conditions.

METHODS USED FOR THE NORTHEAST DAIRY SECTOR SIMULATOR

NEDSS is a transshipment and plant location model which 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 Goodin, 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.

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[1]A third scenario involving projections for 2000 is also reported by Pratt et al. in their bulletin which more thoroughly describes NEDSS and its uses.

NEDSS differs from its predecessors in the degree of its spatial aggregation; it is highly disaggregated compared to similar models. This is made possible through the use of recently developed solution algorithms. Typically, plant location models have been forced to seriously restrict the size of the problems which they analyzed. This usually required limiting the numbers of possible supply or processing points or to independent analyses of each product class. Also, in many previous analyses, the movements of processed products from processing to consumption points were ignored.

In NEDSS, raw milk is aggregated at the farm level into geographic centers. These aggregation centers correspond to the supply nodes 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 into which the raw milk is converted. Each category forms a subset of the transshipment nodes. Each processing center may have a limit on the amount of raw milk which may be processed into each product type. Consumption of each product group is also grouped geographically into centers. Raw milk is shipped from the supply centers to the processing centers and from processing centers to the consumption centers subject to the following common restrictions:

1) The amount of milk shipped from a supply center to the processing centers does not exceed the amount of milk originating at the supply center.
2) No processing center processes more raw milk than its capacity for any product type.
3) The summation of shipments from the processing centers to each consumption center meets the demand for each 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, by product type. Although unit transportation costs are constant with respect to the amount of milk shipped, processing cost functions are used which exhibit returns to size. The model is solved when a set of shipments is found which satisfies the restrictions above while minimizing transportation plus processing costs.

Figure 1 depicts the transshipment formulation of NEDSS. Supply originates at points S_i, consumption of each product group exists at points C_i, and processing may occur at any of the geographic points P_i. A second set of processing nodes has been added to the structure so that a single arc goes from each processing node to a corresponding 'dummy', D_i, processing node. These arcs allow for the inclusion of a capacity (cap. = i) and a processing cost (RI_i, RII_i, $RIII_i$). Product flows over the arcs from supply points through processing points to demand points in order to satisfy product demands.

The number in parentheses at the top of each node or arc section in Figure 1 represents the actual number of nodes or arcs in each section in NEDSS. An out-of-area supply node and processing node for each product class are added to the number of nodes described earlier in the supply and processing sections. There are a total of 324,705 arcs and 2,370 nodes.

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

1) the network structure of NEDSS. 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 Grigoriadis and Hsu (Grigoriadis and Hsu and Grigoriadis) 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 1, it can be seen that there are actually four 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 processes that are independent of the size of the problem.

3) the small percentage of arcs which are capacitated. From the problem description, the only arcs which are capacitated are the processing arcs. There are fewer of these arcs than there are nodes in the network. This observation is used to store the capacities as a function with internal storage equal to the number of processing nodes 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.

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 decline with increased volume, and 4) processing capacities can be constrained and processing costs assumed to decline. When operated with variable processing costs, NEDSS is not guaranteed to find the global optimum solution (King and Logan). An iterative heuristic procedure is used to find an approximate solution.

RESULTS

Comparing results of the two 1980 scenarios provides insights into how plants might be better located and/or utilized relative to "current" supply, demand, and cost conditions. In Class I markets, average assembly and distribution miles travelled were reduced 29% and 47% respectively, when plants were reorganized, even though quantities transported did not change. Unit assembly and distribution costs were likewise reduced 23% and 47% respectively; however Class I processing costs did not change appreciably. Changes in miles travelled can be visualized by comparing the lengths of arcs connecting supply centers to processing centers in Figure 2 and processing centers to consumption centers in Figure 3.

There are 14% fewer locations for Class I plants in LOCATE1980 viz-a-viz BASE1980. This is depicted in Figures 2 and 3. Both figures show the reduction in Class I plant locations, especially away from the large population centers along the Atlantic coast. In general, the optimally located Class I plants are placed at the centers of major consumption areas, with plant sizes corresponding to consumption levels. Plants were 16% larger in LOCATE1980, and the BASE1980 locations that are not in urban areas are eliminated.

On a regional basis, the general pattern is the same, but there are some differences. Class I plant locations are reduced a third in the New England and New York subregions; they are relocated but stay the same in number in the Middle Atlantic subregions. In the eastern Ohio-western Pennsylvania subregions, Class I plant locations actually increase 50%.

Class II Market

A 61% decrease in average unit Class II milk assembly costs is realized by moving Class II plants and reducing their number by a third (from 10 to 7). This is illustrated in Figure 4. Class II processing cost is actually unaffected, but unit distribution costs increase a third as plants are more sparse, as reflected in the longer distribution distances shown in Figure 5. The results indicate that the current number and size of Class II plants is close to optimal, but these plants would be better placed nearer to points of significant production rather than near major consumption areas. In all locations, Class II processors are estimated to assemble supplies from local or nearby sources. The average increased 32%.

In BASE 1980, New York City is served by local Class II processing and plants in central New York and Massachusetts. After reorganization, all of

New York City's Class II demand is served by two plant locations in central New York and one in central Pennsylvania. Similarly, Philadelphia, Baltimore, and Washington move from Class II processing located in Philadelphia to processors located in south central Pennsylvania. The Pittsburgh market moves from Class II products made in upstate New York to south central Pennsylvania products, but continues to receive some product from eastern Ohio.

Class III Market

Unlike Class I and II plants, Class III plant locations increase 12% in number. This is accompanied by a 50% reduction in unit assembly costs, as reflected in the shorter assembly movements shown in Figure 6. There are small changes in processing and distribution costs, as reflected in Figure 7. As was true with Class II assembly, assembly movements to Class III are restricted to local and nearby sources. Whereas Class II plants tended to move outward from major metropolitan areas into relatively higher production areas such as central New York and central Pennsylvania, Class III processors move toward the major supply areas furthest from the metropolitan seaboard. They congregate in the northwestern parts of the region, along the St. Lawrence and the Great Lakes. Because regional milk production is insufficient to meet regional demand requirements, 29% of the Class III demand in the Northeast is served from the Midwest. Class III processors are eliminated in southern New England, southeastern New York, and southern and eastern Pennsylvania. New England markets are served by plants located in northern New York and Vermont. About one-fourth of the Class III demand in central and southeastern New York is served from the Midwest. The Philadelphia market receives Class III products from northern and western Pennsylvania and western New York, but a large share continues to come from the Midwest, 56% under LOCATE 1980 versus 73% under BASE1980. Virtually all of the Class III demand in the Pittsburgh and Ohio markets is satisfied with Midwestern products in both 1980 scenarios.

Conclusion

The analysis confirms the dairy marketing axiom that suggests that Class I plants should be located nearest the major consumption areas, that Class III processors should be located near distant but large supply areas, while Class II plants fall in between. Although the 1980 scenarios assume that milk is assembled and dairy products are distributed in a cost minimizing way, the optimal location of plants reduces total system marketing costs 8%.

Changes consistent with this strategy result in lower Class I utilization in the New England and New York subregions, with a small increase in the Middle Atlantic subregion and a large increase in the eastern Ohio-western Pennsylvania subregion. This suggests that farm prices would be reduced slightly in New England and New York and would increase elsewhere.

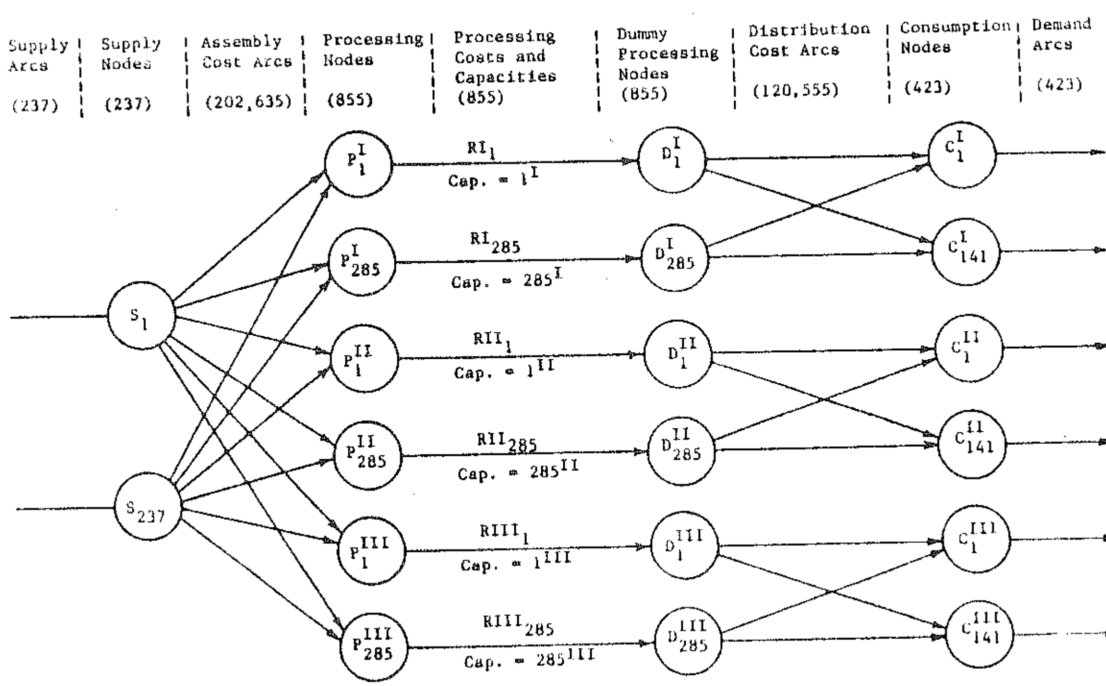

Figure 1. Network Representation of NEDSS

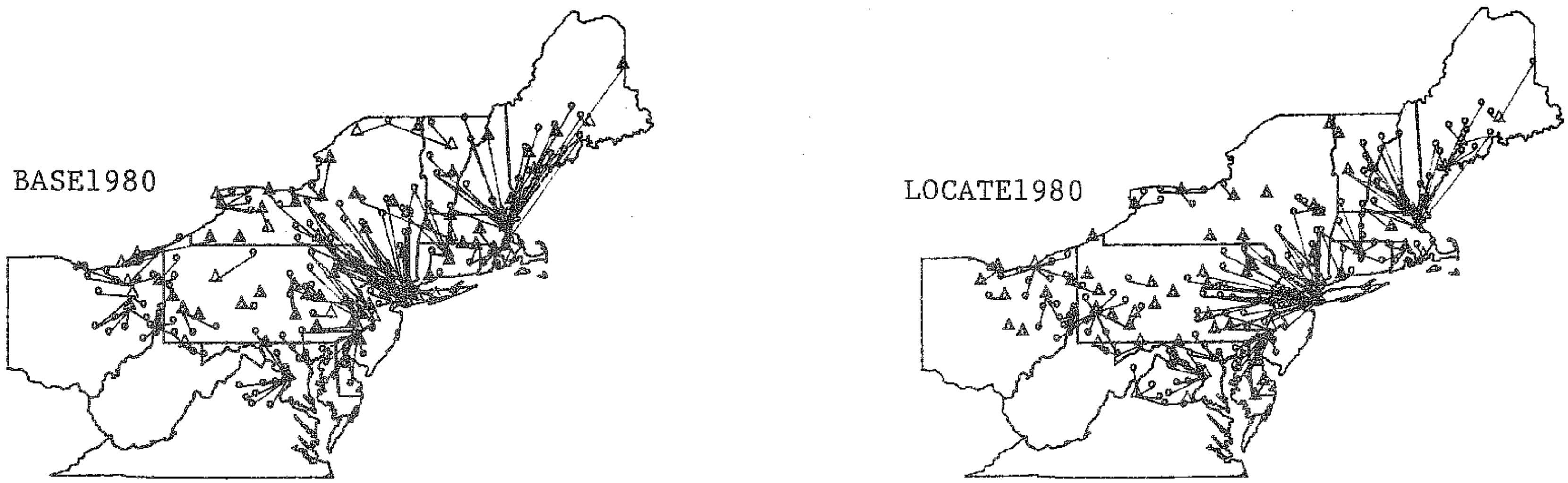

Figure 2. Class I Assembly Movements

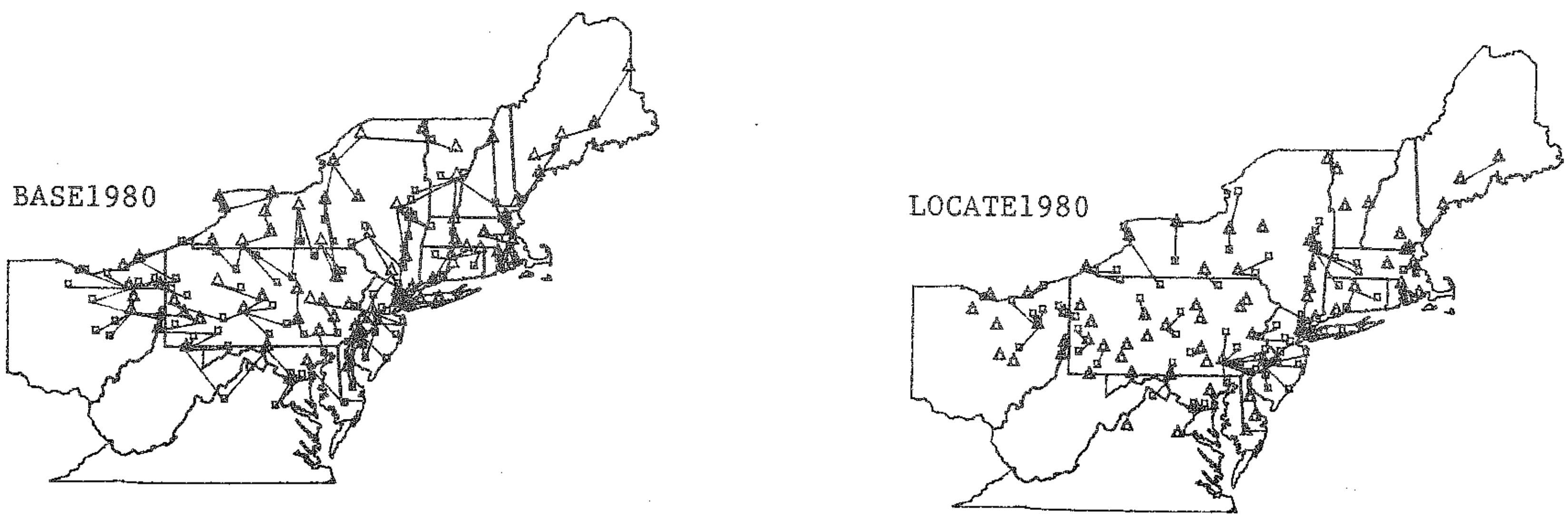

Figure 3. Class I Distribution Movements

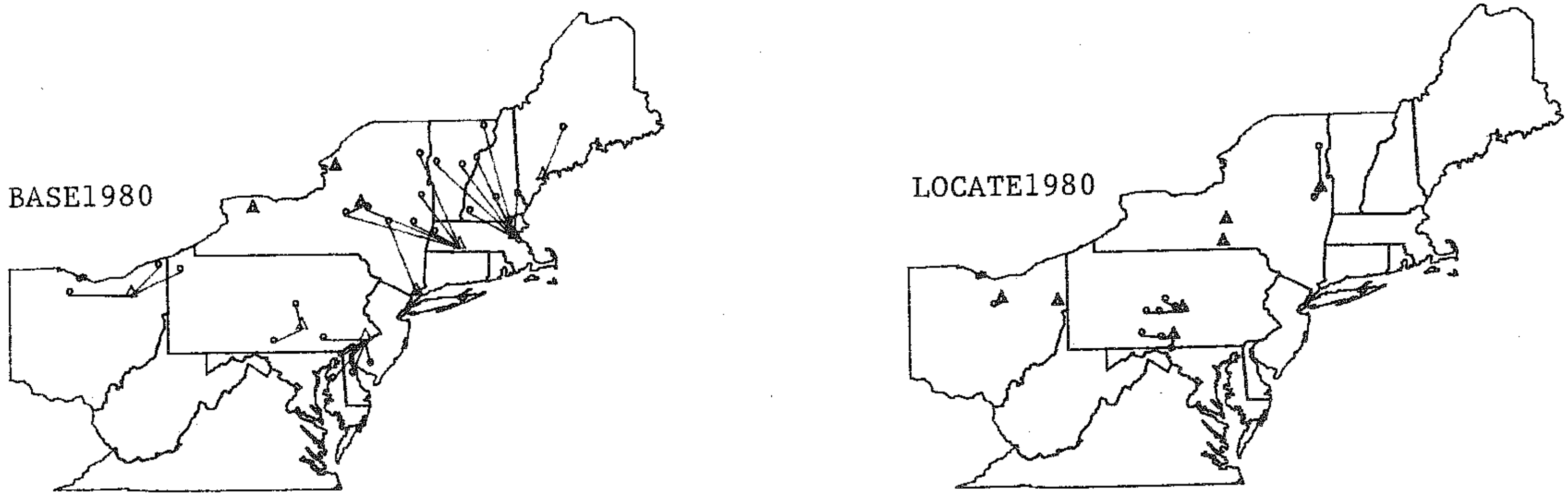

Figure 4. Class II Assembly Movements

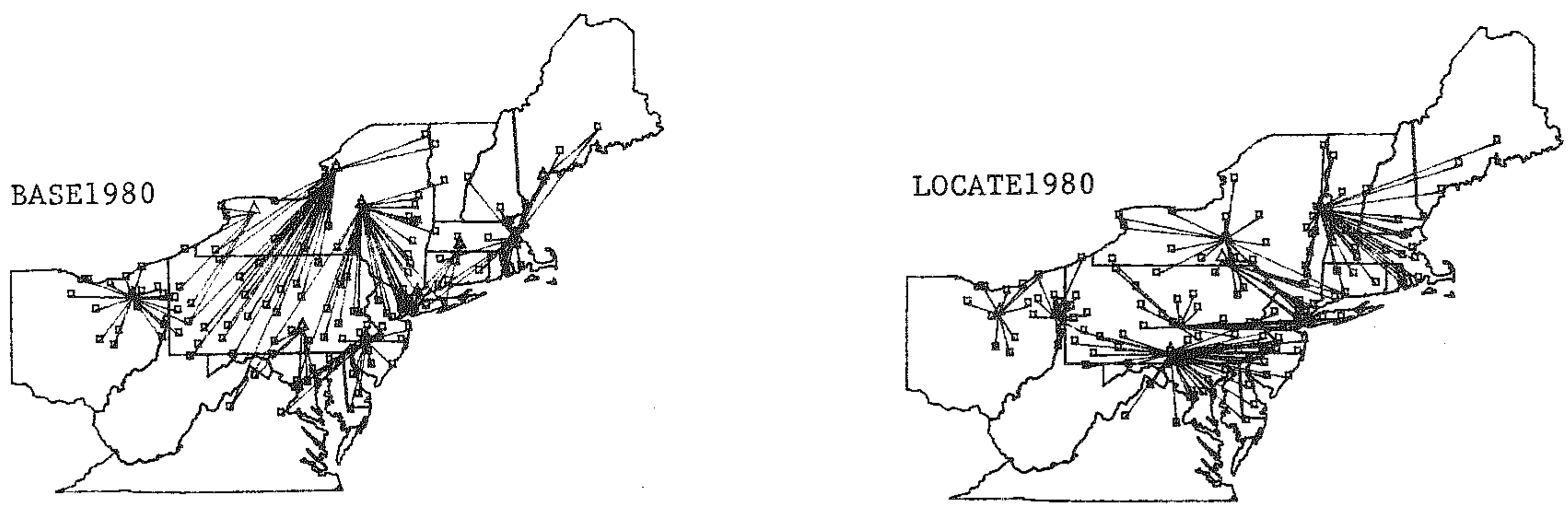

Figure 5. Class II Distribution Movements

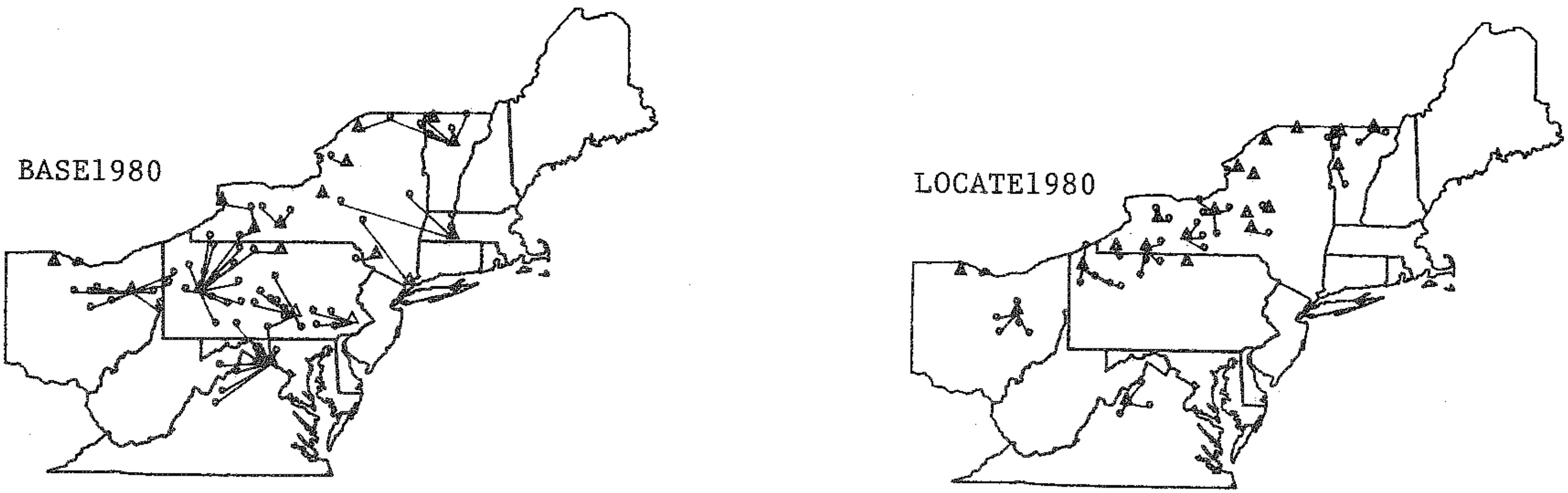

Figure 6. Class III Assembly Movements

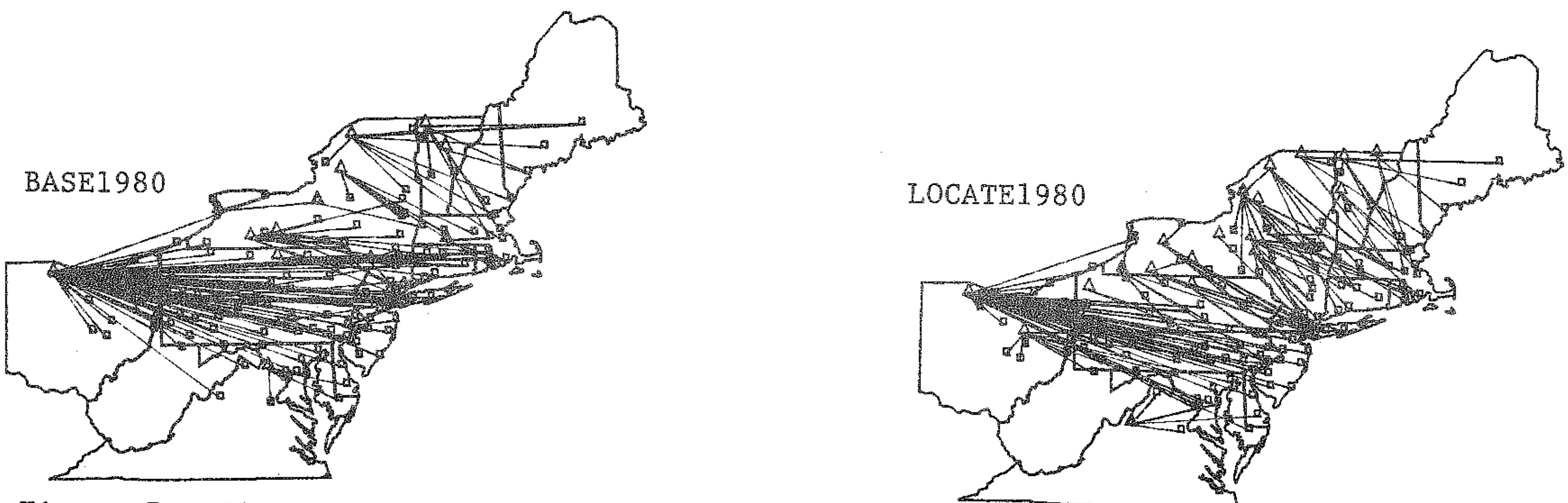

Figure 7. Class III Distribution Movements

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