Optimizing the Assembly–Processing–Distribution System of Processed and Further-Processed Chicken in Pennsylvania

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The economic efficiency of the assembly–processing–distribution system for chicken in Pennsylvania was analyzed to determine the impact of changes in processing capacities, unit processing costs, transportation costs, the location of processing facilities, and the location of producing areas on total system cost. The system was analyzed using a capacitated network flow algorithm. It was found that while processing costs are relatively more important than transportation costs, processing plants must be properly located with respect to both production and consumption points for the system to operate with maximum efficiency. © 1992 John Wiley & Sons, Inc.

INTRODUCTION

The broiler industry has become a leading sector of agribusiness during the past 40 years. While part of the industry's growth has come from favorable trends in consumer tastes and preferences, much of its success in marketing increasing quantities of broilers comes from the decline in the real prices of chicken. Lower prices are possible because of lower costs gained from the application of good business and technical management, and from strong competition within the industry and from competing meat industries.

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Since 1950, the broiler industry successfully managed: (1) the adoption of new technology with the development of genetically improved birds that are ready for market in 50% less time and new housing systems that allow year-round production; (2) the development of an industry structure that makes substantial use of vertical integration and coordination that allows consumer product needs to be quickly translated into production changes; and, (3) the adoption of a consumer-oriented marketing strategy that emphasizes the development of value-added products.

THE OBJECTIVE

For the broiler industry to continue to grow and prosper, it must persist in its search for better and lower cost ways to meet consumer demand. Consumers are normally attracted to low-priced products that are convenient to use. One way to keep prices low is to minimize the total cost of processing and transporting broilers from the farm to the consumer. The objective of this article is to analyze the economic efficiency of the current broiler assembly–processing–distribution system in Pennsylvania to see if the potential exists to lower total cost. A systems approach is employed to estimate and analyze the economic impact of changes in processing capacities, unit processing costs, transportation costs, the location of processing facilities, and the location of producing areas on total system cost.

The analysis is done in Pennsylvania because it is a major broiler producer (13th nationally in 1990 on a pounds-produced basis with more than 2% of national production) and the largest producer in the Northeast (PA, NY, NJ, VT, NH, ME, MA, CT, and RI).[1] The structure of the state's industry closely matches the national industry. Like the industry, Pennsylvania has experienced increased concentration of processing capacity. The direction of change is towards larger and fewer plants.[2] These plants are typically part of a larger, vertically integrated system that allows a firm to capture the economies of scale from large-volume operation, as well as the profits at each vertical stage. In 1990, the eight largest firms in the United States produced 57% of the total industry output.[3] Pennsylvania's five largest plants accounted for 62.7% of the state's total broiler-processing capacity.[4]

The concentration in the further-processed segment of the industry (e.g., producers of chicken nuggets, chicken burgers, and other read-to-cook products) is similar to that found with broilers. Pennsylvania's five largest plants account for about 74% of the state's total further-processing capacity.[4] There are 23 broiler processing plants and 20 further-processing plants in the state. Only five of the further-processed plants do not also produce broilers.[4] Most of the production and processing is concentrated in a few counties located in southeastern Pennsylvania.[5]

METHODOLOGY

Pennsylvania's broiler assembly–processing–distribution system was analyzed using GNET, a network analysis algorithm. GNET is a primal network code for the solution of capacitated network flow problems. The objective is to minimize the total cost of transshipment, transportation, and cost assignment across a network.[6]

The algorithm was applied to a data set that included: (1) the geographic location and annual broiler production of each county; (2) annual physical capacity and geographic location of each broiler and further-processing plant; (3) the per unit processing cost for each type and size of processing facility; (4) the annual consumption of chicken and geographical location of the consumption center of each county; and (5) the truck transportation cost per unit per mile for each type of product (i.e., live chickens, chicken meat, and further-processed items). All costs and quantities are for 1989. County annual consumption rates were determined by multiplying national per capita chicken consumption rates by the estimated county population in 1989.[7] To insure consistency in the data across the network, all physical product flows were measured in annual, ready-to-cook (RTC) weights using a RTC to live-weight conversion ratio of 0.726 : 1.00.[2]

The Production Nodes

Nineteen of Pennsylvania's 67 counties provide 97.7% of the state's total broiler production. Lancaster (44.4%) and Lebanon (11.1%) Counties account for over half (55.5%) of the state's production.[5] The remaining 2.3% of production is distributed throughout the rest of the state, but for this model it is assumed to be located in Indiana County. Indiana County was selected because it is the geographic center of the remaining small-scale broiler production in the state. Production is assumed to take place at the geographic center or each producing county.

The Processing Nodes

There are two sets of processing nodes. There are 46 nodes in the first set, 2 for each processor. The cost to move chickens between the two processing nodes is the processing cost per unit for that size plant. There are 40 nodes in the second set, 2 for each further processor. The cost to move chicken meat between the two further-processing nodes is the further processing cost per unit for that size plant. The locations of all the state's plants were known, so the highway distance between them and the production and consumption points could be measured.[4] The highway distance between each processor and further processor was also measured. Shipments were not restricted to current vertical integration arrangements and were allowed to flow to plants that would yield the lowest overall system cost. Three plant size categories were used for each type of plant to differentiate processing costs per unit. Data on sizes, costs, and number of plants is given in Table I.[7]

The Consumption Nodes

Each county has two consumption nodes. The first node was for consumption of whole and cut-up chicken. It was estimated to be 70% of each county's annual total poultry consumption.[8] The second was for consumption of further-processed items. It was estimated to be 30% of each county's annual total poultry consumption. The community with the largest population was chosen as the consumption point in each county.

Table I. Broiler Processing and Further-Processing Plant Sizes, Capacities, Costs, and Numbers, Pennsylvania, 1989.

	Number of Plants	Annual Processing Capacity (Million Tons)	Processing Cost (Per 1000 RTC lbs.)
Processing Plants			
Small	13	Less than 10	$106
Medium	6	10–30	$93
Large	4	More than 30	$80
Further-Processing Plants			
Small	15	Less than 5	$215
Medium	4	5–20	$200
Large	1	More than 20	$185

Sources: Plant Capacities: *Who's Who*, 1990; USDA, 1988.
Processing Costs: Lasley et al., 1988, updated with the USDA Livestock and Poultry Situation and Outlook Report.

Out-of-State Processing and Production Nodes

Pennsylvania is deficit in broiler production, processing, and further-processing capacity. To satisfy the state's demand, large amounts of all forms of chicken must be imported from other states. Additional nodes were created to represent out-of-state broiler production, processing, and further processing. Products were only permitted to flow into Pennsylvania from these nodes. These nodes were assumed to be 100 miles from the nearest in-state node (e.g., out-of-state production node to nearest Pennsylvania node) and were assigned a processing cost per unit equal to the highest in-state rate. This permitted the acquisition of birds, chicken meat, or further-processed products from other areas such as Ohio and the Delaware–Maryland–Virginia Peninsula to meet Pennsylvania's consumption needs.

Transportation Costs

The broiler industry uses trucks almost exclusively for assembly and distribution. An estimate of total cost of $1.52/mile for truck use was developed from USDA Office of Transportation Truck Cost Data.[9] An estimate of transportation cost per 1,000 RTC lbs. was made for each product form using industry truckload standards. The following truck costs per mile per 1000 RTC lbs. were used for each product form: $0.104 (live chickens), $0.114 (chicken meat), and $0.1248 (further-processed items).[7]

THE MODELS

A basic model was constructed to represent the current plant capacities and costs. Additional models were developed by varying processing capacities, cost differentials between plant sizes, production and processing locations, and transportation costs. For this article, the change in total system cost relative to the Basic Model will serve as the primary indicator of how the efficiency of the system was affected by each change.

The Basic Model

The Basic Model was developed to serve as a benchmark for comparison with the other models. Because Pennsylvania's broiler production is a little over half its consumption, the Basic Model showed that all its processing and further-processing plants were fully utilized (Table II).

Increasing the Capacities of Processing and Further-Processing Plants

To test the effect of expanding in-state processing capacity on total system cost, the processing capacities of the state's plants were increased 50%, 100%, and 200%. Processing costs per unit were adjusted if a plant moved to a larger size category. Because of the hypothetical changes in size, the number of plants in each group may change, but the total number of plants stays the same. All other

Table II. Changes in Total System Cost and Plant Usage for Processed and Further Processed Chicken, Pennsylvania.

Model	Processing Plants Utilization			Further Processing Plants Utilization			Percentage Change in Total System Cost
	Full	Partial	Not Used	Full	Partial	Not Used	
Basic Model	23	0	0	20	0	0	—
Capacity Increased							
50%	20	2	1	9	6	5	−6.8%
100%	13	3	7	9	4	7	−8.9%
200%	8	7	8	7	6	7	−11.5%
Processing Cost Differential							
Reduced	23	0	0	20	0	0	−1.9%
Increased	23	0	0	20	0	0	+3.1%
Transportation vs. Processing Cost							
Double Trans.	23	0	0	20	0	0	+10.0%
Double Proc.	23	0	0	20	0	0	+90.0%
Shifting Production							
Only Reduce Lancaster	23	0	0	20	0	0	−0.05%
Reduce Lancaster w/Adjust.	23	0	0	20	0	0	−0.11%
New Plant & Shifted Prod.	24	0	0	13	7	2	−4.9%

costs and production levels were left unchanged. Additional birds were assumed to be available from out-of-state sources.

(a) 50% Increase in Capacity. Twenty of the state's 23 broiler-processing plants were still used at full capacity and 97.6% of the state's processing capacity was used when plant sizes were increased by 50%. Two of the three plants not fully utilized were small plants. One was not used at all and one operated at 27% of capacity. This suggests that economies of size and scale play an important role in determining which plants are efficient additions to the system. The other partially utilized plant was the second largest in the state and according to the parameters of the model was assumed to have the lowest processing cost per unit. It operated at 96% of capacity. This suggests that low processing costs alone are not enough for a plant to be considered as part of an efficient assembly–processing–distribution system. To accomplish this, a plant also must be located near production and consumption points in order to maximize system efficiency.

In the case of further-processing plants, the reduction in the number of fully utilized plants was much greater. Only 9 of the 20 plants representing 69.8% of the state's capacity remained fully used: 5 small, 2 medium, and 2 large plants. Six partially used plants were all medium sized. The plants that were not used were three small- and two medium-size operations. The expansion of capacity by 50% decreased overall system cost by 6.8% relative to the Basic Model solution.

(b) 100% Increase in Processing Capacity. In this model, only the 20 broiler processing plants and the 9 further-processing plants used at full capacity in the previous model had their processing capacity increased 100% from the level in the Basic Model. The remaining plants were left with their capacities increased by 50% as in the previous model. Thirteen of the 23 broiler-processing plants operated at full capacity, with 3 plants partially used and 7 plants not used at all (Table II). The fully used plants were in all size categories and the system used 60.2% of the total capacity.

In the case of further processing plants, 9 of the 20 plants were fully used, with 4 partially used and 7 plants left unused (Table II). As was the case with the broiler plants, there is no clear pattern toward the utilization of any particular plant size. The plants that were not used were all small- and medium-size operations. Total system cost declined 8.9% from the Basic Model solution.

(c) Processing Capacities Increased 200%. The plants that had their capacities adjusted for this trial were only those that were fully used in the previous model. If a plant had not been fully utilized, its capacity was left at the level used in the previous model. In this model the state's processing and further-processing capacity exceeds current demand. Despite this the in-state system met only 85.6% of the state's demand for broiler meat and 87.8% of its demand for further processed items.

In this case eight processing plants (six medium size, two large size) were used at full capacity. Additionally, seven more plants (one small, two medium, and four large) were partially used. Eight plants (three small, four medium, one large) were not used at all. The large plant not used was located close to two other large plants that were both partially used.

In the case of further processing, seven plants (four small, two medium, and one large) were used at full capacity. There were seven plants left out of the system (three small, and four medium). The total system cost for this model declined 11.5% from the Basic Model.

Again this shows that processing costs are not the only ones that determine the optimal plant selection. Location, as reflected through transportation costs, also helps define the optimal system.

Changing the Processing Cost per Unit Differential Between Different Sizes of Plants

To test the solution's sensitivity to changes in the processing cost per unit, the cost differential between different sizes of processing plants was reduced to $6 and doubled to $26 for processing plants and reduced to $5 and doubled to $30 for further-processing plants.

(a) Reducing the Processing Cost Differentials. The processing cost per unit of small, medium, and large processing plants of $106, $93, and $80 per 1000 lbs. was changed to $99, $93, and $87 to reduce the cost differential. When this was done, all the Pennsylvania broiler plants continued to be fully utilized with no change in product flows from the Basic Model solution. The processing cost per unit of small, medium, and large further-processing plants of $215, $200, and $185 per 1,000 lbs. was changed to $205, $200, and $195 per 1,000 pounds. Again the product flows were the same as was found in the Basic Model solution.

(b) Doubling the Processing Cost Differential per 1,000 lbs. The processing cost per unit of small, medium, and large processing plants of $106, $93, and $80 per 1000 was changed to $119, $93, and $67 to increased the cost differential. When this was done, the same solution emerged as was found in the Basic Model solution. The processing cost per unit of small, medium, and large further-processing plants of $215, $200, and $185 per 1000 lbs. was changed to $230, $200, and $170 per 1000 lbs. Again the same solution emerges as was found in the Basic Model. This indicates that the amount of the processing cost differential has little impact on optimal product flows and whether a plant is selected for inclusion in the optimal system when demand exceeds processing capacity.

Determining the Relative Importance of Transportation and Processing Costs per Unit to System Total Cost

To determine the relative importance of processing costs and transportation costs to total system cost, two additional models were constructed. In the first model, the transportation cost per unit of the Basic Model was doubled while leaving the processing costs per unit unchanged. In the second model, the processing costs per unit of the Basic Model were doubled while leaving the transportation cost per unit unchanged.

Doubling the transportation cost did not alter the product flows. The change in transportation cost did cause total system cost to increase 10%. Doubling processing costs also did not change the solution found in the Basic Model. The change in processing costs did cause total system cost to increase 90%. Thus, the processing cost is far more important than transportation cost to overall system cost.

Calculation of the maximum number of extra miles that can be driven before the change in transportation cost exceeds the savings in processing cost makes this point again. A truck transporting live broilers to a processing plant can travel up to an extra 125 miles before the added cost of transportation exceeds the savings of processing the broilers in a plant one size larger. It is 250 miles for a two-size increase in plant size. A truck transporting chicken meat to a further-processing plant can go up to an extra 131.6 miles before the added transportation cost exceeds the savings of further processing the meat at a plant one size larger. It is 263.2 miles for a two-size increase in plant size. Thus, chicken in either form can be transported a considerable distance for processing and further processing at a lower-cost plant without any loss in system efficiency.

The relative importance of processing and transportation costs to overall system efficiency varies across agribusiness. In the dairy business, transportation is more important than processing.[10] In the egg industry, the costs are about equally important.[11] It is critical that agribusiness managers understand the role that each cost has to play in determining overall system cost. Each must be effectively managed if the firm is to operate at maximum efficiency.

Changing the Location of Broiler Production

To evaluate the impact of changes in broiler production levels and location in Pennsylvania, two models were developed. The first model assumed that the production in Lancaster County, which accounts for 44% of state broiler production, was reduced by 25% without any offsetting production expansion anywhere else within Pennsylvania. The second model assumed that production in Lancaster County was reduced 25%, but production in selected counties was expanded to compensate for it.

These models were undertaken to see the impact on the system of changing the location of in-state broiler production. It was also carried out because Lancaster County is under increasing pressure to limit its agricultural production as a way to help solve its manure disposal problem. It is argued that the manure from the county's farms is a primary source of pollution of local groundwater and the Chesapeake Bay. The manure is said to be transported as agricultural run-off by way of the nearby Susquehanna River that empties into the Chesapeake Bay. These models are an attempt to measure the impact of a shift in the location of production on the efficiency of the system.

(a) Reducing Lancaster County Production by 25% without Expanding In-State Production. As might be expected, the product necessary to compensate for this loss of production came from out-of-state sources with all in-state plants operating at capacity. Despite the high transportation and processing costs from using out-of-state production and processors total system cost declined 0.05%.

(b) Reducing Lancaster County Production by 25% with Expansion of In-State Production. In this model, the decline in broiler production in Lancaster County was compensated for by increases of 33.9% in 12 counties north and west of the most concentrated production areas (Fig. 1). These counties were chosen for an increase in production because they already have some poultry production in them, and it would be easier to expand operations there than try to establish an industry in a new location. These counties are also suffering less environmental stress from animal waste than the counties in the southeast.

The model showed all the processing plants still operating at full capacity and total system costs declining 0.11%. This indicates that transportation is a relatively minor part of total system cost and that decentralization of the state's poultry business could be accomplished with little impact on the efficiency of the overall system.

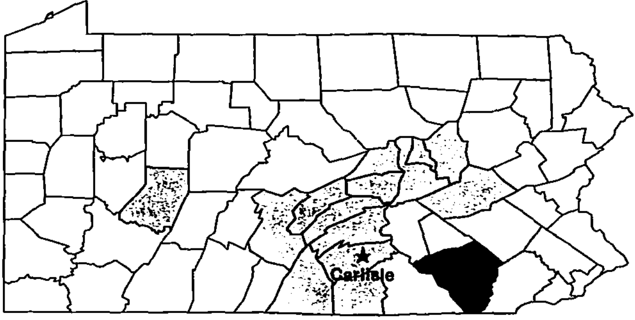

Figure 1. Decentralized Chicken Production Counties, Pennsylvania.

Construction of New In-State Processing and Further Processing Facilities

The last model considered was the construction of new processing facilities within Pennsylvania. This was done to see if the system would benefit from shifting production and processing out of the southeast part of the state. A new processing plant with an adjacent further-processing plant was assumed to be built in Cumberland County in the town of Carlisle. The new processing plant was assumed to have an annual capacity of 130 million lbs. and a processing cost of $80/1000 lbs. The large further-processing plant was given an annual capacity of 65 million lbs. and a processing cost of $185/1000 lbs. These plant capacities were selected because they represent the typical size of new plants. To make this expansion more realistic broiler production in the counties identified for expansion in the previous model were doubled from their original levels, while the production in Lancaster County was still reduced by 25%.

In this model all the broiler plants, including the new one, were used at full capacity. Only 13 (5 small, 7 medium, and 1 large) of the 21 further-processing plants were used at full capacity. Seven (five small, one medium, and one large plant) plants were partially used. The large new plant operated at 82.1% of capacity. In this situation total system cost declined 4.9%. It appears there is an opportunity to reduce costs and environmental pressure by shifting production and processing out of the southeastern counties.

SUMMARY AND CONCLUSIONS

The economic efficiency of the assembly–processing–distribution system of broilers in Pennsylvania was analyzed to determine the impact of changes in processing capacities, unit processing costs, transportation costs, the location of processing facilities, and the location of producing areas on total system cost. The system was analyzed using a capacitated network flow algorithm. The node network connects all the production counties, processing and further-processing plants with chicken consumption in each county of Pennsylvania. Additional nodes were formed to allow out-of-state production, processing, and further processing. A basic model was constructed to represent the current plant capacities and costs. Ten variations of this model were run to see the impact of various changes on total system cost.

Several conclusions can be drawn from the results that may have implications for the future directions of growth in the broiler industry. First, low processing costs play an important role in determining which set of plants constitutes an optimal system. Location, as revealed through transportation costs, also impacts on the decision. To be a part of an efficient assembly–processing–distribution system a plant must offer relatively low processing costs and be located so as to minimize total cost of processing and transportation.

Second, processing costs are relatively more important than transportation costs to overall system cost. Chicken can be transported a considerable distance (125 to 263 miles) to be processed or further processed at a lower cost plant. This implies that production, processing, and further processing can be located a considerable distance from population centers with little impact on overall system cost. Given lower wage rates and operating costs in a more rural setting total cost might even decline.

One limitation to the model and its conclusions is that the algorithm is designed to solve cost minimization problems involving only one product form. Further research could analyze this problem using a profit maximizing algorithm that would deal with varying prices, costs, and profit margins of the different product forms encountered within the system. A second limitation is that the model does not consider broiler production and feed costs which would provide a total system view.

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