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Location of Refueling Stations for Geographically Based Alternative-Fuel Vehicle Demand

Jong-Geun Kim*

Abstract : The initial market of alternative-fuel vehicle (AFV) will show geographically uneven distribution due to AFV's high price, and thus efficient location model should consider spatial variation of demand. This paper estimates AFV trips by incorporating an AFV demand estimation model with origin-destination (OD) trips. The estimates are the input for the flow-refueling location model that maximizes the OD flows that can be refueled by the given number of stations considering AFV's limited range per refueling. A scenario analysis is conducted by varying assumptions in estimating demands and AFV acceptance rate. Optimal location alternatives for Orland metropolitan area are provided and results are compared.

Key Words : Uneven demand, Alternative-fuel vehicle, Refueling station, Optimal location, Trip, FRLM

1. Introduction

After several decades of discussion and false starts, policy makers, automobile manufacturers, and fuel providers appear now to be seriously developing road maps for a transition from a petroleum-based transportation system to a more sustainable system utilizing alternatives such as biofuels, natural gas, electricity, and hydrogen. One of the major barriers to the success of alternative-fuel vehicles (AFVs) is the lack of infrastructure for producing, distributing, and delivering alternative fuels (Greene, 1996; Ogden, 1999; NAS, 2004; Melendez, 2006b). Given that refueling stations are more noticeable to the consumers than other types of infrastructure, the availability of alternative-fuel stations will accelerate the market acceptance of AFVs.

Based on a survey of the literature and of experts involved in alternative fuel deployment, Melendez (2006a) identified the following as four major barriers of infrastructure development: lack of availability of alternative-fuel stations; the high construction costs of alternative-fuel stations; the high costs of AFVs; and the relatively short range of

*Postdoctoral Fellow of National Research Foundation of Korea, Seoul National University

AFVs between refueling. The short range of AFVs implies that drivers may need to stop multiple times in order to finish their trips. In addition, given the high costs of AFVs, the consumers' likelihood to purchase AFVs will be geographically uneven.

A facility location model for alternative-fuel refueling stations, therefore, should consider both AFV's inherent short range per refueling and the spatial variations of consumer demand for AFVs. The Flow Refueling Location Model (FRLM) by Kuby and Lim (2005) determines the location and combination of refueling stations to be built in order to maximize the flows covered by a given number of facilities, assuming that drivers "stop along their way" to refuel. The model takes into account the paths of drivers from their origins to destinations (OD), the amount of flows on the paths, and the driving range of vehicles. However, the uneven spatial pattern of AFV purchase likelihood is not explicitly reflected on the model. For this end, Melendez and Milbrandt (2006a) of the National Renewable Energy Laboratory used a Geographic Information System (GIS) to model the potential hydrogen demand using demographic characteristics and policy variables by census boundary. This approach has not been widely used in estimating the flow volumes of AFVs for recommending optimal refueling station sites.

This paper integrates geographically uneven demand for AFV into the flow-based location model to account for early AFV demand pattern in optimizing a network of AFV refueling stations. Given that flow-based location models require data on flow volumes of OD pairs, a method to weight the flow volumes to reflect estimated demand is needed. Such weighted flows can be used as input for the location models, and as a result refueling service can be provided at more convenient locations for the likely early AFV drivers. This research proposes a method to integrate AFV demand and OD flow volume and explores its results.

Next section explains the flow capturing and refueling location models. Section 3 reviews previous approaches to estimating AFV demand using GIS. Section 4 describes the data used; discusses a modified method to estimate AFV demand; presents a framework to analyze the sensitivity of the estimation model; and proposes a process to integrate estimated demand density and trip flows. The results are discussed in Section 5, and it is followed by summary and conclusions in Section 6.

2. The Flow Capturing and Refueling Location Model

Recently there has been increasing research interest in modeling flow-based demand that is expressed by flows travelling on paths between OD pairs in a traffic network. The flow-intercepting location model (FILM) sites facilities within a transportation network and explicitly considers the flow over the network arcs. Refueling stations (Kuby and Lim, 2005), convenience stores, and automated teller machines, vehicle inspection stations (Hodgson *et al.*, 1996), pickup locations for grocery purchased online (박종수 · 이금숙, 2011), and billboards (Hodgson and Berman, 1997) are examples of flow-dependent facilities. Hodgson (1990) and later (independently) Berman, Larson, and Fouska (1992) designed the Flow Capturing (Intercepting) Location Model (FCLM, FILM) to locate these kinds of flow-dependent facilities. The objective of this model is to locate the facilities so as to maximize the total flow of customers that are "intercepted" during their travel. The basic model was extended to provide full coverage (Wang and Lin, 2009), to consider relative location of facilities along the path (Zeng *et al*., 2009), or to account for congestion or probabilistic flows (Berman *et al*., 1995).

Kuby and Lim (2005) extended the FCLM to locate a given number of facilities to maximize the number of flows they can refuel. The new model (FRLM: Flow Refueling Location Model) is intended to deal with location of refueling stations for range-limited vehicles, with vehicle range being the key element. A limited driving range means that a single facility anywhere on the path cannot necessarily succeed in refueling a trip on a given shortest path—a combination of facilities may be needed. Whereas the FCLM counts a flow as captured if a facility is located anywhere along the path of the flow because one stop will satisfy consumers' need, the FRLM regards a flow as refueled only when a satisfactory number of facilities (stations) are spaced properly along the path because consumers on the path need multiple stops. A mixed-integer linear programming (MILP) formulation of the FRLM is presented as follows:

Formulation of the FRLM

$$\text{Maximize } Z = \sum_{q\in Q} f_q y_q \qquad (1)$$

subject to

$$\sum_{h\in H_q} v_h \geq y_q \quad \forall q\in Q \qquad (2)$$

$$x_k \geq v_h \quad \forall h\in H,\ k\in K_h \qquad (3)$$

$$\sum_{k\in K} x_k \geq p \qquad (4)$$

$$x_k,\ v_h,\ y_q \in \{0,1\} \quad \forall k\in K,\ h\in H,\ q\in Q \qquad (5)$$

where:

Indices

q=a particular O-D pair (the shortest path for each pair)

k=a potential facility location

h=index of combinations of facilities

Sets

Q=set of all O-D pairs

K=set of all potential facility locations

K_h=set of facilities k that are in combination h

H=set of all potential facility combinations

H_q=set of facility combinations h that can refuel path q

Parameters

p=the number of facilities to be located

f_q=flow between O-D pair q

Decision Variables

x_k=1 if there is a facility at location k, 0 if not

y_q=1 if f_q is captured, 0 otherwise

v_h=1 if all facilities in combination h are open, 0 otherwise

The objective function (1) locates p facilities to maximize the total flow that can be refueled. Constraints (2) ensure that for an OD pair q to be open, at least one combination of facilities h has to be open. Determination of the eligible combination is exogenous in that it is generated outside the model and depends on the network structure and the given vehicle range. An algorithm to generate the combination h for each path q and other considerations such as obtaining a tighter set H by removing supersets are discussed in Kuby and Lim (2005). Constraints (3) bind v_h to one only after all the facilities in combination h are open. Constraint (4) requires exactly p facilities to be open. Constraints (5) are integrality constraints. The facility location variables xk are defined as binary variables in (5).

To improve the FRLM's solution quality for a given network, Kuby and Lim (2007) proposed methods to add candidate locations along arcs. Upchurch *et al*. (2009) extended the FRLM to consider capacity of facilities while Kim and Kuby (2012) allowed the drivers to deviate from their shortest paths. Given that solving a FRLM problem instance to the optimality is computationally challenging, heuristic algorithms (Lim and Kuby, 2010) and a new formulation of the model (Capar *et al*., 2010) were also proposed. The FRLM was used to provide strategic station locations for in Florida at two different scales of analysis: metropolitan Orlando and statewide (Kuby *et al*., 2009).

3. Geographically Uneven Demand for AFV

Previous research, without available data on flow volume of AFVs, devised methods to estimate consumer demand for AFVs incorporating a variety of assumptions and rules. In terms of their application to AFV infrastructure planning, the models can be grouped into five categories according to modeling method employed: logistic choice models (Greene, 1996; 2001; Greene and Bowman, 2007; Greene *et al*., 2008; Keles *et al*., 2008), supply chain models (Ogden, 2004), system dynamics simulation models (Welch 2006; 2007; 2007), GIS approaches studies (Kitamura and Sperling, 1987; Melaina, 2003; Melaina, 2005; Melendez and Milbrandt, 2005; Ni *et al*., 2005; Melaina and Bremson, 2006; Melendez and Milbrandt, 2006a; Melaina and Bremson, 2008), and operation research (OR) facility location models.

Unlike most models that assume spatially uniform distribution of demand, Melendez and Milbrandt (2006a) of the National Renewable Energy Laboratory (NREL) used GIS to estimate consumer demand for hydrogen (H2) vehicles across the US based on geographical distribution. The demand was assumed to be proportional to the estimated "composite score" of a spatial unit (Figure 1). To obtain the scores, they first identified key attributes affecting consumer acceptance of hydrogen vehicles. Such attributes include income, education level, the number of vehicles they own, and policy. Each attribute was standardized by assigning a classification rank score, and weights were assigned to each attribute to acquire composite score. The attributes/variables they used and the weights on the variables were based on the consensus judgments of a panel of experts convened by NREL for this purpose. This result of the linearly weighted sum was expected to represent relative likelihood of a consumer's purchasing a hydrogen vehicle.

Melendez and Milbrandt (2006)'s method is based on a suitability analysis (McHarg, 1969) and map algebra (Tomlin, 1990). One of the analytic issues in their estimation model is the possibility of errors introduced by integrating data that are based on different zoning systems such as census tracts, traffic analysis zones, and regularly spaced polygons. The fundamental reason for this problem is the fact that continuous space is usually represented in discrete forms, which results in loss of geographic details (Goodchild, 1979; Murray, 2003). As a matter of fact, they converted nationwide census tracts into a raster format by applying a 20 by 20 mile grid, and thus their approach is prone to the modifiable areal unit problem (Openshaw and Taylor, 1981). The implicit assumption in doing so is that households are evenly distributed within each grid, which may not be the case considering

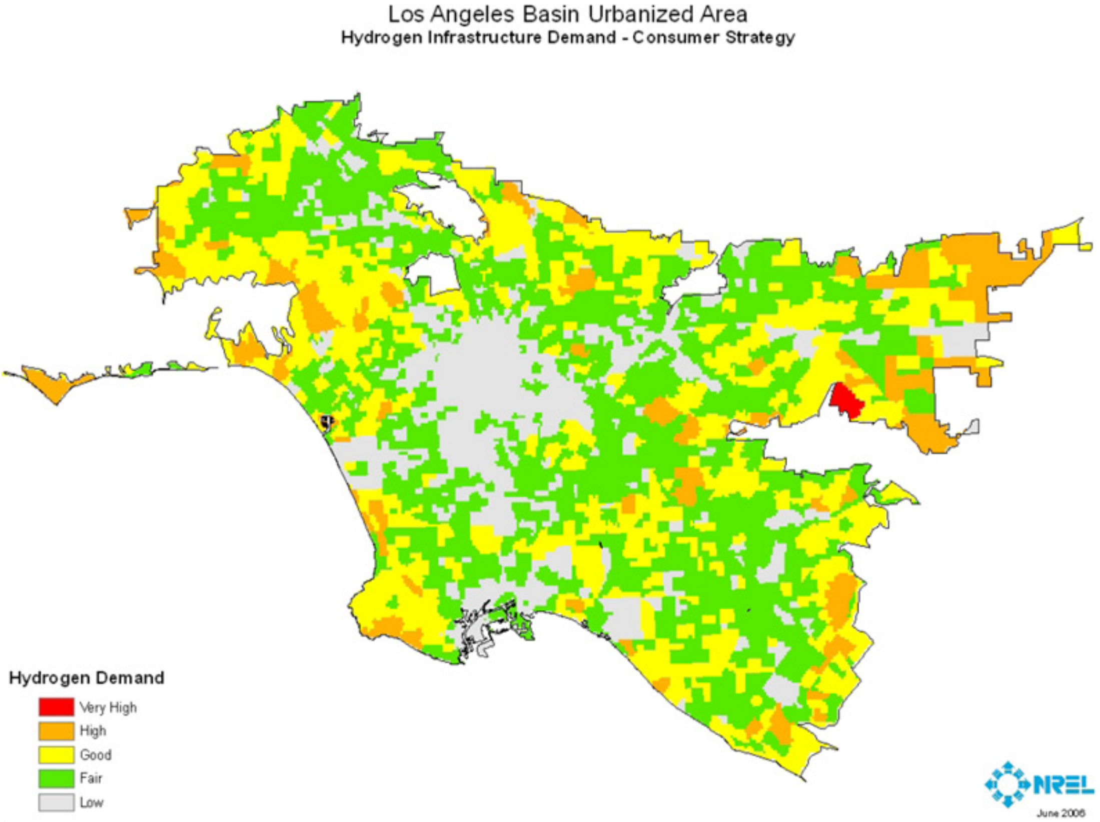

Figure 1. An Example of Geographically Uneven Demand for Alternative Fuel

Source: Melendez and Milbrandt. 2006. 16

the real world population distribution and the relatively large size of the grid. Given that any zoning system cannot contain all the details, a method that reduces or eliminates errors in integrating attributes from different zoning systems is required. Goodchild and Lam (1980) referred to this as the areal interpolation problem and suggested a straightforward method. Furthermore, Goodchild, Anselin, and Deichmann (1993) discussed and suggested a framework that utilizes complementary information to derive control zones where a uniform distribution of source zone attributes is assumed. Gan (1994) proposed that network density can be used as the complementary data. In this paper, we suggest that using the smallest unit as consistently as possible in a vector format and apply an areal interpolation method if needed.

4. Methods

1) Data

This research used real-world road network and census data[1)] of year 2000 for the Orlando metro-

Table 1. Spatial Data Layers

Layer	Description
OD Centers	Aggregated TAZ centers
Junctions	Defined by analysts at all intersections of arcs
Candidate Facilities	Combines the OD and junctions layer
Road Network	Florida Department of Transportation layers. Aggregated.
Shortest Path Routes	Least-cost paths were generated based on Dijkstra's algorithm. TAZs are the input nodes and maximum speed of arc is the cost.
Demographic Data	2000 US Census data collected by census tracts

politan area (Lines *et al.*, 2007; Kuby *et al.*, 2009). Figure 2 shows the study area. The data used for building the network for Orlando and estimating the alternative-fuel demand-weighted flows were collected from many sources including Florida DOT, US Census Bureau, and Department of Energy, and ESRI Inc. (Table 1). The raw street network data were investigated to ensure no topological error exists. Traffic Analysis Zones (TAZs) were aggregated into 102 areas and a single OD point was selected to represent each TAZ. The OD points were located at intersections of major roads or traffic-inducing business centers. Least-time paths for all OD pairs were generated using the posted speed limits of the network arcs as costs. TAZ trip flows obtained from FDOT travel demand models were aggregated and assigned to the least-cost paths assuming traffic flows occur on the shortest paths. Selection of the TAZs to be merged and location of OD centers involved extensive discussion among participant scientists of the FHI project and iterative calibration of data (Kuby *et al.*, 2009). Demographic data of year 2000 collected by census block were obtained from US Bureau of Census.

2) Estimation of Alternative Fuel Demand

Alternative-fuel demand was estimated using geographic information system and multi attribute decision making analysis based on NREL's approach. But it was modified for flow-based models. Adapted and NREL's original GIS model are shown in Table 2. Specific differences are detailed as below.

The flow-based location models require flow volume between OD pairs, but the NREL method was developed to estimate the total demand in a zone, and therefore the estimates need to be revised on a per capita basis so that they can be multiplied by the total number of trips between two zones. For example, an extensive attribute "total number of people with bachelor's degree" was changed to be an intensive attribute "percentage of people with bachelor's degree." Some of NREL's attributes were state-level (state incentives, zero-emission vehicle mandates, and hybrid registration) or not applicable to state of Florida (there are no counties of non-attainment status for air quality). These attributes were not used and their weights were re-assigned to

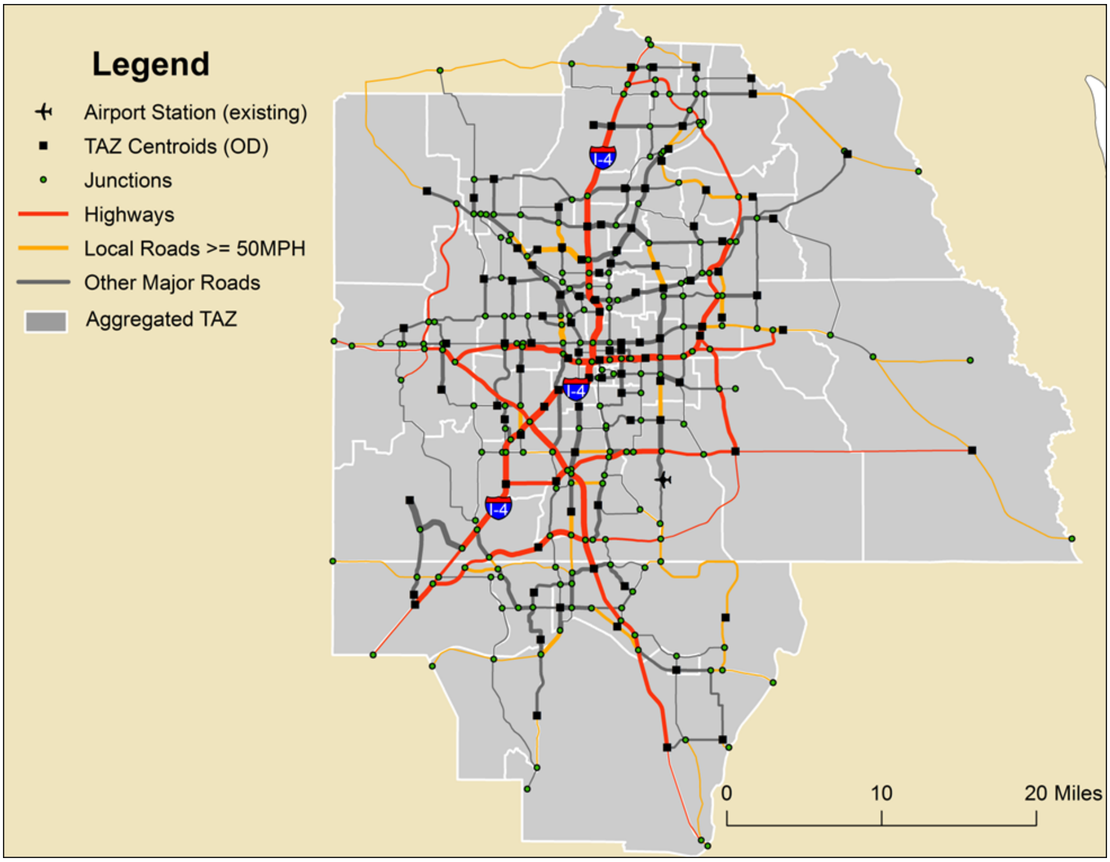

Figure 2. Orlando Metropolitan Area

other attributes.

Equal-interval classification was used instead of natural break method in assigning a standardized rank score to each census tract. The range of values was the maximum and minimum of all the tracts in Florida rather than those in Orlando area. The range was divided equally into seven classes. Figure 3 shows spatial distribution of the rank scores of each attribute.

Once the rank score for each attribute was obtained, it was multiplied by the weight assigned for each attribute. The base case weighting scheme is shown in Table 2. Weighted rank scores were summed for all attributes to obtain a composite rank score for each tract. The next two sub-sections present details of weighting scenarios and aggregation method.

3) Sensitivity Analysis on Demand Estimation Model

Sensitivity analyses were conducted to explore the sensitivity of AFV demand estimates to changes in attribute weighting scheme. Five scenarios—base case, equal weighting, policy emphasis, demographic emphasis, and no policy—were created and

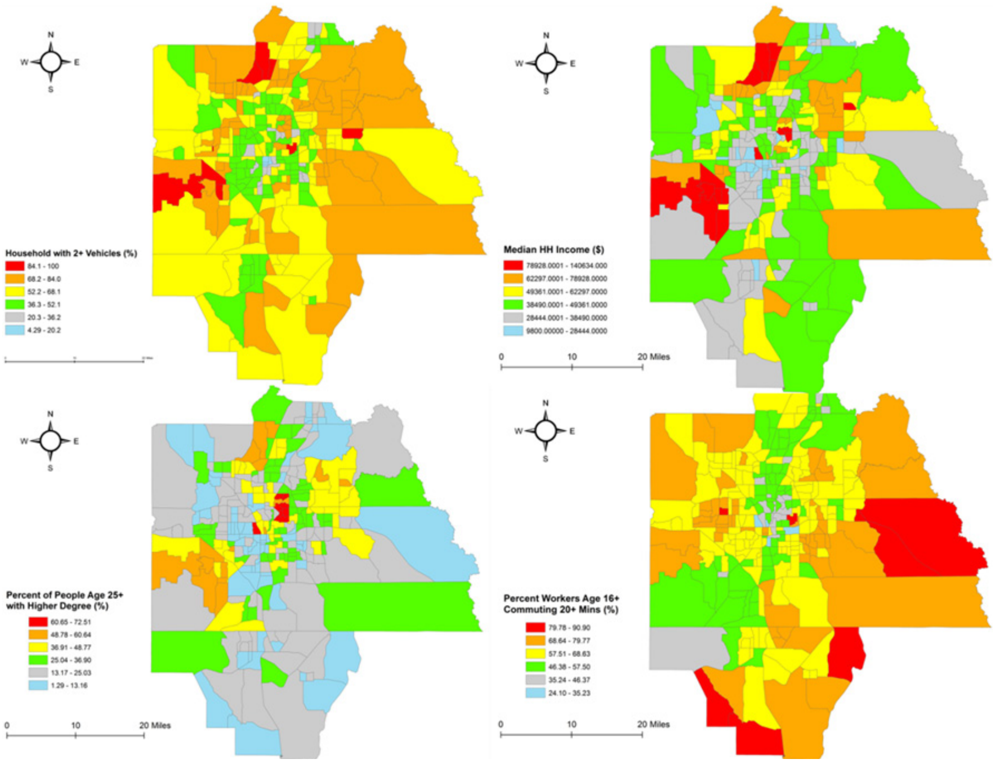

Figure 3. Spatial Distribution of Rank Scores

Table 2. Proposed Attributes Affecting AFV Demand and Rank Score Scheme

NREL Data Layer (weight - %)	NREL Classes	NREL Rank Score	Data Layer (base case weight - %)	Adapted Classes	Rank Score
Median Household Income (High - 15%)	54,955–86,901	7	Median Household Income (High - 23%)	172,515 – 200,001	7
	43,109–54,954	6		145,029 – 172,514	6
	36,152–43,108	5		117,542 – 145,028	5
	30,673–36,151	4		90,056 – 117,541	4
	24,748–30,672	3		62,569 – 90,055	3
	15,405–24,747	2		35,083 – 62,568	2
	0–15,404	1		0– 35,082	1
Number of People with Bachelor's Degrees (Medium - 10%)	943,877–1,770,650	7	***Percentage*** of People with Bachelor's Degrees (Medium - 18%)	75.7 – 100	7
	415,521–943,876	7		63.1 – 75.6	6
	228,465–415,520	6		50.5 – 63.0	5
	123,779–228,464	5		38.0 – 50.4	4
	51,563–123,778	4		25.5 – 37.9	3
	14,107–51,562	3		12.84 – 25.4	2
	0–14,106	2		0 – 12.83	1

NREL Data Layer (weight - %)	NREL Classes	NREL Rank Score	Data Layer (base case weight - %)	Adapted Classes	Rank Score
Number of Workers Age 16+ who commute more than 20 minutes (Medium - 10%)	908,659–1,572,668	7	***Percentage*** of Workers age 16+ who commute more than 20 minutes (Medium - 18%)	78.6 – 100	7
	418,740–908,658	7		66.3 – 78.5	6
	219,920–418,739	6		53.9 –66.2	5
	109,577–219,919	5		41.5 –53.8	4
	47,249–109,576	4		29.1 –41.4	3
	12,529–47,248	3		16.8 –29.0	2
	0–12,528	2		0 – 16.7	1
Number of Households with 2+ Vehicles (High - 15%)	179,419–312,470	7	***Percentage*** of Households with 2+ Vehicles (High - 23%)	80.8 – 100	7
	312,471–516,079	7		68.0 – 80.7	6
	118,941–179,418	6		55.2 – 67.9	5
	68,543–118,940	5		42.4 – 55.1	4
	30,240–68,542	4		29.6 – 42.3	3
	8,065–30,239	3		16.6 – 29.5	2
	0–8,064	2		0 – 16.5	1
Clean Cities Coalitions, by County (Medium - 10%)	Yes No	7 1	Clean Cities Coalitions, by County (Medium - 18%)	Yes No	7 1
Air Quality (Medium - 10%)	Severe Moderate Marginal None	7 6 5 1	Not applicable	Florida has no counties in non-attainment status for air quality	
State Incentives (Medium - 10%)	Yes None	5-7 1	Not applicable	(State level attribute, Not used because it is the same for all TAZs)	
ZEV Sales Mandate (Medium - 10%)	Yes No	7 1	Not applicable	(State level attribute, Not used because it is the same for all TAZs)	
Registered Hybrid Vehicles, by State (Medium - 10%)	1,551-2,875 686-1,550 372-685 169-371 68-168 12-67 0-11	7 6 5 4 3 2 1	Not applicable	(State level attribute, Not used because it is the same for all TAZs)	

Note: Modified from Melendez and Milbrandt (2006)

Table 3. Five Scenarios and Weighting Scheme

	Base Case (%)	Equal Weighting (%)	Demographic Emphasis (%)	Policy Emphasis (%)	No Policy (%)
VEH[a]	23	20	21	23	25
INC[b]	23	20	21	18	25
EDU[c]	18	20	21	18	25
COMM[d]	18	20	21	18	25
POL[e]	18	20	16	23	0

[a] Percentage of Households with 2+ Vehicles
[b] Median House-hold Income
[c] Percent-age of people with bachelor's degrees
[d] Percentage of workers age 16+ who commute more than 20 minutes
[e] Clean Cities Coalitions, by County

Table 3 shows weighting scheme for each scenario. Spatial clusters of the resulting rank scores were visualized using Local Moran's I statistics. The percentage of population falling in each demand category was also identified.

4) Aggregation of Demand Density

The spatial units of original data sources were different, and thus areal interpolation was needed to aggregate composite rank scores of tracts to TAZ boundary. In doing so, population density was used as intermediate control value. Aggregation of demand density calculated on each tract into TAZ needed special attention in choosing the interpolation method. The census zoning system is different than the TAZ zoning system. The delineation of TAZ boundaries is not only based on the census boundaries but also on a transportation network. The cardinality of the relationship between TAZ and tracts is not one-to-one or one-to-many. It is many-to-many cardinality; most tracts fall in one TAZ, but in some cases one tract may fall in multiple TAZs. Most tracts fall in only one TAZ, thus aggregation for such tracts is relatively easier; each demand density can be weighted by the tract's weight variable and then the average of all the weighted values from the tracts is assigned to the covering TAZ. The weight variable could be a constant, population, area, or any variable that can represent the relative importance of each tract. We think population serves better than area as a weight variable for demand density aggregation.

5) Weighting Flow Volume by Alternative Fuel Demand

The next step was an integration of composite rank scores with the trips between an origin-destination pair to obtain alternative-fuel demand weighted trips. Rank scores that were assigned for a pair of origin and destination were averaged. The average rank score for an origin-destination pair needed to be converted to a weighting factor between 0 and 1 using a transformation function (Figure 3). The resulting value (AFV adoption rate) was a multiplier to the trips to acquire alternative fuel demand weighted trips. Two transformation

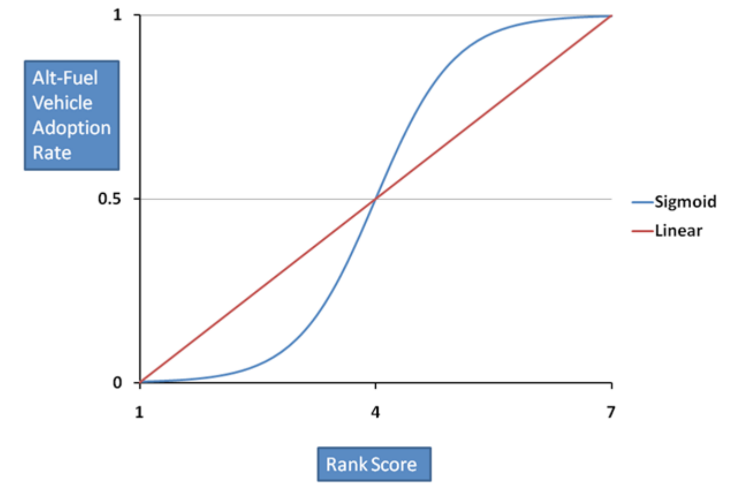

Figure 3. Transformation Function Curves

functions (linear and sigmoid) were employed and the resulting link flow patterns were compared. Note, however, AFV adoption rate should be interpreted in relative terms. For instance, if an OD pair *A* that has an average composite score of 5, which translates to 0.67 by the linear transformation function. There may be another OD pair *B* with the composite score of 2, and thus 0.167 for AFV adoption rate. In this case, we are estimating that four times as many customers are likely to adopt AFV for trips on *A* than for the trips on *B*, but we do not claim to estimate that 67% or 16.7% of drivers will adopt AFVs.

6) Solving the FRLM with AFV-Demand Weighted Scenarios

For each demand density score from five attribute weighting scenarios, two sets of weighted trip flows (linearly weighted and sigmoid function weighted) for each OD pair were assigned to its shortest time path. The FRLM was solved using greedy algo-

Table 4. Example of Demand-Weighted Flows

ID	O	D	OD TRIPS	Sigmoid Function Weighted Trips					Linearly Weighted Trips				
				BC[a]	NP[b]	EW[c]	PE[d]	DE[e]	BC[a]	NP[b]	EW[c]	PE[d]	DE[e]
1	1	2	1804	1533	673	1702	1924	879	1802	1517	1850	1915	1599
2	1	3	957	777	312	856	990	427	956	795	978	1017	844
3	1	4	597	432	161	486	573	234	590	485	606	631	521
4	1	5	1359	1120	463	1244	1423	626	1366	1141	1401	1453	1209
5	1	6	454	368	154	414	471	208	452	379	465	482	402

[a] Base Case [b] No Policy [c] Equal Weighting
[d] Policy Emphasis [e] Demographic Emphasis

rithm with substitution (1 substituting iteration) at a vehicle's range of 100 miles for p = 10 and p = 20 using the demand-weighted flows. Therefore, there were 10 demand-weighted flows (5 scenarios x 2 transformation functions) as input for the FRLM. Table 4 is an example of the weighted flows.

5. Analysis

1) Spatial and Probability Distribution of AFV Demand Estimate

Figure 4 shows the maps of composite rank scores from each scenario. In addition, breakdown of population by each demand score range is shown in Figure 5. The policy emphasis scenario resulted in more tracts with high rank scores. Specifically, about 49% of population falls in the tracts with high (> 4.6) scores. This contrasts to no policy scenario where the similar percentage of population falls in fair to high score ranges. This may be interpreted that policy could push up consumers to the next higher class in terms of demand density category.

Probability distribution of all scenarios had positive skewness (0.12 ~ 0.16). This suggests there are a small number of tracts with high rank scores, which will be good target areas. The composite rank scores showed high correlation (> 0.998) among different weighting scenarios, and thus to identify clusters this research mapped Local Moran's I of composite ranks scores (Figure 6). The LISA maps, for which a queen-type contiguity weight matrix was used for modeling neighbors, show that high- and low-value cluster pattern look about the same at all weighting scenarios. Three predominant areas were identified as high-value clusters: north, northeast, and southwest of Orlando metropolitan.

2) Effects of AFV Demand Estimate on Locating Refueling Facilities

The dispersion of probability distribution of AFV adoption rate for 104 TAZs in Orlando area was shown in Table 5. The most dispersed adoption rate was observed when sigmoid function was used in transforming composite scores of no policy scenario (CV: 0.696), whereas the least dispersed one was linearly transformed scores of policy emphasis scenario (CV: 0.115). The former can be interpreted as a situation where market mostly drives AFV acceptance, and the latter simulates the case when the policy is actively involved in transitioning to an AFV transportation system.

Using the above two sets, demand-weighted flows were computed as inputs for the FRLM, and the problem instances were solved using the greedy algorithm with one substitution for p = 10 and p = 20. The solutions for linearly transformed scores of policy emphasis scenario (LWT-P) were the same as those for non-weighted flows (TRIPS), but with a little less coverage (Table 6). However, transformation of no policy scenario scores by a sigmoid function (SWT-NP) resulted in higher coverage (0.01~4.44%) than TRIPS and different facility locations (Table 6 and Figure 7). Note that total flows to cover were reduced for LWT-P and SWT-NP as a result of AFV demand weighting from 146,694,202 to 91,337,483 and 46,109,611 respectively. Therefore, the actual flows that can be refueled by the solution for SWT-NP scenario are generally less than LWT-P solution. For example,

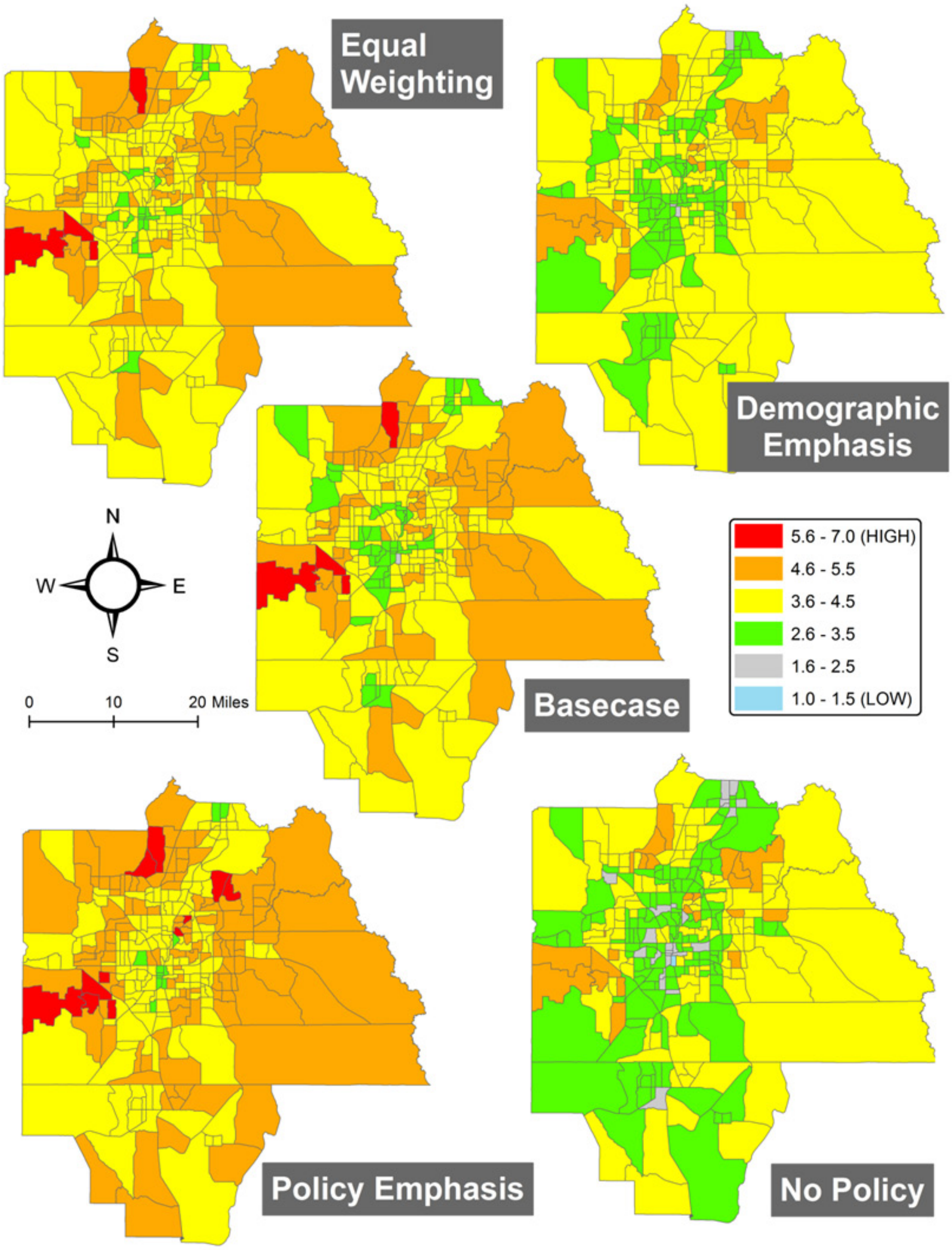

Figure 4. Composite Scores from Different Scenarios

the 10 selected stations for SWT-NP scenario cover more percentage (54.92%) of the total weighted flows than those for LWT-P do (54.32%). incur

But the actual number of trips that are refuelable by the former (253,216) is less than the weighted-trip number refuelable by the latter (496,179). This

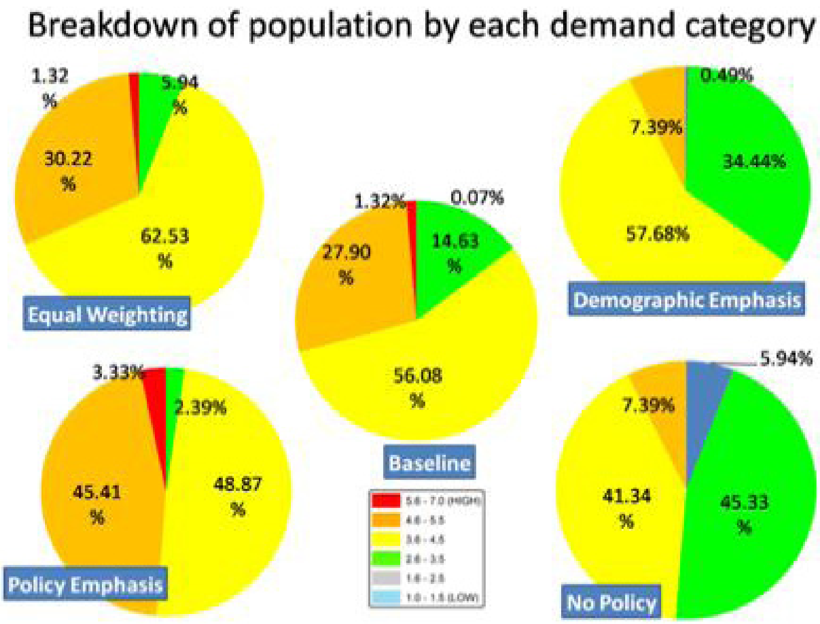

Figure 5. Breakdown of Population by Demand Score Range

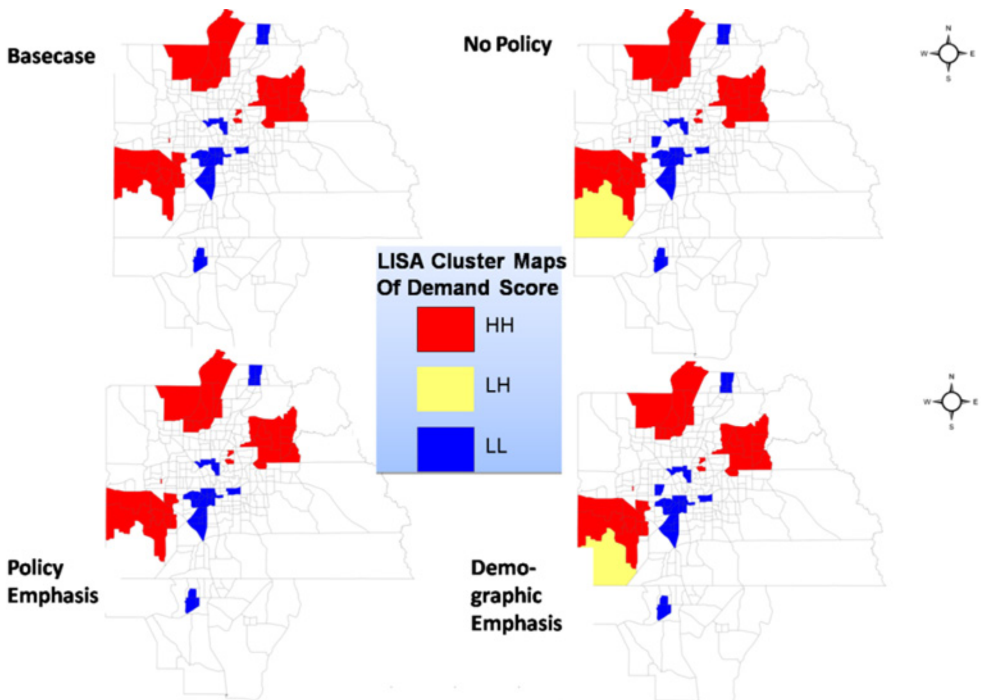

Figure 6. LISA Cluster Maps of Demand Scores

Table 5. Dispersion of AFV Adoption Rates

	Sigmoid Function Transformation					Linear Transformation				
	BC[a]	NP[b]	EW[c]	PE[d]	DE[e]	BC[a]	NP[b]	EW[c]	PE[d]	DE[e]
Mean	0.550	0.324	0.589	0.653	0.360	0.590	0.504	0.603	0.626	0.523
Standard Deviation	0.214	0.225	0.203	0.192	0.193	0.076	0.091	0.073	0.072	0.069
Coefficient of Variance	0.389	**0.696**	0.345	0.295	0.535	0.129	0.181	0.121	**0.115**	0.132

[a] Base Case
[b] No Policy
[c] Equal Weighting
[d] Policy Emphasis
[e] Demographic Emphasis

Table 6. Effect of AFV-Demand Weighting on Coverage

p	Percentage of Coverage: Non-Weighted Flows	Coverage Gain of Weighted Flows (% of Non-Weighted Flows Covered)	
		No Policy / Sigmoid Function Transformation	Policy Emphasis / Linear Transformation
1	14.23	**-26.99**	**-5.62**
2	21.12	-10.40	-4.23
3	26.53	-1.16	-3.06
4	31.45	**1.93**	-1.55
5	36.14	**4.33**	-0.91
6	40.50	**4.44**	**0.04**
7	44.70	**3.63**	**-0.37**
8	48.19	**2.26**	**-0.09**
9	51.62	**1.14**	**-0.39**
10	54.59	**0.60**	**-0.49**
11	57.52	**0.01**	**-0.56**
12	60.02	**0.16**	**-0.48**
13	62.21	**0.35**	**-0.59**
14	64.41	**0.50**	**-0.79**
15	66.54	**0.43**	**-0.91**
16	68.60	**0.46**	**-0.93**
17	70.38	**0.79**	**-0.90**
18	72.09	**1.13**	**-0.78**
19	73.72	**1.34**	**-0.56**
20	75.46	**1.16**	**-0.51**

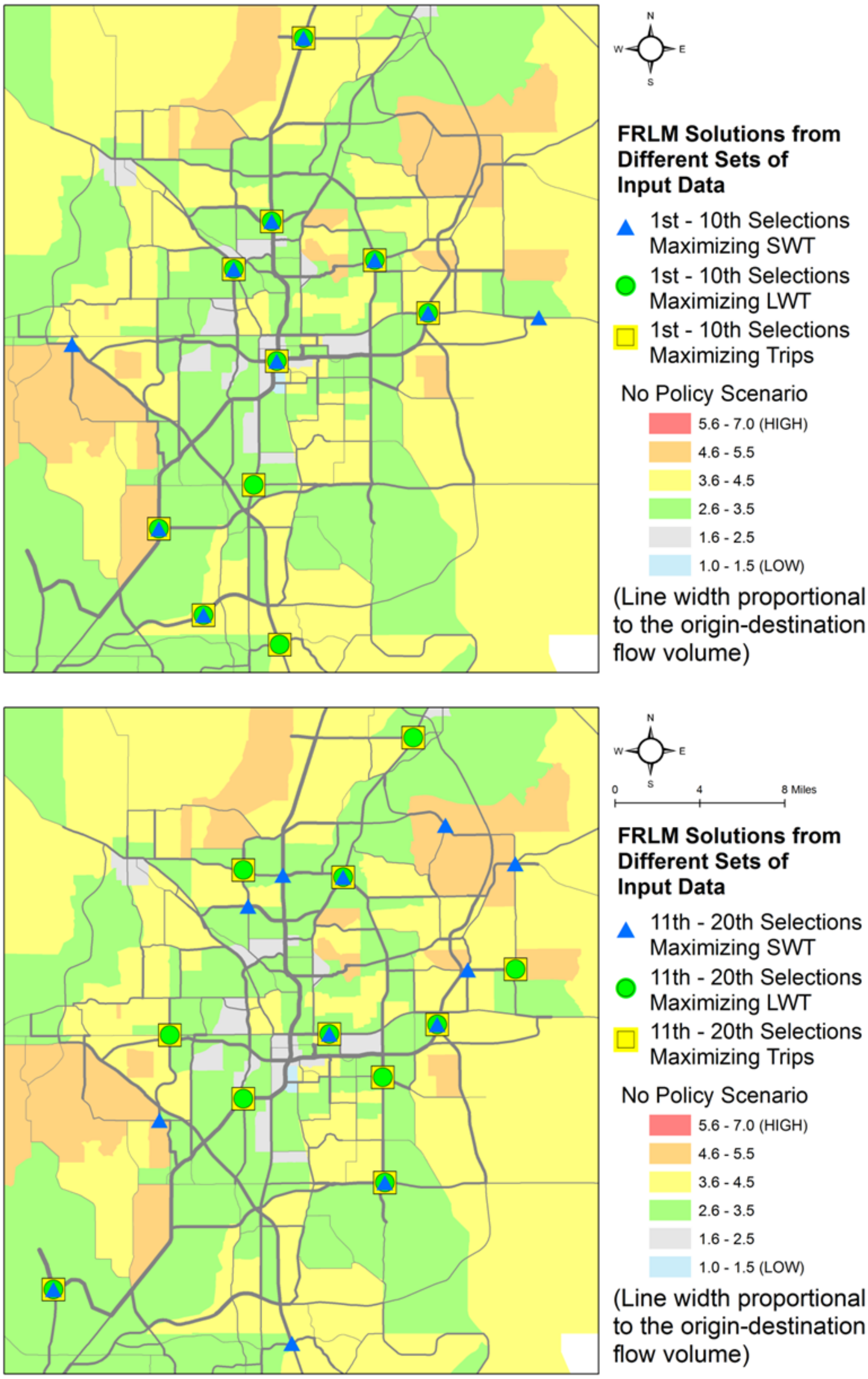

Figure 7. Different Selection of Facilities by the FRLM with AFV demand

should be interpreted that the application of a sigmoid function resulted in more reduction of total weighted flows than a linear function did. Given that the sigmoid function sets more penalties on the OD pairs where their average rank score is less than 4 (See Figure 3) and such penalties get complemented by putting more weight on the OD pairs with higher (>4) average rank score, this conforms to the distribution of AFV adoption rates shown in Table 5.

Previous research demonstrated that the optimal locations chosen by the FRLM are stable at the metropolitan scale (Upchurch and Kuby, 2010; Zeng *et al*., 2010). Therefore, any changes in the solution imply that there are significant changes in the traffic flow patterns. Regarding facility locations chosen to serve demand-weighted flows, the six initial facilities were selected at the same locations even though there was slight difference in the order of stations added. The 10 facilities from TRIPS and LWT-P located mainly to cover high-volume north-south flows and to serve some other high-volume flows on southwest and northeast regions. Both TRIPS and LWT-P selected 11th - 20th stations that can cover east-west flows. They selected stations for further southwest and northeast regions as well so that drivers could drive further to that direction. We observe different pattern of facilities selected by SWT-NP. When SWT-NP selected 10 facilities, it replaced two stations in south Orlando in areas with demand scores of 2.75 and 3 with the ones in west and east areas having 4.5 and 5.5 for the demand scores to obtain higher objective value. For 11^{th} -20^{th} stations, it seemed to locate stations further to northeast, northwest, and southwest of Orlando, where high demand clusters exist. This suggests that optimal solutions for maximizing SWT-NP have reflected the modified structure of alternative-fuel demand, which had more dispersed distribution of AFV-demand scores than LWT-P or TRIPS.

6. Conclusions

The anxiety of potential AFV drivers that their trips may not be completed because of AFV's short driving range per refueling must be resolved by efficiently placing necessary multiple facilities to enable longer trips. In addition, the geographically uneven likelihood of purchasing AFVs also needs to be considered to maximize the impact of initial investments both from government and private sectors. Current path-based network design and location model considers AFV's short range but spatial variations of consumer demand for AFVs have not been explicitly incorporated. This study, therefore, considered uneven distribution of AFV demand that is expected in the initial phases of AF station development. More specifically, this paper proposed a method that incorporates NREL's raster-based AFV demand estimation model into the path-based FRLM, and it was applied to the Orlando metropolitan data. The method has integrated enhanced procedures to provide more reality to the network design and facility location model.

Several important findings of this study can be highlighted. The most significant one is that the existence of supporting policy has a substantial impact on the distribution of AFV demand and as a result on the locations and performance of the optimal facilities. An active involvement of policy can push up the likelihood of consumers purchasing the AFVs, as the spatial pattern of estimated demand and population composition showed. Consequently, the optimal facilities provided higher coverage of demand, measured by the number of trips, when supporting policy was expected to exist. This finding is consistent with previous research on AFV demand (Melendez and Milbrandt, 2006b; Melaina, 2007; Greene *et al.*, 2008) where the importance of supporting policy was stressed. A second major finding is that the scenarios analysis is essential in identifying robust solutions that are optimal regardless of variations in the future scenarios and in detecting critical conditions that may not break through the barriers of AFV acceptance. The optimal locations chosen by the FRLM are generally stable as the infrastructure is built out and the number of stations increases. Previous research demonstrated that the optimal locations chosen by the FRLM are stable at the metropolitan scale (Upchurch and Kuby, 2010; Zeng *et al.*, 2010). This research, however, showed that they can shift toward areas with high AFV purchase potentials when there is no supporting policy. Even though the effect on station locations seemed minor at the first glance, considering the FRLM's property of providing stable solutions even with removal of OD pairs and network arcs (Zeng *et al.*, 2010), such shift is critically important for decision makers. Decision makers such as government agency or private fuel providers need to find a robust set of stations that can remain good even after more stations are added later as the infrastructure development phase progresses. In this sense, the FRLM provides stale solutions for many of the scenarios. On the other hand, they also want to know the critical conditions that change the optimal sites and they will put their efforts to find a solution to avoid such adverse conditions. The scenario analysis, thus, provides the decision makers with important information.

Even though this research's approach is straightforward and has the capability of providing enhanced representation of early consumer demand, the model's inherent uncertainties in the data, attribute ranking scheme, or scenario parameters requests further elaboration in order to apply it to real world. For this end, without empirical data to verify or evaluate the model's results, it would be extremely valuable for the alternative-fuel refueling network planners to have an explorative framework that integrates the AFV estimation model and location model where various scenarios can be generated and alternatives are efficiently compared.

Notes

1) Originally these data were collected as a part of DOE funded project (Florida Hydrogen Initiative Project).

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Correspondence: Jong-Geun Kim, Department of Geography Education, Seoul National University, Seoul, Korea, Tel: +82-2-880-7717, Fax: +82-2-882-9873, e-mail: jgkim25@snu.ac.kr

교신: 김종근, 서울특별시 관악구 대학동 서울대학교 지리교육과, 전화: 02-880-7717, 팩스: 02-882-9873, e-mail: jgkim25@snu.ac.kr

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수요의 지역차를 고려한 대체연료 충전소 최적입지선정: 플로리다 올랜도를 사례로

김종근*

요약 : 초기 대체연료차 시장은 고비용으로 인해 수요 잠재력의 지역차가 존재할 것이며 효율적 입지모델은 이러한 지역차를 고려해야 한다. 본 논문은 지역차를 고려한 대체연료차 수요 모델을 기종점 통행량에 통합하는 방법을 제안하며 이를 통해 대체연료차 통행량을 추정한다. 추정된 통행량은 주어진 수의 시설물이 기종점 통행량을 최대로 포괄할 수 있도록 하는 입지모델 (Flow Refueling Location Model)에 입력되어 대체연료 충전소 최적 입지 대안을 제시한다. 사례지역은 플로리다 올랜도 대도시권이며, 수요 추정 및 통행량 통합 시나리오의 결과를 비교 분석한다.

주요어 : 수요의 지역차, 대체연료차, 충전소, 최적입지, 통행량, FRLM

* 한국연구재단 박사후 연구원, 서울대학교 지리교육과