OPTIMAL WHOLESALE FACILITIES LOCATION WITHIN THE FRUIT AND VEGETABLES SUPPLY CHAIN

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USDA

Outline

- Introduction and background
- Hub Location Problem
- Objective and Problem Formulation
- Experimental Results and Analysis
- Conclusions and Future Work

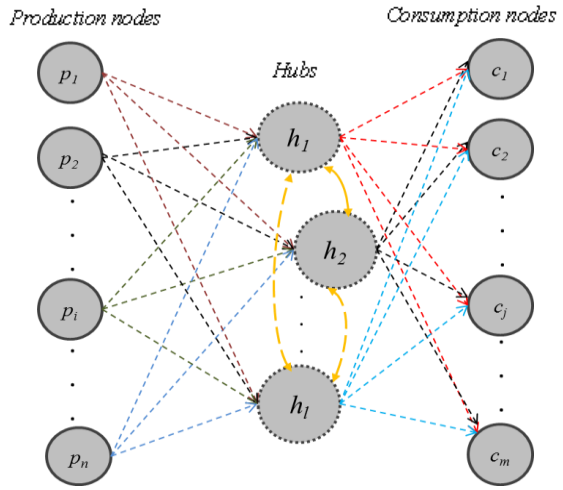
Introduction

- Population growth is posing a challenge to food availability and accessibility.
- To maintain the balance between supply and the growing demand for the food products, the number of production and consumption sites increase.
- The emergence of more production-consumption nodes also complicates food accessibility and availability.
- Interest in locally produced food has increased sharply in recent years.
- “Know Your Food, Know Your Farmer” educational program to promote local and regional agriculture (USDA)

Question : “What is a practical way of bringing food products to customers at reasonable cost by significantly increasing the role of locally produced foods in satisfying existing demand and consumers’ need?”

Hub Location Problem

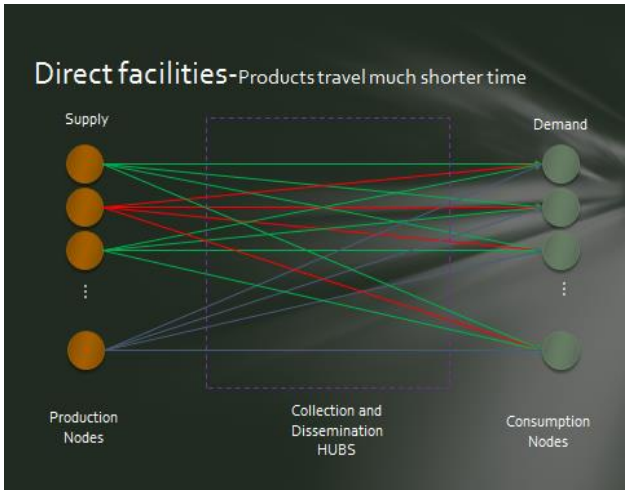
- The hub location problem arises when flow (travelers, airline passengers, cargos, farm products, mails, etc.) must be sent from an origin node to a destination node.
- A hub location is defined as existing wherever placing a direct link between each OD pair is either challenging or costly.

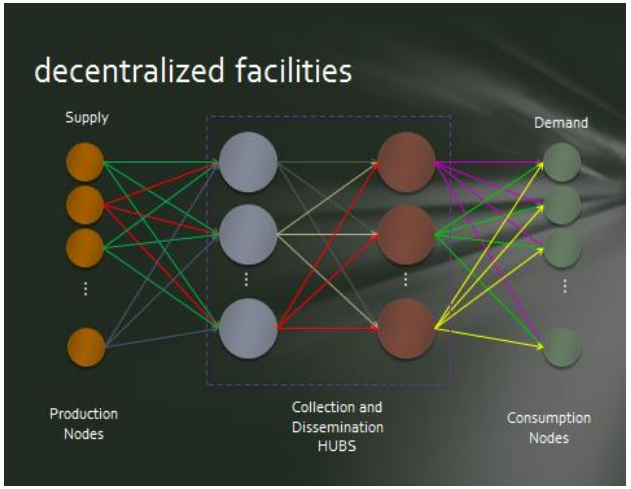


- Campbell (1994)and Campbell and O'Kelly (1994 – 2012) provide Comprehensive introduction, survey, and commentary review on hub location research. Formulations and solution approaches for the Capacitated Multiple Allocation Hub Location Problem (CMAHLP) are presented in (Ebery et al. 2000).
- GIS-based solutions are also proposed to solve the location problem by finding the optimal number and location of facilities in a supply-demand management network (Gu et al. 2009, Trubint et al. 2006, Large et al. 2004).

Food Distribution Hubs

- The hub network allows a large number of production and consumption nodes to be connected with fewer links.
- In all of the studies the origin-destination demand flow is known.
- In the food supply chain problem no information is available on the exact flow from a certain production node to a certain consumption node
- Reducing the number of links and their distances reduces food transportation costs and final product prices.
- To reduce costs and provide food to nodes efficiently, hubs are introduced.
- A food hub is defined as an intermediate node that is able to connect with more than one production location and also to more than one consumption node.
  - The success of a food hub will depend on:
    - The characteristics of the regional food system
    - The size of and reach appropriate for the hub‘s context
    - Understanding of current and past attempts to create aggregation and distribution infrastructure in the region



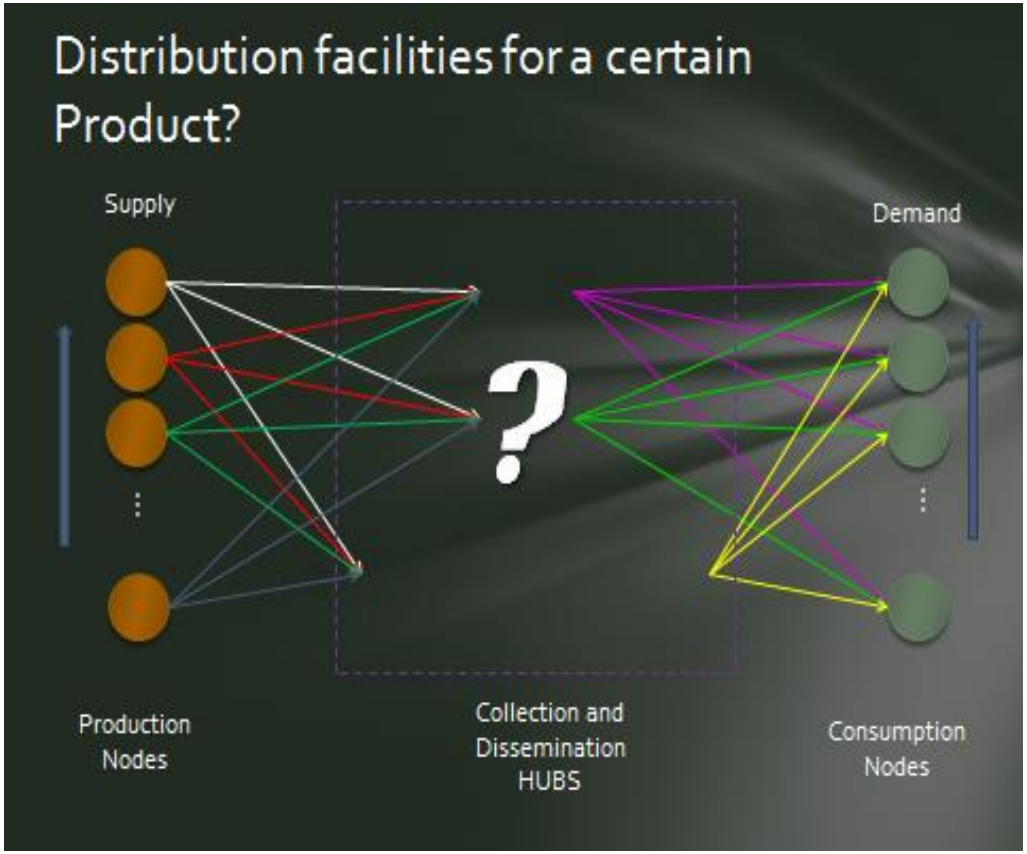


Objective

- Design and locate an optimal hub-based logistics network of wholesale markets within the food supply chain system through the followings:

  - Considering transportation impedance where the total travel cost between the processing and retail markets is minimized.
  - The product does not travel more than the maximum allowed predefined distance between the processing-wholesale hub and retail market (regional food access).
  - Wholesale hubs are closer to the retail markets than to the processing facilities.
  - The optimal number of wholesale market hub locations is determined based on logistic performance, hub capacity and demand in the supply chain network.

Objective (Cont.)



Problem Formulation

Minimize

$$(\sum_{i,h \in FS} ms_{ih} f(d_{ih}) + \sum_{h,f \in FD} md_{hj} f(d_{hj})).\mathrm{C} + \sum_h F_h Z_h \qquad (1)$$
$$i, j, h \in N$$

Subject to:

$$\sum_{h \in FS} ms_{ih} \leq p_i \quad \text{for all } i \qquad (2)$$

$$\sum_{h \in FD} md_{hj} \geq c_j \quad \text{for all } j \qquad (3)$$

$$\sum_i ms_{ih} = \sum_j md_{hj} \quad \text{for all } h \qquad (4)$$

$$\sum_i ms_{ih} \leq Z_h . V_h \quad \text{for all } h \qquad (5)$$

$$\sum_j md_{hj} \leq Z_h . V_h \quad \text{for all } h \qquad (6)$$

Where

$$Z_h = \begin{cases} 1 & if\ county\ node\ h\ is\ a\ hub \\ 0 & therewise, \end{cases}$$

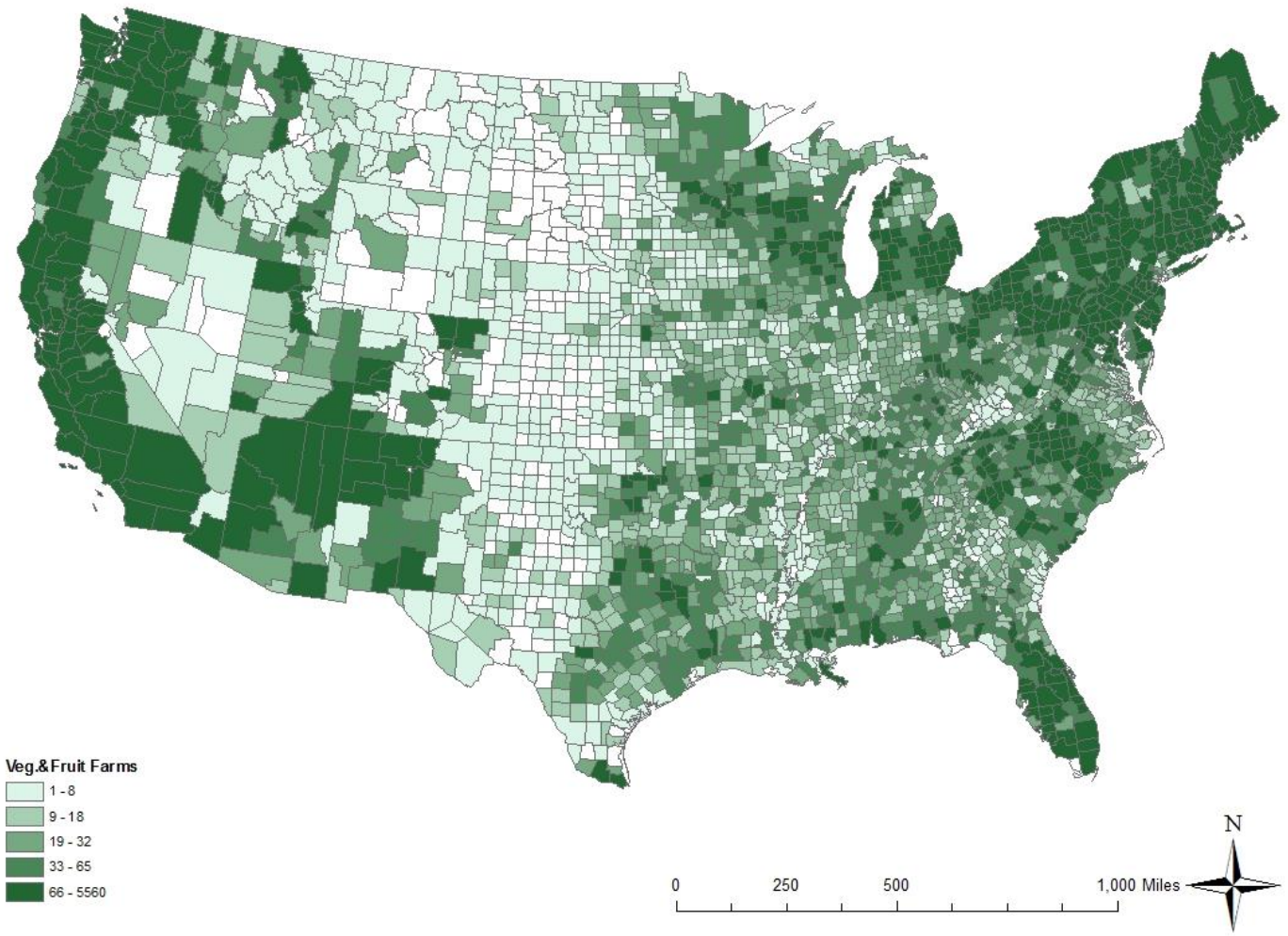
$$ms_{ih}, md_{ih} \geq 0$$

Variable Definition

Index (variable)	Definition
i	production region
j	consumption location
h	hub location index
I	import port
E	export port
$f(d_{ij})$	impedance values as function of highway miles between any $i-j$ location pairs
C	fixed cost (gas and truck maintenance) per mile per ton value ($ per ton mile)
F_h	fixed cost of locating and operating a hub in county h ($)
N ($\|N\| = n$)	a set of counties to be interconnected
H ($\|H\| = h$)	the estimated set of total hubs to be constructed
p_i	total supply in production region i(tons)
c_j	total demand in consumption location j(tons)
ms_{ih}	fraction of the quantities shipped from production location i to hub location h (tons)
md_{hj}	fraction of the quantities shipped from hub location h to consumption location j (tons)
Z_h	integer variable: $Z_h = 1$ if region is a hub, and 0 otherwise
V_h	capacity of hub facility in location h (tons)
TP	threshold distance between production regions and hub locations (mile)
TM	threshold distance between hub locations to consumption locations (mile)
FS	subsets of distances between production regions to hub locations with respect to TP
FD	subsets of distances between hub locations to consumption locations with respect to TM
OS_j	outsource quantity for consumption location j
C_{os}	cost associated with an outsource for a consumption location ($ per ton mile)

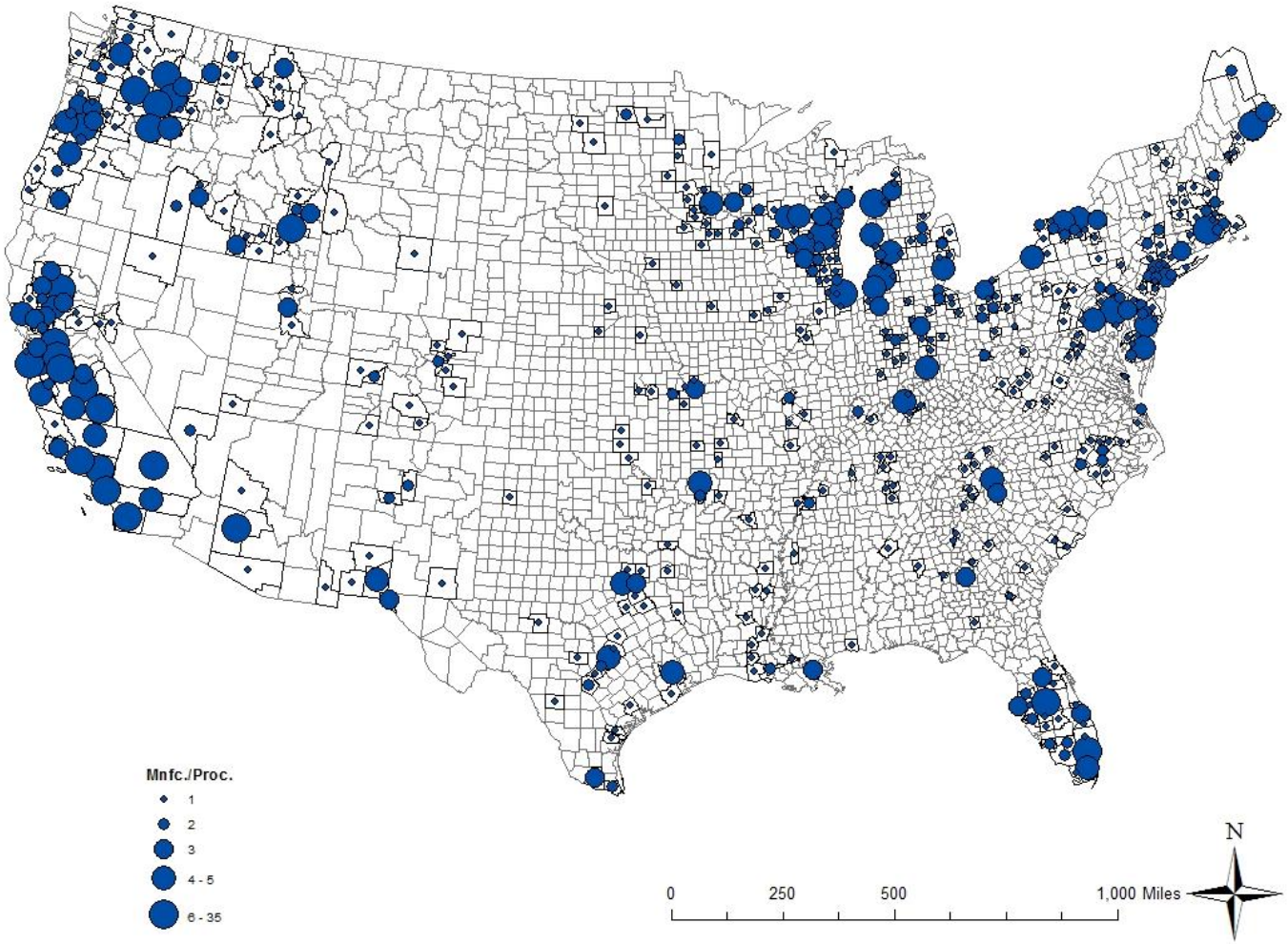
Fruit and Vegetable Industry

Vegetable and Fruit Farms (2007).



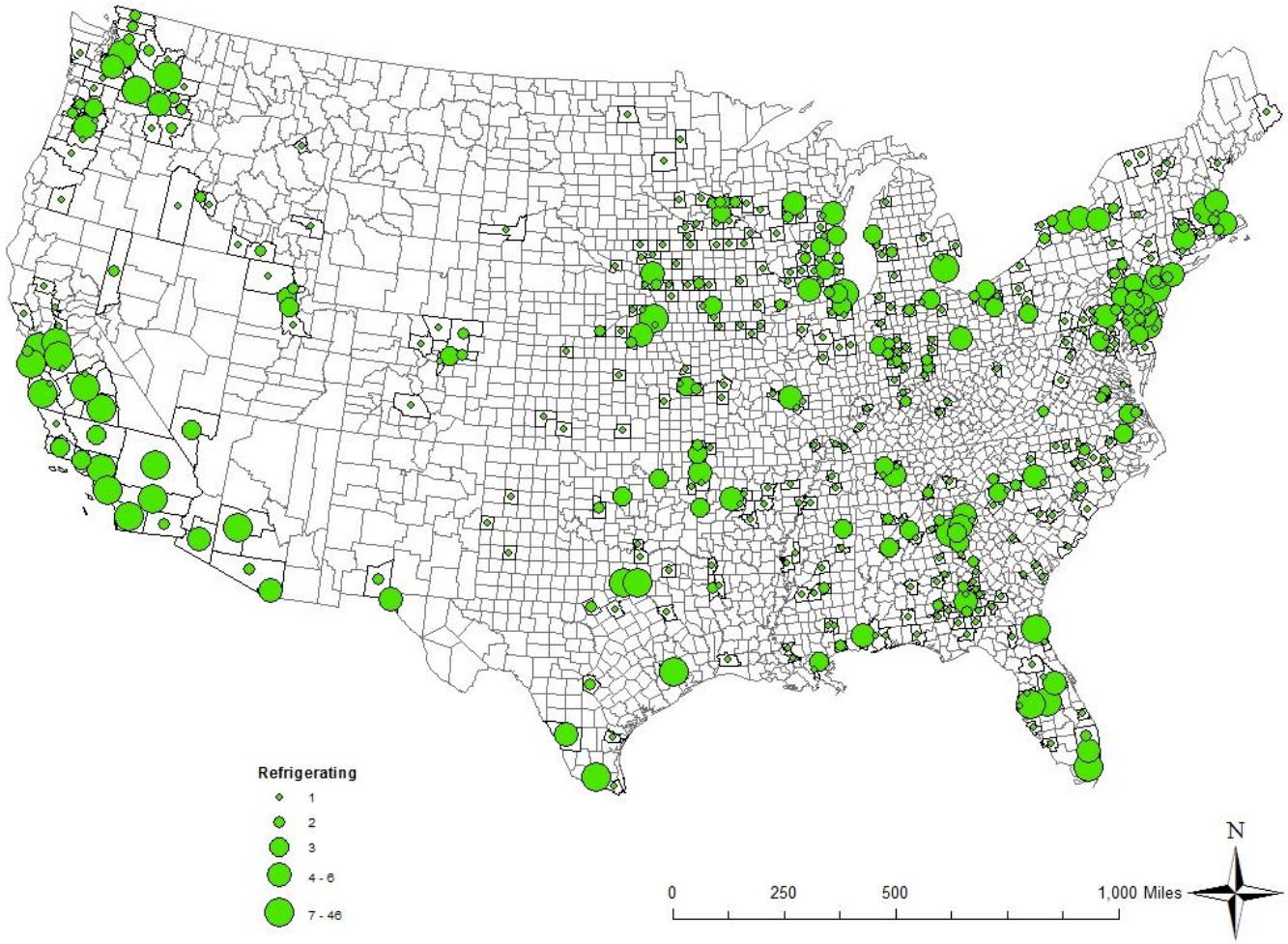
Fruit and Vegetable Industry

Vegetable and Fruit Manufacturing and Processing Facilities (2007).



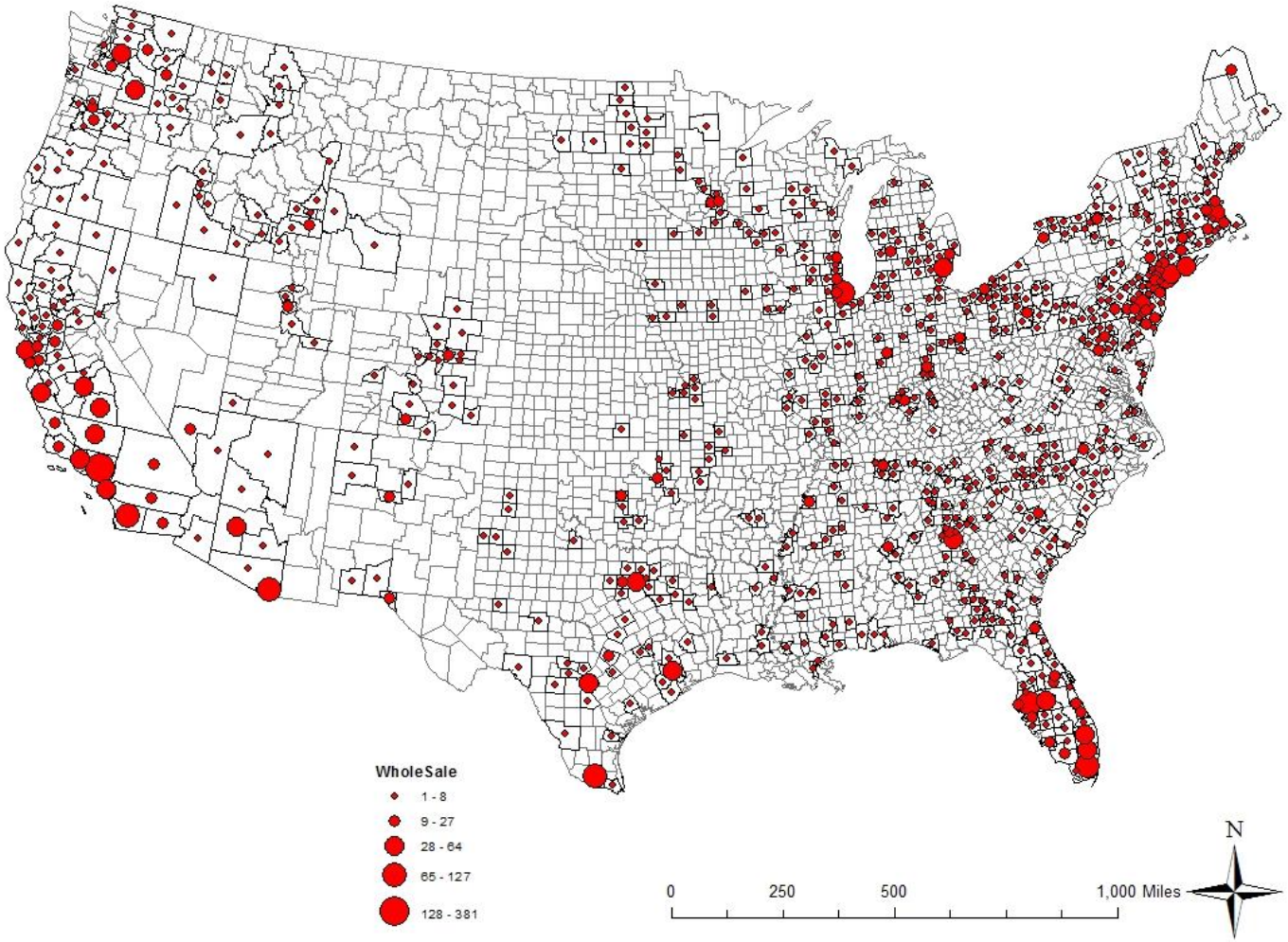
Fruit and Vegetable Industry

Vegetable and Fruit Refrigerating Facilities (2007).



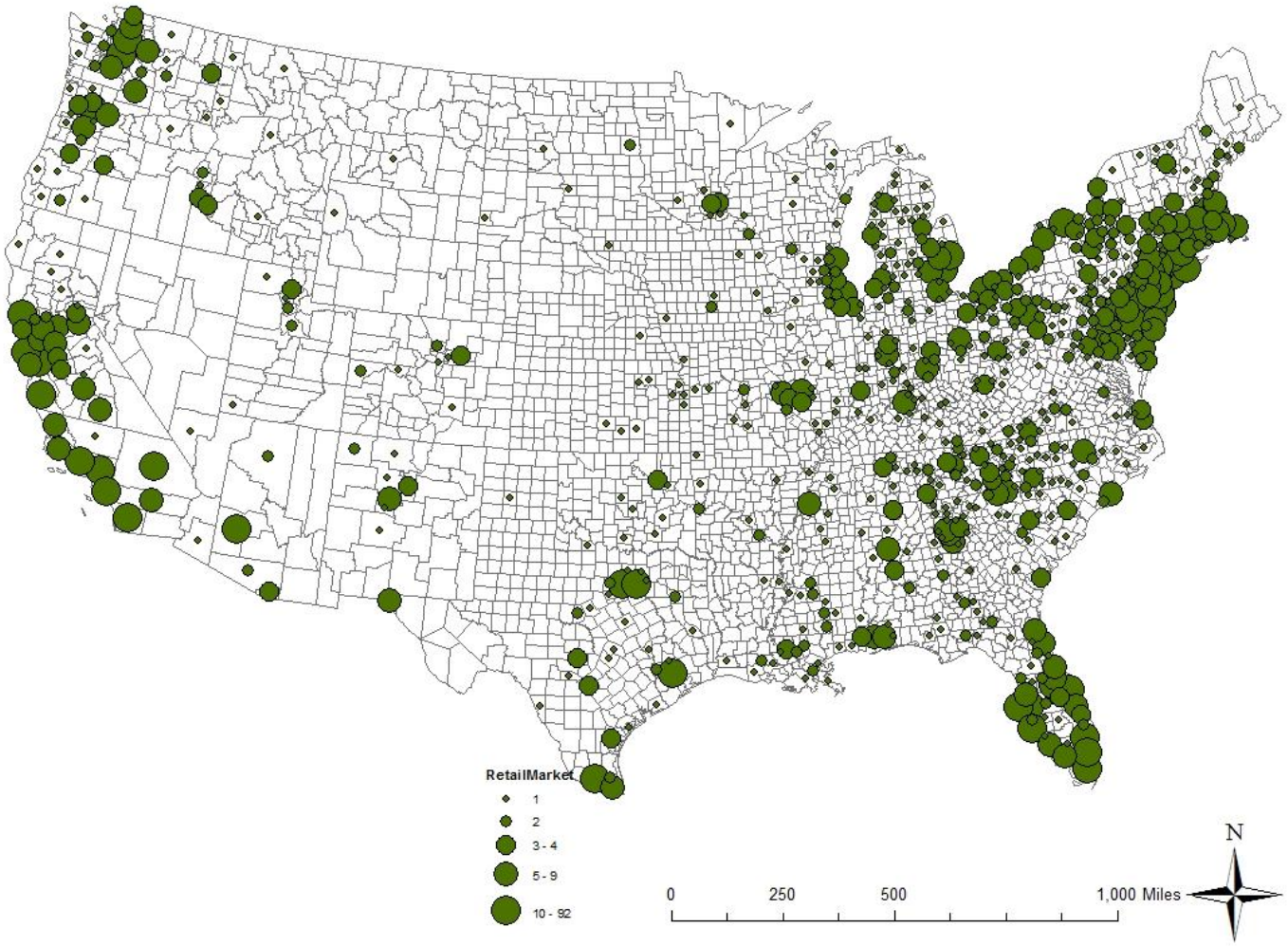
Fruit and Vegetable Industry

Vegetable and Fruit Wholesale Facilities (2007).

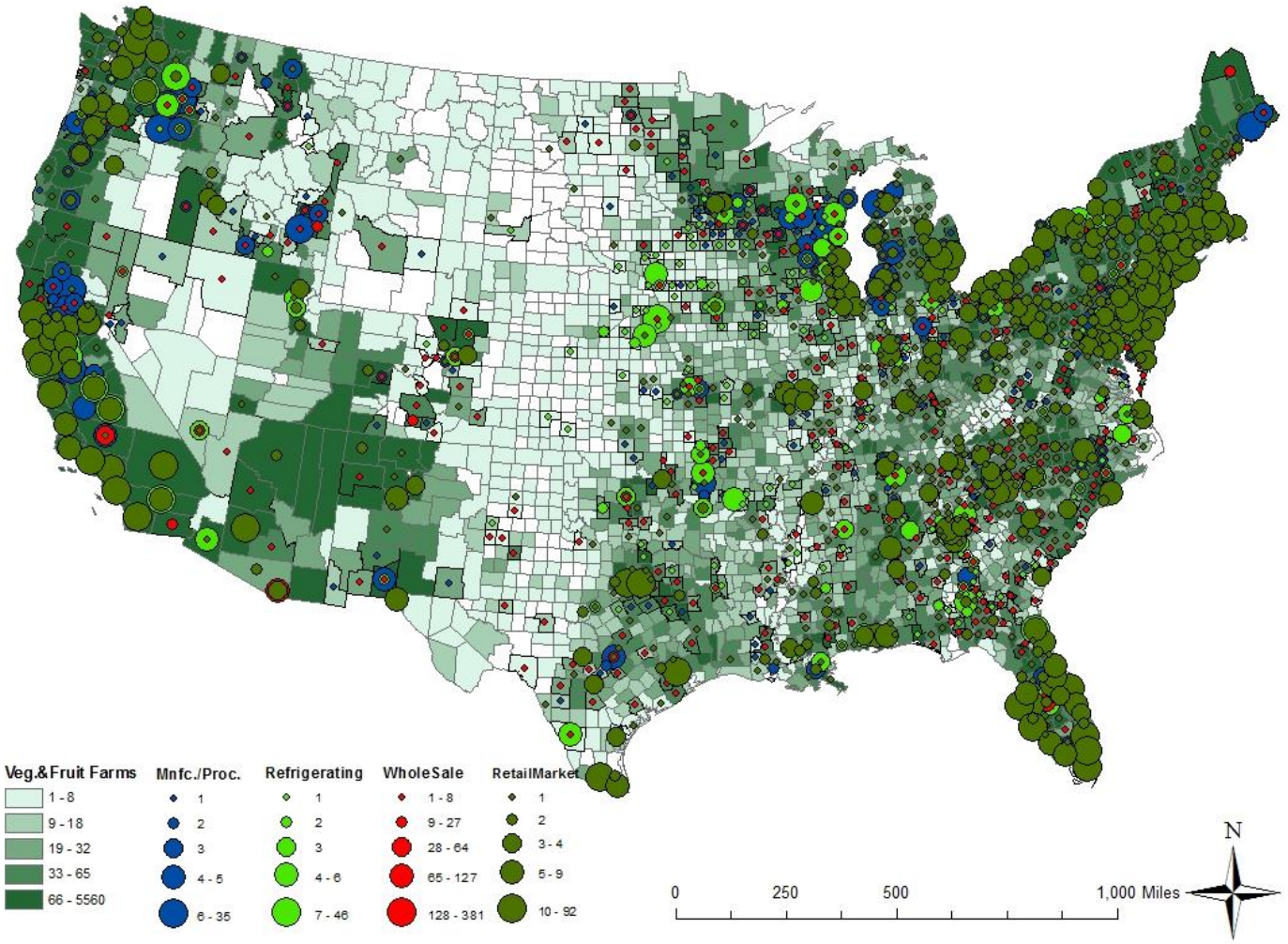


Fruit and Vegetable Industry

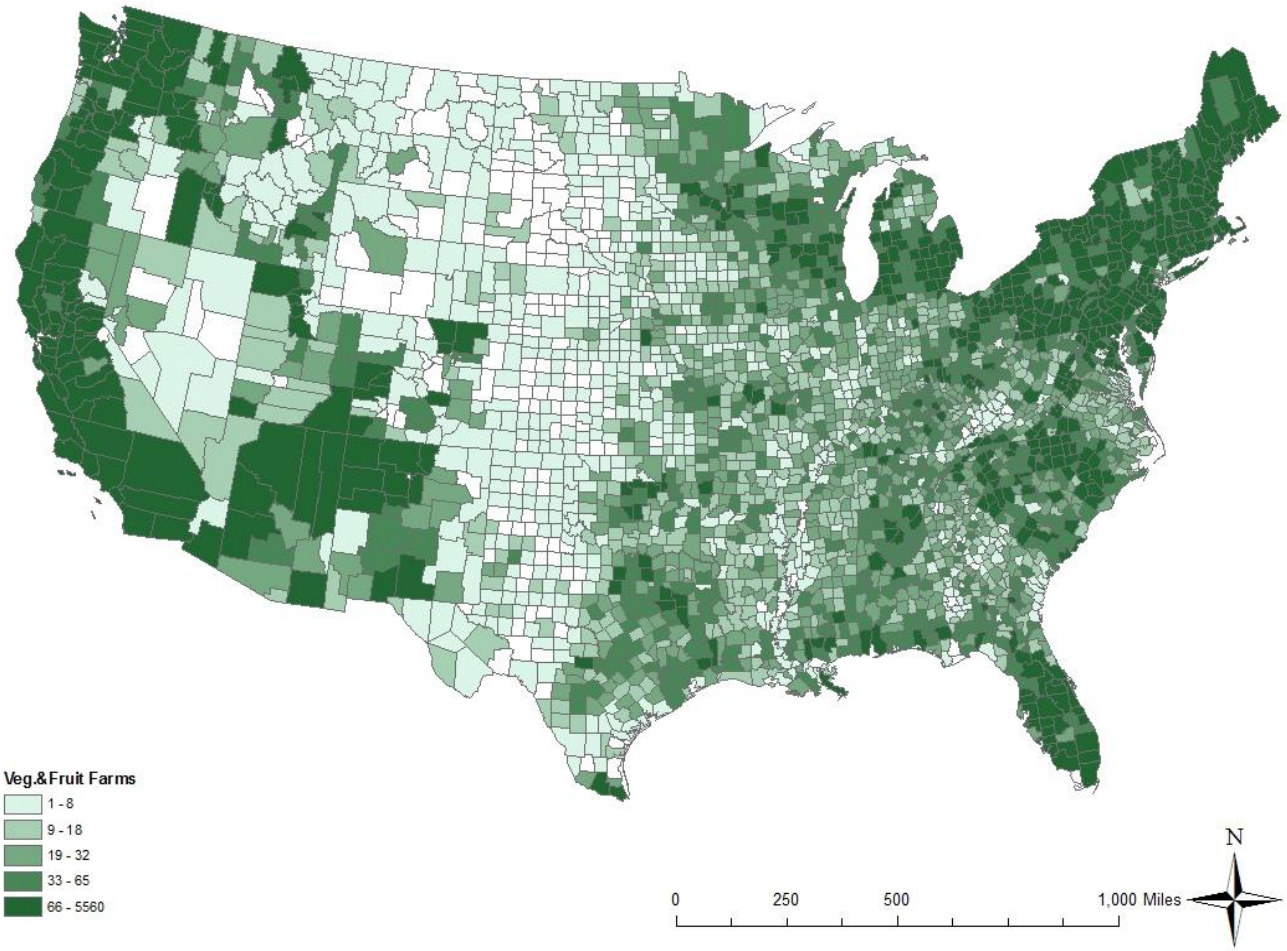
Vegetable and Fruit Retail Markets (2007).



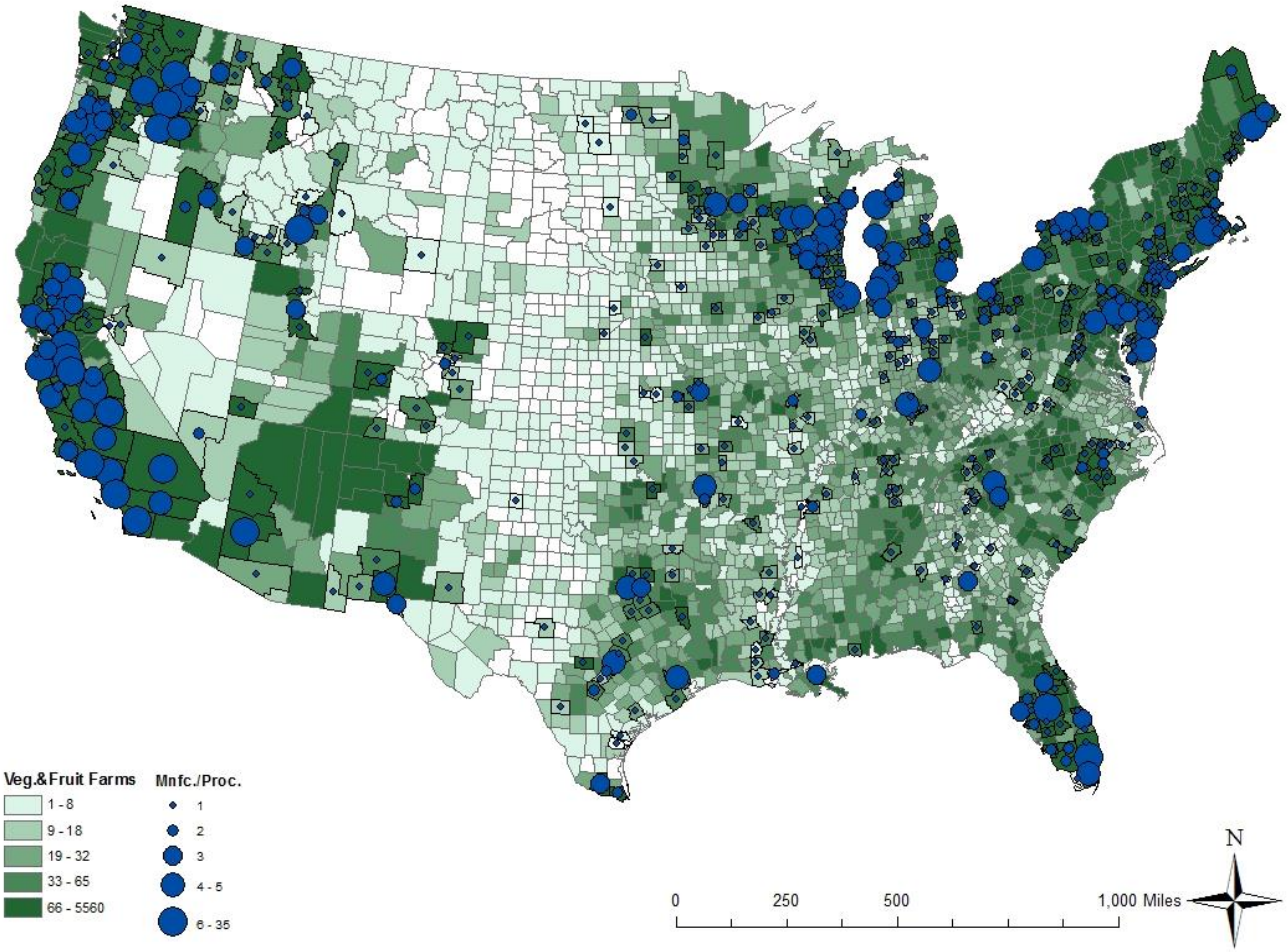
Fruit and Vegetable Industry



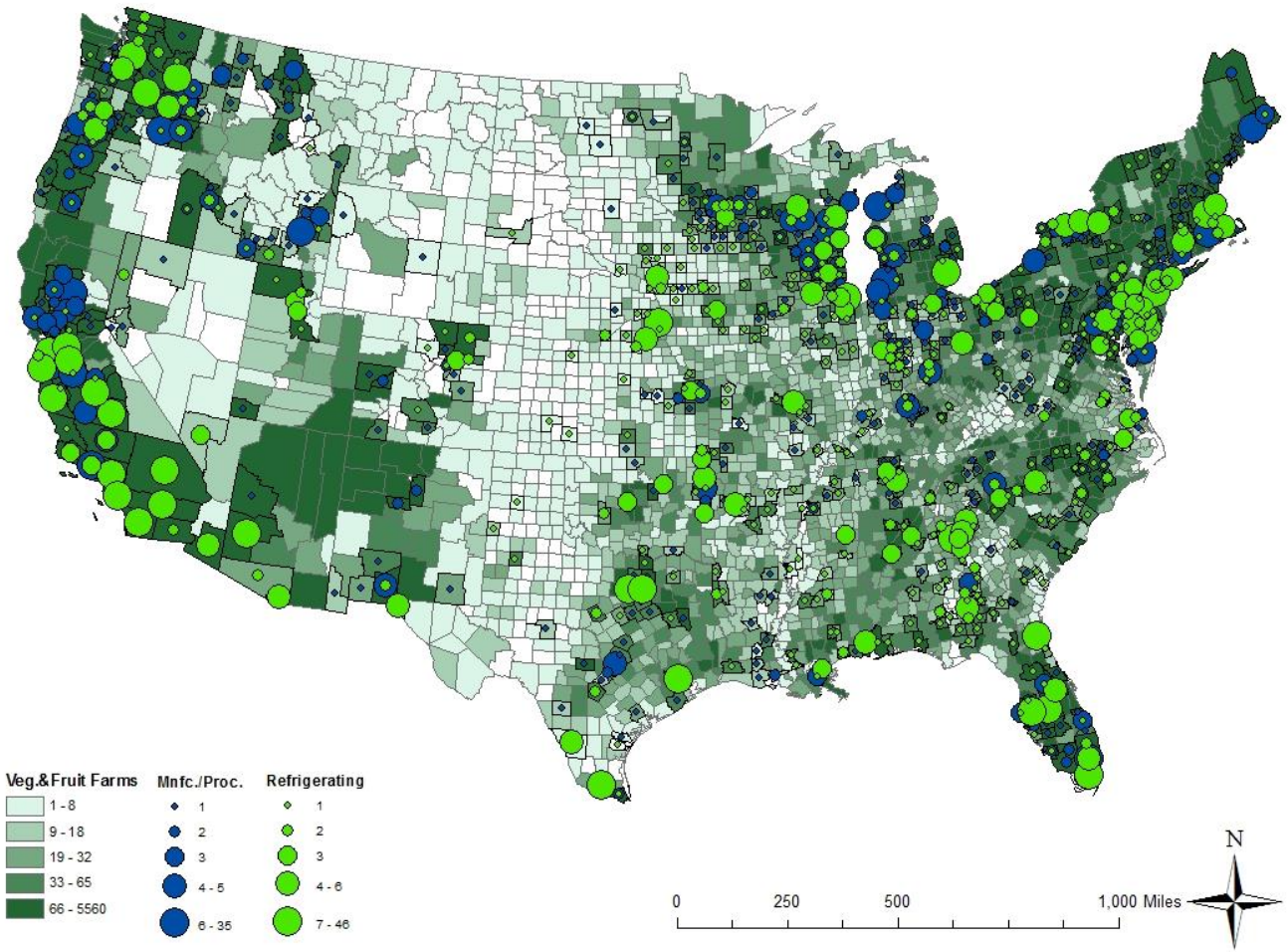
Fruit and Vegetable Industry



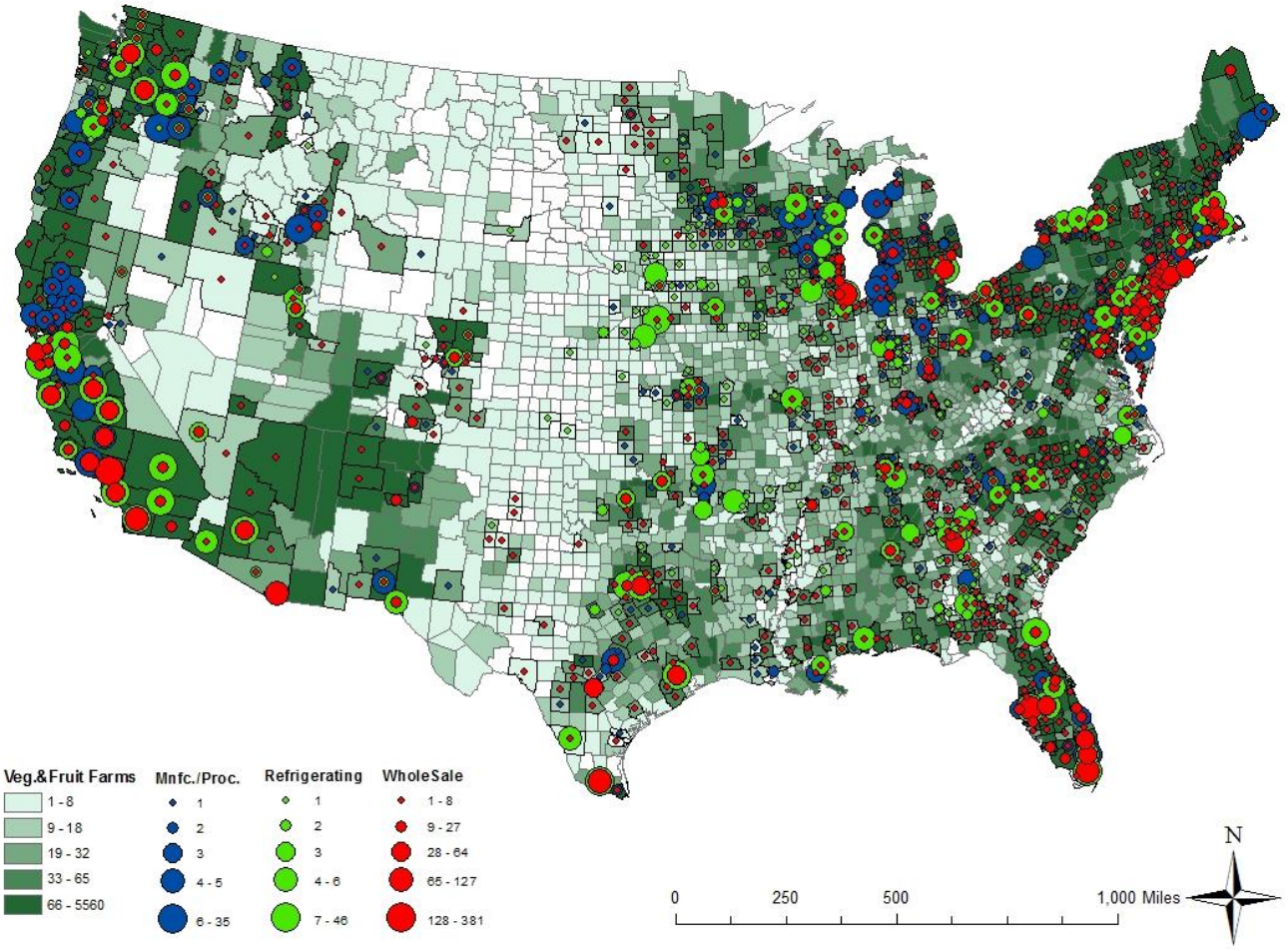
Fruit and Vegetable Industry



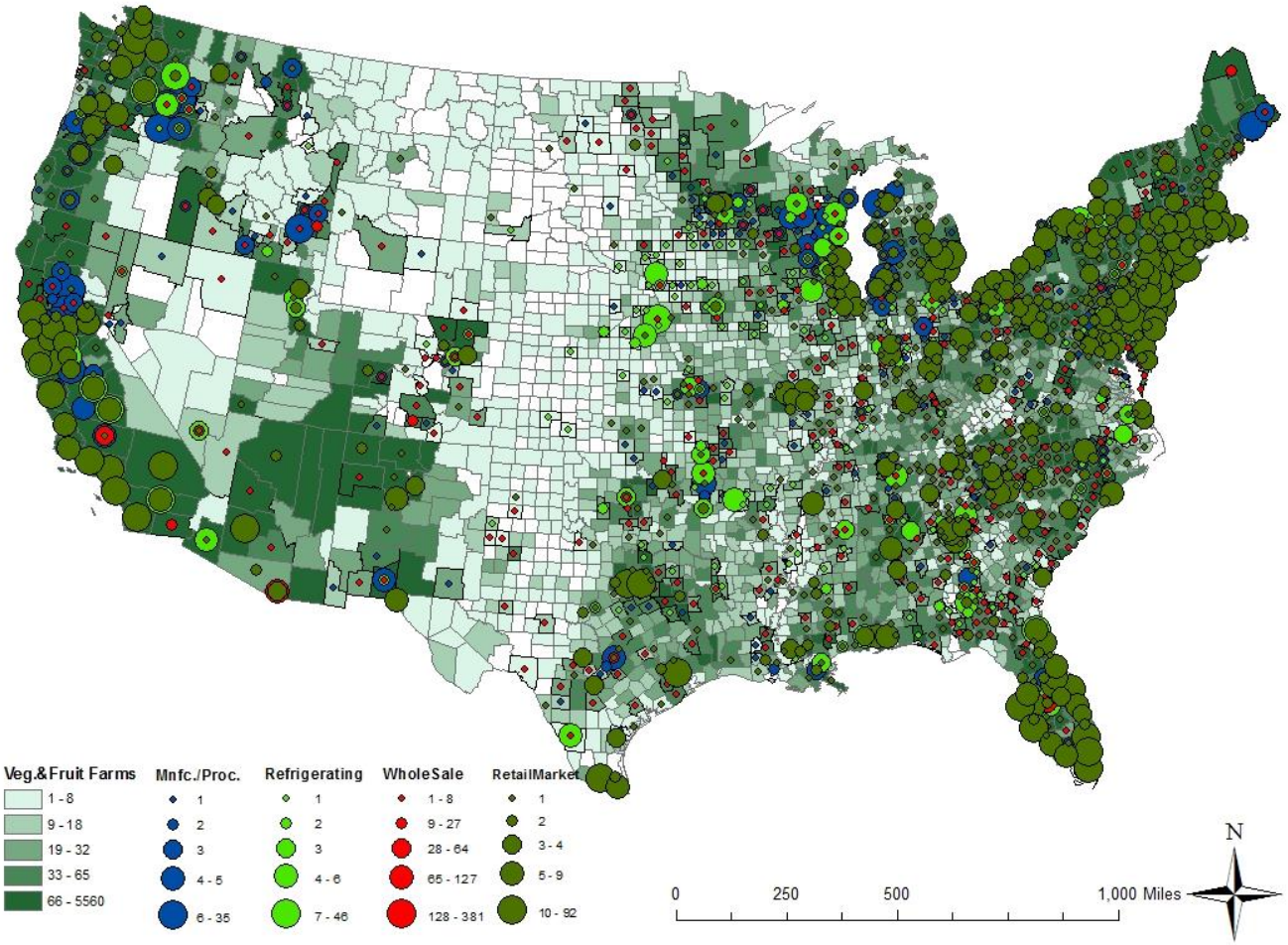
Fruit and Vegetable Industry



Fruit and Vegetable Industry

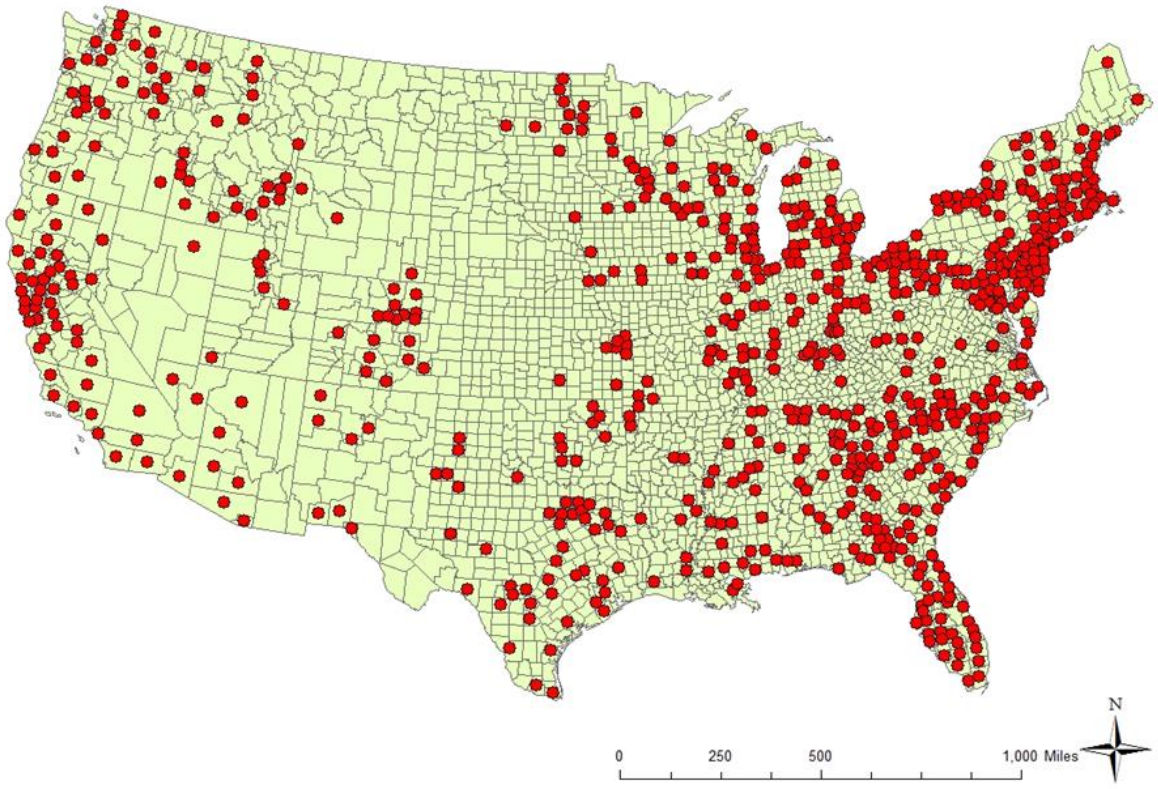


Fruit and Vegetable Industry



Fruit and Vegetable Industry

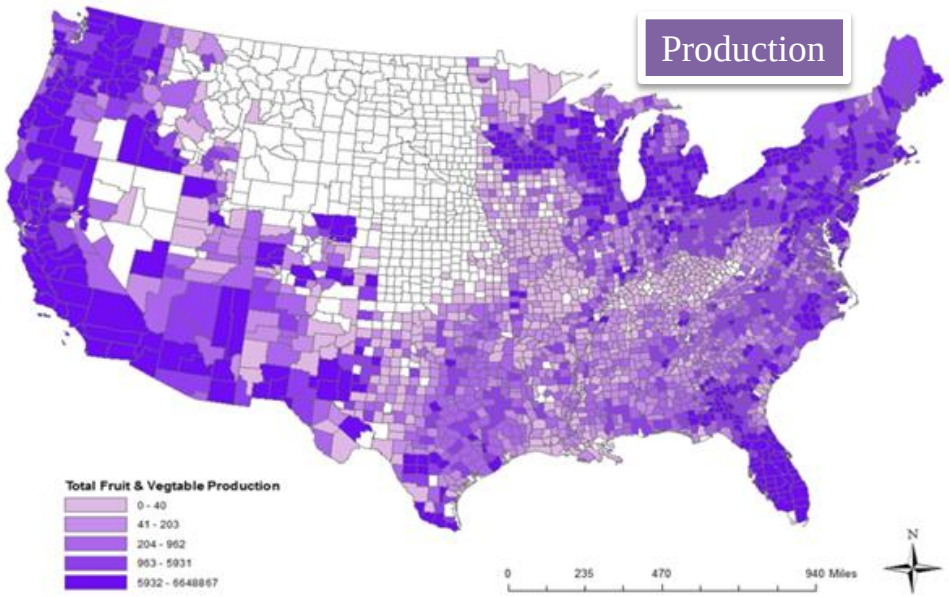
- Existing wholesale hub counties (locations) are shown.



Goal:

- To understand how optimal locations of the Wholesale Markets adjust over time with changing hub capacity constraints and products' travel distance.

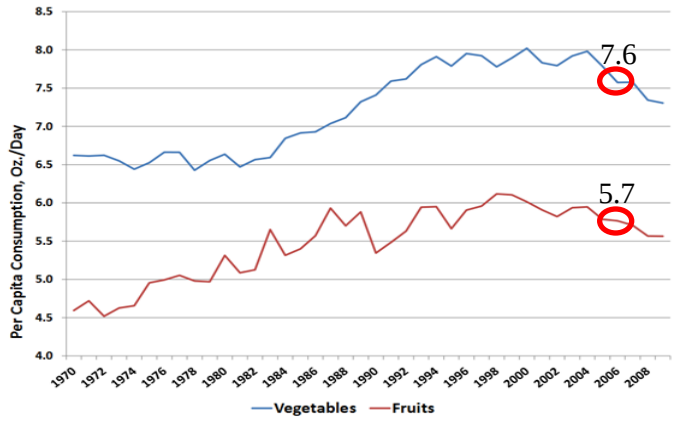
Total Fruit and Vegetable Production and Consumption Distribution (2007)

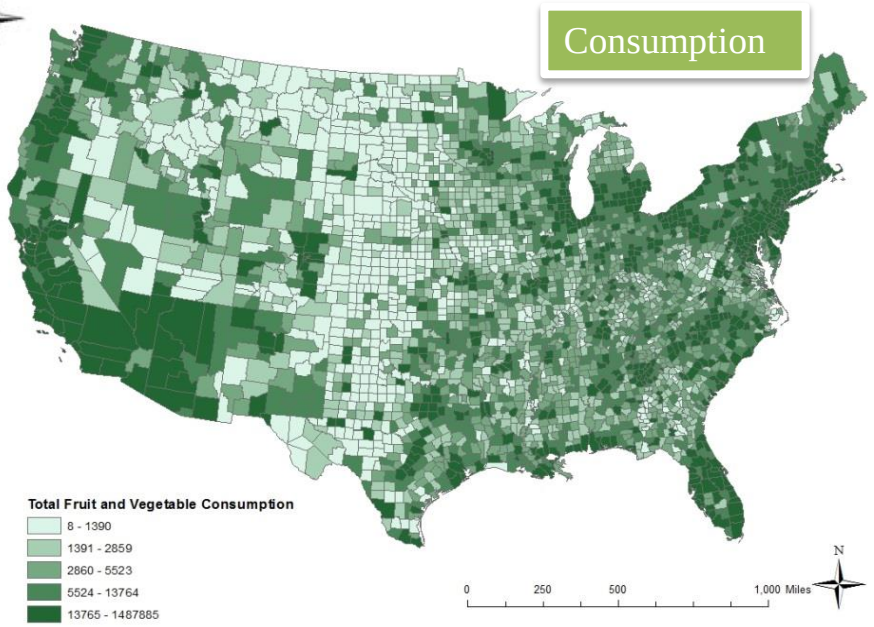


State FIPS	State
11	District of Columbia
31	Nebraska
38	North Dakota
46	South Dakota
56	Wyoming

No Data Available for these states in this study

US Per Capita Consumption of Fruits and Vegetables (Source: USDA ERS - USDA Rural Development, Executive Summary (2013))





Fruit and Vegetable Industry

- The network consists a total of **3080** counties
- Maximum **distance** of **3,637.3** miles is between Monroe, Florida and San Juan, Washington
- Maximum production is estimated to be **6,648,867** tons in **Fresno County** in the state of **California** (1,682,763 (tons) fruit and 4,966,104 (tons) vegetable).
- Maximum demand is estimated to be **1,487,885** tons in **Los Angeles** County in the state of **California**.
- Total Fruit + Vegetable **production** is **75,454,796** tons
- Demand in each county is estimated by multiplying US per capita consumption of fruits and vegetables by county population
- Total **demand** for Fruit + Vegetable is **45,409,579** tons

The total number of hubs as well as their locations varies based on:

- hub capacity
- road conditions, and
- travel distance
- economic factors (average gas price and land price for establishing a facility in an area).

Travel Distance and Local Food Constraint (Modified)

$$(\sum_{i,h\in FS} ms_{ih} f(d_{ih}) + \sum_{h,f\in FD} md_{hj} f(d_{hj})).\mathrm{C} + \sum_{j} (OS_j . \max(d_{hj} f(d_{hj})). C_{os} + \sum_{h} F_h Z_h \qquad (1\text{-}1)$$

$$i, j, h \in N$$

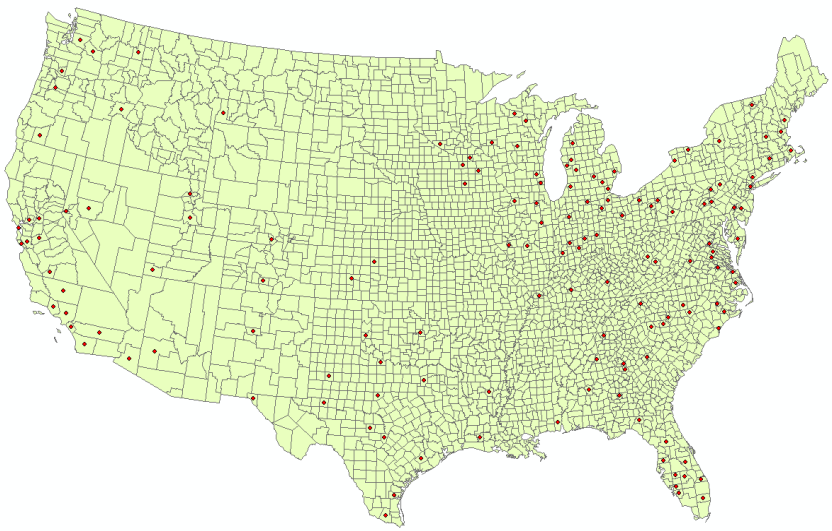
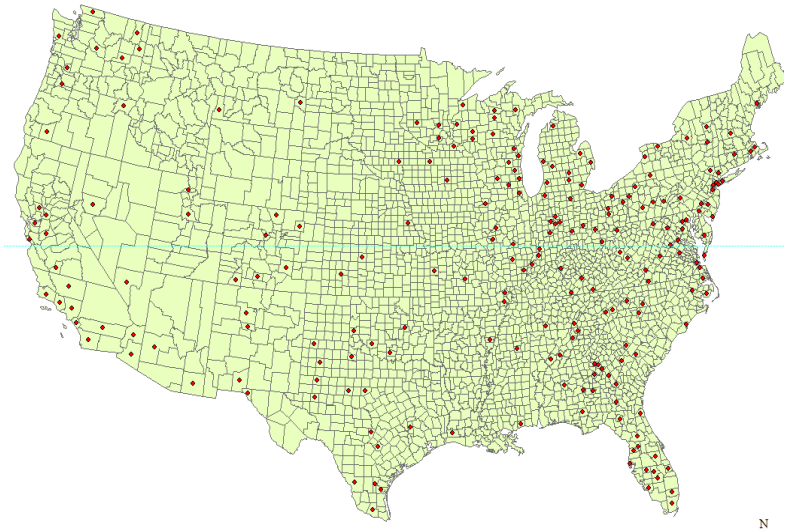
$$\sum_{h\in FD} md_{hj} + OS_j = c_j \quad \text{for all } j \qquad (3\text{-}1)$$

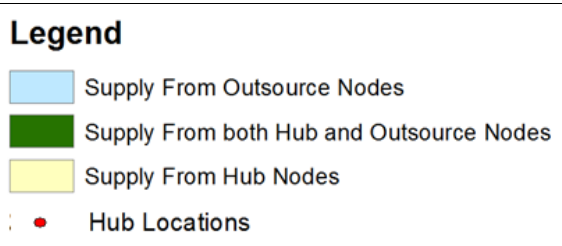
Experimental Results and Analysis(Cont.)

Result of number of hubs with unlimited average travel distance and bounded hub capacity

Case No.	Production-Hub Max Dist (Mile)	Hub-Consumption Max Dist (Mile)	Hub(s) Capacity (Ton/100)	No. of Hub(s)	No. of Demand nodes supported only with OS	No. of Demand nodes supported only from Hubs	No. of Demand nodes supported from OS&Hubs	Objective function	Optimality GAP
A	Unlimited	Unlimited	20,000	138	0	3080	0	735,480,000	0.016450
B	Unlimited	Unlimited	10,000	144	0	3080	0	736,340,000	0.016614
C	Unlimited	Unlimited	5,000	221	0	3080	0	744,698,901	0.019177

Experimental Results and Analysis(Cont.)

Case B: Unlimited, Unlimited, 10,000	Case C: Unlimited, Unlimited, 5,000
	



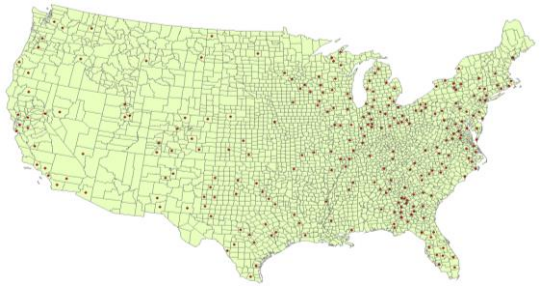
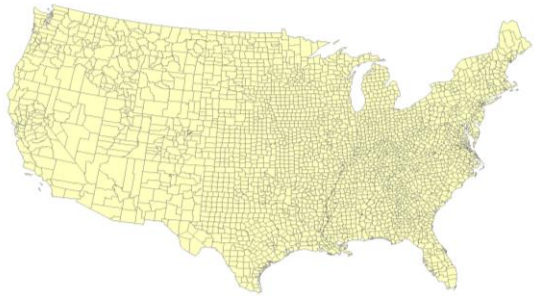
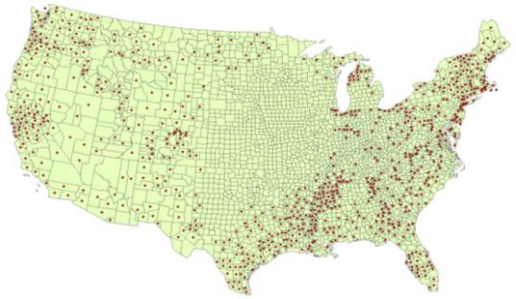
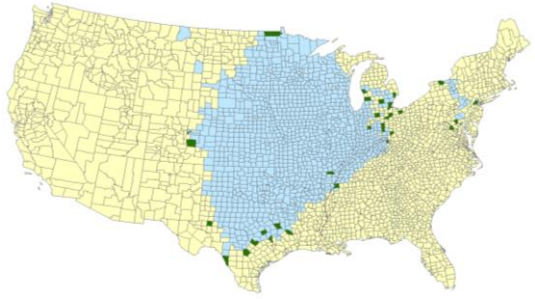
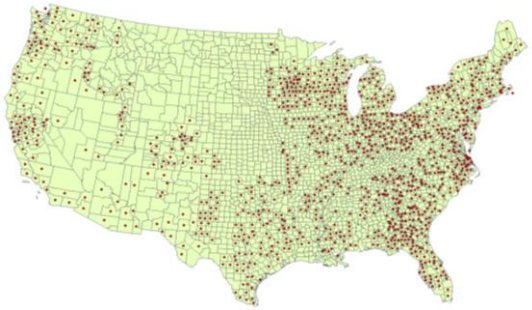
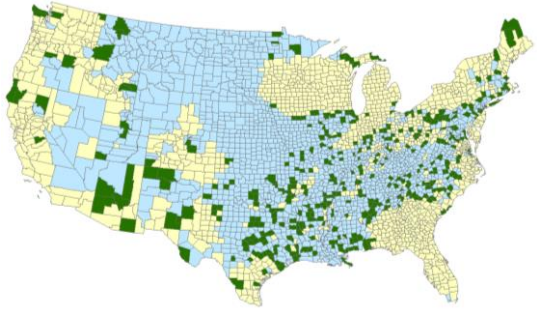
Experimental Results and Analysis(Cont.)

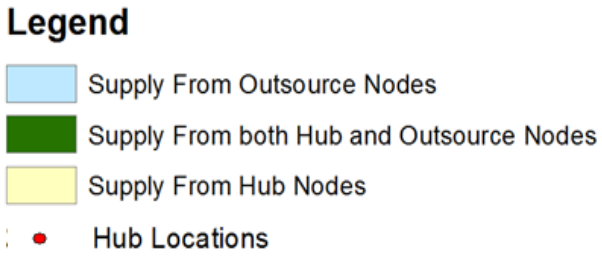
Result of number of hubs with bounded average travel distance and hub capacity

Case No.	Production-Hub Max Dist (Mile)	Hub-Consumption Max Dist (Mile)	Hub(s) Capacity (Ton)	No. of Hub(s)	No. of Demand nodes supported only with OS	No. of Demand nodes supported only from Hubs	No. of Demand nodes supported from OS&Hubs	Objective function	Optimality GAP
D1	1,000	1,000	10,000	254	0	3080	0	744,580,000	0.026823
D2	500	200	10,000	848	1227	1819	34	3,026,000,000	0.026222
D3	200	200	10,000	1002	1546	1350	184	4,531,400,000	0.020738
D4	200	100	10,000	1110	1482	1325	273	4,982,700,000	0.019391
D5	100	100	10,000	1153	1463	1239	378	5,676,000,000	0.016757
E1	1,000	1,000	5,000	184	0	3080	0	742,890,000	0.016468
E2	500	200	5,000	867	1225	1819	36	3,029,600,000	0.025868
E3	200	200	5,000	1000	1547	1349	184	4,532,780,000	0.020237
E4	200	100	5,000	1116	1479	1326	275	5,105,300,000	0.018853
E5	100	100	5,000	1154	1462	1237	381	5,829,300,000	0.016263

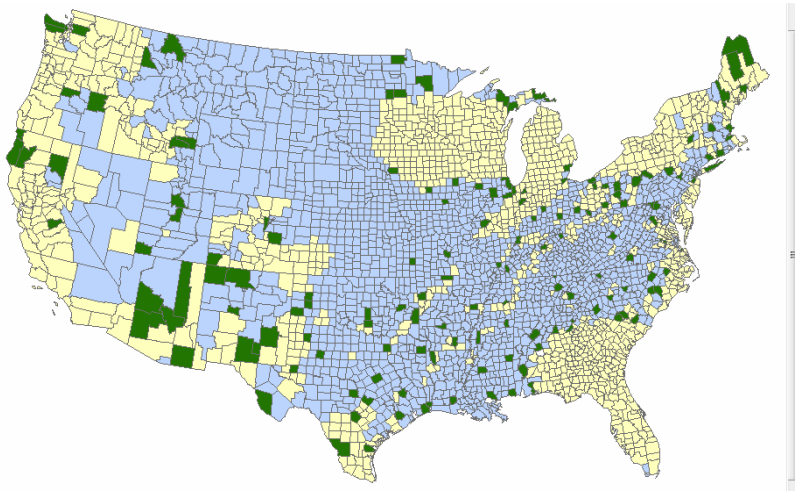
Experimental Results and Analysis(Cont.)

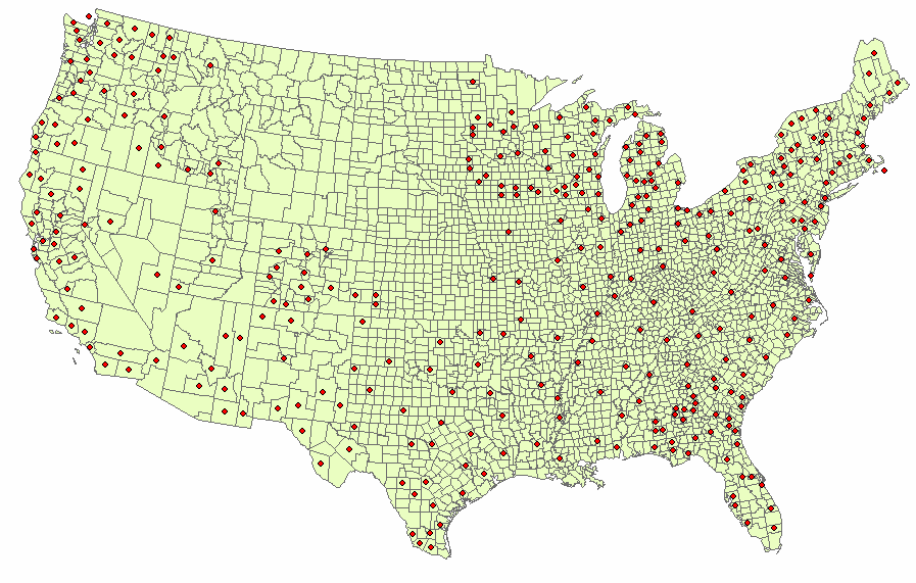
Case study D : Hub Capacity =10,000

Map (a)	Map (b)
Production regions to Hub: 1000 – Hubs to Consumption sites:1000 (miles)	
	
Production regions to Hub: 500 – Hubs to Consumption sites:200 (miles)	
	
Production regions to Hub: 100 – Hubs to Consumption sites:100 (miles)	
	



Experimental Results and Analysis(Cont.)





Legend

- Supply From Outsource Nodes
- Supply From both Hub and Outsource Nodes
- Supply From Hub Nodes
- Hub Locations

Conclusion and Future Work

- This paper presents a mathematical formulation of the food industry hub location problem.
- The mathematical program considers distances shipped, hub capital cost and capacity, road condition and transportation cost.
- An application to the Fruit and Vegetable industries for the US Continental is carried out, for a potential network consisting of 3080 counties.
- The results show the effect of varying these parameters on the selection of hub locations.

Conclusion and Future Work(Cont.)

Several extensions could be considered for this work:

- To modify the model to show the outsource locations instead of only considering the amount outsourced.
- To examine variation in establishment costs and the effect of the land use economy.
- To Work with only vegetables data since fruits are highly regional.
- To consider extending incorporating Census of Ag data with the NASS annual reports for the States production quantity not covered by NASS data.

THANK YOU

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