Charging Station Optimization

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(Integer-ordered variables, constrained.)
This problem is adapted from the paper by Sebastiani, Lders, and Fonseca presented at the 2014 Winter Simulation Conference. Allocation of Charging Stations in an Electric Vehicle Network Using Simulation Optimization.

Problem Description Consider a city with K potential locations for electric vehicle charging stations. The goal is to select $N \leq K$ locations at which to set up stations in order to minimize the wait times for vehicles that require a recharge.

This example has been obtained from a urban area of Curitiba, Brazil. Three different paths are considered as shown in Figure 1. They represent favorite paths in the urban area, which are expected to have higher concentration of vehicles. Table 1 shows the distances, D_{ij}, in kilometers between any two potential station locations.

The parameter TF_{ij} (Traffic Factor) is introduced to penalize sections between stations that are shared by two or more paths according to Table 2. This variable assumes values that represent sharing of sections between two stations. For example, TF receives value 1 between stations 2 and 4 as this section is only used by path 2. However, TF is 1.25 between stations 1 and 3 as 25% of this section is shared by paths 1 and 2. Similarly, TF is 1.50 between stations 1 and 6 as 50% of this section is shared by paths 1 and 2. This variable captures delays caused by cross traffic due to vehicles from different paths. These delays are taken into account when computing vehicles energy consumption.

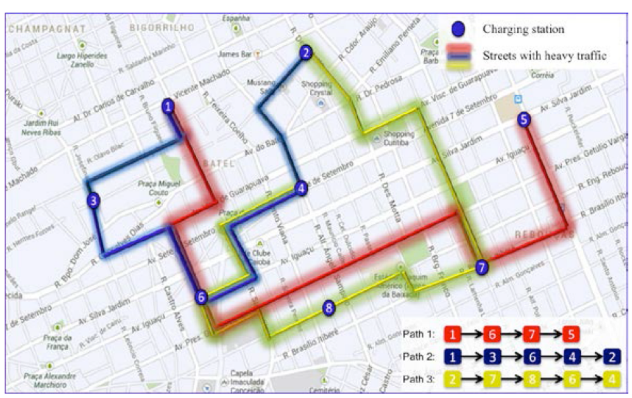

Figure 1: Map of the three paths considered in the urban area of Curitiba, Brazil

	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.8
St.1	0	0	2	0	0	4.5	0	0
St.2	0	0	0	3	0	0	5	0
St.3	2	0	0	0	0	3	0	0
St.4	0	3	0	0	0	3.5	0	0
St.5	0	0	0	0	0	0	4	0
St.6	4.5	0	3	3.5	0	0	5	2.5
St.7	0	5	0	0	4	5	0	2.5
St.8	0	0	0	0	0	2.5	2.5	0

Table 1: Distances in kilometers between two station locations

	St.1	St.2	St.3	St.4	St.5	St.6	St.7	St.8
St.1	0	0	1.25	0	0	1.50	0	0
St.2	0	0	0	1	0	0	1.20	0
St.3	1.25	0	0	0	0	1.40	0	0
St.4	0	1	0	0	0	4	0	0
St.5	0	0	0	0	0	0	1	0
St.6	1.50	0	1.40	2	0	0	1.40	1.45
St.7	0	1.20	0	0	1	1.40	0	1
St.8	0	0	0	0	0	1.45	1	0

Table 2: TrafficFactor between station locations

The decision variable is $x \in \{0,1\}^K$, where $x_i = 1$ if and only if there is a station at location i, and 0 otherwise. Let $S = \{i : x_i = 1\}$ be the set of chosen station locations.

There are V vehicles that operate in the city, and the simulation is of length T. Vehicles have a maximum energy of E units, and consume $TF_{ij} * D_{ij} * F$ units of energy to travel between locations i and j, with F being a coefficient used to convert between (traffic-adjusted) distance and energy consumption.

Vehicle v_i spawns at a uniform-randomly chosen station in S at time s_i with initial energy e_i, where s_i are i.i.d. normal random variables with mean μ_s and variance σ_s^2, truncated at 0, and e_i are i.i.d uniform random variables in $[0, E]$.

A vehicle picks a different station in S at random to travel to. If it does not have enough energy to reach the station (this is deterministic, and can be calculated while at the current station), it recharges before leaving, entering a single queue to use the current station. Charge time is normally distributed with mean $E - e_i$ and variance σ_q^2, with the variance representing external factors such as waiting for attendants or paying for service. It is assumed that the distance between any two locations requires $\leq E$ units to traverse.

After potentially charging at the station, the vehicle leaves for its target destination, incurring a travel time of $Q/D_{i,j} + tr_k$, where Q is the speed of the vehicle, and tr_k is a random additional transit time, i.i.d. normal with mean μ_{tr} and variance σ_{tr}^2. μ_{tr} should be fairly large, as tr represents activity done between station visits. The vehicles repeat this pattern until time T.

The goal is to minimize the total queueing time summed over all vehicles (this does not include time spent recharging).

Recommended Parameter Settings: $K = 8$, $N = 3$, $V = 1000$, $T = 28800$ (seconds), $E = 100$, $F = 3$, $\mu_s = \mu_{tr} = 3600$ (seconds), $\sigma_s = \sigma_{tr} = 200$, $\sigma_q = 10$, $Q = 60/3600$ (kilometers per second).

Starting Solution(s):
$x = [1, 0, 0, 1, 0, 0, 1, 0]$
If multiple starting solutions are required, sample uniformly across $\{x : x \in \{0, 1\}^8, \sum_{i=1}^{8} x = 3\}$

Measurement of Time: Number of simulation replications.

Optimal Solutions: Unknown.

Known Structure: Unknown.