Comparison of Suburban Commuting Characteristics

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Rapid growth in suburban population over the past two decades has inevitably turned once lightly traveled rural roads into heavy-traffic highways that require considerable investment for upgrading. However, such a need was not recognized in time to develop suburban-oriented traffic management strategies, and unprecedented levels of suburban congestion resulted. Mobility improvement in suburbs has thus become one of the most pressing transportation issues. In response to increasing public concern, reports and articles have been produced to explore various short- and long-term strategies. However, one vital aspect, a fundamental understanding of suburban commuting behavior, has not been adequately addressed in the transportation literature. An exploratory analysis is performed to characterize suburban commuting behavior on the basis of surveys conducted at three suburban activity centers. A comparison of the 14 travel and socioeconomic variables was performed first, followed by a discrete estimation of their relations with suburban workers' trip-stop frequency behavior. It has been found that suburban workers, even though from geographically different locations, reveal similar commuting patterns. The estimation results were further supported by a multivariate cluster analysis through which survey respondents from each location were classified into six groups of unique characteristics. Whereas each cluster of survey participants exhibits a similar pattern at these three locations, its shape varies substantially from the other five clusters. This confirms that in contending with suburban congestion different strategies should be developed to target different groups of suburban residents.

In the past several decades, concern over the growing severity of urban traffic congestion has led to migration of both population and business to suburbs. The nature and direction of suburban travel demand have changed significantly since the migration is often accompanied by major traffic generators such as shopping malls, office complexes, and recreation centers. In fact, because of a rapid increase in suburban population, the once dominant suburb-to-city-center commute has now been superseded by suburb-to-suburb travel.

The change in population and commuting patterns has taken place since the 1960s. Whereas center city and rural populations have remained relatively stable since then, most of the population increase has been in suburbs, where the national share of population grew from 23 percent in the 1950s to 40 percent in 1986. The rapid growth has inevitably turned once lightly traveled rural roads to heavy-traffic highways that require considerable investment for upgrading. However, such a need was not recognized in time to develop suburban-oriented traffic management strategies, from either the demand or the supply side. A failure to understand the changing role of suburbs, compounded by meager levels of transit services and a substantial curtailment in new road construction, has compelled suburban commuters to become more dependent on automobiles for accessing workplaces and has resulted in unprecedented levels of suburban congestion. Mobility improvement in suburbs has thus become one of the most pressing issues in transportation.

In response to increasing public concerns on this issue, reports, articles, and media accounts have been produced to explore various short- and long-term strategies. Most studies were conducted along the following two directions: (*a*) exploring the interrelations between land use development patterns and suburban traffic congestion (*1–10*) and (*b*) diagnosing suburban congestion problems and developing public policy options (*9,11–14*). Whereas these two dimensions are undoubtedly necessary in understanding the evolution of suburban land use patterns and travel demand, the development of effective strategies for traffic congestion requires better knowledge of suburban trip-making behavior. This vital aspect, however, has not received adequate attention in the transportation literature (*15*). One area where there has been very little research and where a considerable knowledge gap remains is in the differences between suburb-to-city-center and suburb-to-suburb trip-making behavior. That, in turn, precludes an effective use of valuable experiences obtained in contending with urban congestion (*16–18*) in improving suburban mobility.

In response to this research need, this paper focuses on the following two aspects: (*a*) understanding of suburban commuting behavior with an emphasis on the interrelations between commuting trip stop frequency and some background factors, and (*b*) classification of suburban commuters into several distinct groups with unique characteristics allowing for a better design of various demand management strategies.

SURVEY DESCRIPTION

The survey results presented in this paper were collected as part of NCHRP Project 3-38(2), "Travel Characteristics at Large-Scale Suburban Activity Centers." The primary purpose of this project was to develop a comprehensive data base on travel characteristics for various types of large-scale, multiuse suburban activity centers throughout the United States. Travel characteristics data were collected at six representative large-scale suburban activity centers through person and vehicle counts, workplace surveys, intercept surveys at hotel and retail sites, and daily trip diaries completed by residents of housing complexes within the activity centers. A detailed

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description of the sampling design and survey results can be found in *NCHRP Report 323* (*19*).

The survey results analyzed in this paper were taken from three workplace surveys completed at the Parkway Center, approximately 10 mi north of the Dallas central business district (CBD) in Texas; Tysons Corner, 12 mi west of downtown Washington, D.C., in Fairfax county, Virginia; and the Southdale Mall, located roughly 10 mi south of the Minneapolis CBD within the cities of Bloomington and Edina.

The Parkway Center consists of approximately 17 million ft^2 of office space, 7 million ft^2 of retail space (including three regional malls), 8 hotels with a total of more than 3,100 rooms, and 12,000 dwelling units. Workplace surveys were distributed to employers in 12 multitenant office buildings at the Parkway Center, containing approximately 4.3 million ft^2 and 6,900 employees. Employers were responsible for distributing the surveys to their employees and encouraging their returns. Of the 6,580 surveys distributed in these buildings, 1,781 were returned (27 percent), and 1,005 were completed and used in the analysis.

The Tysons Corner activity center has more than 13 million ft^2 of office space, a regional shopping mall, several hotels and high-rise residential buildings, and numerous shopping plazas. The workplace surveys were conducted in eight office buildings in which 8,522 survey forms were distributed. Of these surveys, 3,164 were returned (37.1 percent), and 2,194 were completed and used in the preliminary study. The Southdale activity center encompasses an area of roughly 4 million ft^2 of office space, several shopping plazas, numerous low-rise apartments, and condominium complexes. The workplace surveys were conducted in 21 office buildings and distributed to 13,231 employees. Whereas 3,951 people responded to the survey, only 3,313 answered all questions included in the survey form.

Workplace surveys consisted of three categories of questions: commuting characteristics, trip-making characteristics, and respondent background information. Questions pertaining to commuting characteristics are work location, commuting distance, travel times on morning and evening commutes, work starting time, and the commuting mode. The frequency of stops in work-to-home and home-to-work trips and the number of trips made per day constitute the category of trip-making characteristics. Also included are the purpose of each stop and the means of travel. The category of respondent background information comprises questions on age, sex, household size, occupation, and automobile ownership. Unfortunately, information on a critical variable, income level, was not asked for in the survey.

As is well recognized in travel behavior research, an individual's income level is a critical explanatory variable, and its omission may result in some difficulties in trip characteristics classification. It is also recognized that the relatively low response rate in all three suburban activity center (SAC) surveys may result in significant nonresponse bias. However, since the data set as well as the survey design are made available to the research community after the preliminary results have been published, the use of any sophisticated statistical methods for estimating the potential nonresponse bias is not feasible. Besides, the survey provides only a "snapshot" rather than a representative day of commuters' travel behavior, since questions on commute and trip-making characteristics were posed only for the current day. Nevertheless, the results of the survey contain useful information and provide a basis for understanding the complex suburban trip-stop frequency behavior.

PRELIMINARY ANALYSIS AND COMPARISON

The preliminary analysis starts with a comparison of key travel and background variables associated with survey respondents in the SACs. Table 1 presents the mean and standard deviation of 14 variables available from the three SAC surveys. The variables provide the profile of survey participants' background and their trip-stop frequency behavior. Since the three SACs were located in different states, a sequence of statistical tests, as shown in Figure 1, was performed to identify their key characteristic differences. For instance, Levene's test for variance homogeneity was conducted first for each variable. It was then followed by a simultaneous examination of sample means from the three SACs. A pairwise comparison with the least significance difference (LSD) method was further performed if the null hypothesis of equal means was rejected. The test results are summarized in Table 2, and their implications are briefly described as follows.

Despite the distinct geographical differences, the participants in the three SAC surveys reveal the following common characteristics: an average of 0.48 stops from work to home, an average automobile occupancy of 1.1 persons, and an average household size of 2.76 persons. These results seem consistent with the perception that suburban workers mostly have relatively small families, use the drive-alone mode on commutes, and often make some stops during their work-to-home trips. The apparently low automobile occupancy certainly contributes to the increasing suburban congestion and suggests the need to better understand suburban commuting behavior and to design effective demand management programs. We now discuss some variables that vary significantly across these three SACs.

- Average travel time to work and home: The statistical results in Table 2 indicate that suburban workers at Tysons Corner experienced the longest commuting time even with the same average travel distance as those working in the Parkway Center. Their average travel speed is about 26 mph, compared with 31 mph in Parkway and 33.8 mph in Southdale. This is mainly due to more severe traffic congestion in Northern Virginia than at the other two locations. Suburban workers in Southdale on average have the shortest travel time and commuting distance. Travel time reported by survey participants is actually the door-to-door time, including both the trip time and stop times for performing activities. The failure to separate these two components of travel time makes the analysis more difficult and is one of the major deficiencies of the survey design.
- Average stops from home to work: Suburban workers at the Parkway Center appear to make significantly more stops in their home-to-work trips than those at the other SACs. A further analysis of those trip purposes reveals that this is mostly due to the relatively high fraction (30 percent) of workers at Parkway Center who need to complete work as well as child-care-related activites on their morning commutes.

TABLE 1 Mean of Key Commuting Characteristics Obtained from Three SACs

Variables	Suburban Location		
	Parkway	Tysons	Southdale
1. Average stops from home to work	0.27 (0.60)	0.22 (0.56)	0.21 (0.54)
2. Average mid-day trips	0.64 (1.07)	0.84 (1.16)	0.62 (1.07)
3. Average stops from work to home	0.46 (0.77)	0.49 (0.81)	0.48 (0.82)
4. Travel time to work (minutes)	28.50 (14.73)	43.28 (18.95)	22.62 (12.39)
5. Travel time to home	31.50 (16.40)	37.03 (19.54)	25.66 (14.37)
6. Commuting distance	14.91 (12.04)	14.89 (10.79)	12.72 (10.03)
7. Total number of trips made per day	2.45 (0.57)	2.58 (0.60)	2.43 (0.58)
8. Auto occupancy	1.12 (0.51)	1.10 (0.47)	1.10 (0.47)
9. Average length of employment (years)	1.72 (1.43)	4.18 (4.43)	3.57 (4.11)
10. Household size	2.57 (1.21)	2.81 (1.26)	2.76 (1.24)
11. Average number of vehicles	1.97 (0.87)	2.21 (1.01)	2.12 (0.99)
12. Average number of children	0.55 (0.88)	0.49 (0.85)	0.54 (0.92)
13. Average number of full-time workers	1.34 (0.85)	1.51 (1.01)	1.49 (0.91)
14. Average number of part-time workers	0.15 (0.44)	0.25 (0.58)	0.33 (0.66)
Number of samples	1005	2194	3313

•Standard deviation for each cell is shown in the parentheses

• Average midday and total number of trips per day: The frequency of midday trips is defined as the number of trips made during the working hours on the day of survey. Some trips that take place in the same buildings, such as for meals in the mall, are not included in this category. The total number of trips refers to those made during both working and non-working periods. As expected, suburban workers in Tysons Corner, a very large shopping area, made a significantly higher number of both midday trips and total trips per day than those in the other SACs. Most of those trips (more than 50 percent) were mainly for shopping rather than work-related activities. In contrast, the differences in these two variables between Parkway and Southdale workers are not statistically significant.

• Average number of available vehicles: The results of pairwise comparison indicate that there is no significant difference in the average number of vehicles per household between Tysons Corner and Southdale. Those in Parkway Center seem to own a relatively low number of vehicles, probably because of their relatively small family size and low number of full-time workers (see Table 1). Another reason may be their significantly shorter length of employment (1.72 years). Most respondents in Parkway are relatively young workers.

• Average length of employment: This varies particularly significantly among the three SACs. Whereas survey respondents at Tysons Corner indicate the longest employment (4.18 years), those from Parkway Center in Texas have a relatively short working experience (1.72 years). This is consistent with other observed characteristics that suburban workers at Parkway Center, compared with those from the other two SACs, on the average have the smallest household size and a relatively small number of full-time workers as well as vehicles available (see Table 1).

Given this preliminary comparison, we now explore the interrelations between principal survey variables. A classification of survey respondents with respect to the frequency of stops and travel time is summarized in Tables 3 and 4. Since all three SAC surveys reveal similar relations among key variables, only the results for Parkway Center are discussed.

Tables 3 and 4 classify commuting characteristics by the frequency of stops and travel time in work-to-home trips. Some variables exhibiting no systematic trends are not included in these tables. As expected, among the selected variables for travel measures, travel time to work appears to correlate posi-

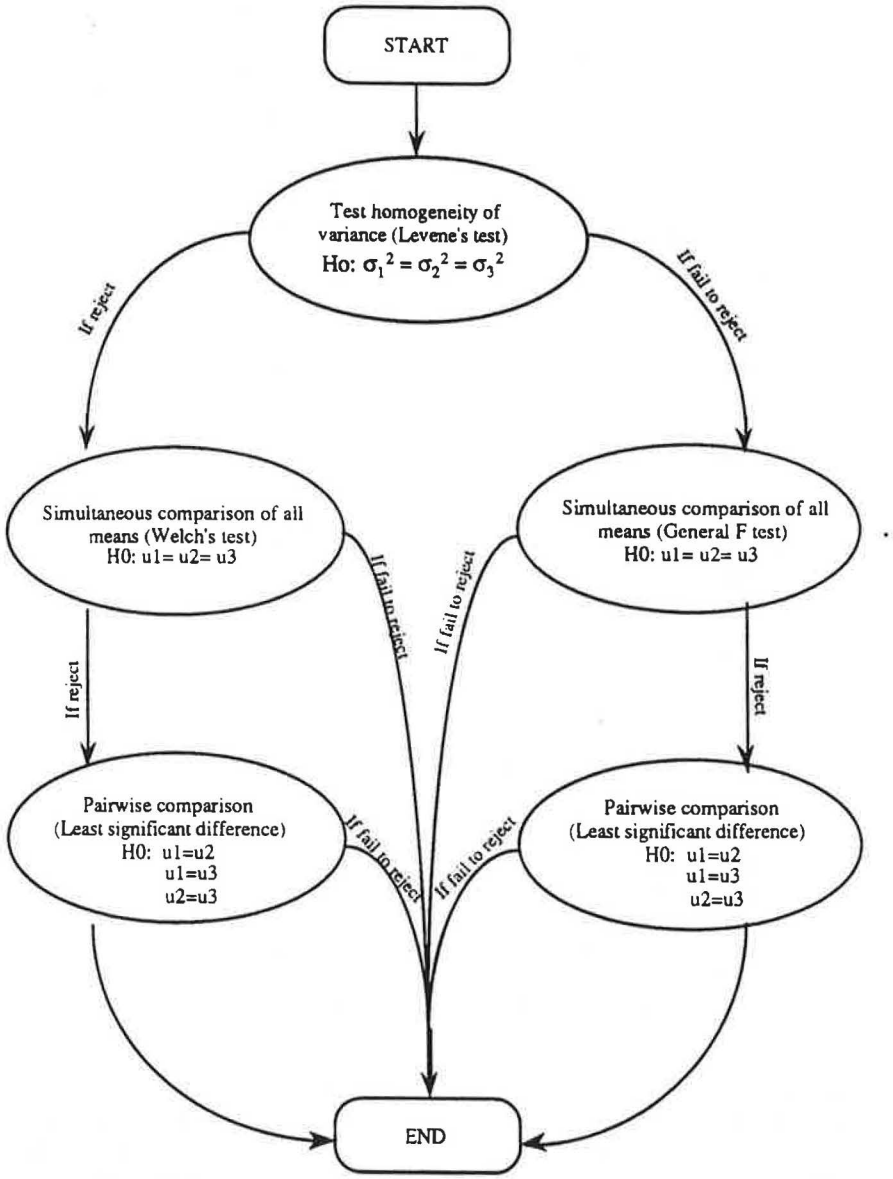

FIGURE 1 Procedures for comparing the survey results obtained from different activity centers.

tively with the frequency of stops both to home and to work, except in the last category (i.e., three or more stops), which contains only limited observations (14 in Table 1 and 20 in Table 2). This is consistent with the fact that given the same travel distance, a trip with more stops is expected to take a longer time. In contrast, the midday trip frequency (Table 4) seems to correlate negatively with the travel time both to home and to work, implying that people living near their workplaces tend to make more midday trips, going home either for meals or for work-related activities.

The frequency of stops both to work and to home appears to correlate with variables such as automobile occupancies, household size, and the number of working persons and children per family. With respect to automobile occupancy, a plausible explanation is that commuters having a high number of ridesharers are likely to stop more frequently to pick up or drop off other occupants. For similar reasons, respondents with large households and more children are often required to make more stops on their daily commutes.

The relations between the frequency of stops and other variables are not so distinct and thus cannot be observed directly at the aggregate level (i.e., from the computed average values). For instance, differences in the car ownership and in the number of working family members across all four categories do not exhibit any systematic trend with the frequency of stops. A more detailed investigation of such relations is presented in the next section.

Table 4 summarizes the commuting characteristics classified by travel time to work. Reported travel times of respondents are divided into five categories. To relate the travel time with the "average stops from home to work," it appears that respondents who experienced longer travel times (>40 min) generally made significantly more stops, possibly to pick up or drop off other passengers or children. In contrast, no sys-

TABLE 2 Equality Test for the Mean Value of Each Variable Obtained from Three SACs

Variables	Test Homogeneity of variance (H_0: $\sigma_1^2=\sigma_2^2=\sigma_3^2$)	Compare all mean H_0:$u_1=u_2=u_3$	Pairwise Comparison H_0:$u_1=u_2$ PW&TS	$u_1=u_3$ PW&SD	$u_2=u_3$ TS&SD
1. Average stops from home to work	R	R	R	NR	NR
2. Average mid-day trips	R	R	R	NR	R
3. Average stops from work to home	R	NR			
4. Travel time to work (minutes)	R	R	R	R	R
5. Travel time to home	R	R	R	R	R
6. Total number of trips made per day	R	R	R	NR	R
7. Auto occupancy	R	NR			
8. Average length of employment (years)	R	R	R	R	R
9. Household size	R	R	R	R	NR
10. Average number of vehicles	R	R	R	R	R
11. Average number of children	R	NR			
12. Average number of full-time workers	R	R	R	R	NR
13. Average number of part-time workers	R	R	R	R	R
14. Commuting distance	R	R	NR	R	R

* R: reject the null hypothesis at the 5% level of significance

** NR: fail to reject the null hypothesis at the 5% level of significance

*** PW: Parkway center; TS: Tysons Corner; SD: Southdale center.

tematic relation can be identified between the frequency of midday trips and the travel time to work. For instance, the group of respondents with very short commutes (<15 min) generated a significantly high frequency of midday trips. A further analysis of their trip purposes indicates that those with a high frequency of midday trips were mostly returning home for meals or family-related activities because of their relatively short travel distances. Those trips constitute about 40 percent of total observed midday trips at the Parkway Center.

Table 4 also indicates a positive correlation between automobile occupancy and travel time, implying that respondents with longer commuting distance (>26 mi) have experienced higher automobile occupancies. This is consistent with the perception that individuals with long commutes tend to form carpools more readily than those with short commutes. However, the average automobile occupancy is low in all categories, confirming that most trips were made by drive-alone commuters. Such a positive interrelation can also be observed in the following two pairs of variables: household size versus travel time and the average number of vehicles versus travel time. As indicated in Table 4, it appears that respondents from large households generally experienced longer commuting times than those from small households. This may be because individuals having fewer children are more likely to find affordable houses of adequate size within a shorter commuting range. The existence of a positive correlation between the travel time to work and the number of children seems to further support such an explanation.

Regarding the variable "average number of vehicles per household," it appears that respondents with longer commutes tend to own more vehicles. This may be due partly to the large household size for various activities and partly to poor transit services (e.g., 91 percent of trips use the drive-alone mode).

CLUSTER AND DISCRIMINANT ANALYSES

The preceding estimation provides the preliminary interrelations between suburban workers' commuting behavior and some of their background variables available from the surveys. To further understand their behavior patterns, it is natural to ask two questions: Can suburban commuters be classified into a number of distinct groups with a certain homogeneity in their behavior? Is it likely to identify each individual's travel pattern on the basis of associated factors such as socioeconomic background? Hence, in this section the method of cluster analysis is first applied to identify groups

TABLE 3 Classification of Commuting Characteristics by the Frequency of Stops to Work

Variables	Number of stops on the way to work				
	0	1	2	≥3	Total
1. Travel time to work(minutes)	27.53 (13.80)	32.84 (17.45)	34.37 (18.28)	**22.50** (13.28)	28.50 (14.73)
2. Average mid-day stops	0.61 (1.06)	0.68 (0.96)	0.81 (0.91)	1.43 (2.17)	0.64 (1.06)
3. Average stops from work to home	0.37 (0.68)	0.81 (0.85)	0.91 (1.27)	1.14 (1.40)	0.46 (0.77)
4. Total number of trips made per day	2.43 (0.57)	2.49 (0.54)	2.53 (0.50)	2.71 (0.83)	2.45 (0.57)
5. Auto occupancy	1.07 (0.39)	1.25 (0.69)	1.51 (1.10)	**1.36** (0.93)	1.12 (0.51)
6. Household size	2.48 (1.17)	2.84 (1.12)	3.28 (1.67)	**3.00** (1.24)	2.57 (1.21)
7. Average number of vehicles	1.98 (0.87)	1.91 (0.75)	2.02 (0.96)	2.43 (1.45)	1.97 (0.87)
8. Average number of children	0.47 (0.84)	0.81 (0.88)	1.09 (1.19)	**0.79** (1.05)	0.55 (0.88)
9. Average number of full-time workers	1.32 (0.87)	1.43 (0.75)	1.60 (0.88)	**1.21** (0.70)	1.34 (0.85)
10. Average number of part-time workers	0.14 (0.41)	0.16 (0.50)	0.26 (0.66)	0.36 (0.63)	0.15 (0.44)
Observations	807	141	43	14	1005

• **The standard deviation for each cell is shown in the parentheses**

TABLE 4 Classification of Commuting Characteristics by Travel Time to Work

Variables	Travel time to work (minutes)					
	(0-15)	(16-20)	(21-25)	(26-40)	(≥41)	Total
1. Average stops from home to work	0.27 (0.69)	0.20 (0.53)	0.19 (0.55)	0.27 (0.63)	0.41 (0.67)	0.27 (0.63)
2. Average mid-day stops	0.91 (1.31)	0.52 (0.99)	0.56 (0.85)	0.59 (1.07)	0.57 (0.88)	0.64 (1.07)
3. Average stops from work to home	0.48 (0.74)	0.45 (0.84)	0.37 (0.68)	0.41 (0.71)	0.60 (0.90)	0.46 (0.78)
4. Total number of trips made per day	2.58 (0.61)	2.34 (0.55)	2.43 (0.53)	2.41 (0.58)	2.42 (0.53)	2.45 (0.57)
5. Auto occupancy	1.057 (0.327)	1.078 (0.390)	1.081 (0.522)	1.167 (0.598)	1.198 (0.626)	1.121 (0.512)
6. Household size	2.16 (1.07)	2.47 (1.22)	2.67 (1.27)	2.66 (1.16)	2.98 (1.22)	2.57 (1.21)
7. Average number of vehicles	1.86 (0.98)	1.89 (0.78)	1.91 (0.69)	2.01 (0.83)	2.19 (0.94)	1.98 (0.87)
8. Average number of children	0.30 (0.67)	0.51 (0.86)	0.60 (1.01)	0.59 (0.84)	0.81 (1.03)	0.55 (0.88)
9. Average number of full-time workers	1.21 (0.86)	1.26 (0.84)	1.37 (0.87)	1.42 (0.85)	1.46 (0.83)	1.34 (0.85)
10. Average number of part-time workers	0.14 (0.42)	0.13 (0.43)	0.11 (0.33)	0.12 (0.40)	0.22 (0.58)	0.15 (0.44)
Observations	227	179	123	294	182	1005

• **The standard deviation for each cell is shown in the parentheses**

of survey respondents with similar travel characteristics, and their similarities and differences among clusters and across different locations are compared. Travel characteristics variables used for clustering observations are travel time in work-to-home and home-to-work trips, total number of trips per day, frequency of stops in the work-to-home and home-to-work trips, and the number of midday trips. Each cluster is then characterized by six background descriptors, including the commuting distance, household size, the number of available vehicles, the number of children, the number of part-time workers, and the average length of employment.

As is noted in the statistical literature, a satisfactory method for determining the optimal number of clusters remains to be developed (*20,21*). Since the purpose of this study is to dissect observed travel behavior rather than to uncover "real clusters," it is generally sufficient to use R^2 for each variable and for all variables together to determine the appropriate number of clusters. With this logic in mind, observations from each survey were grouped into six distinct clusters on the basis of the centroid method available in the SAS package (*22*). The selection of six clusters is based on an extensive experimental analysis, which consists of three principal steps: (*a*) classification of survey respondents into a preselected number of clusters, ranging from two to nine; (*b*) development of a linear discriminant function for each cluster with its background descriptors; and (*c*) computation of the posterior probability for each individual who is then assigned to the cluster of highest probability. The degree of success achieved in classifying survey respondents to their original clusters was then measured. An investigation has indicated that the selection of six clusters has yielded the best results, which can successfully predict the travel pattern (i.e., the assigned cluster) of the 72 percent of survey participants on the basis of only the six background descriptors.

Table 5 summarizes the cluster means and standard deviations of the six travel-related variables, indicating the variation of individual travel behavior in different clusters. Five of the six clusters in all three SACs exhibit two distinct patterns: the travel time to home is consistently longer than the travel time to work, and the frequency of stops in work-to-home trips is higher than that in home-to-work trips. These two systematic patterns are logically consistent, because the time for each stop constitutes a fraction of the total travel time. Thus, given the same travel distance, it is reasonable to expect a longer travel time if more activities are conducted during the trip. These two consistent patterns seem to represent the common features of suburban commuting behavior (except for the 38 individuals in Cluster 2). Some unique character-

TABLE 5 Cluster Means of Travel-Related Variables

Cluster	Location	TRW	TRH	TNP	NSW	NSH	NMT	Sample
	Parkway	34.20	35.27	2.53	2.47	2.86	0.73	15
1	Tysons	60.36	64.85	2.73	1.73	2.39	1.24	33
	Southdale	60.07	71.73	2.60	2.40	2.58	1.27	15
	Parkway	27.26	26.29	2.58	2.29	0.18	0.95	38
2	Tysons	33.78	32.24	2.53	2.53	0.55	0.90	49
	Southdale	27.76	33.36	2.42	0.62	1.03	0.55	507
	Parkway	25.55	28.57	2.36	0.11	0.23	0.40	717
3	Tysons	25.19	27.46	2.48	0.10	0.23	0.57	1265
	Southdale	15.01	16.61	2.34	0.10	0.18	0.40	1576
	Parkway	55.14	62.07	2.37	0.36	0.59	0.45	106
4	Tysons	57.76	61.16	2.49	0.18	0.31	0.67	522
	Southdale	33.30	38.94	2.34	0.12	0.01	0.40	797
	Parkway	25.62	29.62	2.39	0.29	2.36	0.50	66
5	Tysons	32.00	36.54	2.67	0.29	2.27	0.94	198
	Southdale	19.72	25.00	2.44	0.27	2.07	0.63	263
	Parkway	19.71	21.30	3.54	0.21	0.52	3.67	63
6	Tysons	25.14	28.61	3.76	0.16	0.46	4.06	127
	Southdale	19.26	20.85	3.76	0.21	0.35	4.13	155
	Parkway	0.40	0.42	0.25	0.62	0.55	0.61	
R^2	Tysons	0.49	0.51	0.26	0.19	0.53	0.76	
	Southdale	0.54	0.54	0.25	0.52	0.49	0.59	

TRW: Travel time to work, including both stop and commuting times (minutes).
TRH: Travel time to home, including both stop and commuting times (minutes).
TNP: Total number of trips made per day.
NSW: Total number of stops on way to work.
NSH: Total number of stops on way to home.
NMT: Total number of mid-day trips.

istics associated with each cluster are briefly discussed in the following paragraphs.

In all three SACs, Cluster 1 contains the smallest fraction of respondents (15 people in both the Parkway and Southdale SACs and 33 in Tysons Corner). In comparison with the other five clusters, suburban workers in this cluster have the following unique characteristics: (*a*) the highest frequency of stops in their work-to-home trips, (*b*) either the highest or the second highest number of stops on their home-to-work commutes, (*c*) the largest household size and the largest number of children, (*d*) the lowest number of vehicles per household, and (*e*) the longest or the second-longest commuting distance. The fact of having a large family size and a relatively long commuting distance, along with the lack of adequate vehicles, seems to explain their need to stop more frequently than others on daily commutes. This is consistent with the fact that 90 percent of commuters in Cluster 1 use carpools as the main commuting mode.

Cluster 1 workers not only exist in all three SACs but also have similar travel and socioeconomic patterns. Although they may be a relatively small fraction of suburban residents, and most of them have low income and large household size, they need more help and are the potential users of effective suburban public transportation systems.

In all three SACs, suburban workers in Cluster 2 feature a high frequency of stops in work-to-home trips. Among the six clusters, they have on the average the highest or second-highest number of stops on the evening commute and the largest or second-largest number of children. In addition, as indicated in Table 6, they tend to have a relatively large household size and part-time workers, and they make frequent trips in the middle of a working day.

Both Tysons Corner and Parkway survey results indicate that Cluster 2 workers' frequency of stops on their way to work is much higher than that in their work-to-home trips (2.29 versus 0.18 in Parkway). This seems contrary to the assertion that commuters tend to stop less frequently in their trips to work than to home because of the concern of being late to work as revealed in the commuting patterns of respondents in the other five clusters. To understand the underlying reasons, the trip purpose of home-to-work stops made by Cluster 2 respondents was further investigated. It was found that the work- and child-care-related stops constitute 55 percent of the 83 stops made by them (in Parkway) during the morning commute. The two main reasons for those intermediate stops do not exist for this cluster of people in their evening returning trips and account for less than 10 percent of the total stops incurred. A similar pattern exists for those working in Tysons Corner.

In all three SACs, Cluster 3 consistently consists of the largest fraction of respondents (e.g., 717 out of 1,005 people in Parkway), representing the typical suburban workers. As indicated in Table 5, this cluster is distinguished from others with its (*a*) lowest mean frequency of stops in home-to-work

TABLE 6 Cluster Means of Background Variables

Cluster	Location	FR	CD	HS	NVH	NCH	NPW	EL
	Parkway	0.73	16.33	3.27	1.80	1.13	0.33	1.92
1	Tysons	0.73	25.39	3.12	1.79	1.06	0.15	3.66
	Southdale	0.80	31.27	3.53	1.97	1.13	0.60	1.79
	Parkway	0.66	11.18	3.13	2.08	0.95	0.21	1.70
2	Tysons	0.61	12.82	3.10	2.22	0.65	0.30	3.65
	Southdale	0.75	15.75	2.81	1.99	0.70	0.27	3.31
	Parkway	0.57	13.05	2.48	1.93	0.48	0.13	1.68
3	Tysons	0.41	11.11	2.73	2.20	0.41	0.26	4.44
	Southdale	0.68	7.97	2.68	2.14	0.42	0.38	3.93
	Parkway	0.64	32.72	3.03	2.33	0.84	0.21	1.81
4	Tysons	0.51	25.32	2.97	2.22	0.65	0.26	3.65
	Southdale	0.62	21.14	2.93	2.21	0.66	0.28	3.01
	Parkway	0.76	12.30	2.52	1.88	0.59	0.20	1.96
5	Tysons	0.60	13.58	2.76	2.20	0.47	0.19	3.80
	Southdale	0.83	9.89	2.57	1.98	0.56	0.26	3.90
	Parkway	0.48	10.70	2.40	2.00	0.46	0.14	1.79
6	Tysons	0.39	10.14	2.75	2.33	0.45	0.19	4.65
	Southdale	0.45	10.78	2.81	2.02	0.59	0.36	3.20

FR: Female commuters/total number of commuters
CD: Commuting distance (miles)
HS: Household size
NVH: Number of vehicles per household
NCH: Number of children per household
NPH: Number of part-time workers per household
EL: Length of employment (years)

trips (e.g., 0.11 stops in Parkway), far below the mean value of all respondents; and (*b*) the smallest or second-smallest number of children. In addition, those individuals, as indicated in Table 6, are mostly from small households and have relatively short commutes (e.g., <15 mi). This is consistent with previous findings that commuters from small households are likely to live relatively near their workplaces.

Among the six clusters, survey respondents in Cluster 4 have the following consistent features in all SACs: the longest or second-longest mean travel time and commuting distance and the lowest or second-lowest midday trips. In addition, those individuals generally have a large household size (e.g., 3.03 persons in Parkway), a large number of part-time workers, children, and available vehicles. This conforms with previous findings that respondents having a large family tend to move toward distant suburbs to own an adequately large house within an affordable price range. To accommodate the long commuting distance and multiple workers per family, those individuals often own more than one vehicle, as indicated in the survey results.

In all three SACs, Cluster 5 is set apart from the other groups because of the uniquely high ratio (about 8:1) of work-

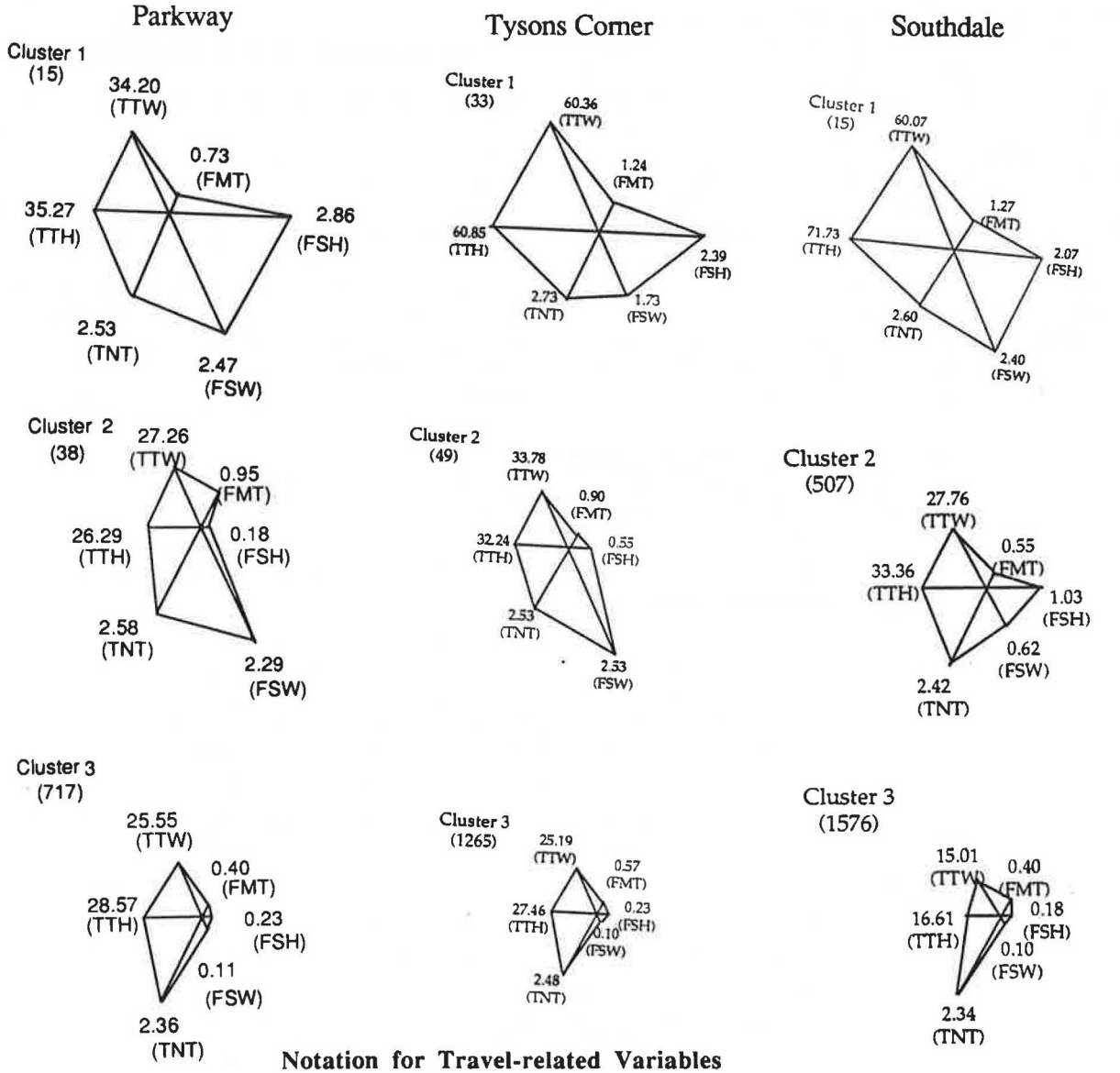

FIGURE 2 Travel-related variables for each cluster. (*continued on next page*)

to-home stops versus home-to-work stops and because it has the largest or second-largest proportion of females. A further analysis of trip purposes indicates that the high frequency of stops in returning trips are mainly due to their needs for shopping and recreation-related activities, which constitute around 68 percent of the total stops. Those individuals are mostly female, having relatively long employment experience but a relatively low number of children and available vehicles.

Cluster 6 stands out from the others with its highest fraction of males and largest number of midday trips in all three SACs. As indicated in Table 6, most respondents in this cluster have a relatively small family and can thus afford to live in a small house close to their workplaces. The resulting short commuting distance appears to account for their high-frequency of midday trips, mostly (about 72 percent) for coming home for meals or family-related activities. This is also consistent with the previous finding that the frequency of midday trips is correlated negatively with commuting distance or travel time.

To further compare the overall travel pattern between clusters in different SACs, each cluster is represented with one star plot in Figure 2. In comparing the shape of star plots, it is noticeable that in all three SACs the travel pattern varies significantly among clusters, indicating the existence of unique

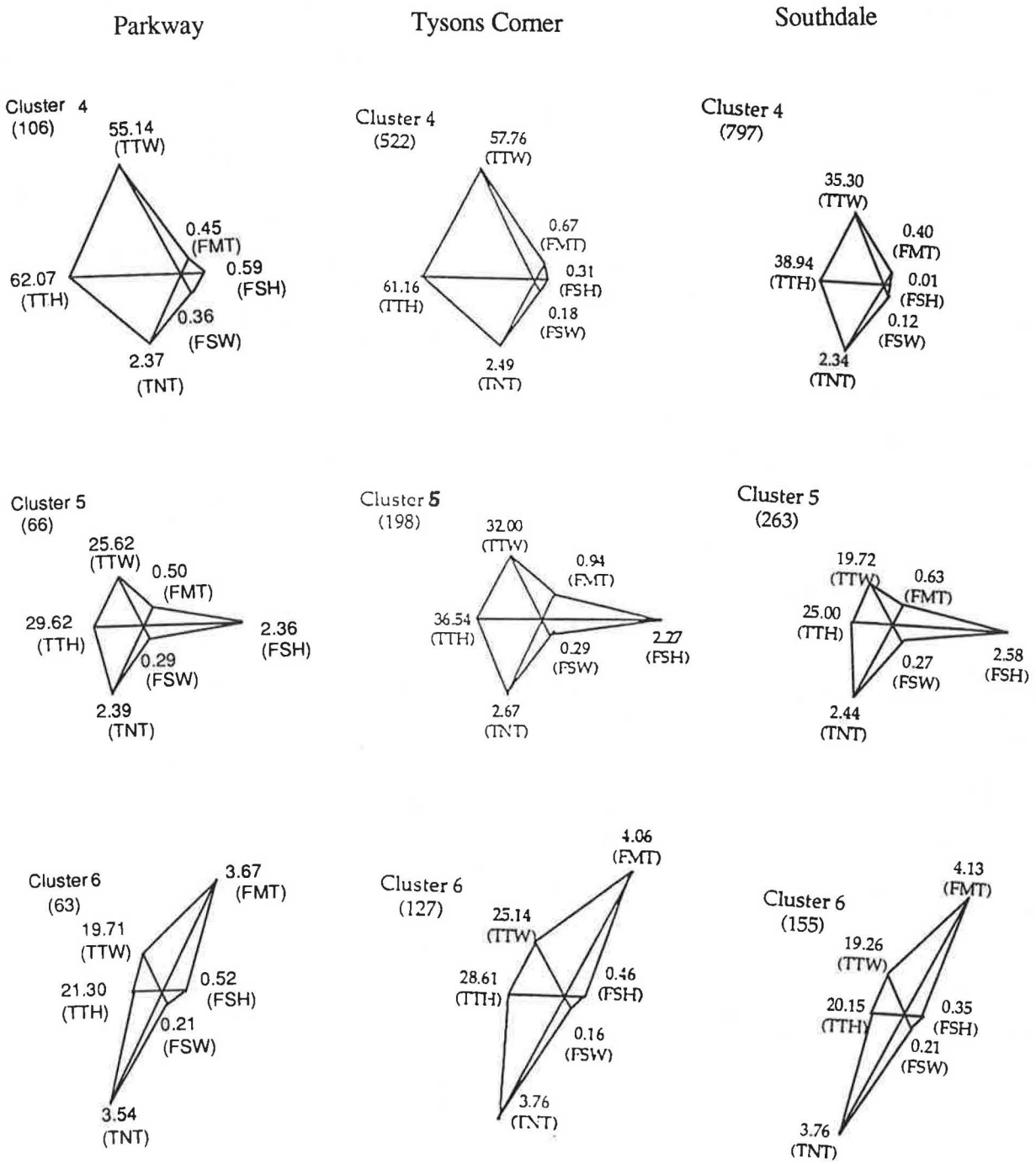

FIGURE 2 *(continued)*

travel characteristics for each group of individuals. In contrast, except for a slight difference in the shape for Cluster 2, the other five clusters, after being standardized, exhibit consistent patterns across the three locations in their travel-related measures. This seems to suggest that the possible overlap among clusters is negligible, and the application of such an approach has indeed yielded a reasonable classification of suburban commuting patterns.

In brief, even though the three suburban surveys were conducted from different regions, survey respondents can be classified into six consistent clusters, each having a similar pattern across the three SACs. Such distinct suburban commuting patterns should encourage transportation planners to develop diversified demand management strategies to serve each target group of suburban workers.

CONCLUSIONS

This paper has investigated suburban travel behavior with an emphasis on the interrelations between survey respondents' socioeconomic background and their manifested behavior patterns, especially concerning their frequency of stops to work and to home. In the absence of individual income information it has been found that variables such as work starting time, sex, commuting automobile occupancy, and available vehicles per family are significantly correlated with suburban workers' choices of stop frequency on their daily commutes. Single- and multiple-stop workers show different levels of sensitivity to any changes in these critical factors.

It has also been observed that suburban workers of relatively large households and limited employment experience tend to reside in relatively distant suburbs to afford houses of adequate size. To cope with the long commuting distance and the meager level of transit service, most suburban workers, as indicated in the survey results, were compelled to choose the drive-alone mode.

To further compare suburban commuting behavior, a multivariate cluster approach was used to classify survey respondents on the basis of selected travel characteristic variables. The results indicate that regardless of the geographical differences in the three SACs, suburban workers in each cluster exhibit similar travel as well as background patterns. In contrast, substantial differences among clusters exist, suggesting that different strategies or plans should be developed for different groups of suburban residents to effectively relieve suburban congestion.

Because of limitations of the original survey design, this research provides only preliminary understanding of complex suburban commuting behavior. To effectively contend with suburban congestion, much remains to be learned about the interrelations between suburban workers' background, behavior, and responses to different transportation management strategies. For instance, an ongoing research task is to understand the distribution of trip purposes on commutes and in the midday. The likelihood of minimizing those trip stops or changing their patterns can then be investigated.

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