Transit stop location

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October 15, 2024

Questions to answer

- How many stops should we locate in the service area?
- Where should those stops be located?
  - What should be spacing between stops on a transit route?

Stop spacing

- Many stops located close to each other are advantageous from the accessibility perspective (walk time is shorter) but it may increase the overall time of the ride (transit vehicle has to stop more frequently).
- When stops are further apart, the walk time gets longer but ride time gets shorter.

An ideal stop spacing would minimize the sum of walking, waiting, and in-vehicle time.

Walking to a stop

- Passengers within a certain buffer area (computed based on a walking time threshold) around a stop would be able to access it.
- Usually, the walking time threshold is selected as quarter mile (400 m) for a local bus stop and half mile (800 m) for an express service.
- Passengers are willing to walk more if they get access to a fast and frequent service (e.g., BRT)

Types of service

1. Local
   - serving closely spaced stops such that all points on or near the line are within the walking distance of a stop.
2. Rapid
   - regularly but widely spaced stops, usually every 0.5 miles (800m) or more.
3. Express
   - serving a long, non-stop segment.
   - typical express service is focused on a single major destination (e.g., Downtown)
   - runs non-stop between destination and the area it serves but has close stops within that area.

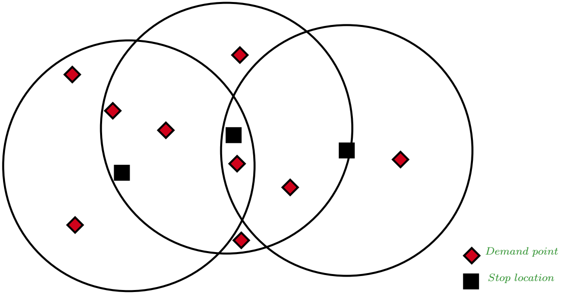
Optimal stop location choice

- Set covering approach
- Maximum demand covering approach
- m-center approach

Set covering approach

- Consider a set of candidate stop locations $N = \{1, \cdots, n\}$ and demand points $M = \{1, \cdots, m\}$
- Assume each trip starts and ends at exactly one of the demand points in M.
- Let $A = \{a_{ij}\}_{i \in M, j \in N}$ be a matrix, where

$$a_{ij} = \begin{cases} 1 & \text{if demand point } i \text{ can be accessed from stop } j \\ 0 & \text{otherwise} \end{cases}$$



Set covering approach

Definition (Set covering approach). Given a set of demand points M, a set of stop locations N, and an incidence matrix A (defined above), find the least number of stops to locate so that each demand point is covered by at least one stop.

Let us introduce decision variable $x_j = \begin{cases} 1, & \text{if stop } j \text{ is located} \\ 0, & \text{otherwise} \end{cases}$

$$\underset{\mathbf{x}}{\text{maximize}} \quad \sum_{j \in N} x_j \tag{1a}$$

$$\text{subject to} \quad \sum_{j \in N} a_{ij} x_j \geq 1, \forall i \in M \tag{1b}$$

$$x_j \in \{0, 1\}, \forall j \in N \tag{1c}$$

Remark. Given c_j is the cost of setting up stop $j \in N$, one can consider minimizing the total cost of setting up the stops $\sum_{j \in N} c_j x_j$. This version of the problem is called weighted cover approach.

Maximum demand covering approach

- This approach is useful in case we do not have enough resources to locate stops so as to cover every demand point.
- Let's assume that budget allows locating at most p stops.
- We want to maximize the number of passengers covered. Let d_i be the passenger demand at point $i \in M$
- Further, we would like each demand point to have at least one stop within a maximum distance ζ.
- Assume another incidence matrix $B = \{b_{ij}\}_{i \in M, j \in N}$, where

  $$b_{ij} = \begin{cases} 1, & \text{if stop } j \text{ is within } \zeta \text{ distance of demand point } i \\ 0, & \text{otherwise} \end{cases}$$

Maximum demand covering approach

Definition (Maximum demand covering approach). Given a set of demand points M, a set of stop locations N, and incidence matrices A and B (defined above), locate at most p stops so as to maximize the overall demand covered. Let us introduce another decision variable

$$y_i = \begin{cases} 1, & \text{if demand point } i \text{ is covered} \\ 0, & \text{otherwise} \end{cases}$$

$$\underset{\mathbf{x},\mathbf{y}}{\text{maximize}} \quad \sum_{i \in M} d_i y_i \tag{2a}$$

$$\text{subject to} \quad \sum_{j \in N} b_{ij} x_j \geq 1, \forall i \in M \tag{2b}$$

$$\sum_{j \in N} a_{ij} x_j \geq y_i, \forall i \in M \tag{2c}$$

$$\sum_{j \in N} x_j \leq p \tag{2d}$$

$$x_j \in \{0, 1\}, \forall j \in N \tag{2e}$$

Remark. If (2c) is ignored, one can try greedy heuristic to solve the problem i.e., assume the optimal stops $N^* = \phi$. Find a stop that covers highest number of demand points and add it to N. Then, find a stop that covers highest demand points which are not covered by any of the stops in N. Continue until $|N| < p$.

m-center approach

- Let us consider a undirected connected graph $G(X, \Gamma)$, where X is the set of nodes (which includes the demand points) and Γ is the set of edges.
- Each edge $e \in \Gamma$ is considered as the collection of infinite number of points. Let P be the set of those infinite points on all edges.
- Let $\pi = P \cup X$ and let $d(v_1, v_2)$ be the shortest distance between $v_1 \in \pi$ and $v_2 \in \pi$.

Definition (m-center problem). Givem $G(X, \Gamma)$ and $\pi = P \cup X$ (defined above), find a set $U^* \subseteq \pi$ of m points (stop locations) that solves the following optimization problem.

$$\boxed{\min_{U \subseteq \pi} \max_{x \in X} \textbf{dist}(x, U)}$$

where $\textbf{dist}(x, U) = \min_{w \in U} d(x, w)$.

Suggested reading

- Jarrett Walker Human Transit Chapter 6
- Gkiotsalitis, Konstantinos. Public transport optimization, Chapter 8

Thank you!