Modeling and Optimizing the Beef Supply Chain in New York and New England

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Abstract: *Seasonality of beef cattle supply raises different service demands. While farmers in New York and New England region argue that there are not enough slaughter and processing facilities, slaughterers and processors cite that there are not enough farmers bringing them enough livestock. Through solving an optimization model, this study will examine whether the physical capacity of existing slaughter and processing infrastructure in the region meets the cattle slaughtering and processing demand, identify the minimum-cost optimal solution to efficiently utilize those facilities, and assess relative costs associated with product handling. The analysis explores the spatial structure of the New York and New England beef cattle assembly, slaughter, processing and distribution system that might result if these supply chain activities were regionally coordinated. Our results provide critical information that may lead to a more timely recognition of challenges that need to be addressed. This study provides information, guidance and direct technical expertise concerned with establishing and improving regional coordination mechanism. In addition, a number of future modeling scenarios are suggested.*

Key words: *optimization, beef supply chain, coordinated system, cost analysis, agricultural policy*

1. Introduction

In agribusiness, a lot of decisions are made under uncertain conditions (van Berlo 1993). The beef industry is a perfect example of this problem. In the Northeast U.S., beef industry activity is strongly seasonal due to seasonal calving and farrowing throughout the year (Gwin and Thibournery 2013). Intensive slaughter and processing activities occur in the late summer and fall within a year. The inconsistent flow of product throughout the year may raise bottleneck problem of animal slaughter and processing. In peak finishing seasons for livestock, farmers in a given geographic region may all have finished animals ready for slaughter at the same time. Some livestock producers in New York and New England[1] complained that they have great difficulty in accessing slaughterhouses for services, putting a constraint on their business success and expansion (CISA 2008; Zezima 2010). In the meantime, existing slaughter and processing plants complain that they often lack the steady, consistent business required to keep skilled workers and

[1] New England includes Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

expensive equipment utilized and remain profitable (Gwin, Thiboumery and Stillman 2013; Johnson, Mariti and Gwin 2012). From their perspective, capacity is often not lacking but in excess. New slaughter and processing ventures built specifically to handle local product often do not survive (DeHaan 2011; Raines 2011). These arguments are all manifestations of a fundamental tension between farmer needs and processor needs. Farmers cannot grow because processing capacity is limited, but slaughters and processors cannot grow or provide certain services or availability because they do not have enough steady work to provide steady revenue. Investigation and modeling are needed to determine the nature of the problem and optimize the structure of the beef supply chain in New York and New England region.

In response to farmers and plant handlers' concerns about whether there is a lack of animal slaughter and processing capacity, we proposed to 1) assess the demand for slaughtering and processing services, 2) assess the capacity of slaughtering and processing plants, and 3) use an optimization model to design a consolidated network that allows for coordination of the regional beef supply chain system and examines the bottleneck problem of plant capacity.

Besides providing slaughter and processing service, a plant in the beef supply chain acts as a transfer point at which either traffic from several farms (origins) is added up and forwarded to another plant, or disaggregated to several streams of beef products that are forwarded to their destinations, i.e. consumption sites such as retail stores, restaurants, and caterers. In reality, the individual interest, local perspective and opportunistic behavior of supply chain participants often result in operational inefficiency (Minnich and Maier 2006). To improve the overall performance of supply chain in the best interests of participants, the participants must behave as a part of a unified system and coordinate with each other to execute supply chain operations (Simatupang and Sridharan 2002; Zou, Pokharel and Piplani 2004). Such coordination can be achieved when the supply chain participants jointly minimize the collective operating risks and costs and share the benefits (Arshinder, Kanda and Deshmukh 2011, 2007; Hill and Omar 2006; Kleindorfer and Saad 2005). Then all participants can achieve greater success than when acting in isolation and competition. In this study, we model a regionally coordinated system to efficiently route the traffic between origin-destination pairs with an objective to minimize the costs of the whole supply chain system. The coordination assumes that individual producers and handlers become indifferent over the destination of their beef cattle and beef product shipment.

This paper proposes an optimization approach to determine the optimal slaughter, processing and distribution plans with the aid of mathematical programming. A Linear Programming Model was formulated which optimizes the utilization of currently existing slaughter and processing capacity of plants to meet the service demand, given constraints on seasonality and capacity of individual plants. It is well documented that the interest in solving facility utilization problems in agricultural supply chain systems using optimization has been growing steadily in the past decade (Ge, et al. 2018; Gebennini, Gamberini and Manzini 2009; Gribkovskaia et al. 2006; Kate et al. 2017; Thanh, Bostel and Peton 2008).Through building and solving an optimization model, this study will examine whether the physical capacity of existing slaughter and processing infrastructure in New York and New England region meets the cattle slaughtering and processing demand, identify the minimum-cost optimal solution to efficiently utilize those facilities by allowing for production seasonality, and assess relative costs associated with product handling. The analysis explores the spatial structure of the New York and New England beef cattle assembly, slaughter, processing and distribution system that might result if these supply chain activities were regionally coordinated.

The remainder of the paper is structured as follows: we start by describing the structure of the beef supply chain and specifying the optimization model. The following section introduces data and sources of data. Subsequently, we solve the model for the regionally coordinated system that minimizes total costs of cattle assembly and handling, and product distribution. These optimal solutions are then visualized and analyzed and the implication for coordination mechanism is explored. We then discuss the extension of the methodology to some future research topics in the beef supply chain system.

2. Supply Chain Structure Description

In the beef supply chain, cattle from different production locations are consolidated at plants, slaughtered and processed there and then distributed to consumers in different regions. Figure 1 shows the structure of the beef supply chain in this study.

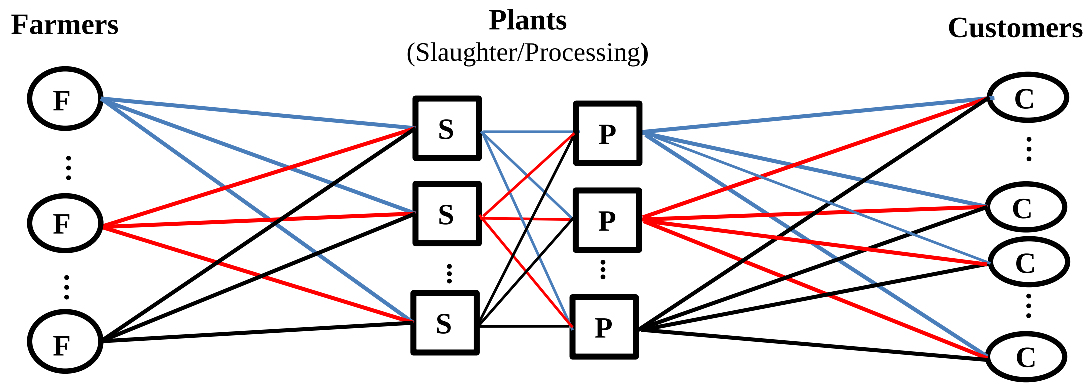


Figure 1. Stylized beef cattle supply chain

In this study, we assume that cattle supply chain participants' activities can be leveraged and coordinated regionally to minimize the system cost. Unprocessed beef product (carcass) shipping between plants is considered in the model. There are two reasons for this consideration, 1) our survey results suggest the processing capacity of some plants in New York State is larger than their slaughter capacity. The inter-plants shipment provides an opportunity to make those plants' processing capacity get fully utilized in case of high demand in processing service; 2) there are economic incentives to consider carcass shipment between plants. If so, an animal can be slaughtered at a plant with a lower slaughter fee and then shipped to another plant with lower processing fee. As our results show later, inter-plants shipment can reduce the total system operating costs.

We use the term "slaughter" and "processing" to include all the steps involved in turning a live animal into a carcass or meat for sale. Slaughter operation includes stunning, skinning, eviscerating, and cleaning the animal to a carcass and cutting carcass to halves or quarters. The carcass accounts for 62 percent of the weight of the live animal (dressing percentage) (Goodsell and Stanton 2011). Processing operations are limited to those activities that include cutting half/quarter carcasses to subprimal, cutting subprimals into fixed-weight steaks, roasts, and other boneless and trimmed retail cuts and then packaging as desired. In this study, value-added processing such as grinding, casing, smoking, cooking, drying, and otherwise transforming meat and trimmings from the cutting step into sausage, ham, bacon, jerky, and other products are not included in the processing procedure in plants. The processed meat products account for 72 percent of the weight of the carcass (Goodsell and Stanton 2011).

Transportation costs are one of the biggest expenses in any market channel (Gwin, Thiboumery and Stillman 2013). Transporting animals from farms to plants is costly, especially for small farms with a few heads of animals at a time. Many farmers must drive multiple hours one-way to reach even the nearest slaughterhouses (Maltby 2018; Shinn 2018). The most efficient use of a delivery vehicle is to deliver a full load of product. In reality, beef cattle in dispersed locations are assembled by producer cooperatives and collectively provide a plant with steadier throughput (Maltby 2018; Shinn 2018). In our modeled coordination system, farmers can come together to share equipment as a first step towards collective action to work together. Allowing for this, we assume that animals in sparse locations in the same county is aggregated and shipped to plants. Producers in the same county jointly share the transport vehicles and cost. Aggregation points for animals are at the population density weighted centroid of the county.

3. Data

USDA's National Agricultural Statistics Service (NASS) reports county-level annual production statistics for beef cattle (USDA/NASS 2012). In the seven states, a subset of the counties is not reported for reasons of the disclosure. In these cases, we use the average production for those counties with data suppression[2]. However, estimated production only accounts for a small proportion of annual domestic production (5 percent) so the estimation error should have limited influence on the model solution.

The annual production data from the Census of Agriculture were disaggregated into monthly data. The monthly distribution of beef cattle production in 2012 across counties was estimated using slaughter statistics from USDA/NASS (2013). This study assumes that the volume shipped to each county is proportional to the population of the county based on 2012 U.S. Census Bureau data. Figures 2 and 3, respectively, show the distribution of beef cattle production and of beef product consumption in October.

[2] The Economic Census provides the total annual production at the state level (state-wide totals). For each state, the Economic Census only provides data for some counties (county totals). The production for counties with data suppression is just the difference between state-wide totals and published county totals. For each county, the production average is obtained through dividing the production difference by the total number of counties with data suppression.

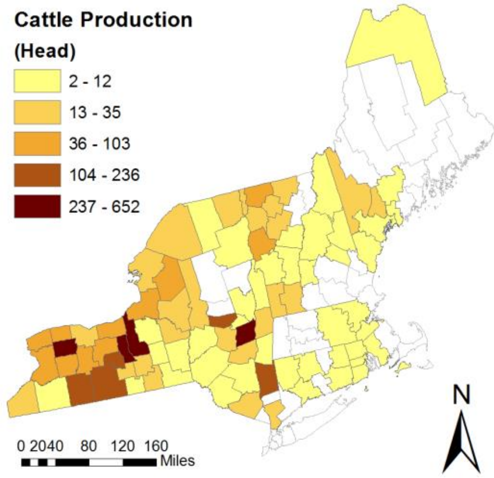


Figure 2. Distribution of beef cattle production across counties (October)

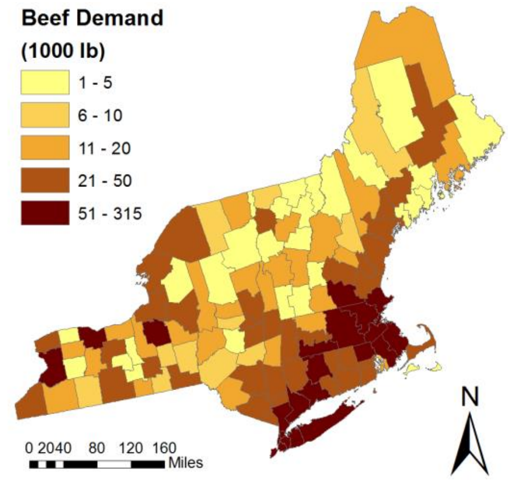
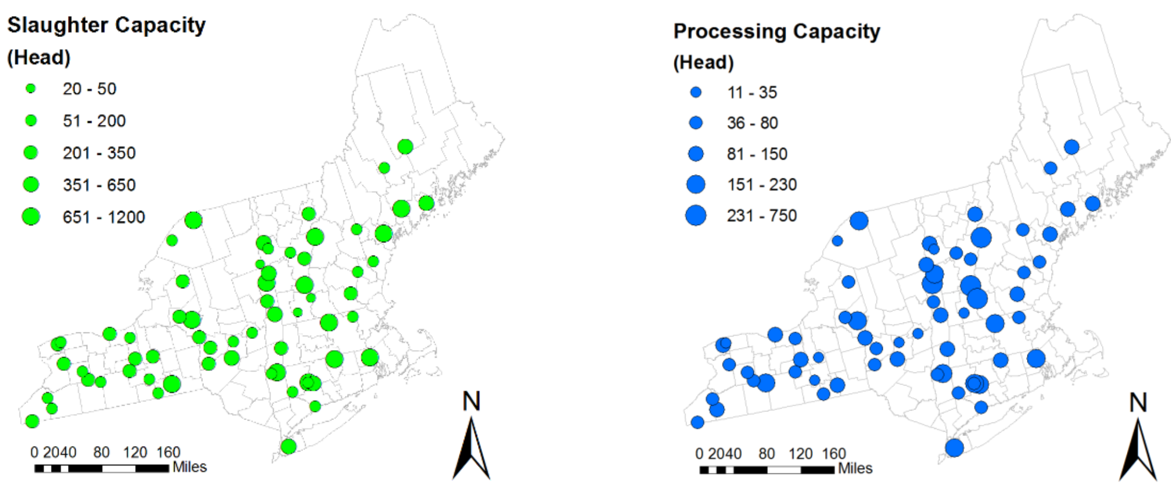


Figure 3. Distribution of beef consumption across counties (October)

To understand existing slaughter and processing infrastructure, capacity and operating costs in the region, we conducted a survey via questionnaires and interviews during 2017 and 2018 of all New York and New England's USDA red meat packing plants. The present slaughter and meat processing plants in New York and New England were identified using an approved USDA list. All plants were sent an initial letter with information about the project and requesting an interview, after which they were contacted via phone to schedule a time for the survey interview. The year 2017 survey questions were collected in person due to the extensive nature of the questions being asked in the survey instrument. In the year 2018, we conducted a short follow up via telephone. There are 62 USDA red meat plants throughout study region, 36 plants in New York and 26 plants in New England. A total of 52 responses (31 in New York and 21 in New England) were collected and analyzed, representing a cumulative response rate of 81%. Most respondents were plant owners or managers, with a few plants designating an employee to answer the survey questions. The ten plants for which data was not collected were assigned a capacity equal to the average capacity of the 52 plants for which data were collected.

Data were collected assuming single-species days. That is, survey respondents were asked to quantify plant capacity based on the number of animals of a single species that could be harvested or processed in one day. To account for the fact that multiple species may be harvested within a single day, we convert each livestock into a single unit called "cattle equivalent". The average ratio of capacity for cattle to the capacity for each other type of livestock for each plant was calculated to estimate equivalence. As estimated by Lewis and Peters (2012), a factor of 3.77 and 5.22 hogs per head of cattle is used when covering slaughter and processing capacity from number of hogs to number of cattle while a factor of 4.18 and 5.17 lambs per head of cattle is used when converting slaughter and processing capacity from the number of lambs to the number of cattle. The number of hogs and lambs slaughtered and processed in 2012 were then converted to cattle equivalents to approximate the capacity used by slaughtering and processing hogs and lambs. The capacity can be utilized for cattle slaughter or processing is the left capacity after excluding the capacity for hog and lamb slaughter or processing.

Capacity in October is based on the daily kill and processing capacity from survey via questionnaires and interviews during 2017 and 2018, 25 workdays, and an institutional constraint factor of 0.9. The institutional constraint was used to adjust monthly capacity due to daily procurement problems and scheduling problem (Wulff et al. 1990). A slaughter or a processor does not have the alternative (option) to inventory a supply of raw material to maintain a constant product process. Eventually, Figure 4 shows the slaughter and processing capacity of the 62 plants for the month of October.



(a). Slaughter capacity (b). Processing capacity

Figure 4. Slaughter and processing capacity of plants in October

Meat food products must be shipped in an enclosed vehicle, such as refrigerated truck, in such a manner to assure delivery and wholesomeness of those products while maintaining product safety. The average refrigerated truck transportation costs statistics reported by USDA's Agricultural

Marketing Service (2016). When transporting animals, larger farms with larger shipping volumes can increase the capacity utilization of trucks. For county production is less than one truckload, the unit shipping cost will be high. We charge each truck on a specific route equally, based on a cost of $4/loaded mile for a truck carrying up to 10 cattle, whether it is full or (nearly) empty.

With these data, we design a realistic beef supply chain network with structure and characteristics similar to the realistic system. Generated results can offer direct implications for how to build efficiencies into the beef supply chain and logistics operations under given operational conditions.

4. Model specification

A crucial challenge is to determine how to coordinate and consolidate the production flows for the best overall plant allocations and logistics performance for the consumer markets. New York and New England plants encounter a very volatile monthly livestock slaughter volume. Monthly commercial cattle slaughter, as a percentage of the 2012 slaughtered number in total, ranges from 7 percent to 11 percent for New York and 7 percent to 10 percent for New England. Animals typically are slaughtered in the fall after grazing during the summer, resulting in high demand at one particular time of the year and lower activity at other times. For example, the volume of beef cattle available for slaughter is typically highest in October and is lowest in April. The seasonality of beef cattle production activity determines the seasonal operational patterns and operating cost dynamics for facilities in the region. To account for geographic and seasonal variation of livestock production, the framework is based on a monthly basis. We consider the typical peak production month of October. Our hypothesis is that if there is a bottleneck problem for slaughter and processing, the constraint will likely appear more pronounced in October than in other months. Identifying the operation pattern in October has more potential to generate policy implications.

The beef supply chain optimization problem will be mathematically formulated as a linear programming model with the objective of minimizing the overall cost of beef assembly, slaughtering, processing, interplant shipments and distribution to final demand locations. The objective function of the model (Model 1) to solve this problem is as follows,

$TC_i =$ (1)

$\sum_{f\in F}\sum_{s\in S}\{int(x_{f,s,i}/k)\cdot d_{f,s}\cdot t_1)\}$ Assembling costs

$+\sum_{f\in F}\sum_{s\in S}\{x_{f,s,i}\cdot u_s\}$ Slaughtering costs

$+\sum_{s\in S}\sum_{p\in P}(y_{s,p,i}\cdot q\cdot \delta_1\cdot d_{s,p}\cdot t_2)$ Shipping costs between plants (unprocessed product)

$+\sum_{s\in S}\sum_{p\in P}(y_{s,p,i}\cdot v_s)$ Processing costs

$+\sum_{s\in S}\sum_{g\in G}(z_{s,g,i}\cdot q\cdot \delta_1\cdot d_{s,g}\cdot t_2)$ Distribution costs (unprocessed product)

$+\sum_{p\in P}\sum_{g\in G}(m_{p,g,i}\cdot q\cdot \delta_1\cdot \delta_2\cdot d_{p,g}\cdot t_2)$ Distribution costs (processed product)

Subject to:

$\sum_{s\in S} x_{f,s,i} = p_{f,i}$ $\forall f,i$ (2)

$\sum_{f\in F} x_{f,s,i} = \sum_{p\in P} y_{s,p,i} + \sum_{g\in G} z_{s,g,i}$ $\forall s,i$ (3)

$\sum_{s\in S} z_{s,g,i} = c^1_{g,i}$, $\sum_{p\in P} m_{p,g,i} = c^2_{g,i}$ $\forall g,i$ (4)

$\sum_{f\in F} p_{f,i} = \sum_{g\in G}(c^1_{g,i} + c^2_{g,i})$ $\forall i$ (5)

$\sum_{f\in F} x_{f,s,i} \le a_{s,i}$ $\forall s,i$ (6)

$\sum_{s\in S} y_{s,p,i} \le b_{p,i}$ $\forall p,i$ (7)

$x_{f.s.i}(DT - d_{f,s}) \ge 0$ $\forall f,s,i$ (8)

$x_{f,s,i} \ge 0$, $y_{s,p,i} \ge 0$, $z_{s,g,i} \ge 0$, $m_{p,g,i} \ge 0$ $\forall f,s,p,g,i$ (9)

where set *I*={1,2} denotes the two specific months, *F*={1,2,3…,*f*} denotes a set of production locations, *S*={1, 2, 3,…,*s*} denotes a set of slaughtering locations, *P*={1,2,3,…,*p*} denotes a set of processing locations, *G*={1,2,3,…,*g*} denotes a set of consumption nodes, parameter *t* denotes the unit shipping cost, *d* denotes distance between origin and destination, *k* denotes the upper bound of truck capacity (heads of animals), *u* denotes unit slaughtering cost, *v* denotes unit processing cost, c^1 denotes consumption of unprocessed products, c^2 denotes consumption of processed products, *a* denotes slaughter capacity of plant, *b* denotes processing capacity of plant, t_1 denotes animal transport cost ($/loaded mile), *q* denotes the average live weight of cattle, t_2 denotes refrigerated truck rate for transporting processed or unprocessed products ($/ton mile), δ_1 denotes dressing percentage, δ_2 denotes carcass cutting yield[3], x denotes quantity shipped from production location to slaughtering location, y denotes quantity shipped from slaughtering to processing location (unprocessed products), z denotes quantity shipped from slaughtering location to consumption location (unprocessed), and m denotes quantity shipped from processing location to consumption location (processed).

Eq. (1) states the objective function that minimizes total cost. Eq. (2) ensures that the total quantity of cattle shipped from production region (county) f to slaughter plants is equal to total quantity produced in region f in month i. That is, all products must be assembled into plants. Equation (3) indicates a balance between the inbound flow and outbound flow of a plant. Eq. (4) and Eq. (5) state a market clearing condition, i.e., the total production of beef cattle equal to the total demand of consumers. Eq. (6) and Eq. (7) define the threshold of slaughter or processing capacity of a plant, i.e. the capacity of any plant is not exceeded. Eq. (8) defines the maximum transportation (assembly) distance between production locations and plant locations. Eq. (9) reflects the standard restrictions of non-negativity that ensures shipments only flow from farms to plants and from plants to consumers, and not vice versa.

Survey data suggest that interplant shipments of carcasses are uncommon. An overwhelming number of respondents (94%) reported they would keep both harvest and processing on site at their plant. To highlight the contribution of inter-plant shipping to cost savings, we run the other model (Model 2) that assumes that there is no inter-plant shipping of unprocessed product. That is, if a live animal is assembled to a plant, it will be slaughtered and processed at the plant. The quantity of animals handled at the plant is constrained by both the slaughter and processing capacity of the plant. Besides all constraints applied to Model 1, Model 2 is subject to an additional constraint to ensure that there is no inter-plant shipment,

$$\sum_{p \in P} y_{s,p,i} = 0 \qquad \forall s, i \qquad (10)$$

The optimization problem includes four types of variables that can be chosen to minimize the total costs of the aforementioned activities. They are the quantity of live cattle shipped from farms to slaughter and processing facilities, amounts of final and intermediate products processed at plants, shipments of intermediate products from one plant to another, and distribution of beef products to

[3] Dressing Percentage = Carcass Weight / Live Weight; Carcass Cutting Yield = Pounds of meat/ Carcass weight.

final demand. We solve for these variables to examine the capacity bottleneck problem and identify optimal product flow patterns in the beef supply chain allowing for the spatial distribution of infrastructure and spatial and temporal distribution of production.

5. **Results and Analysis**

For the optimization model presented in Section 2, an algorithm is designed to determine the optimal solutions of the model. The optimization problem is compiled in GAMS and solved using the linear programming solver CPLEX. The computational executions are performed on a computer with 2.84 GHz CPU and 2GB RAM. It takes 3.5 hours and 2 hours to accomplish the execution for Model 1 and Model 2 respectively. Table 1 shows the optimal solution of two models, including the number of utilized plants, relative costs and travel distance.

Table 1. Optimal solutions for Model 1 and Model 2

Costs/Distances	Model 1 (with inter-plant trans.)	Model 2 (no inter-plant trans.)
Slaughtered and processed (head)	4,094	4,094
Inter-plants shipping (no. of carcasses)	1,574	0
Utilized plants	48	45
Utilized plants - slaughter	31	45
Utilized plants - processing	46	45
Total costs ($)	1,948,057 (100%)	1,982,650 (100%)
Assembly costs	107,329 (5.5%)	133,716 (6.7%)
Inter-plant shipping costs	33,702 (1.7%)	0 (0%)
Distribution costs	91,268 (4.7%)	90,234 (4.6%)
Slaughter costs	241,768 (12.4%)	278,505 (14.0%)
Processing costs	1,473,990 (75.7%)	1,480,195 (74.7%)
Average costs in total ($/CWT)	95.17	96.86
average transportation costs ($/CWT)[a]	11.35	10.94
average slaughter costs ($/CWT)	11.81	13.61
average processing costs ($/CWT)	72.01	72.31
Average trans. in total (miles)	282	275
average assembly dist. (miles)	121	150

average inter-plant dist. (miles)	79	0
average distribution dist. (miles)	127	125

[a] Transportation costs = assembly costs + inter-plant shipping costs + distribution costs

Both models suggest that a great reducing of the number of utilized plants will save the systematic costs in spite of the increased assembly and distribution costs due to a reduction in the number of links between origin and destination nodes. Among cost components, processing costs are the largest, accounting for three-quarter of the total costs. Slaughter costs and assembly costs rank the second and the third respectively. Finally, the average costs for per 100 pound of processed product shipped to retailers are $95.17 and $96.86 for Model 1 and Model 2 respectively. Although additional inter-plant shipping increases the total transportation costs of Model 1, the slaughter and processing cost savings stemming from inter-plant shipping are more significant. The total operating and transportation costs for Model 1 are $1,948 thousand. This translates to a roughly 2% cost reduction as compared to the costs generated by the model without inter-plant shipping.

Due to the involved inter-plant transport, the average transportation distance of product from the origin (farmer) to the destination (consumer) is 282 miles in Model 1, 7 miles longer than that in Model 2. The assembly distance range from 2 to 312 miles with an average of 121 miles. The inter-plant shipping distance ranges from 17 to 271 miles with an average of 79 miles. The distribution distance ranges from 2 to 475 miles with an average of 127 miles. Figure 5 displays the most efficient pattern to assemble cattle into utilized plants. To save assembly costs, plants generally serve farmers in their local counties or neighboring counties (highlighted areas where plants are located or neighboring). A few farmers have had to drive multiple hours one way to the nearest slaughterhouse. For example, farmers in Aroostook County in Maine State cannot find a plant unless they ship animal further than 228 miles. Specifically, farmers in four high production counties[4] in New York State ship their animals to plants further beyond their locations (Figure 5, a thicker line represents a larger volume of animal flow).

[4] They are Wayne County and Seneca County in the Finger Lakes region, Cayuga County in the Central New York region and Albany County in the Capital District region. Cattle production in these four counties accounts for 40 percent of total production in the New York and New England.

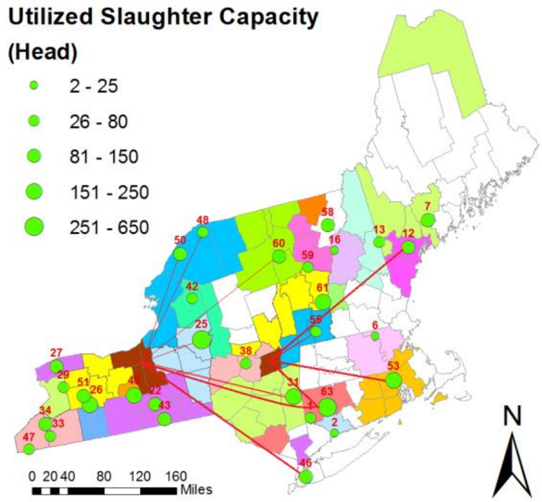


Figure 5. Utilized slaughter plants and optimal assembly pattern. Counties of the same color only utilize the plants within the same-shade area. The exceptions to this rule are the counties with lines to other plants.

Economic incentives for the long rides for cattle in the four counties go as follows, 1) the slaughter fee or/and processing fee in local or neighboring plants is comparatively high; 2) high level of production in those four counties allows animal assembly to enjoy economies of scale, lowering the per unit assembly costs. Lower assembly costs expand the geographic radius of farmers to seek plants with lower slaughter and processing fee; 3) shipping a larger group of cattle in the four counties to plants further away avoids incurring a “squeezing” effect, facilitating small scale producers in neighboring counties to find nearer plants for service. Some counties with low production levels can only collectively bring 1-7 animals at a time. Those counties are unable to capture the economies of scale in long-haul shipping by consolidating partial-capacity. Farms in those counties likely have higher costs for shipping animals and should ship animals on short rides. As suggested by our model, in areas where farms compete for limited capacity of plants, farmers in those low production counties ship their cattle to plants no more than 100 miles while farms in high production counties more likely ship cattle further to plants out of the region; 4) most animals in the four counties are shipped to areas with high demand for beef product, e.g. Great Boston and New York-Newark-New Jersey metropolitan area. Doing so reduces the distribution cost of processed beef products to consumers in those high demand regions. Our regional coordinated system just best balances the tradeoffs between benefits and costs and optimizes the assembly patterns. While the coordination improves the performance of cattle assembly as a whole, the cost distribution among participants is not the same as that if they perform these activities independently. Therefore, implementation of the coordination mechanism in the beef supply chain system requires risk-sharing contracts and benefit-sharing agreements among participants.

Similarly, an incentive to save processing cost and distribution cost jointly shape the inter-plants shipping pattern. Plants likely ship carcasses to plants in high demand regions or to plants with lower processing cost. In total 17 plants ship 1,574 carcasses to other plants for further processing. Figure 6 shows the main streams of inter-plant product flows (80 percent of the total shipments). Plant Nos. 16, 25 43, 45, 50 and 63 ship carcasses to other plants that are mostly located in sites close to New York-Newark-New Jersey metropolitan area and Great Boston. Specifically, two plants, No. 59 in Vermont and No. 16 in New Hampshire, ship all slaughtered animal to other plants in other States. There are two reasons, 1) processing is costly in those two plants; 2) demand for beef product is low in the regions where those two plants are located.

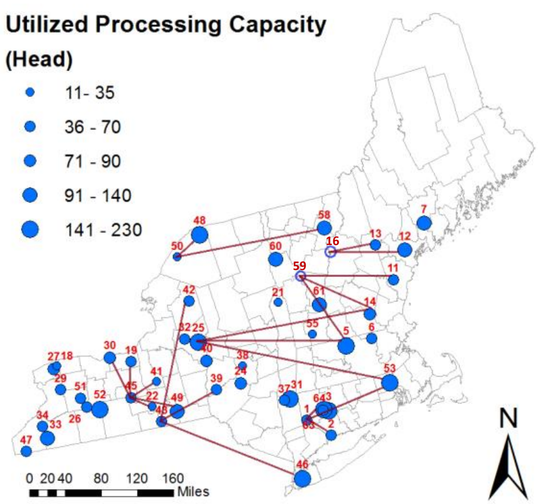


Figure 6. Utilized processing plants and inter-plant shipment

Figure 7 shows the counties to where plants distribute their processed beef products. The distribution pattern is complex. Sometimes one county is served by one plant while sometimes one county is served by multiple counties jointly, and vice versa. To facilitate demonstrating the distribution pattern of the model, based on our results, we geographically classify plants into six clusters and define the region served by a cluster of plants as a marketing area. Generally, counties in each marketing area are jointly served by the plants located in the same marketing area except four large scale plants. Those four plants[5] provide not only local area service but also cross-area

[5] One plant is located in Vermont State (N. 58) and three located in New York State (No. 25, 48 and 60).

service. Mostly, surplus products in those four plants are distributed to more distant consumers in New York-Newark-New Jersey metropolitan area and Great Boston.

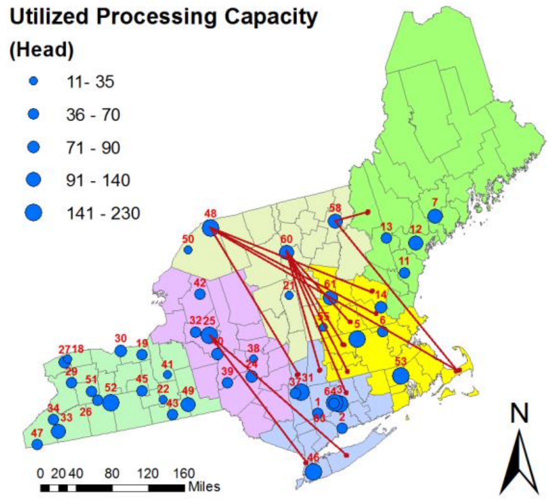


Figure 7. Beef product distribution

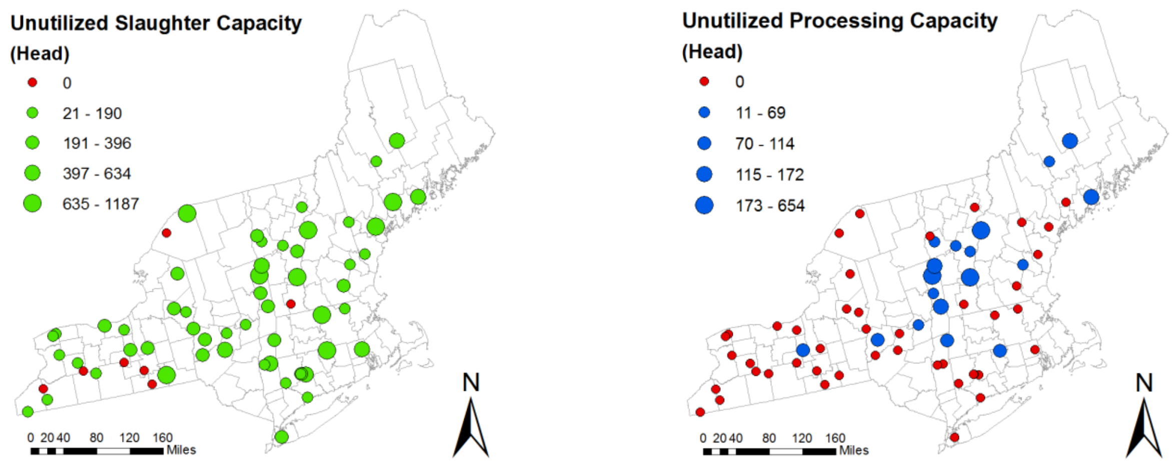
Our results suggest that if the maximum assembly distance (MAD hereafter) is longer than 228 miles, the slaughter and processing capacity of plants in the aggregate is sufficient enough to handle all production in the region and there are no cattle left unhandled. However, transporting animals from farms to plants is costly ($4 per loaded mile), especially for a farm where transported cattle are less than one truckload and thus the unit shipping cost is higher. One would expect that, all things equal, farmers always prefer to ship their animals to nearby plants for slaughter and processing. Our survey suggests that the shipping distance that farmers deem optimal is 0.5 to 2.5 drive hours, i.e. 22.5 to 112.5 miles if a normal truck speed 45 miles per hour is used. If farms all struggle to find the nearest plants for slaughter service in the peak production month, the congestion problem may emerge in some regions, leading to the so-called bottleneck problem. To examine the effect of MAD on the magnitude of the bottleneck, we designed 5 sensitivity experiments in which 30, 45, 60, 90 and 120 miles are set as the MAD threshold respectively. We solve these experiments to identify the resulted bottleneck in each case. As our results show (Table 2), any MAD threshold less than 228 miles will raise the bottleneck problem for animal slaughtering and processing. Under each of the given 5 MAD thresholds, certain percentages of beef cattle will be left unhandled. As the MAD becomes shorter, the bottleneck problem becomes more serious, especially for the portion of New York State where the production level is high. The bottleneck problem becomes considerably critical when the MAD is less than 60 miles.

Table 2. MAD v.s. capacity bottleneck

MAD (mile)	Unhandled volume (head)	Ratio of unhandled volume	Distribution (no. of unserved county, head of unhandled cattle)
228	0	0	/
120	5	0.001	ME(1,5)
90	40	0.010	MA(1,5), ME(1,5), NY(2,30)
60	672	0.164	MA(1,5), ME(2,20), NH(1,5), NY(8,459), VT(1,103)
45	1,318	0.322	CT(2,12), MA(1,5), ME(2,20), NH(1,5), NY(14,1147), VT(3,129)
30	2,041	0.501	CT(2,12), MA(4,28), ME(3,22), NH(3,15), NY(25,1819), RI(1,5), VT(4,140)

Note: CT-Connecticut, MA-Massachusetts, ME-Maine, NH-New Hampshire, NY-New York, RI-Rhode Island, VT-Vermont.

Our results may reveal the potential opportunity for farm business and facility investment regarding physical locations. However, current infrastructure and present services should be evaluated before engaging in new business opportunities. Many plants face the problem of insufficient demand for slaughter and processing. Figure 8 shows the unutilized slaughter and processing capacity in New York and New England. Eighty percent of slaughter capacity and forty percent of processing capacity remains unutilized. To facilitate producers to access plants for slaughtering and processing service, new farms should be located in areas where plants with plentiful handling capacity exist. The decision also depends on factors influencing production and costs such as the land availability and cost of land in the areas and retailing margin (conventional grocery retail often charge 35-50%). New plants should be located near a cluster of farmers that can provide necessary quantities at desired times. However, the low level of utilization for plants reflects the competitiveness of the industry. Building another plant will lead to additional competition or inadequate access to supply. In addition, plants are capital-intensive to start, maintain, and expand and marked by thin profit margins. Building even a very simple new facility requires hundreds of thousands of dollars. If a plant cannot capture full size economies, the investment in the facility and equipment will not generate sufficient incomes to cover the cost. An understanding of current local cattle supply and existing capacity of plants helps inform decisions of a business venture.



(a). Unutilized slaughter capacity

(b). Unutilized processing capacity

Figure 8. Unutilized plant capacity (October)

6. Model Extension and Future Research

Over the past decade, there has been a consistent interest of people to buy local beef products. Local beef represent a potentially valuable market as consumer demand grows and market channels expand (Felix, Williamson and Hartman 2018; Halich et al. 2015). Currently, local beef production in New York and New England suffers a deficit. While New York and New England agriculture officials look to expand local beef industry with an aim to make the region more self-sufficient, many producers expressed similar hopeful sentiments for providing local beef to the community (Keilty et al. 2009). Given the availability of high quality forage, pasture land and markets, expansion of beef production in the region may coincide with a shift toward grass-based finishing systems. Many research and implementation projects have since been undertaken to examine the potential to expand the local production of grass-finished beef so as to increase local food utilization in the region (Peters 2018). However, there is a lack of inherent information on how the handling system should be adjusted to accommodate the production expansion and whether there is a bottleneck for slaughter and processing. Specifically, it remains an empirical problem to assess whether beef can be produced in New York and New England at a cost competitive with meat brought in from elsewhere. Using the above described methodology and modeling framework, further research can be developed to examine several possible expansion scenarios of grass-finished beef cattle production supply in the region given the inherent biological capacity of the region's natural resource base. Our model can also be extended to generate information for developing feasibility analysis and testing economics viability of production expansion plan.

Development of the beef cattle sector is integrated with related sectors and catalyzes further increases in forage productivity and expansion of agricultural land. The optimization model built in the study can be extended to address how the supply chain structure will be reshaped to accommodate the production expansion and assess the costs related to handling expanded production. Under different scenarios, one can examine the bottleneck of slaughter and processing capacity based on the current existing capacity of slaughter and processing plants in New York and New England. If there are bottlenecks for slaughter or processing, further investigation can be conducted to determine to what extent the slaughter or processing capacity of existing plants should be expanded to meet the service demand while minimizing the total operating costs of the beef supply chain system in the region of interest, or alternatively, where new plants should be located to accommodate the extra demand for services, giving costs of setting up a plant with certain capacity, costs of expanding the capacity of a plant to certain level and operating costs of plants. In some areas where plants are lacking, e.g. in rural areas of Maine State, it may make sense to build new plants to serve local farmers if there is enough actual demand to support their businesses. But in areas where there have already been a sufficient number of plants, such as most areas of New York State, it appears that supporting existing plants may be more efficient and effective. The final investment decision should be based on a comprehensive evaluation of tradeoffs between cost and benefit of different capacity expanding strategies.

A beef cattle production expansion plan should be based on economic feasibility analysis of costs of the expanded cattle production, and setup costs and operating costs of expanded capacity of plants needed for accommodating production expansion. Given levels of consumer's willingness-to-pay for grass-finished beef products, if the price of final beef product is more than consumer willingness to pay, the production scenario will be not economically feasible.

Production cost and handling cost are two important cost components of the final grass-finished beef products. With given land in cropland pasture or permanent pasture and yield of hay crops, and hay requirements for grass-finished cattle, the production cost of beef cattle can be calculated. Under the assumption that cattle are raised locally and slaughtered and processed locally and sold locally, the costs of cattle handling, including cattle assembly, slaughter, processing, infrastructure construction, and beef product distribution can be estimated through solving an optimization model. There is also an alternative operational option that needs to be considered - grass-finished cattle can be raised locally, shipped out of the region to be processed and brought back for sale. From an economic perspective, a better option should lower the operating costs and thus lower the final product price. The determination of the optimal operational strategy should be based on a comprehensive evaluation of the cost of the final beef product under options.

7. Conclusions and Discussions

Local producers in New York and New England continue to perceive a lack of local slaughter capacity as a hindrance in trying to meet growing demand. At the same time, small processors cite a lack of throughput to remain profitable. A recent capacity assessment of New England's large animal slaughter facilities seems to support the latter (Waro et al. 2019). The survey revealed there to be sufficient infrastructure to slaughter the beef cattle produced in that region and actually many existing slaughterhouses are not operating at full capacity. To identify and explain the paradoxical statements from both sides, we formulate an optimization model with an objective to minimize the total systematic costs. The present analysis explores the spatial structure of the New York and New England beef cattle assembly, slaughter, processing and distribution system that might result if operating activities of participants were leveraged and regionally coordinated. No research to date has looked across the beef supply chain to explore ways to characterize a nationally coordinated optimal beef supply chain system to examine the bottleneck problem and quantify uncertainty and costs.

In general, a lack of throughput is likely a more limiting factor for local meats than a lack of processing capacity. Our results suggest that in the aggregate, the physical capacity of the infrastructure within the seven Northeastern states is sufficient to handle all beef cattle produced therein regarding the current production level. While 60 percent of the existing processing capacity is utilized, only 20 percent of the slaughter capacity is utilized. Given operating costs of plants in the region, logistics in coordinating plant utilization and deliveries of products suggests that a reduction in plant numbers, and increase in the utilization rate of those remaining, would likely lead to greater cost savings. However, if farmers in some high production areas all struggle to find nearest plants for services, the slaughter and processing capacity bottleneck problem may emerge. The bottleneck problem can be erased if some large farms in the area ship animals further away. Our results also reveal that it will improve cost savings if cattle are slaughtered or processed at plants near major metropolitan areas.

This study provides information, guidance and direct technical expertise concerned with establishing and improving regional coordination mechanism. Our results provide critical information that may lead to a more timely recognition of challenges that need to be addressed. Going forward, insights specific to geographic regions may be used to refine understanding of current beef production handling. This improved understanding, in turn, may assist all industry stakeholders to explore effective and sustainable strategies to expand grass-fished beef production in the region, including strategies for sustainably exploiting land sources, with given demand in grass-finished beef in the region of interest.

The beef supply chain is a complex system. The uncertainty and complexity of logistics operations is determined by production seasonality, geographically dispersed production sites with different production levels and plant locations with different operating costs. This leads to the need for coordination across the supply chain participants. The forming of a regional coordinated supply chain system requires a shift in the relationship between farmers and their slaughters and processors away from a series of independent transactions to a long-term interdependence. The implementation of an coordination mechanism involves not only enhancing coordination and communication but also strengthening commitments on the part of both farmers and meat plant managers: farmers, who know they will have processing dates for their livestock, commit to providing the plants with steady business, either individually or in coordinated groups, while plant managers commit to slaughtering and processing those livestock to farmer specifications consistently and on time (e.g. scheduling), and help their farmers with distribution and marketing. Such a good business relationship and long-term loyalty between supply chain participants is essential to maintaining and expanding the meat plants necessary for growth in local beef. Other elements essential for implementing the coordination mechanism in the beef supply chain include integrated procurement-production-distribution processes information sharing, decision-making coordination, and risk-sharing contract and benefit-sharing agreement specification. The discussion of these issues goes beyond the scope of this paper and might be a subject for further research.

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