The Northeast Regional Center for Rural Development

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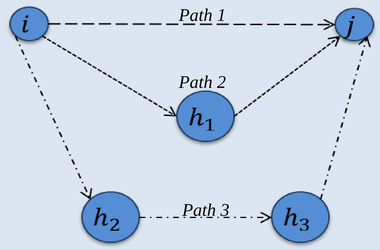
Optimal Transportation Network Hub Locations in Food Supply Chain Systems

Introduction

- Interest in locally produced food has increased sharply in recent years along with the idea of promoting more healthful eating habits and connecting farmers and consumers.
- The presence of food deserts and high obesity rates suggest that food assistance programs and entitlement programs have not fully addressed the nutritional needs of residents.
- A large number of food manufacturers are faced with limited shelf life of their products. Some products may never reach the customer because they expire before arriving, and simply go to waste.
- This poster examines the question, What would be a practical way to bring products to costumers in reasonable time and at lower cost.

Distribution Hubs

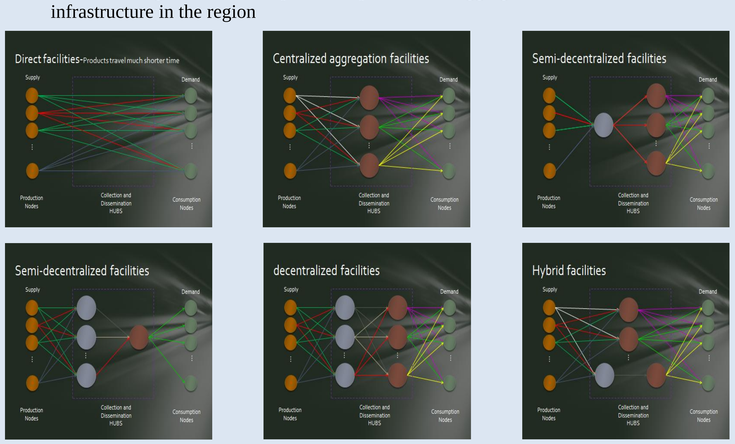
- **Hubs** are used in transportation, logistics, and telecommunication networks to serve as consolidation points, warehouses, and sorting centers allowing for direct shipment between supply and demand nodes with fewer connections between them.
- **Hubs** can result in lower network costs, but it can be challenging to determine where hubs should be located or how customers should be allocated to them.



Three possible paths from origin i to destination j

Food Distribution Hubs

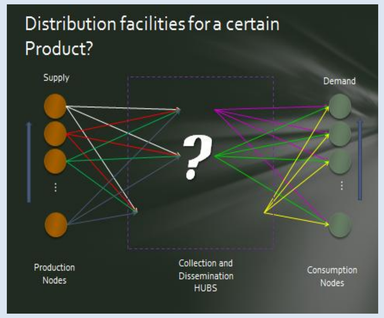
- The success of a food hub will depend on:
  - The characteristics of the regional food system
  - The size of and reach appropriate for the hub's context
  - Understanding of current and past attempts to create aggregation and distribution infrastructure in the region



- Locate an appropriate number of consolidation hubs near the suppliers and service the demand from these hubs.
- The suppliers ship components to the nearest hub as a function of hub capacity, and hubs consolidate outbound products before shipping them.
- Each producer benefits from this arrangement because the consolidation hub is closer than the consumption warehouses.
- With the consolidation hubs, better control is possible of inventories coming from different producers to be distributed to different consumers.

Objective

- Design and locate an optimal hub-based logistics network of wholesale markets within the meat supply chain network. The location of wholesale markets between processing facilities and consumption retail markets are defined such that:
  - Considering the impact of transportation impedance, total travel distance 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;
  - wholesale hubs are closer to the retail markets than to the processing facilities; and
  - the optimal number of wholesale market hub locations is determined based on logistic performance, hub capacity and demand in the supply chain network.



Criteria for Determining the Objective

- Assumptions:
  - Quantity of supply and demand at production and consumption nodes are estimated based on the number of facilities in each county.
  - Each production node can ship its supplies to more than one hub. However, it is more economical to ship a larger quantity to a closer hub.
  - Each hub can serve more than one consumption node. This allows ignoring hub-to-hub inter-links.
  - Gas price is assumed constant over space.
  - Fixed cost of establishing a wholesale hub is the same for all counties.

Objective:
Find the optimal location of hubs in order to
- Minimize trip distance (Food Mile)
- Minimize transportation cost/time

This maximizes revenue/performance.

Problem Formulation

Minimize

$$\sum_i \sum_h ms_{ih} f(d_{ih}) C + \sum_h \sum_j md_{hj} f(d_{hj}) C + \sum_h F_h Z_h \qquad i,j,h \in N \qquad (1)$$

Subject to:

$$\sum_h ms_{ih} \le p_i \qquad \text{for all } i \qquad (2)$$

$$\sum_h md_{hj} = c_j \qquad \text{for all } j \qquad (3)$$

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

$$\sum_i ms_{ih} \le Z_h C_h \qquad \text{for all } h \qquad (5)$$

$$\sum_j md_{hj} \le Z_h . C_h \qquad \text{for all } h \qquad (6)$$

$$ms_{hj}\left(TM - f(d_{hj})\right) \ge 0 \qquad \text{for all } j,h \qquad (7)$$

$$md_{ih}\left(TP - f(d_{ih})\right) \ge 0 \qquad \text{for all } i,h \qquad (8)$$

Where,

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

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

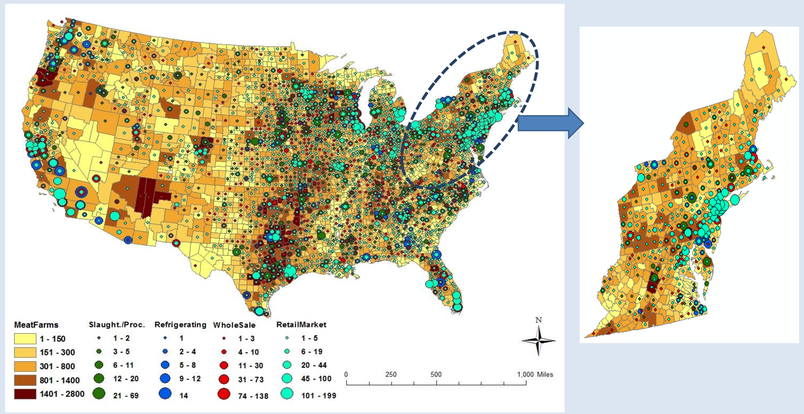
$N = \{1,2,\dots,n\}$: Set of county nodes
C : Fixed cost per mile per ton value
$f(d_{ij})$: Impedance value as a function of highway miles between any two counties
F_h : The fixed cost of locating and operating a hub at county h
H : Set of total estimated number of hubs to be constructed
C_h : Maximum Capacity (Ton) at hub h
$\sum_h ms_{ih}$: Total substancestransferred from a processing facility i to all hubs
p_i : Total supply in node i
$\sum_h m_{hj}$: Total substances transferred from all hub locations to a consumption markets j
c_j : Total consumption demand in a markets j
TM/TP : Threshold distances from hub locations to market places and processing facilities

Experiments and Analysis

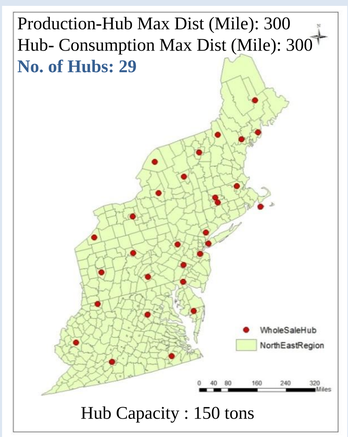
Example: Meat Industry

- The following map shows key locations in the meat industry/supply chain.
- Existing wholesale hub counties (locations) are shown.

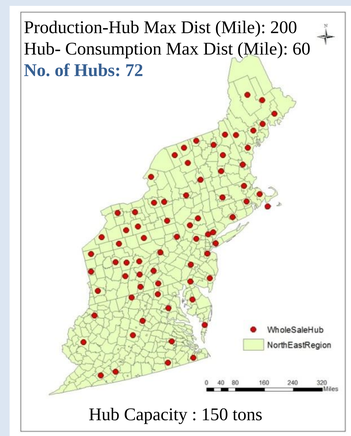
- **Goal:**
  - To investigate whether these wholesale hubs are logistically located optimally considering the impedance values between nodes or counties.
  - To understand how optimal locations adjust over time with changing hub capacity constraints and impedance factors (based on modified level of services in the transportation network).



In this map the locations of county production nodes are considered to be the locations of processing and slaughtering facilities (Proccing/Slau.), consumption nodes (RetailMarket) and wholesale hubs (WholeSale).



Hub Capacity : 150 tons



Hub Capacity : 150 tons

Future Work

- **The model can be improved by:**
  - Considering the entire United States with 1) more products and associated constraints, and 2) more detailed locations of production and consumption.
  - Selecting the hub locations and their capacities based on future potential changes in consumption and production, both in terms of quantities and number of locations (for example, due to climate change).
  - Considering the effects of seasonality on hubs.

- **References:**

1) Campbell, J. (1994) A Survey if Network Hub Location. *Locational Analysis*, **6**, 31-49.
2) Aykin, T. (1995) The Hub Location and Routing Problem. *European Journal of Operation Research*, **83**, 200-219.
3) Ebery, J., Krishnamoorthy, M., Ernst, A., Boland, N. (2000) The capacitated multiple allocation hub location problem: Formulations and algorithms. *European Journal of Operational Research*, **120**, 614-631.
4) Gu, W., Wang, X., and Geng, L. (2009) GIS-FLSolution: A spatial analysis platform for static and transportation facility location allocation problem. Lecture Notes in Computer Science, **5722**, 453-462.
5) Boulé, D., Hubert, G., Jensen, A., Kull, A. ,Van Soelen Kim, J., Marshall, C., Meagher, K., Rittenhouse,T. (2011) Context Matters: Visioning A Food Hub in Yolo And Solano Counties, *Prepared For: The Ag And Food Alliance*, CRD 298: Food Systems Analysis, UC Davis.
6) Campbell, J and O'Kelly, M. (2012) Twenty-Five Years of Hub Locations Research. *Journal of Transportation Science*,**46**, 153-169.

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