Hub and Spoke Logistics Network Design for Urban Region with Clustering-Based Approach

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Situation

- The volume of express delivery gets increasing with the rapid development of e-commerce
- Transportation cost and delivery time are the most important factors
- Logistics network design is concerned with:
  - The number and location of facilities
  - Assignment of stations (spokes) to the distribution center (hub) within its coverage
- The optimal setting must distribute the goods to the customers with the least cost and satisfy the service level agreement

Problems

- Single depot has a limit of serving demand points contribute the difficulty of problem
- The logistics service provider manages to accommodate customer's demanding at time window and price make the operations more challenging
- Limited research incorporate expert's domain knowledge to network design process for the target region

Solution

Utilize the advantages of collaborative multi-depots setting, a multi-stage approach for designing the delivery network is introduced:

1. Clustering: detecting the group of nearby spokes to a cluster
2. Hubs' Locations: detect the cluster's centre in which serve as the local DC
3. Vehicle Routing: determine the flow distribution scenario among the Hubs' network, and perform the vehicle routing

Clustering

The fuzzy c-mean (FCM) clustering algorithm[1] is employed for this step. The approximate transportation cost is calculated as

$$Cost = \sum_{c_k \in C} \left\{ \sum_{c_l \in C \setminus c_k} d_h(\overline{c_k}, \overline{c_l}) + \sum_{x_i \in c_k} d_h(\overline{c_k}, x_i) \right\} \tag{1}$$

$$\overline{c_k} = \frac{\sum_{x_i \in X} w_k(x_i)^m * x_i}{\sum_{x_i \in X} w_k(x_i)^m} \tag{2}$$

Where $\overline{c_k}$ is the centroid of a cluster c_k is defined by the FCM, m is the hyper-parameter that controls the fuzziness of clustering and $w_k(x)$ is the degree of membership that x belong to the cluster k. **Final Cluster Assignment**: The degree of membership feature is utilized for balancing the demand among the cluster together with humans.

[1] Bezdek, Ehrlich, and Full, "FCM: The fuzzy c-means clustering algorithm".

Hub's Location

The center of gravity method[2] is employed to determine the Hub's location. For all $k \in \{1, 2, ..., K\}$ and $\nu(x)$ is the delivery demand for demand point x, the center gravity of each cluster k is calculated as:

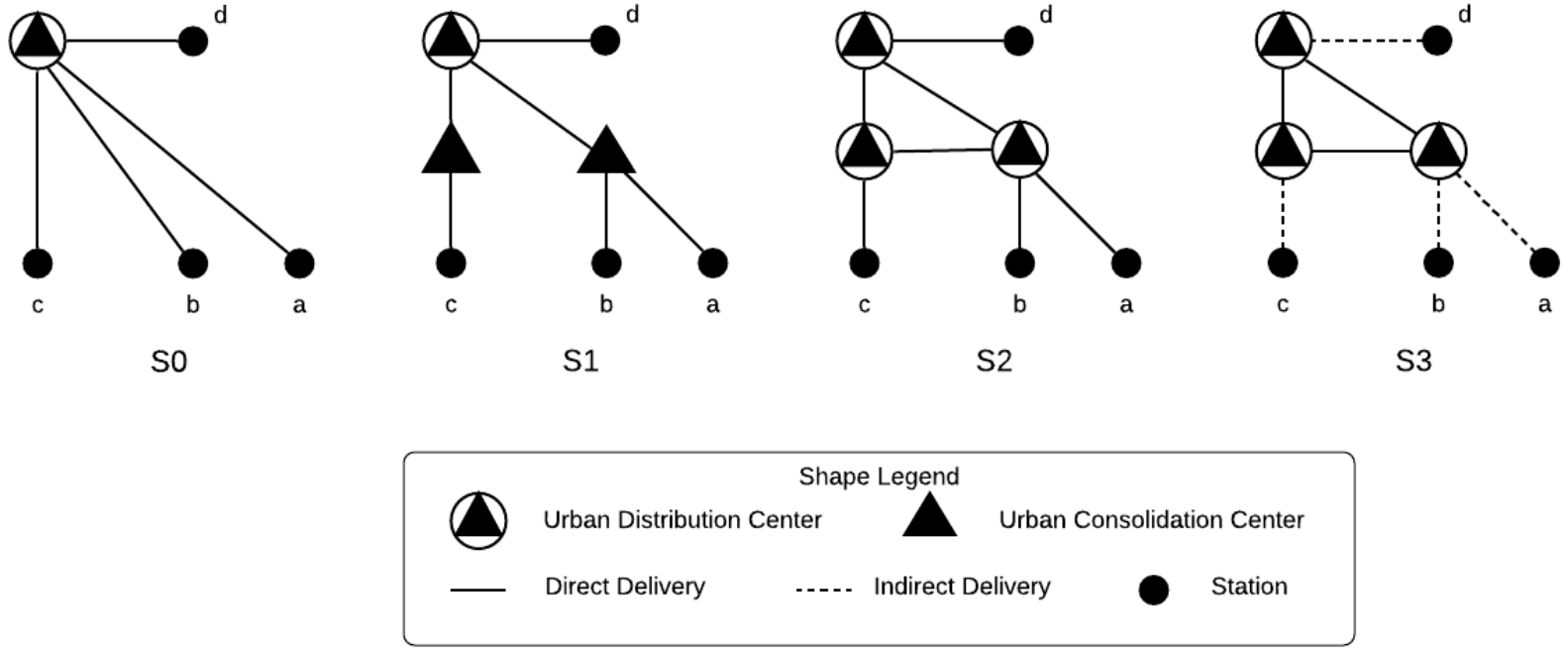
$$h_k = \sum_{x \in c_k} \beta(x) * x \tag{3}$$

$$\beta(x) = \frac{\nu(x)}{\sum_{x \in c_k} \nu(x)} \tag{4}$$

The $\beta(x)$ value serves as the weighted factor within the cluster. The larger value will pull the hub's location to its side.

[2] Ballou, "Business logistics management".

Flow Distribution and Vehicle Routing



Experimental Results

Experimental setting:

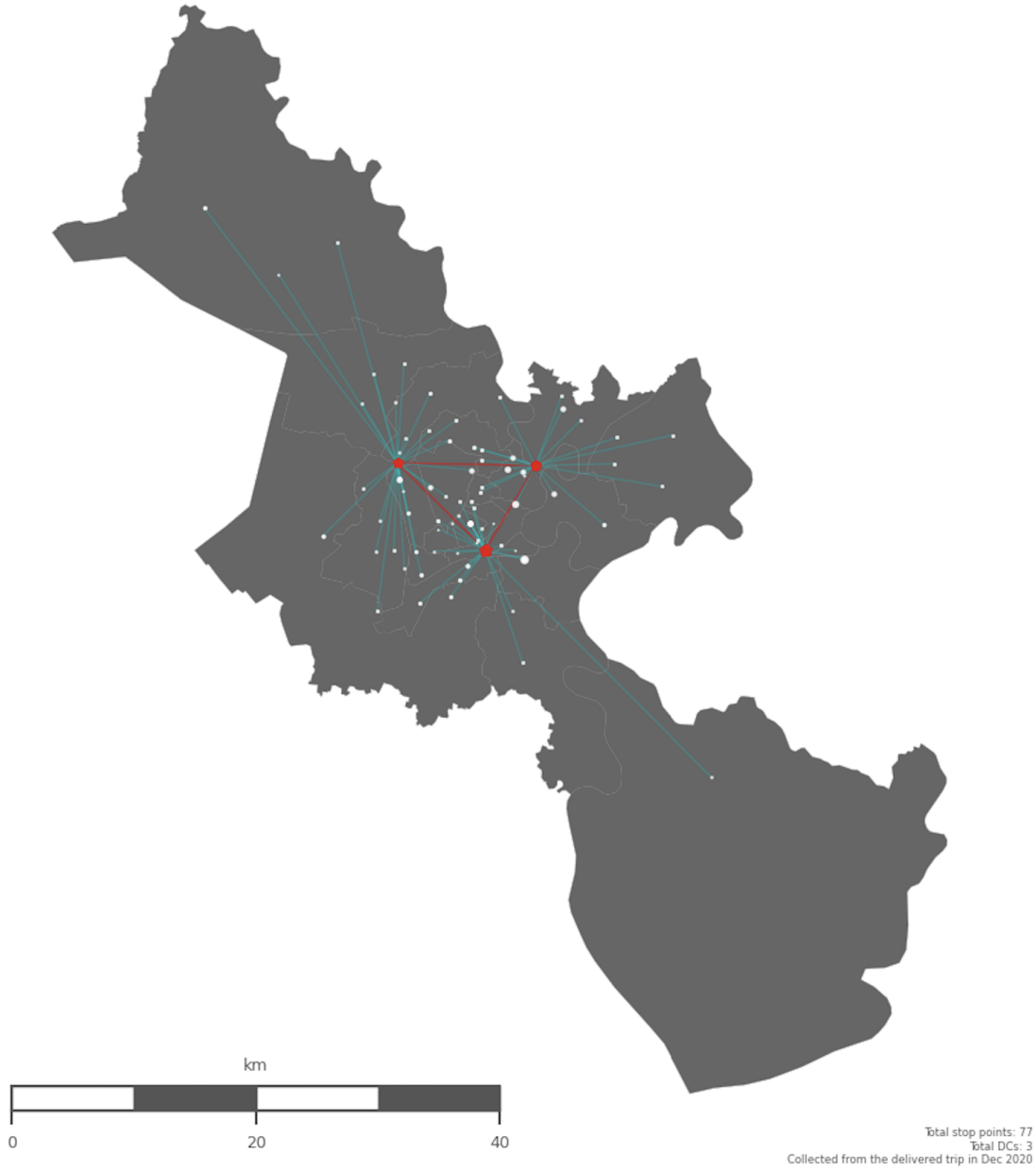
- City: Ho Chi Minh, Viet Nam
- Data: Operational data from GHN[3] for entire Dec 2020 with *77* demand data points is conducted, in which select 22^{nd} *December* for vehicle routing step

Table 1: Summary of Clustering Results

Number of clusters	Approximate transportation cost	Coef
2	527.8	0.568
3	**482.8**	0.424
4	490.3	0.362
5	530.6	0.308

[3] `https://ghn.vn`

Detected Flow and Hub's Location



Actual Transportation Cost

Table 2: Actual Transportation Cost for Scenarios

Scenario	Total trucks	Total cost	Pickup cost	Delivery cost
$S0$	v *	c **	0.7c	0.3c
$S1$	$0.79v$	$0.75c$	$0.44c$	$0.31c$
$S2$	$0.8v$	$0.72c$	$0.47c$	$0.25c$
$S3$	$0.63v$	$0.61c$	$0.46c$	$0.15c$

* Number of trucks need for the *S0* scenario

** The total amount of money take for the *S0* scenario

By introducing the multi-depot in the delivery network, the transportation cost reduces 25%, 28% by adding consolidation and distribution centers respectively. Furthermore, about 20% of the number of trucks have been reduced.

Contributions and Conclusions

- Analyzes the advantages of collaborative multi-depot settings in the urban area, applied the iterative approaches for the logistics network design problem.
- Based on the real operational data in Ho Chi Minh city, actual transportation cost reduce to 28% and 20% trucks used with 3 distribution centers.
- Increasing the truckload utilization for the delivery trips between Hubs not only reduces the transportation cost and improves operational efficiency for the firm, but also put an effort into alleviating the traffic congestion, reducing stress for transportation infrastructure.