Location
Allocation of
Sugar Beet Piling
Centers using GIS
and Optimization

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Geographically Red river valley in the eastern part of North Dakota is the hub for sugar beet production.
• ACSC has five processing facilities in the Red River Valley

• Beets get unloaded at the piling center (piler) in piles and the responsibility shifts from grower to the ACSC.

• Sugar beets are cleaned and are piled 30’ tall x 240’ long for long term storage through the winter. The beets need to stay cold and frozen for long term storage or otherwise they will rot.
Sugar beet processing
• Some beets are directly transported to the processing plants without storing them.
• Farmers and ACSC decide whether to store beets or to take them to processing plant directly.
• This decision is mainly based on the maturity of the beets. The mature beet has the highest sugar content.
• The payment received by the farmer is based on sugar content thus farmers want to keep the beets in the ground to maximize sugar content.
• ACSC desires to start the harvest at an optimal time to ensure the processing plants are busy and remain at capacity
• This balance is important based on the planting time and harvesting time in order to minimize cost and maximize profit to the growers.
• Pilers are considered as natural refrigerators to save beets from rotting. The cold winter temperatures in Red River Valley help the beets to stay at pilers for a longer time after harvest.

• Sugar beets may be stored up to 4 months

• The locations of the pilers are to be optimized to minimize the transportation and storage cost.
Estimate sugar beet supply

Add weights to farms based on maturity

Cluster Farms

Add Pilers to clusters

Road network

Generate OD matrix

Optimization

Weights of Farms

Transportation cost

Set up and operating cost

Optimized piler locations
Stage 1: GIS analysis with clustering

- Generate an Origin – Destination (O-D) matrix
- Clustering of farms
- Weights are assigned to the locations of the farms based on the different harvest times due to different planting dates and weather conditions
- Clustered farms – origins
- Locations of pilers – destinations
- Shortest path algorithm
- Input for optimization
Stage 2: Optimization

- Cost optimization process
  - The objective of the optimization function is to minimize the cost of logistics.
- Inputs –
  1. O-D matrix generated in Stage 1
  2. Weights of farms from Stage 1
  3. Transportation cost of sugar beets
  4. Set up and operating cost of piler
- Assumptions –
  1. Sum of all shipments should not exceed the total yield at farms
  2. Piler is either open or closed at any given time
  3. Quantity of sugar beets harvested should not be greater than piler capacity
  4. All pilers have the same capacity
Cost of logistics = (set up cost) + (storage cost) + (distance \times number of trucks \times cost per mile) + (yield loss cost)

Minimize \( C_i = \text{Minimize} \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{4} ((S_{uj} \times P_j) + (S_{tj} \times P_j) + S_{yi} + (X_{ijk} \times T_{ij} \times C_d)) \)

Subject to:
\[ \sum_{i=1}^{n} \sum_{j=1}^{m} (T_{ij} \times P_j \times t) \leq Y \]
\[ P_j \in \{0,1\} \forall j \]
\[ T_{ij} \geq 0 \forall i,j \]
\[ y_i \geq 0 \forall i \]
\[ \sum_{j=1}^{m} I_j \times P_j \geq Y \]

Where,
\( X_{ijk} = \text{Distance (miles)} \)
\( i = \text{number of farms (1, 2, ..., n)} \)
\( j = \text{number of pilers (1, 2, ..., m)} \)
\( k = \text{number of distance (1, 2, 3, 4)} \)
\( y_i = \text{yield at farm ’i’ (tons)} \)
\( Y = \text{total yield from all farms } = \sum y_i \)
\( t = \text{sugar beet truck capacity (tons)} \)
\( T_{ij} = \text{number of trucks from farm i to piler j } = y_i/t \)
\( C_d = \text{Cost per mile} \)
\( I_j = \text{Capacity of the piler} \)
\( S_{uj} = \text{Set up cost of piler j} \)
\( S_{tj} = \text{Storage cost at piler j} \)
\( S_{yi} = \text{yield loss cost at farm i} \)
\( P_j = 0 \text{ or } 1 = \text{Piler is used or not used} \)
\( C_i = \text{Cost of logistics} \)
Case Study

Red River Valley of North Dakota and Minnesota is the study area

Data sources

ACSC – locations of the plants, pilers, and farms
The road network – TIGER shapefiles from American Census Bureau
Sugar beet truck fuel efficiency is assumed to be 10 miles per gallon
Average fuel cost is assumed to be $3.00 per gallon for the study period
GIS Analysis

• Combining all data sources and performing a clustering model
• Road network is cleaned and combined for ND and MN

Clustering
• The sugar beet harvest starts late in the months of September and October
• Harvest weeks are divided into four groups
• Four separate clusters are formed for farms
• Locations of Pilers

<table>
<thead>
<tr>
<th>Harvest Weeks</th>
<th>Days of Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week Group 1</td>
<td>Less than or equal to 280</td>
</tr>
<tr>
<td>Week Group 2</td>
<td>281-287</td>
</tr>
<tr>
<td>Week Group 3</td>
<td>288-294</td>
</tr>
<tr>
<td>Week Group 4</td>
<td>More than 294</td>
</tr>
</tbody>
</table>
Clustering using ArcGIS Model Builder.
Sugar beet farm clusters based on Week groups
• Closest facility
• Network analyst in ArcGIS
• Cost / impedance – distance in miles
• Four closest pilers for each farm
• origin-destination (O-D) cost matrix
• Gallons of fuel used
• Cost per gallon
• Total fuel + maintenance cost based on distance
Optimization

- Piler Capacity assumed to be 200,000 tons
  (Hillsboro factory has capacity of 1,402,421 tons and catchment area has seven pilers. So each piler will send around 200,346 tons beets)

- The set-up cost is calculated with the help of overhead expenses. It is calculated with the addition of machinery lease cost, building lease cost, utilities per acre, and labor and management charges.

- The set-up cost comes to nearly $120 per acre. The Hillsboro pilers have an area of around 35 acres. Total Set up cost is calculated by multiplying area by the per acre cost, which comes to $4,200.

- The storage cost is assumed to be $0.01 per ton of sugar beets. A piler capacity is 200,000 tons so storage cost of a piler is $2,000.

- Performed using LINGO software
## Optimization Results

<table>
<thead>
<tr>
<th>Week Group</th>
<th>Open Pilers</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week Group 1</td>
<td>41</td>
<td>1,624,895</td>
</tr>
<tr>
<td>Week Group 2</td>
<td>41</td>
<td>3,696,831</td>
</tr>
<tr>
<td>Week Group 3</td>
<td>41</td>
<td>6,662,072</td>
</tr>
<tr>
<td>Week Group 4</td>
<td>16</td>
<td>304,630</td>
</tr>
</tbody>
</table>

![Graph showing week groups and total cost](image)
Week Group 4: Truck Volumes
Sensitivity Analysis

- If the model is performing as expected
- Examine the assumed values and how they perform
- Week Group 4 model
- Changes in the yield
- Changing piler set up costs
• The number of open pilers reduces as the yield at each farm is reduced by 50% and 75%.

• The number of open pilers increases as the yield at each farm is increased from original yield to 300%.

• As the setup cost reduces, the number of open pilers increases. Even though the number of open pilers increases, the total cost decreases.

• Eight is the minimum required number of open pilers to satisfy all supply at the farms in week 4.
A two-step method using GIS and optimization can be used to allocate the sugar beet piler locations.

As seen in the sensitivity analysis, as yield changes the number of pilers changes which can attribute to the supply variation. This method is also useful to find the optimal piler locations in this scenario.

Saves total transportation cost as well as maintains the sugar content in the beets.

Prediction of the truck volume on rural roads.
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Thank You