Optimal location of discretionary alternative-fuel stations on a tree-network

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Abstract
Due to global concerns about environmental sustainability in ground logistics, there has been widespread research into alternative-fuel (alt-fuel) vehicles. Compressed natural gas buses have been successfully deployed on a commercial scale in public transportation. Also, sales for electric cars have been gradually increasing. However, uses of other alt-fuel vehicles are in their early stages because developing an infrastructure with refueling stations requires a huge investment. When setting up such an infrastructure, it is necessary to decide the number of refueling stations to be built and where they should be located to cover the maximum traffic flow that can be refueled on a given road network. In this research, we propose a mathematical model to determine optimal locations for a pre-determined number of refueling stations to maximize the traffic flow covered on a tree-network, which is a common structure of toll roads in many states. This model includes four types of constraints to identify number of trips covered for four possible ranges of travel distances between all possible pairs of vehicle origins and destinations.

Keywords: Sustainability, Refueling station location, Alternative-fuel vehicle network

Introduction
Reduction of greenhouse gas emissions from ground transportation is increasingly becoming one of the important issues in automobile and heavy-duty vehicle manufacturers in the U.S. and around the world for achieving environmental sustainability in logistics. By 2015, at least 45 alternative-fuel (alt-fuel) vehicle models will be available in the U.S. market, and the market share of alt-fuel vehicles is expected to climb to 5% in 2015 (Crowe 2012). Also, New Flyer, a

manufacturer of alt-fuel buses, recently signed the five-year contract with the Los Angeles County Metropolitan Transportation Authority for up to 900 compressed natural gas buses (Koffman 2013). One of the key factors to invigorate the introduction of alt-fuel vehicles is refueling station availability. If a sufficient number of refueling stations for alt-fuel vehicles is properly located on a transportation network, demand of alt-fuel vehicles would gradually increase and consequently the impact of carbon-based vehicle emissions on the environment would decrease.

The approaches published in the literature to locate refueling stations optimally in road transportation systems can be categorized in three classes (Upchurch and Kuby 2010). The first class is related to the ***p*-median model**, one of the most popular models in facility location theory. The objective of the model is to find the optimal locations of p facilities that minimize the sum of weighted distances between demand nodes and facilities (Francis et al. 1991). The p-median model has been applied to determine where to locate refueling alt-fuel refueling stations to be close to alt-fuel vehicle markets (Greene et al. 2008, Lin et al. 2008, Nicholas and Ogden 2006). The second approach is to locate alt-fuel stations on roads with **high traffic flows**. Assuming a limited vehicle travel range and a maximum distance between two refueling stations, Melendez and Milbrandt (2005) determined the station placements on interstate highways in areas with high traffic flows. However, this approach has a multiple counting problem that the same traffic flows could be counted multiple times even though a vehicle may be refueled once. Lastly, the third approach **maximizes path flows captured by stations** along the paths for a given number of the stations (Berman et al. 1992, Hodgson 1990, Kuby and Lim 2005). These models can avoid the multiple counting problem because each flow is captured by a specific set of the station. This approach has been applied to real-world networks at both the metropolitan scale and state scale in Arizona (Kuby et al. 2004) and Florida (Kuby et al. 2009).

To promote commercialization of alt-fuel vehicles, a sufficient number of initial alt-fuel refueling stations are necessary (Melaina 2008). However, since investment in infrastructures for alt-fuel vehicles has financial risks, it is difficult for alt-fuel providers to carry forward an alt-fuel refueling station business for the public without cooperation. One of the candidate transportation networks to locate initial alt-fuel refueling stations successfully is toll roads operated by commissions. By building a cooperative system with alt-fuel providers and transportation companies (customers), the commissions can ensure a stable demand for alt-fuels in their roads. Toll roads in the northeastern United States, North Carolina, and Illinois form huge tree-networks, and they spread out to 15 states with a total length of about 1,680 miles (E-ZPass 2013). In this respect, this paper presents a model to determine optimal locations of alt-fuel refueling stations in a transportation tree-network. The first section describes the assumptions and the model that locates a given number of refueling stations optimally to maximize the number of vehicle (round) trips covered on the network. In the next section, by analyzing a transportation network of toll roads, our model provides optimal locations of alt-fuel refueling stations. The last section suggests directions for future research.

Methodology

This section presents the development of a model to locate refueling stations for alt-fuel vehicles, e.g., compressed natural gas fueled vehicles. The model requires the number of trips for all alt-fuel vehicles being considered in a given time period for all origin-destination (OD) pairs in a tree-network. The objective of the model is to find the optimal location of refueling stations within a given sets of candidate locations that maximizes the number of trips covered by the stations. Since the distance that a vehicle can travel without refueling depends on its fuel tank capacity, a vehicle may need to be refueled multiple times along its travel path. Therefore, the conditions to cover a trip depend on the length of the path and some other conditions that are specified in the assumptions listed below.

(a) A trip between an OD pair is captured by a set of refueling stations if the vehicle can be refueled in its round trip.
(b) A vehicle enters the road network with at least half of its tank full.
(c) A vehicle leaves the road network with at least half of its tank full.
(d) The safe travel distance of a vehicle, R, is the maximum distance that the alt-fuel vehicle can travel without refueling. All vehicles have the same safe travel distance.

Let $G = (N, A)$ be a tree-network, where N is the set of nodes, including the set of all potential refueling station locations K and the set of intersections (interchanges) P, and A is the set of arcs representing paths between refueling stations and intersections. Note that $N = P \cup K$. Let $Q = \{(i, j) : i, j \in P, i < j\}$ be the set of OD pairs. Also, we denote by d_{ij} the distance between node i and node j. The safe travel distance R, and the flows and distances between all OD pairs are key parameters to determine proper locations of refueling stations because vehicles should be able to complete their round trips without running out of fuel. Thus, we first partition the set of OD pairs Q into four subsets depending on their travel distances:

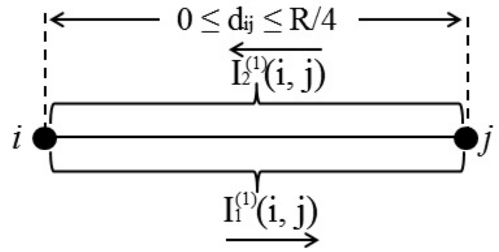
$Q^{(1)} = \{(i, j) \in Q: 0 < d_{ij} \leq R/4\}$: set of OD pairs of type 1,
$Q^{(2)} = \{(i, j) \in Q: R/4 < d_{ij} \leq R/2\}$: set of OD pairs of type 2,
$Q^{(3)} = \{(i, j) \in Q: R/2 < d_{ij} \leq R\}$: set of OD pairs of type 3,
$Q^{(4)} = \{(i, j) \in Q: R < d_{ij} \leq 3R/2\}$: set of OD pairs of type 4.

Note that, in this paper, we consider the maximum distance of OD pairs to be $3R/2$ because R, which is the average safe travel distance for alt-fuel vehicles driving on highways (Honda 2012), is 300 miles and the largest length of toll roads in the northeastern United States is about 450 miles. When distance between OD is greater than $3R/2$, OD pairs of a longer tree-network can be considered by generating new types through every additional R/2 miles.

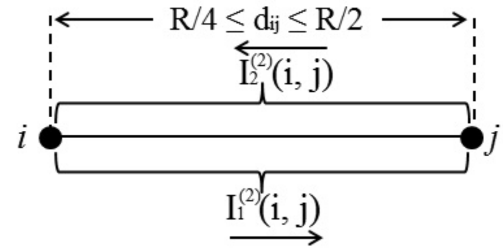
Description of feasible locations on four types of OD pairs
When R and the OD distance matrix are given, we can establish conditions to determine whether or not a round trip between an OD pair is covered. Since we consider the complete round trip between each (i, j) pair, the trip needs to consider two different sets of station locations, one for the path $i \rightarrow j$, and a second one for the path $j \rightarrow i$. Thus, the following sets are used to establish coverage between OD pairs in the four partitions of set Q.

$I_1^{(1)}(i, j) = \{k \in K: k \text{ is located in path } i \rightarrow j\}, \forall (i, j) \in Q^{(1)}$,
$I_2^{(1)}(i, j) = \{k \in K: k \text{ is located in path } j \rightarrow i\}, \forall (i, j) \in Q^{(1)}$,
$I_1^{(2)}(i, j) = \{k \in K: k \text{ is located in path } i \rightarrow j\}, \forall (i, j) \in Q^{(2)}$,
$I_2^{(2)}(i, j) = \{k \in K: k \text{ is located in path } j \rightarrow i\}, \forall (i, j) \in Q^{(2)}$,
$I_1^{(3)}(i, j) = \{k \in K: k \text{ is located in path } i \rightarrow j, d_{ik} \leq R/2\}, \forall (i, j) \in Q^{(3)}$,

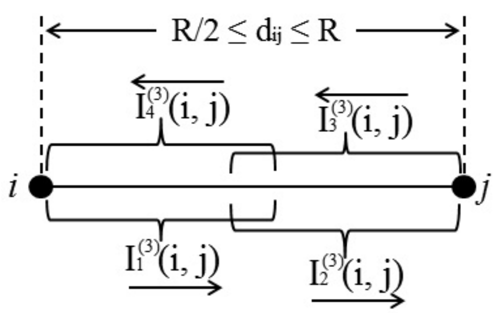
$I_2^{(3)}(i,j) = \{k \in K: k \text{ is located in path } i \to j, d_{kj} \le R/2\}, \forall (i,j) \in Q^{(3)}$,
$I_3^{(3)}(i,j) = \{k \in K: k \text{ is located in path } j \to i, d_{kj} \le R/2\}, \forall (i,j) \in Q^{(3)}$,
$I_4^{(3)}(i,j) = \{k \in K: k \text{ is located in path } j \to i, d_{ik} \le R/2\}, \forall (i,j) \in Q^{(3)}$,
$I_1^{(4)}(i,j) = \{k \in K: k \text{ is located in path } i \to j, d_{ik} \le R/2\}, \forall (i,j) \in Q^{(4)}$,
$I_2^{(4)}(i,j,k) = \{s \in K: s \text{ is located in path } k \to j, d_{ks} \le R, d_{sj} \le R/2\}, \forall k \in I_1^{(4)}(i,j), (i,j) \in Q^{(4)}$,
$I_3^{(4)}(i,j) = \{k \in K: k \text{ is located in path } j \to i, d_{kj} \le R/2\}, \forall (i,j) \in Q^{(4)}$,
$I_4^{(4)}(i,j,k) = \{s \in K: s \text{ is located in path } k \to i, d_{sk} \le R, d_{is} \le R/2\}, \forall k \in I_3^{(4)}(i,j), (i,j) \in Q^{(4)}$.



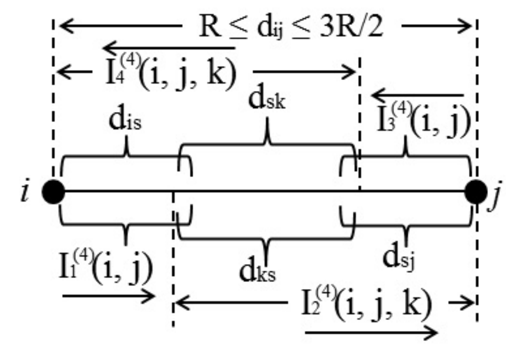
(a) Type 1



(b) Type 2



(c) Type 3



(d) Type 4

Figure 1 – Four different types of OD pairs

Based on Assumptions (a) to (d), we now state conditions under which the trips associated with the OD pairs in the four partitions of set Q are covered. **Type 1** trip, for all $(i,j) \in Q^{(1)}$, i.e., $0 < d_{ij} \le R/4$: trip (i,j) is covered if there is a refueling station on the path from i to j, or on the path from j to i. In this case it is not necessary to have a refueling station each way. Since d_{ij} is a small distance, the fuel consumption will be low, and Assumption (b) or (c) can be relaxed in the direction where no refueling station is available. Figure 1(a) shows that at least one refueling station location in sets $I_1^{(1)}(i,j)$ or $I_2^{(1)}(i,j)$ needs to be selected to cover the trip. **Type 2** trip, for all $(i,j) \in Q^{(2)}$, i.e., $R/4 < d_{ij} \le R/2$: trip (i,j) is covered if there is a refueling station on the path from i to j, and another refueling station on the path from j to i. Figure 1(b) shows at least one refueling station in set $I_1^{(2)}(i,j)$ and another in set $I_2^{(2)}(i,j)$ need to be selected to cover the trip. **Type 3** trip, for all $(i,j) \in Q^{(3)}$, i.e., $R/2 < d_{ij} \le R$. In this case, a trip from i to j is covered if there is a refueling station within $R/2$ miles of i and another station within $R/2$ miles of j. Note that, since the distance between i and j is at most R miles, a single refueling station within a distance of less than $R/2$ miles from i and j would satisfy both conditions. Similarly, the trip from j to i is covered if there is a refueling station within $R/2$ miles of j and another station within $R/2$ miles of i. Based on Figure 1(c), on the path from i to j, at least one refueling station in set $I_1^{(3)}(i,j)$ and another in set $I_2^{(3)}(i,j)$ need to be selected to cover the trip in this direction. A single refueling station common to both sets satisfies the requirement. A similar requirement is necessary on the path from j to i to cover the trip. Lastly, **Type 4** trip, for all $(i,j) \in Q^{(4)}$, i.e., $R < d_{ij} \leq 3R/2$. In this case, a trip from i to j is covered if there is a refueling station within $R/2$ miles of i. Let k be the position of that station. Then, there must be another station within R miles of k and $R/2$ miles of j. Similar conditions have to be imposed in order to cover the trip from j to i. Given the sets in Figure 1(d), the trip from i to j is covered if a refueling station in set $I_1^{(4)}(i,j)$ and another in set $I_2^{(4)}(i,j,k)$ are selected to cover the path in this direction. Note that k is the refueling station selected in $I_1^{(4)}(i,j)$. A similar requirement is necessary for the trip from j to i.

Model formulation

The objective of our mixed integer programming (MIP) model is to maximize the traffic flow that can be covered by p refueling stations located along the tree-network. We first introduce a binary variable x_k , $k \in K$, which equals 1 if refueling station k is selected, and 0 otherwise. Also, we define binary variable y_{ij}, which equals 1 if traffic flows between i and j, $f_{ij} + f_{ji}$, are captured by sets of refueling stations, and 0 otherwise. In particular, for type 4 trip, binary variable y_{ijk} is introduced which equals 1 if a refueling station location k in set $I_1^{(4)}(i,j)$ or $I_3^{(4)}(i,j)$ is selected and then refueling station locations in set $I_2^{(4)}(i,j,k)$ or $I_4^{(4)}(i,j,k)$ is selected, which means that the flow from i to j, f_{ij}, is captured by the two refueling stations k and s. Otherwise, $y_{ijk} = 0$. Based on these decision variables, the MIP model is formulated:

$$\text{Max Traffic Flow} = \sum_{(i,j)\in Q}(f_{ij} + f_{ji})y_{ij} \ , \tag{1}$$

Subject to

$$\sum_{k\in I_1^{(1)}(i,j)\cup I_2^{(1)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(1)} \ , \tag{2}$$

$$\sum_{k\in I_1^{(2)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(2)} \ , \tag{3}$$

$$\sum_{k\in I_2^{(2)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(2)} \ , \tag{4}$$

$$\sum_{k\in I_1^{(3)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(3)} \ , \tag{5}$$

$$\sum_{k\in I_2^{(3)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(3)} \ , \tag{6}$$

$$\sum_{k\in I_3^{(3)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(3)} \ , \tag{7}$$

$$\sum_{k\in I_4^{(3)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(3)} \ , \tag{8}$$

$$\sum_{k\in I_1^{(4)}(i,j)} x_k \geq y_{ij} \ , \qquad \forall (i,j) \in Q^{(4)} \ , \tag{9}$$

$$\sum_{s\in I_2^{(4)}(i,j,k)} x_s + 1 - x_k \geq y_{ijk} \ , \qquad \forall k \in I_1^{(4)}(i,j), (i,j) \in Q^{(4)} \ , \tag{10}$$

$$x_k \geq y_{ijk} \ , \qquad \forall k \in I_1^{(4)}(i,j), (i,j) \in Q^{(4)} \ , \tag{11}$$

$$\sum_{k \in I_1^{(4)}(i,j)} y_{ijk} \geq y_{ij}\ , \qquad \forall (i,j) \in Q^{(4)}\ , \tag{12}$$
$$\sum_{k \in I_3^{(4)}(i,j)} x_k \geq y_{ij}\ , \qquad \forall (i,j) \in Q^{(4)}\ , \tag{13}$$
$$\sum_{s \in I_4^{(4)}(i,j,k)} x_s + 1 - x_k \geq y_{ijk}\ , \qquad \forall k \in I_3^{(4)}(i,j), (i,j) \in Q^{(4)}\ , \tag{14}$$
$$x_k \geq y_{ijk}\ , \qquad \forall k \in I_3^{(4)}(i,j), (i,j) \in Q^{(4)}\ , \tag{15}$$
$$\sum_{k \in I_4^{(4)}(i,j)} y_{ijk} \geq y_{ij}\ , \qquad \forall (i,j) \in Q^{(4)}\ , \tag{16}$$
$$\sum_{k \in K} x_k = p\ , \tag{17}$$
$$x_k \in \{0,1\}, \forall k \in K \tag{18}$$
$$y_{ij} \in \{0,1\},\ \forall (i,j) \in Q\ ; y_{ijk} \in \{0,1\}, \forall k \in I_3^{(4)}(i,j) \cup I_4^{(4)}(i,j), (i,j) \in Q^{(4)} \tag{19}$$

The objective function (1) maximizes the traffic flow that can be captured by p refueling stations located between all OD pairs. Constraint set (2) is related to the trips for OD pairs type 1. If at least one refueling station is selected on the path from i to j or on the path from j to i, the trip between i and j can be captured, i.e., $y_{ij} = 1$. Similarly, the trips for OD pairs type 2 and type 3 can be detected through constraint sets (3) and (4), and constraint sets (5) to (8), respectively. Finally, constraint sets (9) to (16) are used to identify the trips covered by OD pairs type 4. In particular, constraint sets (10) and (14) are logical constraints. That is, if one of refueling stations in set $I_1^{(4)}(i,j)$, k, is selected, then another stations in set $I_2^{(4)}(i,j,k)$, s, should be selected to capture the trip from i to j by these two stations. Similarly, the trip from j to i can be covered by constraint set (14). In addition, we use constraint (17) to make the model select exactly p refueling stations. Lastly, all the decision variables are restricted as binary by constraint sets (18) and (19).

Application to Pennsylvania turnpike network

The Pennsylvania (PA) turnpike comprises several interstate highways and PA state routes. In this section, the proposed methodology is applied to set up initial alt-fuel refueling stations in the PA turnpike mainline between Pittsburgh and Philadelphia (I-70, I-76, and I-276) and the North East PA extension between Philadelphia and Scranton (I-476). From now on, these two segments are called the PA turnpike. The PA turnpike forms a tree-network and has 44 active interchanges. The distance between Pittsburgh and Scranton is approximately 400 miles, which is the longest distance of the PA turnpike. Currently, there are 17 open service plazas and several other service plazas are temporarily or permanently closed in the PA turnpike (Pennsylvania turnpike 2013). In this application, we consider 19 potential locations for alt-fuel refueling stations, including 17 open and 2 temporarily closed service plazas. These service plazas consist of 16 single-access stations and 3 dual-access stations, meaning that vehicles cannot be refueled at the single-access stations when traveling in the opposite direction and the dual-access stations can refuel vehicles in both directions. The service plazas are placed on paths only between certain pairs of consecutive interchanges. Thus, if none of these potential station locations falls between the entrance and exit points of a particular trip, then the trip cannot be covered. Therefore, the PA turnpike can be simplified by aggregating subsequences of interchanges that do not have any service plaza between them. As an approximation, each subsequence can be replaced by a single aggregated interchange which location can be calculated as the weighted average of the original interchange locations, where the weights are the annual entrance/exit traffic counts at each interchange. In this analysis, effective coverage for a particular set of refueling station locations indicates the proportion of traffic flows that can be refueled with respect to the total flows that can be captured by all 19 station locations when a station is placed in each one of the 19 locations. On the other hand, overall coverage is defined as the proportion of traffic flows that can be refueled with respect to the total flows on the PA turnpike.

Since it is often difficult to obtain real world origin and destination flows, in this paper, we have generated random average daily flows following a normal distribution with mean of 120 and standard deviation of 120 for each origin and destination pair. Based on the randomly generated flows, the interchanges are aggregated except for interchange 30. Interchange 30 is a special case because the PA turnpike mainline (I-70, I-76, and I-276) and the North East PA extension (I-476) intersect at this interchange. Also, note that aggregated interchanges 29, 31, and 34 are aggregated by refueling stations 28, 32, and 35, respectively. Even though most vehicles have long distance trips and pass by a service plaza, some vehicles have short distance trips within just one of the aggregated interchanges or within set of aggregated interchanges 29, 31, 34 and interchange 30. In this case, there is no service plaza among these interchanges, thus these vehicles cannot be refueled on the PA turnpike. Figure 2 shows a tree-network of the simplified PA turnpike network with 19 desirable refueling station locations and 19 (aggregated) interchanges.

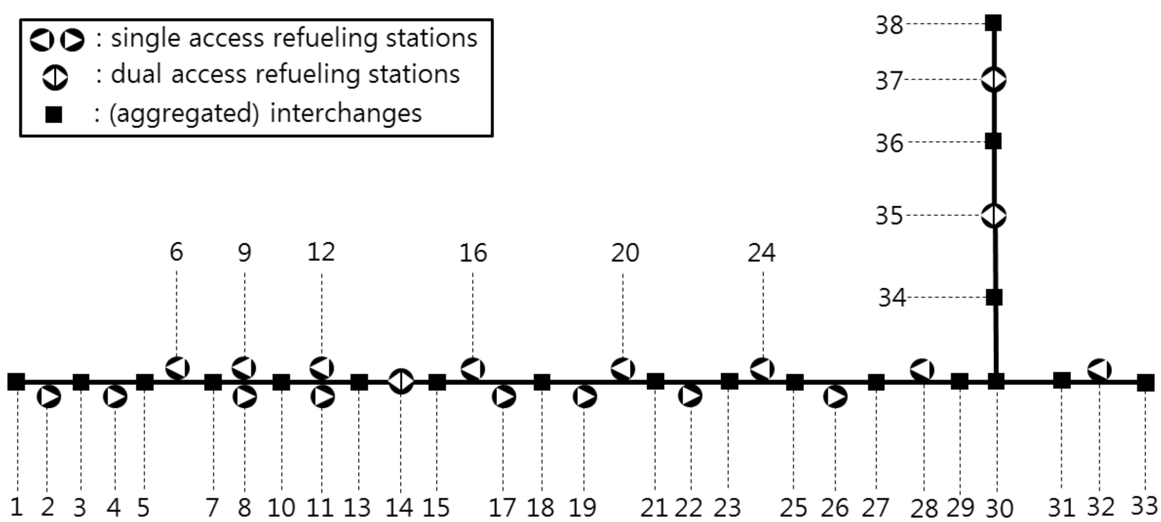


Figure 2 – PA turnpike consisting of aggregated interchanges and refueling stations

We first apply the model considering a safe travel distance of 300 miles, which is a conservative safe travel distance for alt-fuel vehicles. The number of refueling stations to be located varies from 1 to 15, in increments of 1. The reason we stop at 15 is because the entire traffic flow on the PA turnpike can be covered with 15 stations. Table 1 shows the results about captured flow, effective coverage, and overall coverage for different number of refueling stations. Figure 3 describes the network with 5 optimally located refueling stations (stations 14, 20, 26, 32, and 35). Two of them are dual access and the rest of them are single access refueling stations. These stations can cover an average daily flow of 150,076 trips, which is about 83.45% of the trips that can be covered with 15 stations (179,829 trips). The overall coverage of 79.38% is calculated with respect to the average daily traffic flow using the PA turnpike (189,066 trips).

Next, we analyze the effect of safe travel distance to captured flow and coverage on the network because better alt-fuel efficiency is expected in the near future. Three different safe travel distances (R=300, R=450, and R=600) are considered to find optimal refueling stations. The effective coverage as a function of the number of refueling stations for each safe travel distance is displayed in Figure 4. The two functions for R=450 and R=600 are a concave functions representing diminishing marginal return (coverage) for each additional station, meaning that the percentage of traffic flows that can be refueled by the additional station increases at a slower rate. Also, the increments of the two functions are similar until p = 12 and become the same when p is greater than 12. This can explain that effective coverage is insensitive when the safe travel distance is longer than 450 miles and the number of refueling stations increases.

Table 1 – Result with respect to different number of refueling stations when R = 300 miles

Num. of stations	Captured Flow (trips/year)	Effective Coverage (%)	Overall Coverage (%)	Num. of stations	Captured Flow (trips/year)	Effective Coverage (%)	Overall Coverage (%)
1	28,437	15.81	15.04	9	174,308	96.93	92.19
2	67,424	37.49	35.66	10	176,535	98.17	93.37
3	125,192	69.62	66.22	11	177,820	98.88	94.05
4	141,288	78.57	74.73	12	178,584	99.31	94.46
5	**150,076**	**83.45**	**79.38**	13	179,278	99.69	94.82
6	156,333	86.93	82.69	14	179,641	99.90	95.01
7	164,696	91.58	87.11	15	179,829	100.00	95.11
8	170,460	94.79	90.16				

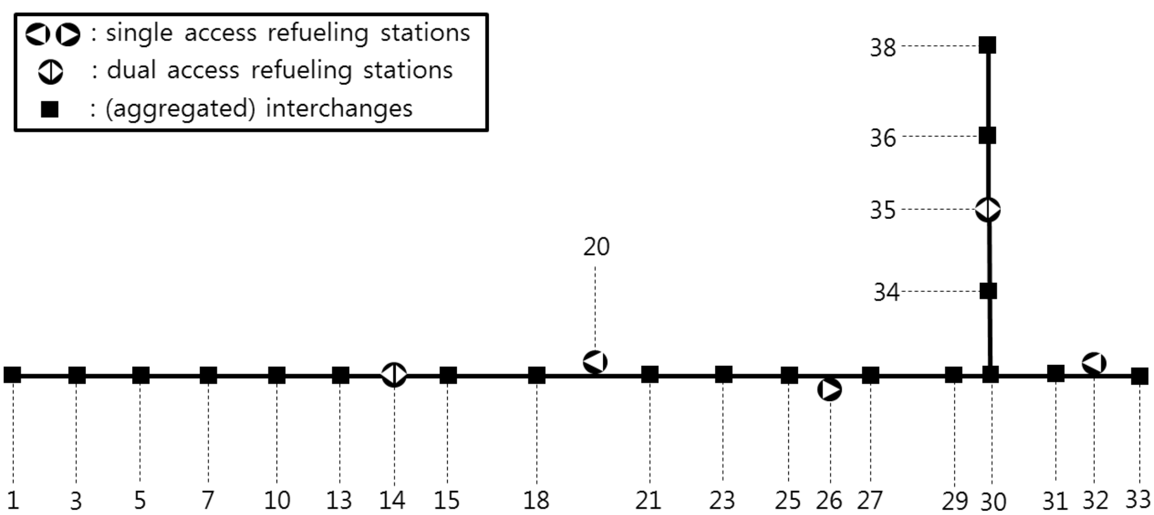


Figure 3 –Optimally located 5 refueling stations on a tree-network when R = 300 miles

Figure 4 also shows that the function for R=300 has a different increasing pattern compared to the functions for the other two safe travel distances. When R=300, the effective coverage speeds up from p = 1 to 3 and from p = 5 to 7, but slows down in the other cases. It is particularly interesting the case where the number of refueling stations increases from 1 to 3. The reason is that the set of candidate station locations includes both single-access and dual-access refueling stations. When p = 1, the model selects a dual-access refueling station (station #14) to be able to capture more flow than any single-access station. Next, when p = 2, the model again selects two dual-access refueling stations located far apart from each other. In our example, when p = 2, dual-access refueling stations #14 and #35 are selected. Note that there are no dual-access refueling stations near to the set of aggregated interchanges 29, 31, and 34, and interchange 30, where the PA turnpike mainline and the North East PA extension intersect. Also, when p = 2, no single-access refueling stations can be selected to capture traffic flow in this area, because of the requirement to cover vehicle round trips. However, when p = 3, one dual-access refueling station can be replaced by two single-access refueling stations near this area to capture more trips. In our example, the model selects one dual-access refueling station (station #14) and two single-access refueling stations (stations #24 and #26) when p = 3.

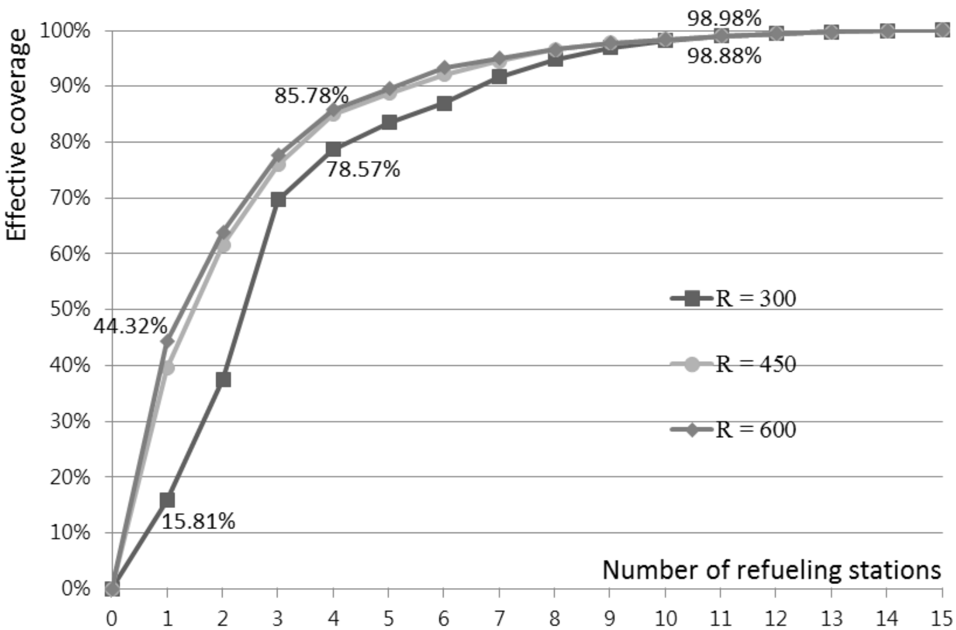


Figure 4 – Comparison of results with different safe travel distance of 300, 450, and 600 miles

Conclusion

This paper has introduced a new discrete location model to maximize the total flow captured by a given number of refueling stations on a tree-network for alt-fuel vehicles. A possible extension of the model is to locate additional stations on a network when there is already an initial alt-fuel refueling station infrastructure. Our model can be extended to consider the initial set of station locations, to determine new locations that avoid retail competition, and maximize the coverage of additional traffic flows. Another direction for future research is to eliminate the assumption that no predetermined set of potential station locations is given and allow the model to locate the stations anywhere in the tree-network.

Since alt-fuel vehicles traveling through interstate highways, toll roads, and other routes have one of the most important roles for environmental sustainability in ground logistics, infrastructures including refueling stations should be designed wisely to consider the interest of potential users such as transportation and distribution companies.

References

Berman, O., R. C. Larson, N. Fouska. 1992. Optimal location of discretionary service facilities. *Transportation Science* **26**(3): 201–211.

Crowe, P. 2012. 5 Percent market share for EV, hybrid and diesel by 2015. *HybridCars*. Available at http://www.

hybridcars.com/5-percent-market-share-ev-hybrid-diesel-2015-52080 (accessed date January 21, 2013).
E-ZPass. 2013. About E-ZPass. *E-ZPass Interagency Group*. Available at http://www.e-zpassiag.com/ (accessed date February 8, 2013)
Francis R.L., L. F. McGinnis, Jr., J. A. White. 1991. *Facility Layout and Location: an Analytical Approach*. Prentice Hall, New Jersey.
Greene, D. L., P. N. Leiby, B. James, J. Perez, M. Melendez, A. Milbrandt, S. Unnasch, D. Rutherford, M. Hooks. 2008. Analysis of the transition to hydrogen fuel cell vehicles and the potential hydrogen energy infrastructure requirements. *Oak Ridge National Laboratory*. Report No. ORNL/TM-2008/30.
Hodgson, M.J., 1990. A flow capturing location allocation model. *Geographical Analysis* **22**(3): 270–279.
Honda. 2012. EPA mileage estimates. *Honda Civic Natural Gas.* Available at http://automobiles.honda.com/civic-natural-gas/specifications.aspx?group=epa (accessed date February 3, 2013)
Koffman, J. 2013. Los Angeles county Metropolitan Transportation Authority awards New Flyer a contract for up to 900 40-foot buses. *New Flyer.* Available at http://www.newflyer.com/index/2013_02_07_los_angeles_award (accessed date February 13, 2013).
Kuby, M. J., S. Lim, K. Wang. 2004. A model for optimal location of hydrogen refueling stations: an Arizona case study. *In: Proceedings of the National Hydrogen Association,* Los Angeles, April 26-30.
Kuby, M.J., S. Lim. 2005. The flow-refueling location problem for alternative-fuel vehicles. *Socio-Economic Planning Sciences* **39**(2): 125–145.
Kuby, M., L. Lines, R. Schultz, Z. Xie, J.-G. Kim, S. Lim. 2009. Optimization of hydrogen stations in Florida using the flow-refueling location model. *International Journal of Hydrogen Energy* **34**(15), 6045–6064.
Lin, Z., J. Ogden, Y. Fan, C.-W. Chen. 2008. The fuel-travel-back approach to hydrogen station siting. *International Journal of Hydrogen Energy* **33**(12): 3096–3101.
Melaina, M., J. Bremson. 2008. Refueling availability for alternative fuel vehicle markets: Sufficient urban station coverage. *Energy Policy*. **36**(8): 3223-3231.
Melendez, M., A. Milbrandt. 2005. Analysis of the hydrogen infrastructure needed to enable commercial introduction of hydrogen-fueled vehicles. *National Renewable Energy Laboratory*. PR-540-37802: 1–32.
Nicholas, M. A., J. Ogden. 2006. Detailed analysis of urban station siting for California hydrogen highway network. *Transportation Research Record* **198**(3), 121–128.
Pennsylvania Turnpike. 2013. Turnpike service plazas. *Pennsylvania Turnpike Commission.* Available at http://www.paturnpike.com/geninfo/srvcplaza/svcplazas.aspx (accessed date January 10, 2013).
Upchurch, C., M. J. Kuby. 2010. Comparing the p-median and flow-refueling models for locating alternative-fuel stations. *Transport Geography* **18** (6): 750–758.