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Scalable Heuristic for Locating Distribution Centers on Real Road Networks

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OBJECTIVE

In this research, a scalable heuristic for locating distribution centers on real road networks is proposed. The proposed algorithm referred to as the *Multi-Threaded Dijkstra's (MTD)* algorithm, is not specific to the distribution center location problem and can be applied to any type of location problem based on the median model.

The MTD algorithm is used to locate 78 Walmart distribution centers on the 28-million node road network of the United States with the objective of minimizing the total demand weighted transportation cost between the distribution centers and 3,163 stores. The population of US urban areas were used to estimate the store demands.

All analyses performed using open source and/or free tolls and all data sources are available to the public.

BACKGROUND

The literature review indicates that none of the proposed algorithms for median problems are scalable to real road networks. All reviewed methods perform pre-processing on the road network data to reduce the size of the network or create a distance matrix containing shortest distances between all possible pairs of nodes on the network, which is a time and computation intensive process for larger networks.

The most scalable methods identified in the literature was applied to a simplified road network with 1,938 nodes created based on the real road network for the country of Sweden. Heuristic solution methods based on genetic algorithm and simulated annealing solved *p*-median problems with up to 100 facilities in the Swedish benchmark with runtimes over 10 hours. No other solution methods were capable of providing a solution to compare the quality of solutions.

METHODOLOGY

Data Preparation- Current locations of 78 Walmart distribution centers in the continental US, the locations 3,163 of Walmart stores in the continental US, shapes and population of 3,592 US urban areas, and the US road network with over 28 million nodes are imported in a spatially enabled PostgreSQL database. In this step, every store is allocated to the closest distribution center using the shortest network distance found by A* algorithm. The demand for each store is also estimated base on the population of the urban area the store is located in.

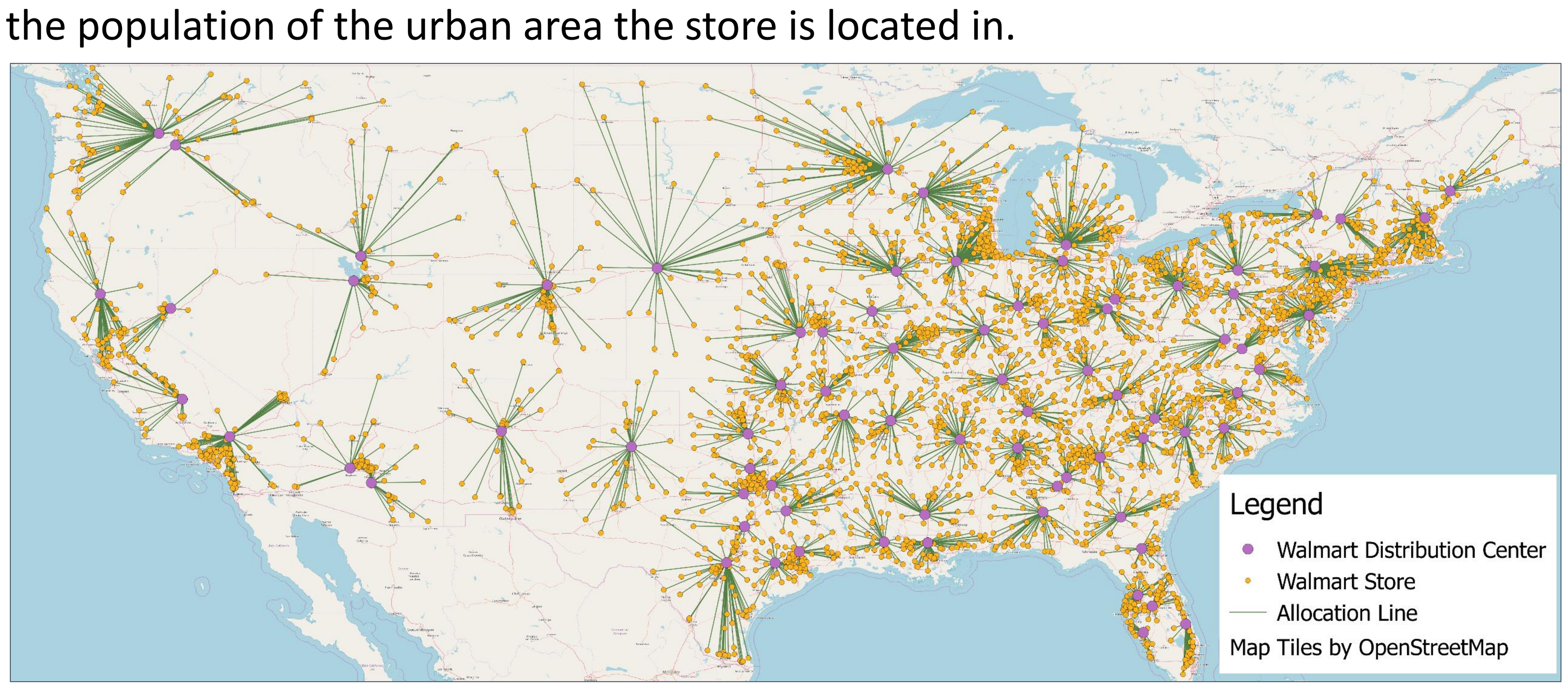

Fig. 1. Stores allocated to closest distribution center based on shortest network distance

Preliminary Evaluation- In this phase, total demand weighted transportation cost for the whole distribution network based on the shortest network distances and estimated demand values found in the previous step is calculated. A total of 1,771 stores with a distribution center within 80 miles were considered in this phase.

Location- The optimal location for each of the Walmart distribution centers is found under the three following scenarios: I) current allocation of 1,771 stores to their closest distribution center, II) clustering 1,771 stores based on proximity, and III) clustering all 3,163 stores into 120-150 clusters based on proximity.

In scenarios I and II, a total of 78 distribution centers were located while in scenario III the number of distribution centers are increased to be able to reach an average of 80 mile distance between stores and distribution centers.

RESULTS AND CONCLUSIONS

In scenario I, relocating the distribution centers using the MTD algorithm with respect to 1,771 stores, reduced the Total Transportation Cost (TTC) by 41%. Applying the clustering heuristic in scenario II, resulted in 46% improvement in TTC.

Table I. Summary of scenarios 1 and 2 results

Weighted TSP Cost	Current	Scenario I	Scenario II
Minimum	1,136.17	1,004.35	12,348.41
Average	124,155.98	73,593.06	66,536.99
Maximum	890,163.57	444,563.13	508,797.9
Total	9,684,166.26	5,740,258.62	5,189,885.12

In scenario III, all 3,163 stores were allocated to 120-150 distribution centers and then each distribution center was located by the MTD algorithm.

Table I. Summary of scenarios I and II results

No. of DCs	TTC	Avg. Dist. (km)	Avg. Weighted Dist.	Runtime (min)
120	11,176,973.91	83.60	93,141.45	89.53
125	10,898,265.34	81.09	87,186.12	83.01
130	10,763,513.47	80.04	82,796.26	79.27
135	10,522,725.42	78.06	77,946.11	91.33
140	10,277,561.33	76.55	73,411.15	73.93
145	10,062,170.83	75.58	69,394.28	83.81
150	9,938,189.86	74.05	66,254.60	63.96

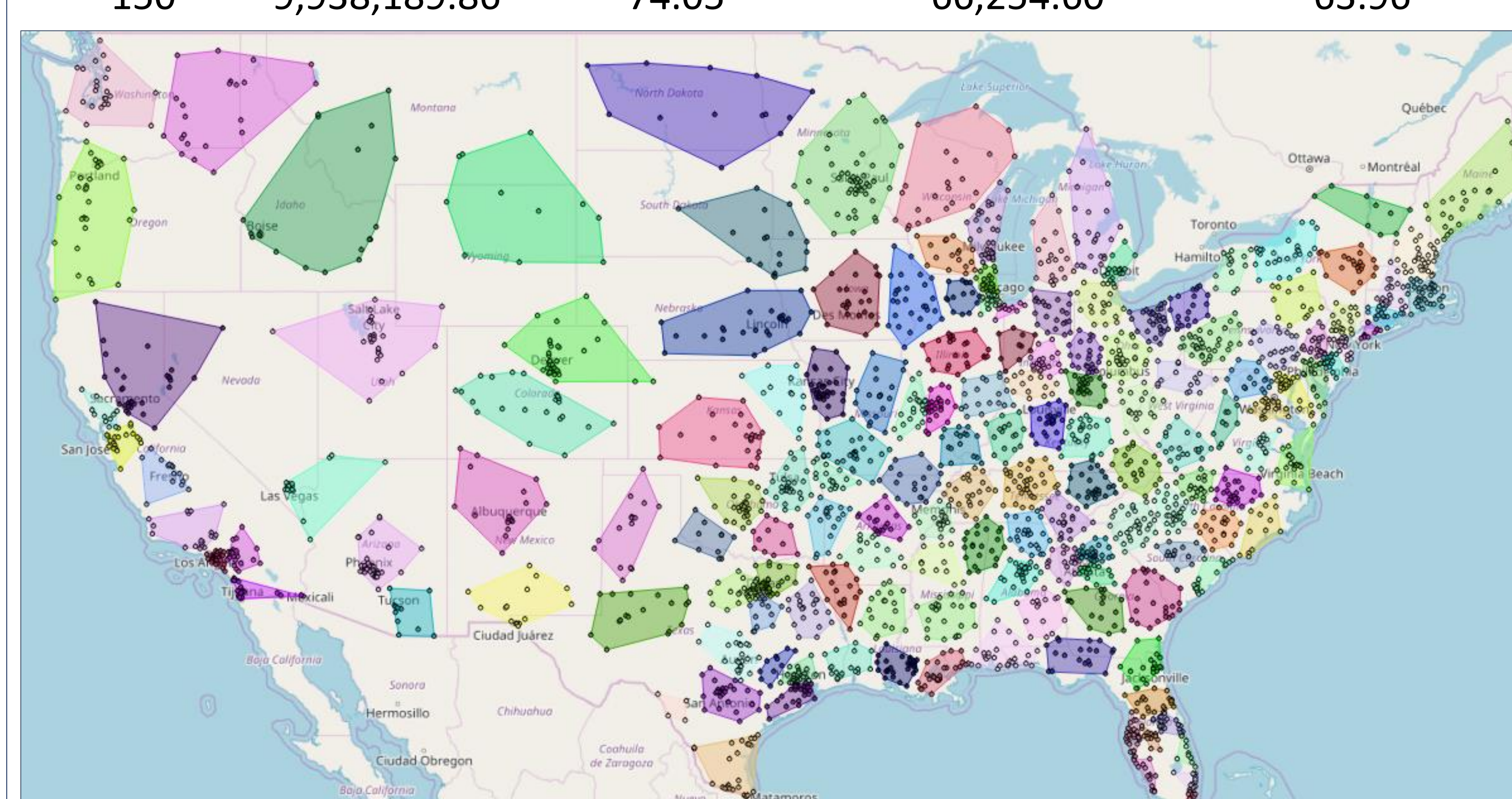

Fig. 2. All 3,163 Walmart stores clustered and allocated to 150 distribution centers

Choosing 150 distribution centers in scenario III resulted in the same average weighted distance as scenario II, although the number of stores in scenario III is almost twice as scenario II.

The MTD algorithm was able to locate the 78 distribution centers in scenarios I and II in 51 and 42 minutes, and 81 minutes on average in scenario III which is reasonable considering the size of the network and problems. The proposed algorithm outperforms the most scalable solution methods in the literature in terms of both scalability and runtime.

FUTURE WORK

Walmart store and distribution center location data used in this research dates back to 2006. Performing the same analysis on newer data can provide an insight on how the location of Walmart distribution centers have evolved in response to the competition.

Demand for the stores were estimated based on the population of urban areas. A more sophisticated demand estimation model can be adopted to improve the accuracy of the analysis.

More complex factors such as traffic and road type could be incorporated in addition to the distance to calculate the transportation cost.

And finally, other objective functions such as minimizing maximum weighted distance, or minimizing maximum weighted travel time can be investigated and compared to the current analysis.

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