Hub Location in Fresh Produce Supply Chains

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Abstract: While demand for locally produced food has increased sharply in recent years, interest in supporting local food systems is rising among Federal, State, and local policymakers. This study explores the idea of endogenous hub location on the fresh produce value chains. To overcome limitations in the literature, we integrate the effect of economies of scale and production seasonality into our models. Three experimental models are designed to assess effect of the application of yearly, seasonal and monthly data on model solutions. We then make explicit comparisons between solutions of models. Although solved using the same method, the three models generate varying solutions and in many respects they lead to different conclusions.

Key words: fresh produce value chain, hub location, economies of scale, seasonal data

Introduction

Food insecurity is a serious challenge for millions of Americans (Coleman-Jensen, Nord and Singh 2013), and interest among consumers and private and public decision makers in the sustainability of food supply chains is increasing as domestic and worldwide population grows (Nicholson, Gómez and Gao 2011). Consequently, the structure and optimization of key agricultural supply chains is of growing importance (King et al. 2010). To this end, sustained and imaginative modeling efforts are needed to identify and validate reactive strategies and policies to improve efficiency of supply chains for maintaining food security and sustainability.

As a focus of food supply chain optimization issue, the problem of regional food hub location has attracted the attention of practitioners, policy makers and academics (Boys and Hughes 2013; Brown and Miller 2008; King et al. 2010; Clancy and Ruhf 2010; Martinez et al. 2010; O'Hara and Pirog 2013; Tropp D. 2008). As a notable example, the U.S. Department of Agriculture (USDA) administers is examining a variety of policies and programs to (i) accommodate the growing demand for food that accompanies population growth, (ii) enhance food access and affordability for low-income communities, and (iii) encourage sustainable growth of the food system. To accomplish these goals while also benefiting food system participants, USDA seeks to strengthen regional and local food systems. Developing regional food hubs is an important

component of this strategy. In 2009, the USDA launched the "Know Your Farmer, Know Your Food" initiative to strengthen the connection between farmers and consumers while supporting local and regional food systems.

This paper examines the roles of regional food hub development by characterizing and modeling of assembly (as opposed to distribution) hub locations in selected fresh produce value chains in the Northeastern United States. The assembly hub location has a great impact on the sustainability and efficiency of the value chains. Assembly hubs provide producers with an entry point to marketing their fresh products, and these hubs aggregate and distribute products to final consumers of local or regional products. Smaller and mid-sized producers can participate in mainstream markets as a result of reduced barriers to entry and other efficiencies created by assembly hubs (Matson, Sullins and Cook 2013). For consumers, such assembly hubs in turn provide access to a greater variety of fresh producers at lower cost (Hardesty et al. 2014). To improve the performance of fresh produce value chain systems, research designed to explore the efficient structure of assembly hubs in regional food systems is needed.

From a formal point of view, the study falls within the scope of strategic planning facility location of supply chains. Previous studies conduct some computational experiments to identify the optimal hub numbers and locations in food supply chain systems (e.g., Etemadnia et al. 2013; Etemadnia et al. 2015). While their analyses contribute to the analysis of optimization of local food systems, these studies impose strong simplifications on the operational level which can dilute uncertainties and realism contained in the system of interest. First, they ignored the role of economies of scale in shaping the optimal network configuration, which means generated solutions are likely to deviate from representative experimental conditions that ought to be used to reach an optimum. Second, these studies use annual production data and neglect seasonal differentials in production which can affect the hub operational strategies and generate heterogeneous costs across marketing seasons. Abstracting from important details limits the contributions of studies for the research goals of interest, so the overall simplicity of a model comes at the expense of generality. Some have observed when more realistic phenomena are incorporated into an analytic model, the more general the model becomes (Lewis 2013). To prevent simplicity from weakening the predictive strength of models, this study relaxes these assumptions and develops more realistic models that fit the supply chain context.

Fresh produce industry activity is strongly seasonal. Product harvesting takes place between production seasons. Each variety is picked in a given range of weeks within the harvest period. These products need to be assembled and consolidated quickly and effectively from multiple sources. The production seasonality of different regions determines the seasonal operational patterns and operation cost dynamics for hubs in those regions. This study embeds seasonality concept into two models, a seasonal model and a monthly model, and compares their solutions with that of a yearly model which is exclusive of seasonal operation differentials and cost dynamics.

Currently fresh production data obtainable from various data sources are mainly annual. Complete version of national seasonal or monthly fresh produce production data during marketing seasons are not available. To build seasonal and monthly models, we disaggregate annual data into seasonal or monthly parts.

To overcome the limitation of literature, this study also integrates an economy of scale effect into the three models. Empirical estimates of fixed and per unit marginal handling costs for each capacity choice are obtained from regression analysis of data. Consistent with the regression results, the models assume varying costs for establishing and maintaining hubs with different handling capacities and different marginal costs for handling products in those hubs.

The remainder of the paper is structured as follows: we start by revealing the pattern of economies of scale inherent in operations of currently existing fresh produce hubs and then incorporate identified scale effect into three computational models that apply yearly, seasonal and monthly data respectively. Subsequently, we solve the three optimization models for both the scale and locations of these hubs that minimize total costs of assembling all fresh produce products across counties. Comparisons for differentials of optimal solutions of three models are provided. This paper ends with a conclusion.

The Effects of Scale Economies

In network design, economies of scale are critical (Camargo, Miranda and Luna 2009; Horner and O'Kelly 2001), and size critically affects firms' operational efficiency, with larger-scale firms often enjoying greater efficiencies (Matson, Sullins and Cook 2013). This also means that

smaller hubs face inefficiencies in the form of higher operating costs, which may reduce the size of the market they can serve (Pressman and Lent 2013). To more clearly understand the actual operating cost patterns and identify empirical evidence of scale effects inherent in hub operations, we collect and analyze data on the scope and scale of food hub operations. Using 2007 Economic Census data regarding county level fresh produce sale values and corresponding operational cost, we compiled data for geotype=03 (county level hubs) and obtained 67 observations for hubs with sale value and operational costs data available. Sale values for county or state level hubs are converted to quantity of production handled in these hubs based on the national weighted average 2007 wholesale price of 31.3 cents per pound for all fresh produce marketed in the U.S. (U.S. Department of Agriculture(USDA), 2009a, 2009c, 2009d). To facilitate identifying the pattern of scale effects, three hierarchy levels with almost equal data sample size are defined based on the average handling quantity handled by three levels of hubs (thousand of pounds),

Level 1: 519,110
Level 2: 986,128
Level 3: 2,820,430

For each hub level, the relationship between the operation costs of hubs (dependent variable) and the product quantity handled at hubs (independent variable(X)) is regressed using OLS and with shown in Table 1,

Table 1. Regression Results for Scale Effect of Economies

Levels	Variables	Coefficients	*t* Stat	*P*-value	*F*	R Square	Obs.
Level 1	Intercept	2223.56	0.20	0.84	4.93	0.20	22
	X Variable	0.04702**	2.22	0.04			
Level 2	Intercept	4472.58	0.32	0.75	9.47	0.32	22
	X Variable	0.04216**	3.07	0.01			
Level 3	Intercept	26208.58**	2.08	0.05	66.95	0.76	23
	X Variable	0.03110**	8.18	0.00			

Note: **significant at 5% level

The operational costs are broken into fixed and variable costs. Fixed costs are independent of product volume handled, and variable costs vary with volume handled at a hub. The intercept terms in these regressions represent the fixed costs of hub operations and the coefficients of independent variables (quantity handled at establishments) represent the marginal costs for one unit increase in the quantity handled in an establishment. The products of coefficients and independent variables represent the variable cost component for hub operations. Regression results show fixed costs (intercept) increase with the scale of hub, and on the contrary, the marginal costs decrease with the scale of hub, i.e., the more products handled, the less the marginal cost for one unit (one thousand pounds) increase in the volume handled. The operational cost for one thousand pounds of products handled is $47.02, $42.16, and $31.10 from lower level 1 (with smaller handling capacity) to upper level 3 (with larger handling capacity). A shipping hub's per unit handling cost thus endogenously depend on volume handled. Under cost minimization principles, the number and scale of facilities to be established typically becomes an endogenous decision. Based on these regression results, this study embodies the economic scale effect into the models and demonstrates how it leads to differing spatial network structures.

The Problem Statement and Experimental Settings

This study builds up models to determine the optimal number, scale and locations for assembly hubs under different data scenarios. We design three experimental models to assess the effects of different data scenarios on the optimal solutions of hub locations. The yearly model, seasonal model and monthly model use yearly, seasonal and monthly county production and import data respectively.

To integrate the scale effects inherent in hub operations into models in this study, we use the insights about the operating cost patterns of hubs from previous studies. Following the scale effect patterns, the models assume varying costs for establishing and maintaining hubs (fixed costs) with different capacities and different unit costs for handling products in those hubs (marginal costs). It is assumed that a hub must handle a certain level of product quantity to achieve a certain level of scale effect. Reminding there are three county levels of hubs defined for scale effect regressions. To appropriately apply the regression results for scale effect, this study defines three different thresholds for quantity handled at hubs the same as those defined in

the regressions. Regression results reported in table 1 are incorporated into these model simulations, where they inform alternative hypothetical hub cost parameters.

Besides those three level hubs, an additional level of hubs are needed to define hubs with handling quantity less than 519,110 thousand pounds, the quantity threshold to establish the lowest level hubs. Counties in some states whose production and import are at low levels may confront difficulties to build hubs with scales as either of the defined three level hubs due to the maximum transportation distance constraint set for models, i.e., they cannot collect enough quantity of products within the maximum transportation distance to meet the threshold to build even the smallest scale hubs. Allowing for this, we set one more level of hubs with handling quantity ranging from 1 to 519,110 thousand pounds. These hubs can be regarded as hubs with 519,110 handling capacity but do not utilize their full capacity. We assume the fixed cost for these hubs are the same as those hubs with 519,110 thousand pounds handling capacity, but the marginal costs are at an extremely high level $200 for one thousand pounds of products handled. The high marginal costs can rule out to great extent the possibility to randomly build establishments with very small handling capacity. Just as we shall see later, these hubs only handle a very small ratio (about 0.3%-1.3%) of total annual fresh produce products in models. So the release of hub capacity threshold for the level 1 establishments should only have a minimal influence on the solution of hub locations. Above all, four different types of establishments are defined based on the quantity of products handled and named as Levels 1-4 (unit: thousand pounds).

Level 1: 1-519,110
Level 2: 519,110
Level 2: 986,128
Level 3: 2,820,430

In order to identify the effect of different versions of production and import on the optimal solutions of the problem, we design three experimental models which are validated by yearly, seasonal and monthly data respectively. Table 2 provides a brief description of experimental setting for the three models, including the fixed costs and marginal costs for handling one thousand pounds of products across hub levels.

Table 2. Fixed Costs, Marginal Costs and Total Costs for Hub Operation ($/1,000 lb)

Level	Fixed Costs	Marginal Costs	Total Costs
1	>4.28	200	>204.28
2	4.28	31.10	35.38
3	4.53	42.16	46.61
4	9.29	31.10	40.39

Due to the highly perishable nature of fresh produce products, the commodity value decreases with transportation time. Fresh produce products have to be assembled and consolidated quickly and then transported to next destinations. Based on 2007 U.S. production and import data and hub locations from county business patterns dataset, the distance of county centroid of fresh produce production or port of unloading from a county centroid of fruit and vegetable wholesale locations is no more than 188 miles . Allowing for this, we set 188 miles as a maximum distance constraint for our models.

Data

Based on 2007 USDA/NASS data, farms in 290 counties in 12 Northeastern States grow 21 different market vegetable crops and 22 different fruit and berry crops (USDA/NASS 2009a, 2009b, 2009c 2009d)[1]. Combined production for the subset of these 33 crops produced in each county are converted to a common unit (1,000 pounds) and summed to a single annual production statistic per county. Annual production statistics are disaggregated into monthly and seasonal marketing segments for validating the seasonal and monthly model. This is achieved by identifying beginning and ending dates for the marketing seasons of each fresh produce crop in each State (USDA/NASS 2006; USDA/NASS 2007). Fresh produce varieties grown in different states differ in their marketing seasons and their production levels differ across seasons. Many States have multiple growing regions with different marketing seasons for the same crop, and in some cases a single crop may have two marketing seasons.

[1] We use data compiled using the method described in Houtian et al. (2015).

Under the given marketing season for each fresh produce variety in each state and an assumption of the distribution pattern of the variety during its marketing season, the daily production level of the variety can be estimated. Here we assume the production of a crop follows a specific normal distribution under the assumption that 100 percent of available product is marketed within 4 standard deviations of the marketing season midpoint. With derived daily marketing data, monthly data can be imputed by creating cumulative total by marketing month. Then seasonal production can be derived from aggregating monthly production.

Monthly fresh produce import data by county of unloading are compiled from Census Bureau sources. 26 counties in 9 states import 68 categories of fresh produce from areas beyond the U.S. The total amount of domestically produced or imported fresh produce is 17.8 billion pounds. Production and imports are as expected unevenly distributed across seasons. The yearly, seasonal and monthly production and import data are shown in figures as follows.

Figure 1 shows the yearly fresh produce production and import distribution across counties in the Northeastern United States. Production and imports are as expected unevenly distributed across counties.

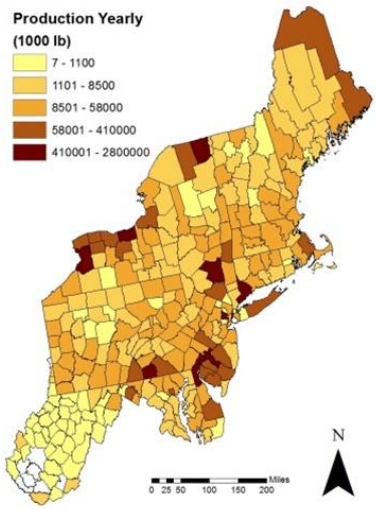


Figure 1. Distribution of Annual Production and Imports

Source: Author

Figure 2 shows the seasonal and monthly production and imports distribution across counties. Seasonal data are aggregated from monthly data which will be shown next. The production and import levels of counties differ across seasons.

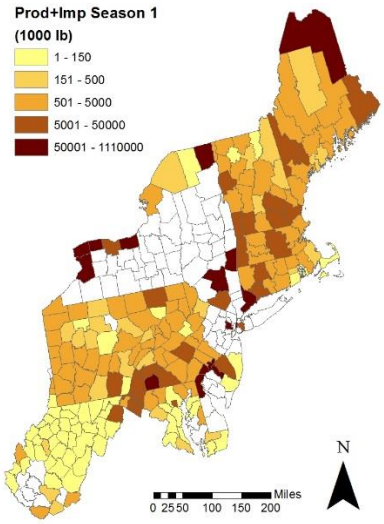


Figure 2(a). Season 1 (Jan.-Mar.)

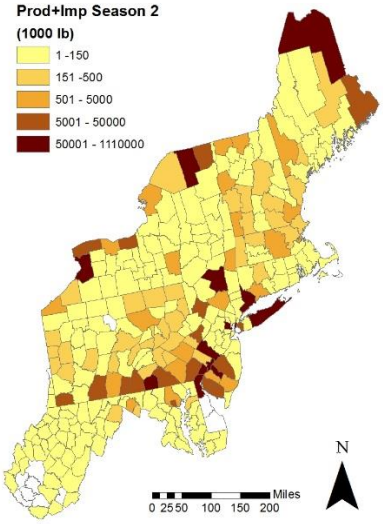


Figure 2(b). Season 2 (Apr.-Jun.)

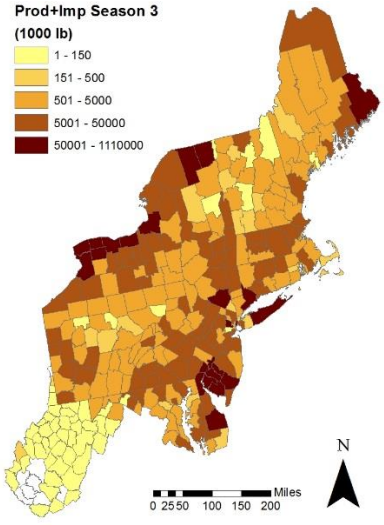


Figure 2(c). Season 3 (Jul.-Sep.)

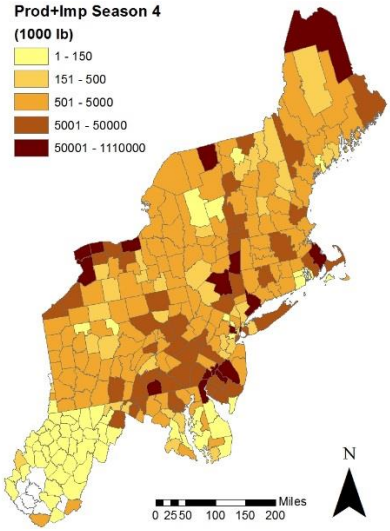


Figure 2(d). Season 4 (Oct.-Dec.)

Figure 2. Distribution of Seasonal Production and Imports

Source: Authors

Figure 3 shows the monthly production and import distribution across counties. We choose March, June, September and December from twelve months as representatives. The production distribution displays significantly different patterns across months.

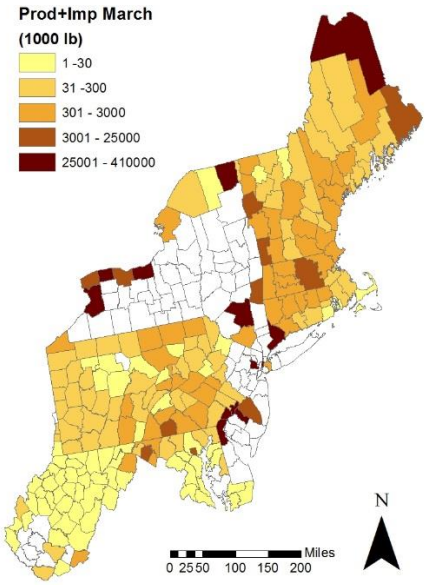


Figure 3(a). March

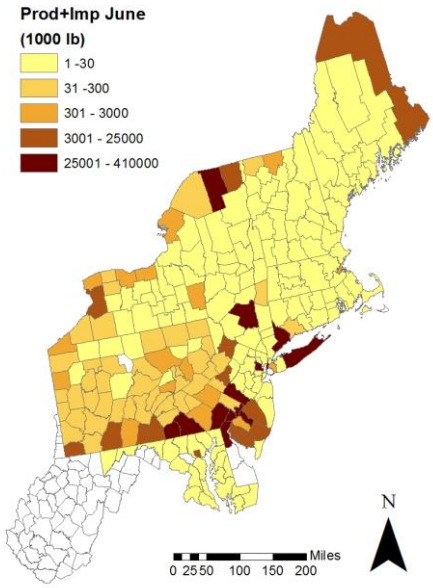


Figure 3(b). June

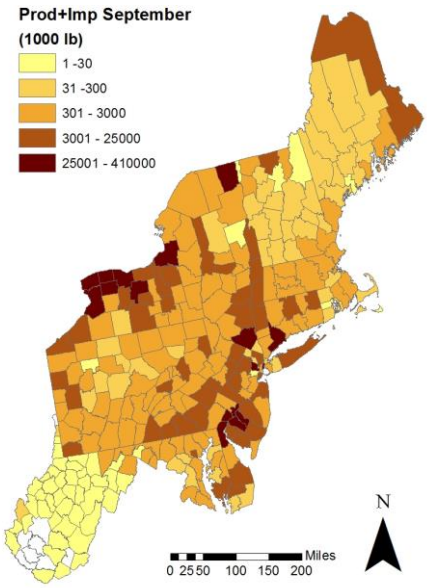


Figure 3(c). September

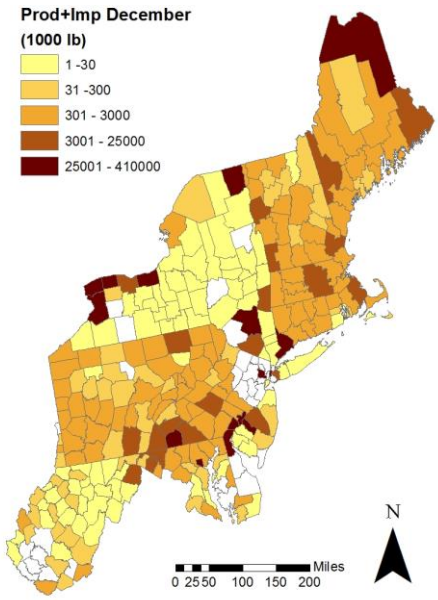


Figure 3(d). December

Figure 3. Distribution of Monthly Production and Imports

Source: Author

The Problem Statement and Methodology

Due to the high costs to establish and maintain an assembly hub, it is assumed that produce hub investors will choose from a finite number of possible hub locations to build assembly hubs with certain level of handling capacities. We formulate the hub optimization problem as a mixed integer linear programming model with the objective of minimizing total costs associated with product assembly and hub operations. The optimization problem is subject to constraints to ensure that total production by region and average per unit supplier and shipping costs meet observed statistics. The following notations are introduced for the models.

Sets:

I={1, …, i} denotes four marketing seasons or twelve marking month in a year for the seasonal model or the monthly model; for the yearly model, i=1;

F={1,2,3…,f} denotes a set of production locations;

S={1,2,3,…,s} denotes a set of hub candidate locations;

C={1,…,c} denotes capacity level of assembly hubs; each capacity level has an interval span;

Parameters:

$p_{i,f}$ denotes production at production location f in marketing time i;

$d_{f,s}$ denotes distance between production location f to hub location s (impedance miles) ;

t denotes fixed transportation cost ($ per thousand pound impedance mile);

DT denotes distance threshold between production locations and hub locations (impedance miles);

$U_{c,s}$ denotes the annual handling quantity threshold of c level hub in location s;

Q_s denotes assembled quantity of products for hub s from multiple county f,

where $Q_s = \sum_{i \in I} \sum_{f \in F} x_{i,f,s}$;

Variables:

$x_{i,f,s}$ denotes quantity shipped from production location f to hub location f in marketing time i;

$z_{c,s}$ denotes an integer variable $= 1$ if location s is a hub with capacity c, and 0 otherwise;

TC denotes system wide total assembly plus first handler costs

An assembly hub facility of capacity *c* is costly to build and maintain. The annual opportunity costs of equity financing, interest costs of debt financing, and replacement costs of physical and economic depreciation are born by owner regardless of hub services produced; denote these as fixed setup and maintenance costs, h_c^0 . In addition, for each unit of produce handled up to the capacity to which hub facility is built, a per unit handling cost is incurred; denote these as marginal costs, h_c^1.

At any given hub location *s* imported produce and domestic regional production from counties (nodes) are assumed to be shipped overland by truck though a network connecting all production nodes and assembly hubs. Transport costs between county pairs vary proportionally with distance but also depend on road conditions, such as traffic which impact time and speed of travel (Novaco, Stokols and Milanesi 1990), or impedance more generally. A higher impedance value implies greater friction or resistance to movement from one node to the next. Here we use impedance data from the Oak Ridge National Lab (2011).

For a national fresh produce transportation and supplier logistics system, optimal assembly hub scales and locations are determined by minimizing total costs of hub operations plus shipping costs of moving all domestically grown fresh produce to a hub. The objective function and system constraints of a model to solve this problem are given in equations 1 to 6.

Minimize

1) $TC = \sum_{c \in C} \sum_{s \in S} \left\{ (h_{c,s}^0 + h_{c,s}^1 \cdot Q_s) \cdot Z_{c,s} \right\} + \sum_{i \in I} \sum_{f \in F} \sum_{s \in S} \left\{ x_{i,f,s} \cdot d_{f,s} \cdot t \right\}$

Subject to:

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

3) $Z_{c,s} \in \{1,0\}$ $\quad \forall\, c, s$

4) $\sum_{c \in C} Z_{c,s} \leq 1$ $\quad \forall\, s$

5) $\sum_{f \in F} x_{i,f,s} = \sum_{c} Z_{c,s} U_{c,s}$ $\quad \forall c, s$

6) $x_{i,f,s} \geq 0$ $\quad \forall\, i, f, s$

The objective function (1) minimizes the total cost. Equation (2) ensures that in each marketing time *i* the total quantity transported from production region *f* to all hubs *S* are equal to total

quantity produced in region *f* in the same marketing time. That is, all products must be assembled into hubs across marketing times. Equation (3) provides the binary condition—build/do not build, while equation (4) guarantees that the total number of hubs built in hub location *s* is not more than 1. Equations (5) ensures (a) products will not be transported to any hub location s unless a hub is installed and there is sufficient capacity to handle all products transported to hub s in marketing time *i*; (b) quantity handled in hub *s* meets the threshold for the hub to enjoy a certain level of scale effect of c level hub. Equation (6) ensures that shipments only flow from farms to hubs and not vice versa.

Results and Analysis

Using the model reported in equations (1) to (6) and the set of parameter values and data, computational simulations for three models allow us to generate data for the hub location problem. Given the current state of computing power and software availability, the optimization problem is compiled using GAMS and solved using CPLEX. A high performance computer with 20 cores, 3.07 GHz CPU and 256 gigabytes RAM was used to run the executions. Next we present the results of computational experiments and conduct analysis.

Table 3 shows the optimal hub number in each level across three models. Hub location overlaps of three models are marked in colors.

Table 3. The Number of hubs at Each Level across Models

Level	Yearly	Seasonal	Monthly
1	#25001 #36083 #54055 #54057	#25001 #36117 #42111 #54055	#25001 #42051 #54055
2	#23019 #33011 #42063	#09001 #23019 #33011	#23019 #33011 #42001 #42025 #42111
3	#36111	#34013	#34007

	#36031	#36019 #36061 #36111 #42051	#36031 #36071 #42045
4	#10003 #36055 #36061 #42045 #42101	#10003 #36055 #42045 #42101	#10003 #36055 #36061 #42101
Total	14	17	17

While the hub location solutions for three models differ from each other generally, there are 9 common hub locations (counties). It is not surprising that there is such a high level of overlaps of hub locations between models, especially for the largest level 4 hubs. The explanation is that whenever operational conditions change, counties that enjoy high production plus import levels or that can source products easily from surrounding counties are ideal candidates for hubs. Although being the same locations, those hubs may differ in scales, e.g. hub #36061 is a level 1 hub in the monthly and yearly models, but it is a level 2 hub in the seasonal model. Furthermore, even if hubs are consistent in both location and scale across models, the counties from where the hubs source products differ across models. As shown in Figure 4-6, hub location solutions using different data display varying assembling patterns.

The locations and scales (annual handling capacity, thousand of pounds) of these hubs and the their serving counties for the yearly model are shown in Figure 4,

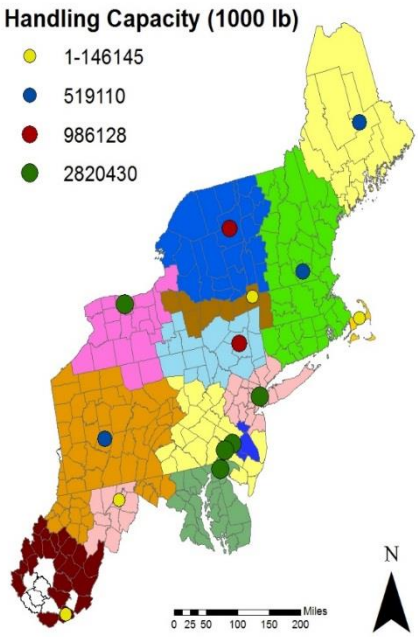


Figure 4. Hub Locations, Scales and Serving Counties for Yearly Model

The locations and scales of these hubs and their serving counties for the seasonal model are shown in Figure 5,

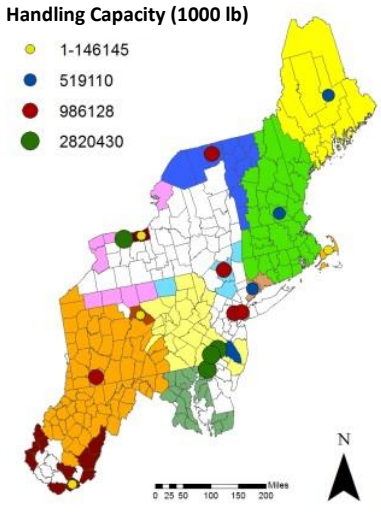


Figure 5(a). Season 1

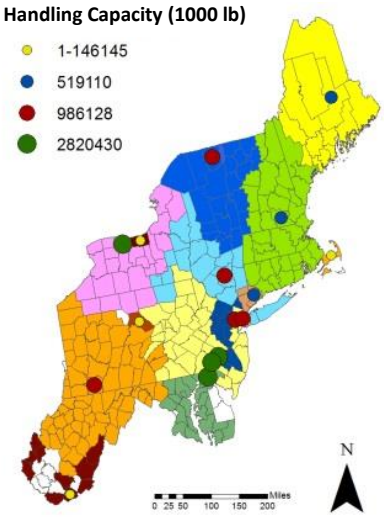


Figure 5(b). Season 2

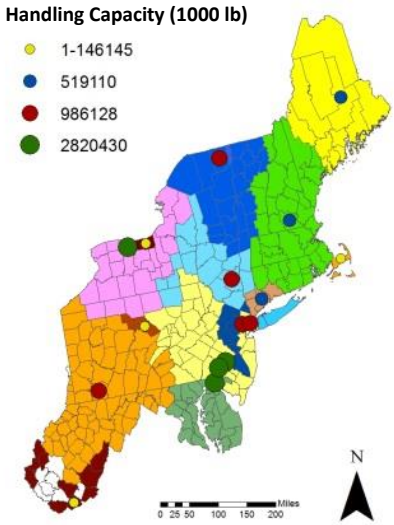


Figure 5(c). Season 3

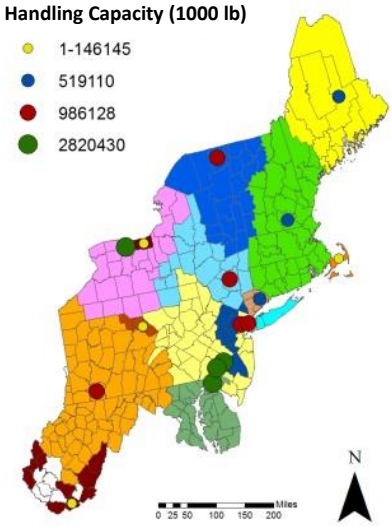


Figure 5(d). Season 4

Figure 5. Hub Locations, Scales and Serving Counties for Seasonal Model

Figure 6 shows optimal locations and scales of hubs and their serving counties for the monthly model. Here months March, June, September and December are selected as representatives.

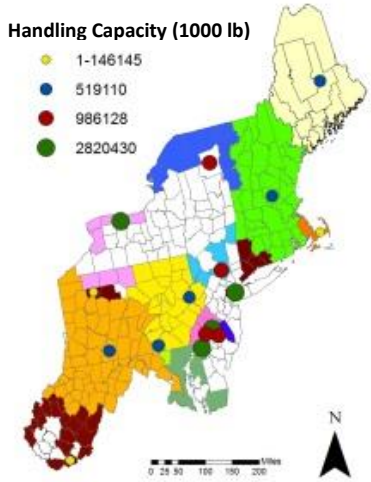


Figure 6(a). March

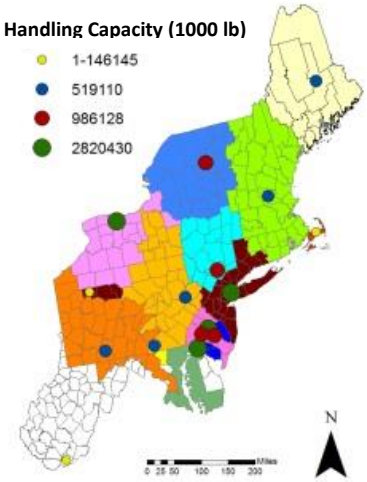
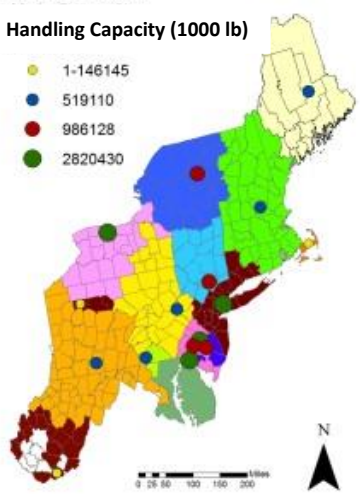


Figure 6(b). June



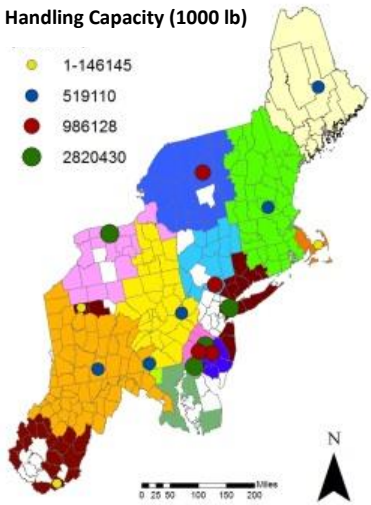


Figure 6(c). September

Figure 6(d). December

Figure 6. Hub Locations, Scales and Serving Counties for Seasonal Model

In reality, the counties from where a hub sources products can be different across seasons or months, that is, a county's products can be transported to different hubs in different seasons or months. Such uncertainty is integrated into the seasonal and monthly models. For the seasonal and monthly models, a hub has more options for assembling fresh produce spatially and temporally based on the seasonal or monthly production and import level of each county, and thus coordinating distribution of assembled products among hubs during marketing months or seasons becomes more strategic, facilitating better catching the tradeoffs between establishment costs, transportation costs and variable costs. For the yearly model, the counties served by a hub keep consistent through a year. This puts a constraint on the flexibility of yearly model for optimizing locations and scales of hubs, increasing the operation costs of the model. Table 5 shows relative costs generated in three models. The total operation costs are $910 million, $ 904 million and $893 million for the yearly model, the seasonal model and the monthly model respectively.

Table 5. Relative Costs across Models

	Yearly	Seasonal	Monthly
Fixed Costs	155,545,000	142,753,000	140,504,000
Variable Costs	640,687,939	649,980,629	646,941,193

Transportation	114,224,041	111,893,443	105,321,305
Total ($)	910,456,980	904,627,072	892,766,498

Although assembling and handling same quantity of products in a specific month for three models, the costs occur in different modes for three models. As shown in Table 5, there are significant divergences between cost components of three models. There are more level 4 hubs in the yearly model than the other two models. While saving more variable costs from taking advantages of scale effects, large handling capacity hubs incur high fixed costs and transportation costs. This explains why the fixed and transportation costs of the yearly model are highest among three models. For the monthly model, a hub enjoys more freedoms (twelve monthly intervals) to select among the surrounding counties for optimal candidates from where it aggregates products to meet the quantity thresholds of a certain level of hubs. Such a freedom not only improves efficiency of selecting hub locations and scales, but also shortens the assembly transportation distance with a big margin. We can see the fixed costs and transportation costs are the lowest for the monthly model, resulting in the lowest total operation costs of the model.

Furthermore, monthly model can simulate the hub operation patterns in comparatively realistic manner, and thus better allow for hub operation cost dynamics than the other two models. If disaggregating yearly and seasonal models' costs into monthly costs components, we can further identify to which extent the monthly costs of the two models deviate from the counterpart of the monthly model. For doing this, based on the optimal solutions of the yearly and seasonal models, we first figure out the monthly assembled fresh produce products attributed to each specific hub and calculate the monthly transportation costs and variable operation costs occurred monthly for the hub. With respect to the fixed costs, we assume they are evenly distributed within twelve months for a hub. Figure 7 shows the monthly costs for three models. Although hubs assemble and handle the same quantity of products in a month for the three models, the created monthly costs of the three models differ in values. There is a significant influence of different versions of data on the model performance.

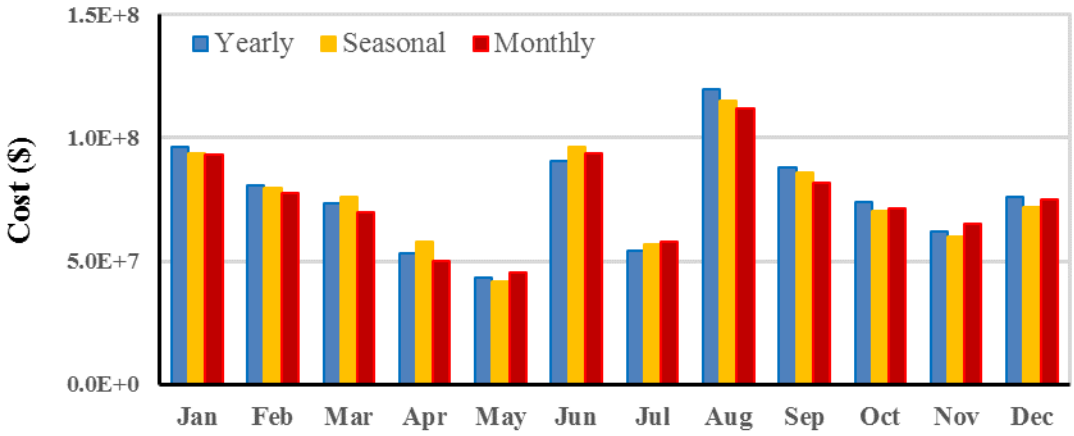


Figure 7. Monthly Costs of Three Models

The capacity of hub is maximum quantity that can be handled on a frequent base. Rationally the capacity of a specific hub should not be designed to handle all fresh produce products assembled by the hub during a year unless a hub cycle frequency of inventory turnover is one time annually. If we assume that the turnover frequency of hubs is once a month, the capacity of individual hubs can be identified through examining the monthly maximum quantity handled at hubs during twelve months. Based on the optimal solutions of the yearly and seasonal models, we disaggregate yearly and seasonal quantity handled at a hub into monthly components. The identified capacities of individual hubs across three models are shown in Table 6.

Table 6. Hub Capacities across Models (thousand pounds)

Hub	Yearly Model		Seasonal Model		Monthly Model	
Level	Hub No.	Capacity	Hub No.	Capacity	Hub No.	Capacity
	#10003	488,484	#10003	433,831	#10003	424,191
	#36055	504,505	#36055	502,756	#36055	507,426
1	#36061	336,021	#42045	443,613	#36061	395,485
	#42045	451,369	#42101	517,702	#42101	403,271
	#42101	429,607				
	#36031	279,960	#34013	365,927	#34007	266,611
	#36111	185,021	#42051	136,442	#36031	268,605
2			#36061	227,156	#36071	184,389
			#36111	116,618	#42045	213,852
			#36019	304,785		

	#23019	92,315	#09001	105,077	#23019	92,315
3	#33011	122,048	#23019	92,315	#33011	114,315
	#42063	183,982	#33011	120,703	#42001	97,261
					#42025	148,192
					#42111	84,898
	#25001	10,567	#25001	25,622	#25001	19,289
4	#36083	103,862	#36117	4,376	#42051	154
	#54055	9,007	#42111	2,161	#54055	4,256
	#54057	59,496	#54055	363		

Because the fresh produce products are highly perishable, their shelf life of products is very short. The monthly model more effectively accounts for actual cycle frequency of hub operations than the other two models. Consequently, the monthly model helps identify the appropriate capacity of different level hubs required to handle assembled products during a year in a more realistic manner than either the yearly or seasonal model does.

Conclusions

Facility location is a well-established research area within operations research. The application of hub location models has long been under discussion in regional and local food system studies due to their presumed potential contribution to the sustainability of food supply chains. While allowing for scale effect of economies, this study builds three experimental models under different data scenarios to determine the optimal number, scale and locations for assembly hubs that serve as first handlers and assemblers for fresh produce sourced from growers and importers located in multiple U. S. counties. To our knowledge, there are virtually no other studies that have compared the results of experimental models generated in different data versions.

Fresh produce has two important traits, perishability and seasonality. All local produce has a specific period of time of production and also there is a need to furnish products for sale timely. Fresh produce products must be aggregated and transported to destinations quickly. A successful fresh produce hub network design should allow for operation seasonality and variability. Earlier studies using annual production data ignored the seasonality in production that not only affects hub operational strategies but also creates heterogeneous costs across marketing seasons. In this

study, we disaggregate yearly production data into monthly and seasonal components and apply them to models.

The hub optimization problem was mathematically formulated as a mixed integer linear programming model with an objective to minimize the total costs associated with produce assembly and hub operations. Our results provide strong evidence that different data versions have significant influences on model solutions concerning hub locations, assembly patterns and cost dynamics. The solution heterogeneity underlines the importance of characteristics of data selected for validating models in conducting analysis. Comparatively, the monthly model better allows for production seasonality and hub operation seasonality in a more realistic manner than the yearly and seasonal models and its solution is more formative for policy implications.

Agriculture is undergoing extreme change. The economic and operational environments keep evolving across time. The agricultural supply chain systems are actually vulnerable to the environment evolution. Sustained and imaginative modeling efforts are needed to identify and validate reactive strategies and policies to improve efficiency of the logistics of supply chains. The capacity of a model in embracing time sensitive phenomenon determines to what extent the model can mirror the actual supply chain systems. To this end, our model solutions may provide useful information on developing a framework for conducting impact and cost assessments for regional and local food systems. Such information is currently lacking and is needed to help inform decisions of the various stakeholders interested in regional food hub infrastructure investment.

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