OPTIMAL WHOLESALE FACILITIES LOCATION WITHIN THE FRUIT AND VEGETABLES SUPPLY CHAIN

Stephan Goetz*,**, 

*Department of Agricultural Economics, Sociology and Education 
Pennsylvania State University, University Park, PA 16802 
**The Northeast Regional Center for Rural Development
• 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?”
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).
The hub network allows a large number of production and consumption nodes to be connected with fewer links.

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 distribution 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 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
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.
Distribution facilities for a certain Product?

Supply

... Production Nodes

Collection and Dissemination HUBS

Demand

... Consumption Nodes

?
Minimize

\[
(\sum_{i, h \in F_S} m_{sih} f(d_{ih}) + \sum_{h, f \in F_D} m_{dhj} f(d_{hj})).c + \sum_{h} F_{h}Z_{h} \]

\(i, j, h \in N\)  

Subject to:

\[
\sum_{h \in F_S} m_{sih} \leq p_i \quad \text{for all } i
\]  

(2)

\[
\sum_{h \in F_D} m_{dhj} \geq c_j \quad \text{for all } j
\]  

(3)

\[
\sum_{i} m_{sih} = \sum_{j} m_{dhj} \quad \text{for all } h
\]  

(4)

\[
\sum_{i} m_{sih} \leq Z_{h}V_{h} \quad \text{for all } h
\]  

(5)

\[
\sum_{j} m_{dhj} \leq Z_{h}V_{h} \quad \text{for all } h
\]  

(6)

Where

\[
Z_{h} = \begin{cases} 
1 & \text{if county node } h \text{ is a hub} \\
0 & \text{therewise,}
\end{cases}
\]

\[m_{sih}, m_{dhj} \geq 0\]
<table>
<thead>
<tr>
<th>Index (variable)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$i$</td>
<td>production region</td>
</tr>
<tr>
<td>$j$</td>
<td>consumption location</td>
</tr>
<tr>
<td>$h$</td>
<td>hub location index</td>
</tr>
<tr>
<td>$I$</td>
<td>import port</td>
</tr>
<tr>
<td>$E$</td>
<td>export port</td>
</tr>
<tr>
<td>$f(d_{ij})$</td>
<td>impedance values as function of highway miles between any $i - j$ location pairs</td>
</tr>
<tr>
<td>$C$</td>
<td>fixed cost (gas and truck maintenance) per mile per ton value ($ per ton mile)</td>
</tr>
<tr>
<td>$F_h$</td>
<td>fixed cost of locating and operating a hub in county $h$ ($)</td>
</tr>
<tr>
<td>$N (</td>
<td>N</td>
</tr>
<tr>
<td>$H (</td>
<td>H</td>
</tr>
<tr>
<td>$p_i$</td>
<td>total supply in production region $i$ (tons)</td>
</tr>
<tr>
<td>$c_j$</td>
<td>total demand in consumption location $j$ (tons)</td>
</tr>
<tr>
<td>$ms_{ih}$</td>
<td>fraction of the quantities shipped from production location $i$ to hub location $h$ (tons)</td>
</tr>
<tr>
<td>$md_{hj}$</td>
<td>fraction of the quantities shipped from hub location $h$ to consumption location $j$ (tons)</td>
</tr>
<tr>
<td>$Z_h$</td>
<td>integer variable: $Z_h = 1$ if region is a hub, and 0 otherwise</td>
</tr>
<tr>
<td>$V_h$</td>
<td>capacity of hub facility in location $h$ (tons)</td>
</tr>
<tr>
<td>$TP$</td>
<td>threshold distance between production regions and hub locations (mile)</td>
</tr>
<tr>
<td>$TM$</td>
<td>threshold distance between hub locations to consumption locations (mile)</td>
</tr>
<tr>
<td>$FS$</td>
<td>subsets of distances between production regions to hub locations with respect to $TP$</td>
</tr>
<tr>
<td>$FD$</td>
<td>subsets of distances between hub locations to consumption locations with respect to $TM$</td>
</tr>
<tr>
<td>$O_{Sj}$</td>
<td>outsource quantity for consumption location $j$</td>
</tr>
<tr>
<td>$C_{os}$</td>
<td>cost associated with an outsource for a consumption location ($ per ton mile)</td>
</tr>
</tbody>
</table>
Fruit and Vegetable Industry

Vegetable and Fruit Farms (2007).

Vegetable and Fruit Farms

- 1 - 5
- 9 - 18
- 19 - 32
- 33 - 65
- 66 - 5500

Scale: 0 - 1,000 Miles
Fruit and Vegetable Industry

Fruit and Vegetable Industry

Vegetable and Fruit Refrigerating Facilities (2007).
Fruit and Vegetable Industry


[Map showing distribution of wholesale facilities across the United States.]
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
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)

<table>
<thead>
<tr>
<th>State FIPS</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>District of Columbia</td>
</tr>
<tr>
<td>31</td>
<td>Nebraska</td>
</tr>
<tr>
<td>38</td>
<td>North Dakota</td>
</tr>
<tr>
<td>46</td>
<td>South Dakota</td>
</tr>
<tr>
<td>56</td>
<td>Wyoming</td>
</tr>
</tbody>
</table>

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))
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
- travel distance
- road conditions, and
- economic factors (average gas price and land price for establishing a facility in an area).
Travel Distance and Local Food Constraint (Modified)

\[
(\sum_{i,h \in FS} ms_{ih} f(d_{ih}) \sum_{h,f \in FD} md_{hj} f(d_{hj})).C + \\
\sum_{j} (OS_{j} \max(\sum_{h} f(d_{hj})).C_{os} + \sum_{h} F_{h} Z_{h})
\] 

\[i, j, h \in N\] 

\[
\sum_{h \in FD} md_{hj} + OS_{j} = c_{j}
\] 

\[i, j, h \in N\]
### Experimental Results and Analysis (Cont.)

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

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

Case C: Unlimited, Unlimited, 5,000

Legend
- Supply From Outsource Nodes
- Supply From both Hub and Outsource Nodes
- Supply From Hub Nodes
- Hub Locations
### Experimental Results and Analysis (Cont.)

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

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

Legend

- Supply From Outsource Nodes
- Supply From both Hub and Outsource Nodes
- Supply From Hub Nodes
- Hub Locations
Experimental Results and Analysis (Cont.)

D : Hub Capacity = 10,000

E : Hub Capacity = 5,000

Travel Distance: Production regions to Hub – Hubs to Consumption sites (miles)

- 1000 - 1000
- 500 - 200
- 100 - 100

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

Maps showing distribution of supply and hub locations across the United States.
• 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.
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.
References


