Decision support with respect to facility location and fleet composition for FoodBank Cape Town

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21 September 2011
40th Annual ORSSA Conference
Outline

1. Background
2. Project Focus
3. Demand & Candidate Sites
4. Facility Location Problem
5. Vehicle Fleet Composition
6. Current & Future Work
What is Food Banking?

- Started by John van Hengel in late 1960s in Phoenix, Arizona, USA. Good food going to waste due to defect packaging or near expiration date.

- Distributed food to local agencies
  Agencies – NGOs that run feeding programmes

- Idea spread to others cities, other countries.
**Food Banking**

![Food Banking Diagram](image)

**Figure:** Sourcing & distributing flow diagram
Global Foodbanking Network

- Established in 2006
- Currently 41 countries

Mission

To work together to alleviate world hunger by developing national networks of foodbanks and strengthening foodbanking around the world
South African Context

Food Security

Access by all households at all times to adequate, safe and nutritious food for a healthy and productive lifestyle.

Approximately 40% of South Africa’s population is vulnerable to food insecurity [2].
FoodBank South Africa

- Established in 2008
- Amalgamation of foodbanking organisations
- Currently located in Cape Town, Johannesburg, Durban and Port Elizabeth

Goal

To establish nationwide network of community foodbanks in urban and rural areas, all working towards eliminating hunger and food insecurity
FoodBank Cape Town

- First in South Africa
- Launched on 2 March 2009
- Warehouse located in Philippi East [1]
- Majority of food sourced from DCs and retail sector
- Distributing to approximately 200 agencies on record
FBCT Project Focus

- Improving the efficiency of FBCT’s logistical setup
- Focusing on the distribution of food to agencies
- Facility location model to find good locations for local distribution depots

**Diagram:**
- Warehouse
- Agency
- FoodBank Cost
- Agency Cost

- Vehicle fleet composition to distribute to depots
FBCT Project Focus

- Improving the efficiency of FBCT’s logistical setup
- Focusing on the distribution of food to agencies
- Facility location model to find good locations for local distribution depots

- Vehicle fleet composition to distribute to depots
Figure: Sourcing & distributing flow diagram
Demand & Candidate Sites

Data

- GIS shape files
  - City of Cape Town population data for 40ha areas
  - National land cover
  - City of Cape Town road network – used to obtain travel distances

- Two agency databases – used to obtain geographical coordinates
Figure: 6560 City of Cape Town 40ha hexagons
Figure: ArcMap: Location 198 agencies being serviced
Figure: Flowmap: Road network used to calculate distances from hexagon centroids
**Figure:** ArcMap: Location 198 agencies
Figure: ArcMap: Agency demand allocated to hexagons
Figure: ArcMap: 157 Demand hexagons
Figure: ArcMap: Demand hexagons demand (kg)
Figure: ArcMap: 1169 Candidate Sites
Figure: ArcMap: 157 Candidate Sites
Facility Location

- Set of demand points $I \in \{u_1, ..., u_n\}$
- Set of candidate facility sites $J \in \{x_1, ..., x_m\}$
- Demand point demand $h_i$
- Facility fixed charge $f_j$
- Facility capacity $C_j$
- Distance ($d_{ij}$) or cost ($c_{ij}$)
Literature Review: $K$-Centre

Minimise $g = \max_{i \in I; j \in J} \{ h_i d_{ij} y_{ij} \}$ \hspace{1cm} (1)

subject to

\[ \sum_{j \in J} x_j = K, \quad j = 1, \ldots, m \] \hspace{1cm} (2)

\[ \sum_{j \in J} y_{ij} = 1, \quad i = 1, \ldots, n \] \hspace{1cm} (3)

\[ y_{ij} \leq x_j, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \hspace{1cm} (4)

\[ x_j, y_{ij} \in \{1, 0\}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \hspace{1cm} (5)
Literature Review: \textit{K}-Median

Minimise \( g = \sum_{i=1}^{n} \sum_{j=1}^{m} h_{ij} y_{ij} d_{ij} \) \hspace{1cm} (6)

subject to

\[
\sum_{j \in J} x_j = K, \hspace{1cm} j = 1, \ldots, m \hspace{1cm} (7)
\]

\[
\sum_{j \in J} y_{ij} = 1, \hspace{1cm} i = 1, \ldots, n \hspace{1cm} (8)
\]

\[
y_{ij} \leq x_j, \hspace{1cm} i = 1, \ldots, n, \hspace{1cm} j = 1, \ldots, m \hspace{1cm} (9)
\]

\[
x_j, y_{ij} \in \{1, 0\}, \hspace{1cm} i = 1, \ldots, n, \hspace{1cm} j = 1, \ldots, m \hspace{1cm} (10)
\]
Minimise \( g = \sum_{j=1}^{m} f_j x_j + c \sum_{i=1}^{n} \sum_{j=1}^{m} h_i y_{ij} d_{ij} \) \( (11) \)

subject to

\[ \sum_{j \in J} x_j = K, \quad j = 1, \ldots, m \] \( (12) \)

\[ \sum_{j \in J} y_{ij} = 1, \quad i = 1, \ldots, n \] \( (13) \)

\[ y_{ij} \leq x_j, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \( (14) \)

\[ x_j, y_{ij} \in \{1, 0\}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \( (15) \)

\[ \sum_{i \in I} h_i y_{ij} \leq C_j x_j, \quad j = 1, \ldots, m \] \( (16) \)
Formulation of Facility Location Model

- Adapted from K-Median & Fixed Charge Location Model
- Fixed charge is the cost or distance from warehouse to local depot
- Formulated as mixed integer linear programming problem
Facility Location Model

Minimise \( g = \sum_{j=1}^{m} f_j x_j + \sum_{i=1}^{n} \sum_{j=1}^{m} y_{ij} d_{ij} \) \hspace{1cm} (17)

subject to

\[ \sum_{j \in J} x_j = K, \quad j = 1, \ldots, m \] \hspace{1cm} (18)
\[ \sum_{j \in J} y_{ij} = 1, \quad i = 1, \ldots, n \] \hspace{1cm} (19)
\[ y_{ij} \leq x_j, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \hspace{1cm} (20)
\[ x_j, y_{ij} \in \{1, 0\}, \quad i = 1, \ldots, n, \quad j = 1, \ldots, m \] \hspace{1cm} (21)
\[ \sum_{i \in I} h_i y_{ij} \leq C_j x_j, \quad j = 1, \ldots, m \] \hspace{1cm} (22)
Facility Location Model

- Solved using LINGO 11.0 or Adaptive Tabu Search (ATS).
- Tightness factor ($\tau$) determines how highly constrained the problem is.

$$\tau = \sum_{i \in I} h_i / (K.C)$$

- $\tau < 0.7$, LINGO - exact solution $< 1$ hour
- $\tau \geq 0.7$, LINGO - exact solution $> 1$ hour
- $0.82 \leq \tau \leq 0.96$, ATS - good solution in 2.5 minutes

- Adaptive tabu search used for $K = 18, 19, 20$
- LINGO used for $K \geq 25$
Figure: ArcMap: 18 Depots - Agency distance
Figure: ArcMap: 18 Depots - Agency & Warehouse distance
Figure: ArcMap: Assignment of Agencies
Vehicle Fleet Composition

- Clarke-Wright Savings Algorithm used to create routes
- Create daily trips for available vehicles
  - 8 hour day
  - Travel time
  - Loading & Offloading time
- Distribution costs calculated
  - Fixed Cost per day
    - Finance Cost
    - Staff Cost
  - Variable Cost per kilometre
    - Fuel & Lubricants
    - Tyres
    - Maintenance
18 Depots (K-Median - Distance) Fleet Distribution Cost

<table>
<thead>
<tr>
<th>Vehicle Fleet Composition</th>
<th>Agency Distance (km)</th>
<th>Agency Cost (R)</th>
<th>FB Distance (km)</th>
<th>FB Cost (R)</th>
<th>Total Cost (R)</th>
<th>FB % Total Cost</th>
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<td>10,382</td>
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<td>Vehicle Fleet Composition</td>
<td>Agency Distance (km)</td>
<td>Agency Cost (R)</td>
<td>FB Distance (km)</td>
<td>FB Cost (R)</td>
<td>Total Cost (R)</td>
<td>FB % of Total Cost</td>
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Current & Future Work

- Calculate distribution costs when replacing distance between points with cost between points, then feedback into Facility Location Problem.
- Compare distribution costs for different values of $K$.
- Compare distribution costs when the Agency costs are weighted.
Bibliography


Mans G, 2010, GIS Specialist at CSIR Stellenbosch, [Personal Communication], Contactable at GMans@csir.co.za.