Trip Generation Procedure for Areas with Structurally Different Socioeconomic Groups

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Many urban areas contain a mix of ethnic groups or households with structural differences in income and social status. Current trip generation techniques do not explicitly allow for the treatment of these structurally different socioeconomic groups. A statistical approach that can be used in such cases is described. The proposed framework allows for the treatment of different ethnic household groups; each group can have different subgroups based on one or more qualitative features, such as dwelling unit type or income. A case study based on data from the Kuwait metropolitan area is presented. Households are classified according to three nationality groups and four house types. The house type is found to be significant for only one of the groups. Differences in important quantitative household characteristics, such as car ownership and number of adults and children, appear both between and within subgroups.

Current household-level trip generation procedures assume a degree of homogeneity in the mix of households in the urban areas under investigation. Households are allowed to differ in such features as size, car ownership, and income, but normally there is no allowance for the presence of structurally different household groups. Many large cities in different parts of the world are growing increasingly into multiethnic urban areas, and the differences between groups may merit special treatment.

Structural differences in household groups in urban areas require that the adopted household-level trip generation procedure establish the extent to which the differences merit consideration and how the features can be allowed for without excessive sample sizes for calibration. Furthermore, there is a need for adopting mean trip rate estimate procedures that overcome the expected problem of poor reliability when trip rates are estimated for groups containing few households.

The purpose of this paper is to present the framework and an application of a procedure based on the concept of generalized linear models that can be used in estimating mean trip rates of households in urban areas with a distinct mix of household groups. The proposed procedure allows for

1. The presence of structurally different household groups;
2. The presence within each household group of subgroups, which differ in other qualitative features such as house type and income category; and
3. Households within each of the preceding classifications varying in other characteristics that can be described using quantitative variables, such as size, car ownership, and number of adults.

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Identification of the significance of any of these classifications is done by using statistical testing procedures. Furthermore, the effects of each variable can be assessed. The proposed approach overcomes several problems associated with the widely used cross-classification analysis procedure, which has several shortcomings when used for urban areas with diverse characteristics.

These difficulties have been reported in the literature (*1–3*). Stopher and McDonald (*2*) presented a multiple classification analysis procedure based on an extension of analysis of variance (ANOVA) to respond to some problems of cross-classification analysis, especially those related to poor reliability of trip rate estimates. Dobson (*4*) discussed the possibility of using the general linear model analysis of variance in conjunction with cross-classification analysis. Rickard (*5*) described an application of generalized linear models to railway trips. Said and Young (*3*) proposed a general linear model (GLM) framework for modeling trips of one of the households groups in Kuwait as a function of quantitative household variables. Said et al. (*6*) extended this analysis to include qualitative variables and addressed the use of GLM with cross-classified household data using its regression and ANOVA specifications.

TRIP RATE DATA OF HOUSEHOLD GROUPS IN KUWAIT

The characteristics of the different population groups in Kuwait have been described previously (*1,7*). The Kuwait population reached 1.697 million in 1985; 40.1 percent were Kuwaitis, 37.9 percent were non-Kuwaiti Arabs, and 21.0 percent were non-Kuwaitis of Asian origin. The age-sex distributions of these groups are markedly different. The Kuwaiti population is dominated by younger age groups. Arab and Asian population groups are dominated by individuals in the working ages, and the number of males is almost double the number of females.

Labor force participation rates of the nationality groups are also different. Kuwaiti females have noticeably low participation rates compared with other groups. Participation rates of Arab males and Asian males and females are extremely high, a result of the labor laws that govern foreigners in Kuwait.

Households of different nationalities vary in size. The average sizes of Kuwaiti, Arab, and Asian households are 9.2, 5.4, and 3.9, respectively. Kuwaiti households are large, with the majority of household members in the school-age group. Non-Kuwaiti Arab households are mostly of the family type, of medium to large size. Asian households are small to medium, with few members at the pre-work ages. The average numbers of working persons in these households are 1.48, 2.00, and 3.30, respectively. The number of workers per household reflects labor force participation rate differences and the age-sex composition. There are also significant variations in the occupation status of workers in the household groups.

The nationality of households in Kuwait is an important qualitative factor that has implications for social status, income, household structure and composition, and possible occupational status of working individuals of these households. Variations in trip rates indicate an important nationality effect, so households of different nationalities need to be treated separately (*1*). Three household groups are identified on the basis of the nationality types listed earlier.

For households within each nationality, house type provides another important qualitative factor. Four house types are commonly available: private villas, government housing (mostly villas), apartments, and "others." The latter includes Arabian houses (old-style villas) and annexes. Only very small Kuwaiti households live in apartments; 70 percent are in private and public villas. Only 2 to 3 percent of non-Kuwaiti households live in villas, whereas more than 75 percent live in apartments, and the rest live in other housing types.

Table 1 classifies households included in the 1988 home interview into three nationalities and four house types. Because government housing is available only for Kuwaitis, the two cells for Arab and Asian households in government housing have zero frequencies.

The raw work trip data used in this study are restricted to trips made in the morning peak period between 6:30 and 8:00 a.m. This restriction has resulted in the recording of fewer trips than expected. If work trip data for a longer morning duration were available, greater differences in the mean trip rates of household groups would have been detected. This is evident from Figure 1, in which the recorded mean trips of households of different sizes are plotted against the number of full-time workers of these households. Figure 1 indicates that the mean number of full-time workers is generally about 50 percent more than the recorded mean trip rates.

Said (*1*) described variations in trip rates of households of the three nationality groups for different levels of household

TABLE 1 HOUSEHOLDS IN 1988 HOME INTERVIEW SURVEY OF KUWAIT CLASSIFIED BY NATIONALITY AND HOUSE TYPE

House Type	Nationality			
	Kuwaitis	Arabs	Asians	Total
Villas	1107	155	12	1274
Public Housing (MHA)	762	0	0	762
Apartments	140	2640	296	3076
Others	183	688	68	939
Total	2192	3483	376	6051

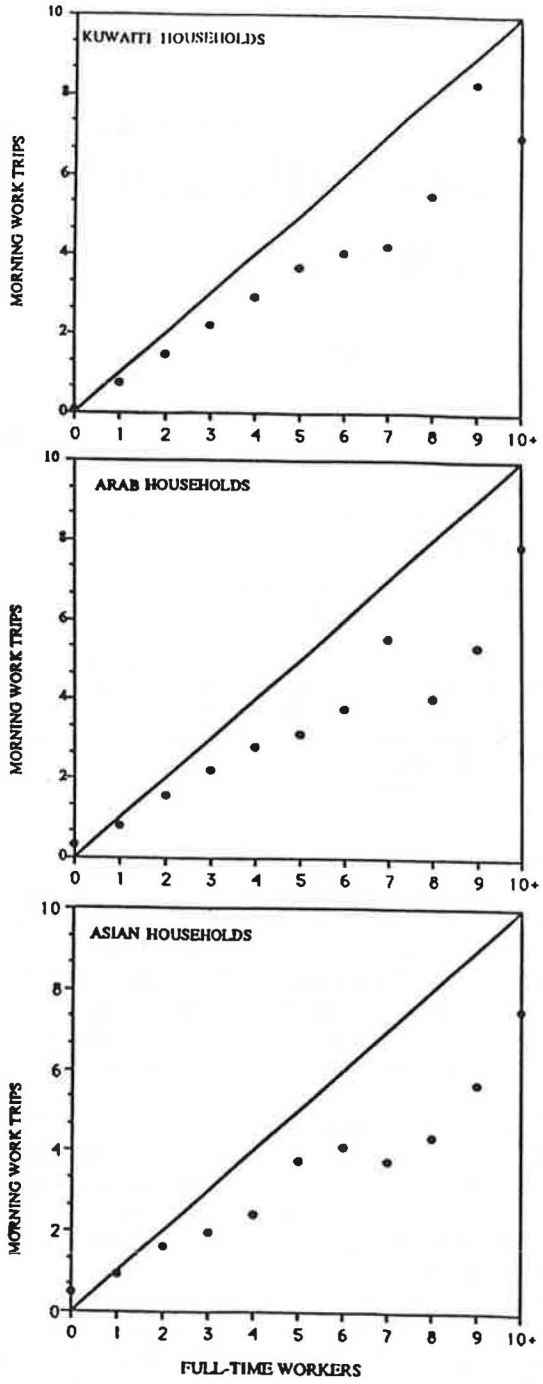

FIGURE 1 Mean morning work trip rates and number of full-time workers for households of various nationality groups.

size, car ownership, income, and numbers of adults and children in the household. Through the use of simple regression, Said and Young (*3*) showed that household size, car ownership, and number of adults in the household, when used as independent variables, are significant in explaining much of the variation in trips made by households. Said et al. (*6*) showed that, for Kuwaiti households, use of the number of children variable instead of household size is more appropriate because it complements the number of adults variable.

The regression analysis using ungrouped data for Kuwaiti households in villas (*3*) uses all combinations of values of the explanatory variables within each house type for which at least one trip rate observation was available. As a consequence, in many cases the mean trip rates are based on small cell household frequencies. Because forecasts of future numbers of households for combinations of specified values of the explanatory variables would be needed, it is advantageous to have a fairly broad grouping of the values of the variables.

The grouping varies for the three nationality groups. For Kuwaiti households a total of 80 cross-classification cells are used, based on five levels of the number of children variable X_1, four levels of the car ownership variable X_2, and four levels of the number of adults variable X_3. The house type effect is ignored for Kuwaiti and Asian households, and the reason will become apparent later in the paper. For Arab households a total of 48 cross-classification cells are used, based on four, four, and three levels for the variables X_1, X_2, and X_3, respectively. The grouping is performed for each of the three house types. A total of 27 cross-classification cells are used for Asian households. The variations in the grouping respond to observed differences between the three nationality groups. For example, whereas the range of the number of children variable extends from 0 to 20 for Kuwaiti households, few Asian households have more than 4 children.

Table 2 presents the cross-classification table for Kuwaiti households as well as the observed trip rates for each household cross-classification cell. Table 3 gives the household frequencies and trip rates for Arab households. The table is organized in three parts corresponding to three housing types (villas, apartments, and others). The most frequent households are those with one to two and three to five adults, one to three and four to eight children, and one or two cars per household. Table 4 presents household frequencies for Asian households. There are small discrepancies between the totals of Tables 2 through 4 and the relevant numbers in Table 1. These occur because a few outlying observations were eliminated.

STATISTICAL MODELS

In the previous discussion, the presence of large structural differences among household groups reflecting nationality was stressed. House type is another qualitative factor that must be evaluated. In addition, previous analyses made using data for Kuwaiti households alone indicate that the quantitative variables X_1 (number of children in the household), X_2 (number of cars owned per household), and X_3 (number of adults in the household) should be included as possible variables for explaining variations in trip rate (*6*).

The statistical models use the following notation, where the superscript i indicates nationality, with 1, 2, and 3 denoting Kuwaitis, other Arabs, and Asians, respectively. Define Cell $(j, k, l, m)^{(i)}$ as the cell corresponding to the group of households with Nationality i, House Type j, kth observed value of X_1, lth observed value of X_2, and mth observed value of X_3. Note that the range of values for j (house type) depends

TABLE 2 TRIP RATES AND HOUSEHOLD FREQUENCIES FOR KUWAITI HOUSEHOLDS

Adults in the Household	Car Ownership	Number of Children Under 18 Years: 0	1-3	4-7	8-11	12-15
1 - 2	0 - 1	0.59(17)	0.62(68)	0.62(120)	0.43(35)	0.00(1)
	2 - 3	1.18(17)	1.08(148)	1.07(203)	0.55(38)	0.00(2)
	4 - 6	1.00(1)	0.86(7)	1.09(11)	0.50(2)	--
	7 - 9	--	--	--	--	--
3 - 5	0 - 1	0.86(14)	0.73(30)	0.54(57)	0.53(40)	0.45(11)
	2 - 3	1.27(33)	1.16(149)	0.93(207)	0.70(81)	0.48(19)
	4 - 6	1.91(11)	1.67(86)	1.65(83)	1.25(24)	2.11(9)
	7 - 9	3.00(1)	2.50(2)	2.17(6)	2.50(2)	--
6 - 8	0 - 1	2.00(2)	0.80(5)	1.88(8)	0.88(8)	0.33(6)
	2 - 3	2.33(3)	1.72(47)	1.61(62)	1.34(41)	1.20(20)
	4 - 6	3.00(12)	2.45(98)	2.20(107)	1.78(37)	1.80(10)
	7 - 9	--	3.00(15)	3.11(18)	4.33(6)	3.50(2)
9 - 12	0 - 1	3.00(1)	3.50(2)	1.00(2)	2.00(2)	0.00(1)
	2 - 3	2.00(1)	--	1.55(11)	1.25(4)	1.00(6)
	4 - 6	--	3.00(11)	3.58(26)	3.10(21)	2.70(10)
	7 - 9	5.00(1)	4.39(18)	4.35(17)	3.42(12)	4.00(3)

-- indicates 0 household frequency

TABLE 3 OBSERVED TRIP RATES AND HOUSEHOLD FREQUENCIES FOR ARAB HOUSEHOLDS

Adults in the Household	Car Ownership	Number of Children: 0	1-3	4-8	9+
		(Villas)			
1 - 2	0	0.00 (1)	0.50 (2)	1.00 (1)	--
	1	0.00 (2)	1.10 (10)	0.61 (18)	1.00 (1)
	2	1.00 (1)	1.00 (14)	0.92 (12)	--
	3+	--	2.50 (2)	1.00 (1)	0.00 (1)
3 - 5	0	3.00 (1)	--	0.75 (4)	1.00 (2)
	1	0.00 (1)	0.86 (7)	1.13 (8)	1.25 (4)
	2	--	1.46 (11)	1.40 (5)	1.00 (1)
	3+	2.00 (1)	1.00 (2)	2.00 (4)	2.00 (1)
6+	0	--	--	1.00 (1)	--
	1	--	--	0.75 (4)	--
	2	--	3.50 (4)	1.75 (4)	0.00 (1)
	3+	3.00 (2)	2.33 (3)	2.00 (2)	1.33 (3)
		(Apartments)			
1 - 2	0	0.96 (24)	0.87 (67)	0.59 (68)	0.50 (2)
	1	0.97 (68)	1.05 (395)	0.83 (43)	0.86 (14)
	2	1.38 (21)	1.29 (161)	1.10 (109)	0.67 (3)
	3+	--	1.33 (3)	1.33 (6)	--
3 - 5	0	2.36 (47)	0.96 (44)	1.00 (55)	0.33 (3)
	1	1.53 (51)	1.22 (232)	1.03 (266)	1.28 (7)
	2	2.14 (42)	1.45 (129)	1.37 (76)	1.50 (4)
	3+	2.00 (18)	2.13 (47)	1.80 (5)	1.00 (1)
6+	0	3.87 (15)	1.00 (4)	2.57 (7)	--
	1	2.53 (15)	2.25 (56)	1.54 (26)	2.00 (3)
	2	3.00 (5)	2.20 (35)	2.58 (19)	3.00 (3)
	3	4.33 (12)	2.23 (13)	2.56 (9)	2.00 (1)
		('Other' Housing Types)			
1 - 2	0	1.00 (3)	0.67 (12)	0.70 (27)	0.43 (7)
	1	1.50 (2)	0.95 (20)	0.77 (104)	0.88 (25)
	2	1.00 (1)	1.36 (11)	1.00 (14)	0.83 (6)
	3+	--	--	2.00 (1)	1.00 (1)
3 - 5	0	2.48 (29)	1.00 (2)	0.82 (22)	1.18 (11)
	1	3.67 (3)	1.21 (34)	0.81 (69)	0.97 (30)
	2	1.55 (11)	1.63 (16)	1.24 (33)	1.52 (23)
	3+	2.50 (4)	1.86 (7)	1.43 (7)	1.25 (8)
6+	0	5.31 (13)	1.00 (2)	0.71 (7)	1.25 (4)
	1	3.75 (4)	1.77 (13)	1.20 (10)	1.00 (3)
	2	6.00 (2)	1.67 (6)	1.45 (11)	2.00 (11)
	3+	3.00 (2)	2.63 (8)	2.15 (13)	2.08 (12)

- indicates 0 household frequency

TABLE 4 TRIP RATES AND HOUSEHOLD FREQUENCIES FOR ASIAN HOUSEHOLDS

Adults in the Household	Car Ownership	Number of Children: 0	1-3	4+
1 - 2	0	0.77 (13)	1.29 (28)	1.00 (7)
	1	1.46 (11)	1.12 (87)	0.79 (19)
	2+	1.00 (1)	1.23 (13)	0.00 (1)
3 - 5	0	2.47 (19)	2.05 (21)	1.33 (6)
	1	2.00 (15)	1.41 (39)	1.12 (17)
	2+	2.00 (9)	2.20 (20)	2.00 (3)
6+	0	2.73 (11)	1.00 (1)	0.50 (2)
	1	1.75 (4)	2.86 (7)	2.00 (3)
	2+	6.00 (6)	3.50 (2)	1.00 (1)

on the i (nationality group) that is being considered and that the ranges of values for k, l, and m depend on which nationality/house type grouping (i, j) is being considered.

For Cell $(j, k, l, m)^{(i)}$ in the sample, let

$N^{(i)}_{jklm}$ = number of households;
$Y^{(i)}_{jklmr}$ = number of work trips observed for the rth household, $r = 1, \ldots, N^{(i)}_{jklm}$; and
$Y^{(i)}_{jklm}$ = total number of observed work trips.

In the population, let

$\mu^{(i)}_{jklm}$ = mean number of household work trips and
$\sigma^{(i)}_{jklm}$ = standard deviation of number of household work trips.

Examination of the observed within-cell variations of trip rates about the cell means indicated that the variance/mean ratios are reasonably stable with values close to 1; this extends a similar finding for Kuwaiti households in villas (*3*). Such a relation between mean and variance suggests that the trip rates for Cell $(j, k, l, m)^{(i)}$ may be taken to have approximately a Poisson distribution with mean $\mu^{(i)}_{jklm}$. To model the dependence of the mean on house type and the three quantitative variables X_1, X_2, and X_3, a logarithmic link is assumed, taking

$$\begin{aligned}\log \mu^{(i)}_{jklm} = {} & \beta^{(i)}_{0j} + \beta^{(i)}_{1j}X_{1k} + \beta^{(i)}_{2j}X_{2l} + \beta^{(i)}_{3j}X_{3m} \\ & + \beta^{(i)}_{4j}X_{1k}X_{2l} + \beta^{(i)}_{5j}X_{1k}X_{3m} + \beta^{(i)}_{6j}X_{2k}X_{3m} \\ & + \beta^{(i)}_{7j}X_{1k}X_{2l}X_{3m} \qquad (1)\end{aligned}$$

This model ensures that the mean is positive and, taken with the Poisson assumption, a Poisson log-linear regression model. The model is general in form because it (*a*) includes interaction as well as linear effects for the variables X_1, X_2, and X_3 and (*b*) allows the regression coefficients to vary over both nationality and house type levels.

More concise model forms are also of interest. Although the order of model simplification is arbitrary, we shall adopt the procedure of first evaluating the house type effects within each nationality group by examining the reduced models

$$\begin{aligned}\log \mu^{(i)}_{jklm} = {} & \beta^{(i)}_{0j} + \beta^{(i)}_{1}X_{1k} + \beta^{(i)}_{2}X_{2l} + \beta^{(i)}_{3}X_{3m} \\ & + \beta^{(i)}_{4}X_{1k}X_{2l} + \beta^{(i)}_{5}X_{1k}X_{3m} + \beta^{(i)}_{6}X_{2k}X_{3m} \\ & + \beta^{(i)}_{7}X_{1k}X_{2l}X_{3m} \qquad (2)\end{aligned}$$

and

$$\begin{aligned}\log \mu^{(i)}_{jklm} = {} & \beta^{(i)}_{0} + \beta^{(i)}_{1}X_{1k} + \beta^{(i)}_{2}X_{2l} + \beta^{(i)}_{3}X_{3m} \\ & + \beta^{(i)}_{4}X_{1k}X_{2l} + \beta^{(i)}_{5}X_{1k}X_{3m} + \beta^{(i)}_{6}X_{2k}X_{3m} \\ & + \beta^{(i)}_{7}X_{1k}X_{2l}X_{3m} \qquad (3)\end{aligned}$$

Model 2 allows for house type to have a systematic effect on the average trip but takes the effects of X_1, X_2, and X_3 to be the same for all house types within each nationality groups. Model 3 implies that house type has no effect at all. Other reduced model forms of interest are obtained by setting subsets of the β terms on the right-hand sides of Models 1, 2, and 3 equal to zero.

Models are fitted by the method of maximum likelihood, and the statistical package GLIM provides a suitable way to perform the calculations (*8*). The goodness of fit of any model is measured by the deviance (*9,10*) and is given by

$$\begin{aligned}D = {} & 2\sum_j\sum_k\sum_l\sum_m\{Y^{(i)}_{jklm}\log[Y^{(i)}_{jklm}/N^{(i)}_{jklm}\mu^{(i)}_{jklm}] \\ & - [Y^{(i)}_{jklm} - \mu^{(i)}_{jklm}]\} \qquad (4)\end{aligned}$$

If the model is correct, D is approximately distributed as chi-square with degrees of freedom equal to the number of cells in the nationality group minus the number of parameters in the model. Changes in the deviances may be assessed using chi-square tests to test the goodness of fit of reduced models. Similar approaches can be used when the values for X_1, X_2, and X_3 are grouped into broader intervals; variable values are then put equal to the central values of the groups.

Finally, if the quantitative nature of X_1, X_2, and X_3 is ignored, the regression models may be replaced by ANOVA models. For example, Model 1 is replaced by the four-factor model

$$\begin{aligned}\log \mu^{(i)}_{jklm} = {} & \mu^{(i)} + A^{(i)}_j + B^{(i)}_k + C^{(i)}_l + D^{(i)}_m \\ & + (AB)^{(i)}_{jk} + (AC)^{(i)}_{jl} + (AD)^{(i)}_{jm} \\ & + (BC)^{(i)}_{kl} + (BD)^{(i)}_{km} + (CD)^{(i)}_{lm} \\ & + (ABC)^{(i)}_{jkl} + (ABD)^{(i)}_{jkm} + (ACD)^{(i)}_{jlm} \\ & + (BCD)^{(i)}_{klm} + (ABCD)^{(i)}_{jklm} \qquad (5)\end{aligned}$$

where A, B, C, and D are factors representing house type, number of children, car ownership, and number of adults, respectively. Models are again fitted by maximum likelihood, and assessments of fit are again based on changes in the deviances.

MODEL FITS FOR KUWAITI HOUSEHOLD DATA

Four house types were considered for Kuwaiti households: villas, NHA (government housing), apartments, and "others." As was indicated earlier, the untransformed trip rates could be taken to have approximately a Poisson distribution with a logarithmic link function for the means, the initial model being given by Model 1. The effect of house type was first examined by comparing Model 1 with the reduced Models 2 and 3 for $i = 1$.

For the ungrouped data, fits by maximum likelihood of Models 1, 2, and 3 for $i = 1$ gave deviances equal to 887.5, 904.1, and 905.1, with 971, 985, and 987 degrees of freedom, respectively. The χ^2 statistic for comparing Models 1 and 2 has value $904.1 - 887.5 = 16.6$ with 14 degrees of freedom. Similarly, the χ^2 statistic for comparing Models 2 and 3 has value 1.0 with 2 degrees of freedom. From χ^2 tables the upper 10 percent points are $\chi^2_{14}(0.9) = 21.06$ and $\chi^2_2(0.9) = 4.61$, so neither value is significant even at the 10 percent level. Thus, there is no evidence of any house type effect, and Model 3 is to be adopted.

Said et al. (*6*) pointed out that the models and associated statistical analyses are the same using the grouped data for

Kuwaiti households as using the ungrouped data. The only change is that the values of the explanatory variables are taken as the midpoints of the ranges selected for each variable. The broad findings are the same as for ungrouped data.

When reduced forms of Model 3 are examined, analysis using the grouped data indicates that only the three-variable interaction term $\beta_7 X_{1k} X_{2l} X_{3m}$ and the two-variable interaction term $\beta_5 X_{1k} X_{3m}$ can be excluded. The equation for the estimated cell mean trip rates was

$$\hat{\mu}^{(1)}_{jklm} = \exp(-0.483 - 0.064X_{1k} + 0.150X_{2l} + 0.120X_{3m} + 0.008X_{1k}X_{2l} - 0.006X_{2l}X_{3m}) \quad (6)$$

Using the ANOVA specification of GLM, if the house type effects are dropped and the chi-square tests are applied to the differences between the deviances of Model 5 with $i = 1$ and its reduced forms, the only significant interaction is $(CD)_{lm}$. The parameter estimates can be used to provide estimates of the cell mean trip rates using

$$\hat{\mu}^{(1)}_{jklm} = \exp(\hat{\mu} + \hat{B}_k + \hat{C}_l + \hat{D}_m + (\widehat{CD})_{lm}) \quad (7)$$

where from the computer fit of the model

$$\hat{\mu} = -0.311,$$
$$\hat{B}_k = (0, -0.170, -0.232, -0.454, -0.450),$$
$$\hat{C}_l = (0, 0.553, 0.479, 0.732),$$
$$\hat{D}_m = (0, 0.064, 0.711, 1.260), \text{ and}$$
$$(\widehat{CD})_{lm} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & -0.083 & -0.237 & -0.880 \\ 0 & 0.494 & 0.165 & 0.050 \\ 0 & 0.612 & 0.300 & 0 \end{pmatrix}$$

These results for the regression and ANOVA models indicate that trip rates of Kuwaiti households increase with car ownership and number of adults but decrease with increasing number of children. The interaction effect of car ownership and number of adults is also significant in the two models. In the regression model the interaction effect of number of children and car ownership is also significant. The estimates of cell mean trip rates provided by the fitted regression and ANOVA models were close and in general agreed well with observed mean trip rates. The largest discrepancies were associated with outlying cells containing low frequencies.

MODEL FITS FOR ARAB HOUSEHOLDS

The effect of house type for Arab households ($i = 2$) has been tested with a procedure similar to that used for Kuwaiti households. When an underlying Poisson distribution with a logarithmic link was assumed for the trips, the deviances for the fits of Models 1, 2, and 3 using the ungrouped data were 511.4, 533.5, and 536.9, respectively. The χ^2 statistic for comparing Model 2 with Model 1 is therefore 22.1 with 15 degrees of freedom. This value, when compared with $\chi^2_{15}(95) = 24.9$, confirmed that the house type effect is significant.

Fits of the Poisson model for the means in Table 3 indicated that the most concise models for households in different housing types are of the following forms:

- For households in villas,

$$\hat{\mu}^{(2)}_{1klm} = \exp(-0.636 + 0.222X_{2l} + 0.117X_{3m}) \quad (8)$$

- For households in apartments,

$$\hat{\mu}^{(2)}_{2klm} = \exp(-0.127 - 0.10X_{1k} + 0.063X_{2l} + 0.148X_{3m} + 0.033X_{1k}X_{2l}) \quad (9)$$

- For households in other dwelling unit types,

$$\hat{\mu}^{(2)}_{3klm} = \exp(-0.193 - 0.057X_{1k} - 0.124X_{2l} + 0.231X_{3m} + 0.047X_{1k}X_{2l} - 0.018X_{1k}X_{3m}) \quad (10)$$

Comparisons among the models are difficult because they have markedly different forms. In all cases, the fitted models show the expected increase in mean trip rate with increasing number of adults. The sign and magnitude of the effect of car ownership depends strongly on whether the number of children has a significant effect on or interaction with other factors.

When the ANOVA specifications of GLM are used, the possible Poisson models for the means that were selected have the following forms:

- For households in villas,

$$\hat{\mu}^{(2)}_{1klm} = \exp(\hat{\mu} + \hat{C}_l + \hat{D}_m) \quad (11)$$

where

$$\hat{\mu} = -0.374,$$
$$\hat{C}_l = (0, -0.009, 0.422, 0.546), \text{ and}$$
$$\hat{D}_m = (0, 0.365, 0.642).$$

- For households in apartments,

$$\hat{\mu}^{(2)}_{2klm} = \exp(\hat{\mu} + \hat{B}_k + \hat{C}_l + \hat{D}_m + (\widehat{BC})_{kl}) \quad (12)$$

where

$$\hat{\mu} = .502,$$
$$\hat{B}_k = (0, -0.739, -0.807, -1.573),$$
$$\hat{C}_l = (0, -0.406, -0.052, 0.089),$$
$$\hat{D}_m = (0, 0.246, 0.761), \text{ and}$$
$$(\widehat{BC})_{kl} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0.656 & 0.505 & 1.393 \\ 0 & 0.450 & 0.457 & 1.279 \\ 0 & 0.528 & 0.652 & 0.651 \end{pmatrix}.$$

- For households in other dwelling unit types,

$$\hat{\mu}^{(2)}_{3klm} = \exp(\hat{\mu} + \hat{B}_k + \hat{C}_l + \hat{D}_m) \quad (13)$$

where

$$\hat{\mu} = .67,$$
$$\hat{B}_k = (0, -0.708, -0.978, -0.851),$$
$$\hat{C}_l = (0, -0.028, 0.164, 0.266), \text{ and}$$
$$\hat{D}_m = (0, 0.220, 0.689).$$

Compared with Models 8, 9, and 10, Models 11, 12, and 13 indicate that both regression and ANOVA approaches lead to fitted models having similar structure, with the exception of households in "other" dwelling unit types.

Table 5 gives the estimated mean trip rates of Arab households in apartments using the regression and ANOVA models. The table indicates that the two models produce similar estimates. The model estimates compare reasonably well with the observed trip rates of Table 3 for high-household-frequency cells. There are some discrepancies for outlying low-frequency cells.

MODEL FITS FOR ASIAN HOUSEHOLDS

Three house types were initially considered for Asian households. The chi-square test indicated that house type has no effect for these households. All Asian households in the home interview survey are therefore treated collectively in this section. The GLM analysis of trip rates using the data in Table 4 indicated that, when applying the regression model, only the main effects of X_1 (number of children in the household) and X_3 (number of adults in the household) were significant. The equation for the estimates of the cell means is

$$\hat{\mu}^{(3)}_{jklm} = \exp(0.086 - 0.109X_{1k} + 0.170X_{3m}) \quad (14)$$

In the case of the ANOVA model, the three main effects were significant, but there were no significant interactions. The estimated means are

$$\hat{\mu}^{(3)}_{jklm} = \exp(\hat{\mu} + \hat{B}_k + \hat{C}_l + \hat{D}_m) \quad (15)$$

where

$$\hat{\mu} = .306,$$
$$\hat{B}_k = (0, -0.143, -0.52),$$
$$\hat{C}_l = (0, -0.102, 0.228), \text{ and}$$
$$\hat{D}_m = (0, 0.430, 0.853).$$

The estimated mean trip rates are given in Table 6 on the basis of Models 14 and 15. The table indicates that the regression and ANOVA model estimates are consistent. The regression model trip rate estimates do not vary for the different car ownership groups, because Model 14 implies that this factor has no effect. This is unlike the ANOVA models, which indicate that some car ownership effects exist. The structure of the two model fits is consistent with the socioeconomic characteristics of Asian households in Kuwait, which are dominated by low-income working adults with low car ownership rates and significant reliance on public transport for work trip purposes.

TABLE 5 ESTIMATED MEAN TRIP RATES BASED ON FITS USING GROUPED DATA OF ARAB HOUSEHOLDS (APARTMENTS) (POISSON MODEL WITH LOGARITHMIC LINK)

Adults in the Household	Car Ownership	Number of Children: 0		1-3		4-6		9+	
		(i)	(ii)	(i)	(ii)	(i)	(ii)	(i)	(ii)
1 - 2	0	1.10	1.65	.90	.79	.60	.74	.42	.34
	1	1.17	1.10	1.02	1.01	.78	.81	.61	.92
	2	1.25	1.57	1.17	1.18	1.01	1.11	.90	1.17
	3+	1.35	1.81	1.36	1.46	1.39	1.55	1.41	0.88
3 - 5	0	1.59	2.11	1.30	1.01	.87	.94	.61	.44
	1	1.70	1.41	1.48	1.30	1.13	1.04	.89	1.18
	2	1.81	2.01	1.69	1.50	1.47	1.41	1.30	1.50
	3+	1.95	2.31	1.97	1.87	2.01	1.98	2.04	1.12
6+	0	2.38	3.54	1.95	1.69	1.30	1.58	.91	0.73
	1	2.53	2.36	2.21	2.17	1.69	1.74	1.33	1.97
	2	2.70	3.36	2.52	2.52	2.19	2.37	1.94	2.50
	3+	2.91	3.87	2.94	3.13	2.99	3.31	3.04	1.88

(i) Regression Model
(ii) ANOVA Model

TABLE 6 OBSERVED AND ESTIMATED MEAN TRIP RATES BASED ON FITS USING GROUPED DATA OF ASIAN HOUSEHOLDS (POISSON MODEL WITH LOGARITHMIC LINK)

Adults in the Household	Car Ownership	Number of Children: 0		1-3		4+	
		(i)	(ii)	(i)	(ii)	(i)	(ii)
1 - 2	0	1.41	1.36	1.13	1.18	.82	.81
	1	1.41	1.23	1.13	1.06	.82	.73
	2+	1.41	1.71	1.13	1.48	.82	1.01
3 - 5	0	2.15	2.09	1.73	1.81	1.25	1.24
	1	2.15	1.89	1.72	1.64	1.25	1.12
	2+	2.15	2.62	1.73	2.27	1.25	1.56
6+	0	3.46	3.19	2.78	2.76	2.00	1.89
	1	3.46	2.88	2.78	2.49	2.00	1.71
	2+	3.46	4.00	2.78	3.47	2.00	2.38

(i) Regression Model
(ii) ANOVA Model

USE OF DEVELOPED TRIP RATES IN PLANNING

The fitted models given in the preceding three sections can be used to construct charts giving estimates of the mean trip rates that allow planners to forecast total numbers of morning work trips for individual zones. Figure 2 shows such a chart based on estimates from the fitted ANOVA models. For convenience, only Arabs in apartments are included. In a more complete representation, Arab households in villas and "other" housing types would be needed.

The use of the chart is straightforward. Estimates of frequencies of households classified by nationality, car ownership, number of children, and number of adults are needed as input. Multiplication of these frequencies by the associated estimated means read from the chart and summation of the resulting products give the required estimate of trips in the zone.

Morning work trips in 1995 for two typical zones, Jahra and Hawalli, are estimated here for demonstration purposes. Jahra is typical of zones dominated by Kuwaiti households. The expected numbers of Kuwaiti and non-Kuwaiti households in 1995 are 15,726 and 9,270, respectively. These estimates are based on the cohort survival technique for population forecasting using the 1985 data base. The household size and relative proportions of households by size are assumed to remain stable over the 1985–1995 forecasting period. The cross-classification of these households is shown in Table 7.

Hawalli is typical of zones dominated by non-Kuwaiti households. The zone is expected to have 33,324 Arab non-Kuwaiti households in apartments, 3,200 Arab households in

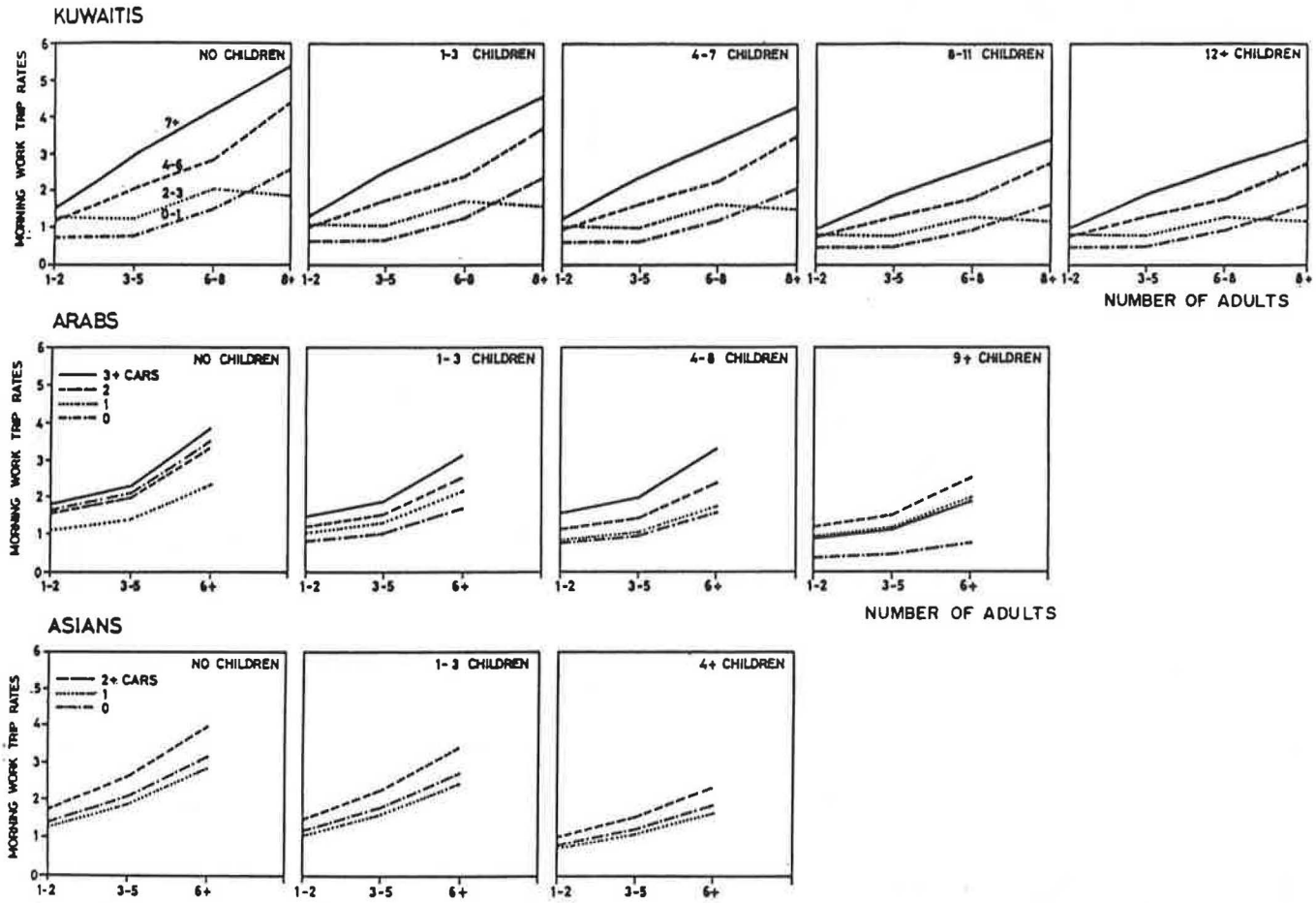

FIGURE 2 Work trip rates of households of different nationalities with levels of three explanatory variables based on fits of ANOVA models.

"other" housing types, and 800 Kuwaiti households. Table 8 shows the 1995 household frequencies for Arab households in apartments for this zone.

The expected numbers of morning work trips that can be generated by the two zones in 1995 are 29,060 and 51,250, respectively. These numbers were estimated on the basis of household frequencies and the appropriate trip rates from Figure 2 supplemented with a similar chart for Arab households in "other" housing types.

STABILITY OF ESTIMATED WORK TRIP RATES

Most trip generation studies assume a degree of stability over the forecasting period of the trip generation equation developed for the calibration year. The stability of the household level trip generation equations could be verified through (*a*) the stability of the estimated values of the regression coefficients for the household groups or the effects estimated when the ANOVA specification of GLM is used and (*b*) the stability of the ranges of the underlying explanatory variables in these equations.

The stability of the regression coefficients or the ANOVA effects is the subject of current research using data collected in a 1977 home interview survey along with the 1988 data. The differences between the magnitudes of the coefficients based on the two data sets will be studied.

Confirmation of stability in the ranges of underlying explanatory variables in the household-level trip generation equations is relevant to this investigation, because these equations can only be used with confidence over roughly the range of the explanatory variables used in the calibration. Large structural shifts in the magnitude of these variables clearly could introduce forecasting errors.

The regression and ANOVA models used three variables: number of children, number of adults, and car ownership. The first two variables are studied jointly through the household size variable, because there are no historical records of households classified by numbers of children and adults.

Household Size

The top of Figure 3 uses census data to show the percentage of households by size of household for Kuwaitis between 1970 and 1985. The figure indicates that household size distribution has been reasonably stable. This will probably be the case for the short and medium term. The trend of large household size because of increased number of children is being compensated for by the increasing presence of extended families where married sons remain within the parent household.

TABLE 7 HOUSEHOLD FREQUENCIES FOR TYPICAL KUWAITI ZONE IN 1995: JAHRA

Adults	Car Ownership	0	Number of Children 1-3	4-7	8-11	12-15
1 - 2	0 - 1	0	336	1193	796	0
	2 - 3	0	192	530	597	66
	4 - 6	0	0	0	0	0
	7 - 9	0	0	0	0	0
3 - 5	0 - 1	66	265	796	928	265
	2 - 3	0	336	2254	928	463
	4 - 6	0	133	265	192	66
	7 - 9	0	0	0	0	0
6 - 8	0 - 1	66	66	66	133	66
	2 - 3	0	398	663	597	463
	4 - 6	66	336	530	265	398
	7 - 9	0	66	0	0	0
9 - 12	0 - 1	0	0	66	0	0
	2 - 3	0	0	66	133	192
	4 - 6	0	66	66	398	66
	7 - 9	0	66	0	0	0

(b) Arab Households in Apartments

Adults	Car Ownership	0	Number of Children 1-3	4-8	9+
1 - 2	0	274	549	0	0
	1	0	823	1646	549
	2	0	0	549	0
	3+	0	0	0	0
3 - 5	0	823	0	0	0
	1	0	0	0	0
	2	0	0	274	0
	3+	0	274	0	0

(c) Arab Households in 'Others' Housing

1 - 2	0	0	27	239	80
	1	0	53	372	266
	2	0	27	53	80
	3+	0	0	0	0
3 - 5	0	0	0	159	159
	1	0	133	478	345
	2	27	53	133	186
	3+	0	0	27	53
6+	0	0	0	53	53
	1	0	0	80	53
	2	0	0	53	80
	3+	0	27	80	80

TABLE 8 HOUSEHOLD FREQUENCIES FOR TYPICAL NON-KUWAITI ZONE IN 1995: HAWALLI (ARAB HOUSEHOLDS IN APARTMENTS)

Adults in the Household	Car Ownership	0	Number of Children 1-3	4-8	9+
1 - 2	0	143	620	620	0
	1	810	3909	4624	143
	2	381	1287	1430	0
	3+	0	95	143	0
3 - 5	0	238	1049	1049	0
	1	1001	3289	4290	95
	2	715	1907	1287	48
	3+	143	620	48	0
6+	0	0	95	95	0
	1	191	953	286	95
	2	48	715	286	0
	3+	143	334	95	0

The bottom of Figure 3 shows household size data for non-Kuwaitis; data for separate non-Kuwaiti nationality groups are not available. These households showed some instabilities in household size over the first 5 years, although the scale of change was not large. Household size remained relatively stable from 1975 to 1985 and can be expected to remain so.

Household Car Ownership

Data on household car ownership in Kuwait are limited. Only the 1970 census contained this information. The two home interview studies of 1977 and 1988 had questions on car ownership for a sample of households. These studies, along with the 1970 census data, are used in this section.

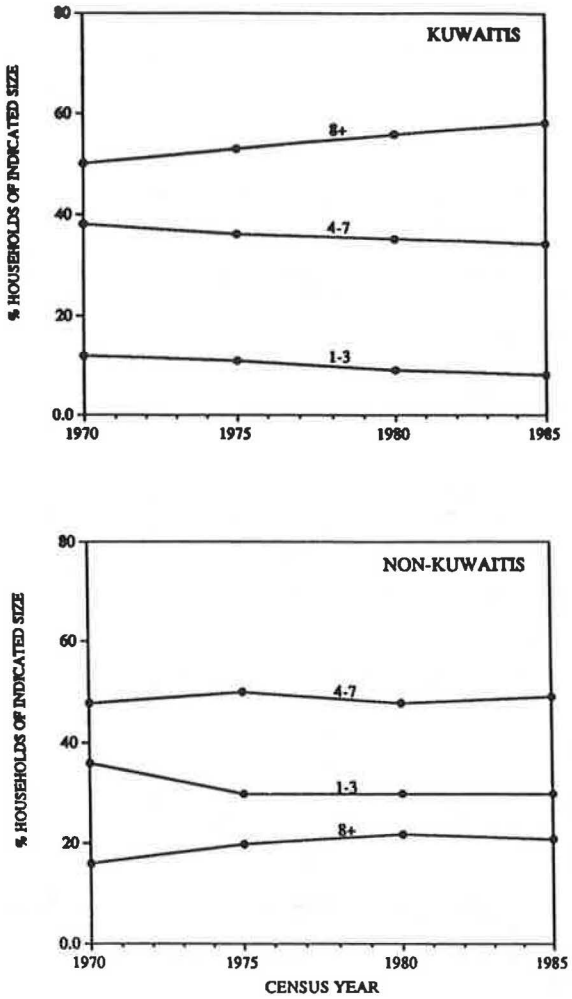

FIGURE 3 Percentage of Kuwaiti and non-Kuwaiti households by size, 1970–1985.

Figure 4 shows the trend in car ownership for Kuwaiti and non-Kuwaiti households. The top shows that for Kuwaiti households the proportion of one-car households declined from 70 percent in 1970 to 17 percent in 1980 and that the proportion of three- and four-or-more-car households rose noticeably between 1977 and 1988. This period corresponds to the era of rising national and per capita income because of the rise in the price of oil, Kuwait's main export, in the early 1970s. It is thought that current car ownership levels reflect saturation levels and that significant increases in the proportion of households with three or more cars are unlikely.

The bottom of Figure 4 shows reasonable stability in the proportions of one-, three-, and four-or-more-car households among non-Kuwaitis. Major shifts occurred in the proportions of zero- and two-car households. Zero-car households declined from 40 percent in 1970 to 15 percent in 1988, whereas the proportion of two-car households increased from 5 percent in 1970 to 20 percent in 1988. The socioeconomic characteristics of non-Kuwaitis and the regulations that govern the issue of operator licenses to various non-Kuwaiti occupational groups suggest that the current household car ownership structure will not change significantly in the short run.

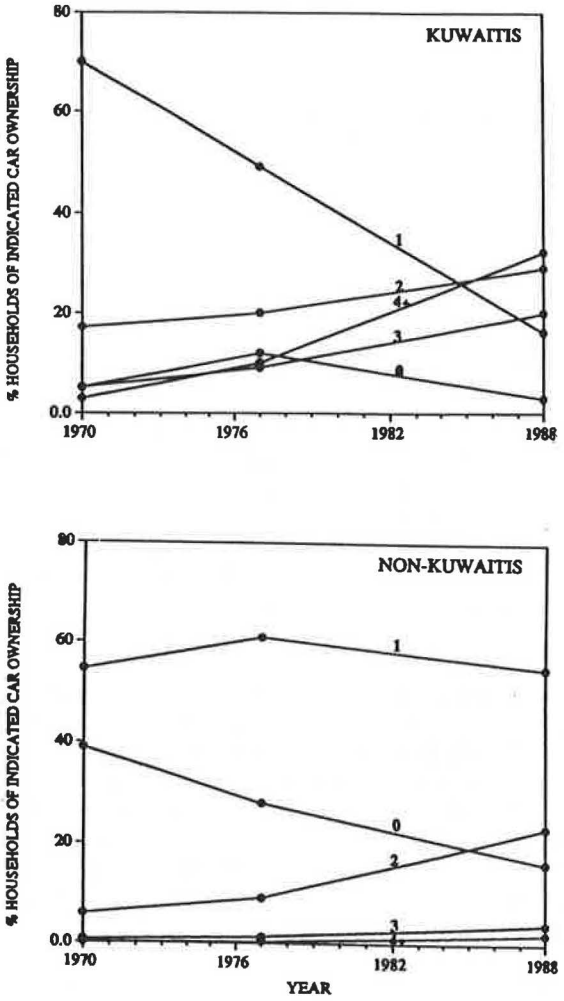

FIGURE 4 Percentage of Kuwaiti and non-Kuwaiti households by car ownership level, 1970–1988.

CONCLUDING REMARKS

The objective of this paper was to present the findings of a 3-year study of trip rates of households in Kuwait. The study led to a proposed general modeling approach that can be applied to a variety of urban areas. In the initial stages of the study, the intent was to refine one of the routinely used trip generation procedures. Further analysis indicated that several features in Kuwait, such as great variations in size in already-large households and variations in car ownership up to levels not common in many urban areas, would make the routine use of one of these techniques inappropriate. Other major variations among these households in characteristics such as income, labor force participation rates, and occupation and variations among subgroups based on nationality and house type were also shown. Situations like these may exist in other areas. Cities in neighboring countries in the Persian Gulf region provide good examples.

When the approach proposed in this paper is to be used for other urban areas, some investigative work will be warranted. Its purpose will be to (*a*) identify potential qualitative variables to be considered and verify their significance, (*b*) identify potential quantitative variables to be used in the analysis and select the most appropriate, (*c*) establish the relation of the variance-mean pattern of the individual household trips to aid in the selection of their underlying distribution, and (*d*) construct the groupings of the quantitative variables. Once these steps have been completed, model fits can be made using the GLM framework.

The specific conclusions of this paper are as follows:

1. There are marked variations among household groups in Kuwait.
2. House type is significant in the case of Arab households as a qualitative variable but not significant in the case of Kuwaiti and Asian households.
3. Regression and ANOVA models produce similar mean trip rate estimates, and these estimates agree with observed trip rates for high-frequency classification cells.
4. The number of adults and car ownership were found to be important variables in explaining variations in observed trip rates.
5. The number of children was found to be significant in most cases, with trip rates tending to decrease as the number of children increased.

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