Kuwait J. Sci. Eng. **27**(2) 2000

Trip chaining comparisons and logistic models for complex trip chains in Kuwait

PARVIZ A. KOUSHKI, OMAR I. AL-SALEH, SALEH Y. ALI AND BASHEER N. MOHAMMAD

Department of Civil Engineering, Kuwait University, P.O. Box 5969, Safat, Kuwait 13060
Fax: (965) 481-7524. E-mail: Parviz@kuc01.kuniv.edu.kw

ABSTRACT

The problem of traffic congestion during daily peak hours has reached serious proportions in recent years in Kuwait. This research project was undertaken to examine the likely contribution of trip chaining to this daily congestion. The distribution of daily trips by purpose, mode, vehicle occupancy, time of day and trip duration is presented, and a comparative analysis of trip chaining patterns is also performed. Results indicate that, in spite of the time-staggering of work and school activities, more than 31 percent of school trips are still made during the morning peak hour. Most of these are by auto and are chained to work trips. The number of complex chains reported by individual households in Kuwait was also found to be significantly lower than that reported by households in the United States and Europe. The very high auto ownership rate of Kuwaiti households, and their tendency to employ drivers, may explain this difference in complex trip chaining behavior. The study also involved the calibration of logistic models to predict the probability of Kuwaiti and expatriate households making complex trip chains. Findings of the research will assist responsible policy-makers in the development of both short-term transport system management (TSM) measures to curb congestion and alternative long-term urban transportation plans.

INTRODUCTION

Traffic congestion during daily commuting hours has gradually assumed serious proportions in Kuwait, and a growing number of commuters experience accidents, delays and stress as a result. Recent research has shown that traffic delay due to congestion was ranked highest among urban traffic-related problems by the commuting public (Koushki *et al.* 2000). Stress, accident potential and noise pollution followed congestion delay in descending order.

Over the last two decades, transport researchers have also recognized and observed a continuous rise in the number of non-work trips during daily commute hours (Adler & Ben-Akiva 1979, Horowitz 1979, Kostynuik & Kitamura 1984, Thill & Thomas 1987, Gordon & Richardson 1988, Goulias *et al.* 1990, Strathman *et al.* 1994). Researchers have highlighted the need for incorporating the concept of trip chaining into the urban transportation modeling system (Adler & Ben-Akiva 1979, Horowitz 1979, Goulias & Kitamura 1989). Some of the earlier works were of

an exploratory nature (Lathrop 1970, Oster 1973, Clark *et al.* 1981). Adler & Ben-Akiva (1979), Horowitz (1979) and Goulias & Kitamura (1989) defined the conceptual framework for the analysis of trip chaining behavior. Their studies also established the existence of trip chaining and its effects on travel demand, as well as its contribution to traffic congestion in urban areas. Probabilistic techniques (mainly the Markov chains) and microeconomic methods—mainly utility maximization (Metaxatos & Sen 1997), are the two principal approaches that have been employed for the explanation and modeling of trip chaining behavior.

A comparative study of trip chaining behavior in the United States and Europe also points to the existence of significant differences in the factors influencing the formation of trip chains (Goulias *et al.* 1990, Strathman *et al.* 1994, Feng-Chia & Mahmassani 1997). Thus, the need for the identification and analysis of trip chaining behavior at different geographical locations has been recognized.

This study examines and compares trip chaining behavior in Kuwait with that of other nations, and presents calibrated logistic models of trip chaining to be utilized in the future prediction of Kuwaiti and expatriate household trip-chaining behavior in Kuwait. Findings of the study could greatly assist the policy-makers concerned with the development of Transport System Management (TSM) measures to reduce daily traffic congestion in Kuwait. Equally important to transport policy-makers is a better understanding of trip-chaining and its effect on home-based/non-home-based trip generation rates. This information can be utilized in the development of long-range urban transportation plans.

THE DATA

A structured questionnaire was designed to integrate two essential types of information: (a) socio-economic traits including family size, family employment, number of driver's license holders, age, education, gender and occupation of head, family income and family car ownership; and (b) trip-making characteristics covering the sequence of trips by each travelling member of the household. Trip start and finish times, number of persons per trip, origin and destination land uses, purpose, and mode, as well as the average number of daily walking trips were also addressed by the questionnaire.

The sample size was computed on the basis of specified sampling error and confidence level. The relationship between sample error and the probability of meeting this precision in the survey result is given (Hamburgh 1977) as:

$$e = [(Z^2_{1-\alpha/2}/N)p.q]^{1/2} \tag{1}$$

where e = sampling error, Z = the Z statistic of a normal distribution at $1 - \alpha/2$ confidence level, N = sample size, p = the probability (percentage) that the population possesses certain traits, $q = 1 - p$, and α = significance level.

Assuming a sampling error of ± 5 percent, a confidence level of 95 percent ($\alpha = 0.05$), and $p = 0.5$ (which result in a maximum sample size), the required sample size from Eq. (1) is nearly 385. The sample size was applied to a number of systematic-randomly selected districts characterized by nationality and income distributions of their residence. Nearly 1500 heads of households were randomly selected (from a systematic random sample of residential blocks in each district),

and person-interviewed. The sample heads were requested to provide information on every trip taken the previous day (weekdays only). One thousand and two hundred completed questionnaires (all reported by the male heads of households) were processed for analysis. The remaining 300 surveys suffered from either incomplete and/or illogical data and were, therefore, eliminated from the analysis. The eliminated questionnaires were rather uniformly distributed among the surveyed districts. An examination of the sample household traits showed close conformity with those reported by other researchers (KEO 1989).

TRIP CHAINING BEHAVIOR

A comprehensive examination of the sample households' socio-economic and trip making behavior is presented elsewhere (Koushki *et al.* 1998). A detailed typology of simple and complex trip chains was prepared and adjusted to correspond approximately to the one adopted by Golob (1986) and Strathman *et al.* (1994), so as to enable the comparison of trip chaining behavior in Kuwait with that of other locations. Six types of simple chains and twelve types of complex chains were considered for the analysis.

The simple chains were designated by the purpose pursued at the destination away from home; for example, a home-work-home trip chain would be designated as a "simple work chain" However, the fifth type of simple chain was designated "home-other simple chain" in order to distinguish it from the last type, namely, "other simple chains". A simple trip chain that did not originate and end at the home base was included in the last category ("other" simple chains).

The distribution of daily trips reported by the Kuwaiti and the expatriate sample households by purpose, mode, vehicle occupancy, time of day and duration, is presented in Table 1. Work and school trips account for nearly 40% of daily trips made by both household categories. The auto is the principle mode of urban travel in Kuwait, especially for the Kuwaitis (95.7%). Most of the auto trips include a single occupant, and approximately 20% of all trips are made during the off-peak hours. It should be noted, herein, that the cost of fuel energy in Kuwait is only 70 cents per gallon.

Table 2 shows the distribution of the sample household trips by purpose during the peak and the off-peak periods. It is clear that a major contributor to the morning peak hour congestion is the concurrence of school trips during this time period. The data in Tables 1 and 2 suggest that the promotion of ride-sharing and school bus transportation, combined with staggered work hours, may have a pronounced impact on daily congestion management in Kuwait.

The mean number of daily trip chains reported by the study sample households was found to be 2.9; the figure being 4.1 for the Kuwaiti sample compared to 1.9 for the expatriate households. The mean and the standard deviation of simple and complex trip chains are shown in Table 3. A higher standard deviation of 2.2 for the Kuwaiti households indicated a greater variability with regard to their total number of daily trip chains compared to the sample expatriate households whose standard deviation was found to be 1.6.

The expatriate households included in the sample were found to make, on the average, less than half the number of simple trip chains made by the Kuwaiti sample households. Again, the standard deviation for the simple trip chains was also found

Table1. Distribution of daily household trips by purpose, mode, occupancy, time and duration

Variable	Kuwaiti household			Expatriate household		
	Frequency	%	Cum. %	Frequency	%	Cum. %
Purpose:						
Work	895	20.6	20.6	1065	29.8	29.8
School	750	17.3	37.9	318	8.9	38.8
Shopping	280	6.4	44.3	321	9.0	47.8,
Social/Recreation	276	6.4	50.6	144	4.0	51.8
Other	2013	46.3	97.0	1683	47.2	99.0
	132	3.0	100.0	37	1.0	100.0
Mode:						
Car	4155	95.7	95.7	2187	61.3	61.3
Bus	128	2.9	98.6	798	22.4	83.7
Taxi	2	0.1	98.7	287	8.0	91.7
Other	58	1.3	100.0	296	8.3	100.0
Occupancy:						
1	2714	62.6	62.6	2108	59.5	59.5
2	565	13.0	75.5	665	18.8	78.4
3	372	8.6	84.1	334	9.4	87.8
4	258	5.9	90.0	278	7.9	95.6
5	198	4.6	94.6	102	2.9	98.5
6 or more	234	5.4	100.0	52	1.5	100.0
Time of day:						
Morning peak (7–8:30)	1450	33.4	33.4	1047	29.3	29.3
Morning off-peak	233	5.4	38.7	180	5.0	34.3
Afternoon peak (2–3)	1250	28.8	67.5	783	21.9	56.2
Afternoon off-peak	221	5.1	72.6	307	8.6	64.8
Evening peak (7–8)	644	14.8	87.4	842	23.5	88.3
Evening off-peak	546	12.6	100.0	418	11.7	100.0
Duration (in minutes):						
10 or less	1252	33.4	33.4	826	25.0	25.0
15	1227	32.7	66.1	1001	30.3	55.3
20	912	24.3	90.4	869	26.3	81.5
30	265	7.1	97.4	458	13.9	95.4
45	49	1.3	98.7	115	3.5	98.9
60 or more	48	1.3	100.0	37	1.1	100.0

Table 2. Percent distribution of daily trips by time of day and purpose

Time of day	Trip purpose						
	Work	School	Shopping	Recreation	Home	Other	Total
Morning peak	61	31	0	0	8	1	100
Morning off-peak	41	13	8	4	30	5	100
Afternoon peak	4	11	1	0	83	1	100
Afternoon off-peak	25	2	8	14	48	3	100
Evening peak	4	1	30	16	45	4	100
Evening off-peak	2	0	6	8	81	4	100

Table 3. Trip chain rates for the sample households

Type	Kuwaiti		Expatriate		All	
	Mean	SD	Mean	SD	Mean	SD
Simple chains	3.7	1.8	1.7	1.2	2.6	1.4
Complex chains	0.4	0.3	0.2	0.3	0.3	0.3
Total no. of chains	4.1	2.2	1.9	1.6	2.9	1.7

SD: Standard Deviation

to be greater for the Kuwaiti sample households. The smaller value of standard deviation for the expatriate households indicated a more uniform travel behavior for them compared to the Kuwaiti households in the sample. The Kuwaiti sample households also made twice as many complex chains as made by the non-Kuwaiti households, the figures being 0.4 for the Kuwaiti and 0.2 for the expatriate sample households, respectively.

The sample households reported 3202 trip chains that included only 338 complex chains. This meant that approximately 90% of all trip chains made were simple chains. This was found to be true for both the Kuwaiti and the expatriate households included in the sample. As can be seen from Table 4, the percentage of complex trip chains was found to be 10.7 for the Kuwaiti, and 10.4 for the expatriate sample households, respectively. The lower numbers of complex trip chains reported by the respondent households compared to those of other countries is an important feature of travel behavior in Kuwait.

The distribution of simple and complex trip chains reported by the sample households is given in Table 5. A considerable difference was observed in the distribution of trip chains between the sample Kuwaiti and expatriate households. Twenty-eight percent of the expatriate sample households did not report any simple trip chain at all. The analysis of the data with respect to car ownership indicated that this figure corresponds approximately to the percentage of expatriate households without a car.

The largest number of sample households—24.5% of the Kuwaiti and 38.5% of the expatriate—reported making two simple chains every day. Only 5% of the expatriate households made more than three simple chains daily. On the other hand, nearly one-third of the Kuwaiti sample households made three or four simple trip chains daily, and about 15% of them made five or more simple chains daily. This

Table 4. Frequency of trip chains for the sampleyouseholds

Type	Kuwaiti		Expatriate		All	
	Frequency	%	Frequency	%	Frequency	%
Simple chains	1886	89.3	978	89.6	2684	89.5
Complex chains	225	10.7	113	10.4	338	10.5
Total no. of chains	2111	100.0	1091	100.0	3202	100.0

Table 5. Distribution of simple and complex trip chains

Type of Chain	Kuwaiti			Expatriate Household		
	Frequency	%	Cum. %	Frequency	%	Cum. %
Simple chains						
0	0	0.0	0.0	163	28.1	28.1
1	85	16.4	16.4	64	11.0	39.1
2	125	24.5	40.6	223	38.5	77.6
3	83	16.1	56.7	99	17.1	94.7
4	67	13.0	69.6	15	2.6	97.3
5	86	16.6	86.3	8	1.4	98.7
6 to 8	45	8.7	95.0	3	0.5	99.2
more than 9	26	5.0	100.0	5	0.8	100.0
Complex Chains						
0	358	69.3	69.3	483	83.3	83.3
1	106	20.5	89.8	82	14.1	97.4
2	40	7.7	97.5	14	2.4	99.8
3	13	2.5	100.0	1	0.2	100.0

significant difference in trip chaining rates between the sample Kuwaiti and the expatriate households can be attributed mainly to the larger family size (7.6 vs 3.7), higher car ownership (3.2 vs 1.0), and higher number of daily family trips (8.3 vs 6.4), reported by the Kuwaiti households. On the other hand, a vast majority of the sample households interviewed—69.3% of the Kuwaiti and 83.3% of the expatriate—did not report any complex trip chain at all. Of the Kuwaiti and the expatriate households, 20.5% and 14.1%, respectively, made one complex trip chain daily. None of the households included in the sample made more than three complex chains.

The breakdown of simple and complex trip chains according to the anticipated trip chain typology is shown in Table 6. The most common type of simple chain was found to be the simple work type. More than half of the simple chains made by the expatriate sample households were of this type. An examination of the data showed that most of the daily trips made by expatriate households were work-related. A predominance of simple work chains over the other types of simple chains also characterized the Kuwaiti sample households. This is explained by their large number of work trips, almost all of them being single person runs.

Simple school chains accounted for 22.5% of all simple chains made by the Kuwaiti sample households, and 5.2% of those undertaken by the expatriates. The considerable number of simple-chain school trips reported by the Kuwaiti sample households is due to the availability of both autos (mean ownership = 3.2 cars/hh), and employed drivers (0.6 driver/hh). The percentage of simple shopping chains was found to be higher for the responding expatriate households compared to the Kuwaiti households. Most of the shopping obligations of the Kuwaiti households reportedly required more frequent major shopping trips than

Table 6. Distribution of trip chains according to type

Type	Kuwaiti			Expatriate Household		
	Frequency	%	Cum. %	Frequency	%	Cum. %
			Simple Chains			
Home-work-home	788	37.3	37.3	596	54.6	54.6
Home-school-home	474	22.5	59.8	57	5.2	59.9
Home-shop-home	270	12.8	72.6	198	18.1	78.0
Home-social/recreation-home	264	12.5	85.1	108	9.9	87.9
Home-other-home	49	2.3	87.4	15	1.4	89.3
Other simple chains	41	1.9	89.3	4	0.4	89.6
Total simple chains	1886	89.3	89.3	978	89.6	89.6
			Complex Chains			
Home-school-work-home	19	0.9	0.9	12	1.1	1.1
Home-work-work-home	7	0.3	1.2	12	1.1	2.2
Home-work-shop -home	5	0.2	1.5	11	1.0	3.2
Home-work-school-home	14	0.7	2.1	5	0.5	3.7
Home-work-other-home	6	0.3	2.4	4	0.4	4.0
Home-school-school-home	22	1.0	3.5	5	0.5	4.5
Home-shop-shop-home	7	0.3	3.8	7	0.6	5.1
Home-social/rec.-shop-home	28	1.3	5.1	14	1.3	6.4
Home-social/rec.-other-home	7	0. 3	5.4	4	0.4	6.8
Home-school-work-school-home	38	1.8	7.2	19	1.7	8.5
Home-work-work-work-home	5	0.2	7.5	10	0.9	9.4
Other complex chains	67	3.2	10.7	10	0.9	10.4
Total complex chains	225	10.7	10.7	113	10.4	10.4
Total no. of trip chains	**2111**	**100.0**	**100.0**	**1091**	**100.0**	**100.0**

those of the expatriate households. The number of "home-other" simple chains reported by the sample households was found to be insignificant, similar to the type of simple chains labeled "other".

It has already been observed that complex chains accounted for just over 10% of all trip chains made by households in Kuwait. Barring the category of "other complex chains", home-school-work-school-home was the most common type of complex trip chain for both the Kuwaiti and expatriate households. Still, of all the trip chains reported by the sample households—both simple and complex—this chain-type accounted for less than 2%. These trip chains were possibly reported by working parents whose places of employment were in the same district as their children's school/college. The second most common complex trip chain was found to be the home-social/recreation-shop-home type; 1.3% of all trip chains reported by the sample households were of this type. These trip chains were mainly made in the late afternoons and evenings.

As can be seen from Table 6, 1% of trip chains reported by the Kuwaiti sample households were of the home-school-school-home type. For Kuwaiti households with large car ownerships and full-time employed drivers, this type of tour is convenient for transporting children to school. Families with large numbers of school-going children tend to arrange the school trips into complex chains. Although about 65% of the Kuwaiti sample households reported two or more employed mem-

bers in the family, the number of complex chains linking home to multiple work destinations is insignificant due to high car ownerships and the prevalent habit of single-occupancy auto use. For the expatriate sample households, however, the percentage of complex work chains was marginally high.

The linkage of a shopping trip to work-commute trips was significantly lower for the Kuwaiti sample households compared to the expatriate households. Nevertheless, the frequency of such trips reported by the expatriate sample households was also very low. The frequencies of all other types of complex chains were found to be insignificant. Even though single-occupant work-commute trips—a predominant pattern in Kuwait—provide great flexibility in linking non-work activities to work trips, the practice is very uncommon in Kuwait as seen above.

A test of homogeneity conducted on the Kuwaiti and the expatriate sample household data with regard to the generation of simple and complex chains produced the expected result. The null hypothesis of homogeneity assumption (H_0: $\bar{X}_1 = \bar{X}_2$) of the two nationality groups in the generation of simple chains was rejected at $\alpha = 0.05$ ($\chi^2 = 266$, df $= 7$, $p < 0.0001$), indicating that the two nationality groups behaved significantly different with respect to the generation of simple trip chains. A similar rejection of the null hypothesis was also observed with regard to the generation of complex trip chains by the sample Kuwaiti and expatriate households ($\chi^2 = 41$, $df = 3$, $p < 0.001$).

COMPARISON OF TRIP CHAINING BEHAVIOR

In order to highlight the peculiarities of trip chaining patterns in Kuwait, a comparative study on trip chaining behavior of the Kuwait sample data and two other available studies was carried out. The trip chaining data for Portland, Oregon, USA, presented by Strathman *et al.* (1994) and for the Netherlands, reported by Golob (1986) were used for comparison.

Golob's typology consisted of seven categories of simple, and fourteen categories of complex trip chains. As was indicated, the typology of trip chains adopted for Kuwait consisted of six categories of simple chains and twelve categories of complex chains. In order to facilitate comparison with the other two studies, the categories of simple chains were reduced to five, and those of complex chains to eight, so that the three sets of data could be compared. The home-personal business-home, home--serve passenger-home, and home-other-home simple chains in Golob's typology were combined into one category—'other simple chains'. This was due to the very low number of such trips reported. For the Kuwaiti data, home-other-home trip chains were added to the category of 'other simple chains'. By the same token, similar categories of complex chains were also added together.

Table 7 shows the comparison of trip chaining frequencies in Kuwait, Portland, Oregon and the Netherlands. The most striking feature of the comparative study was the difference in the split of trip chains into simple and complex classes between these locations. The reported complex trip chains for Portland and the Dutch data sets were 23.9% and 21.6% respectively, compared to 10.6% in Kuwait. This clearly indicates a significant difference ($\chi^2 = 268$, df $= 2$, $p < 0.0001$) in household travel behavior between Kuwait and Western nations with regard to trip chaining. This can, to a great extent, be attributed to differences in the family structure and social behavior of the Middle East and the West. A significant number of complex chains

Table 7. Comparison of trip chains in Kuwait, Portland and the Netherlands

Type	Kuwait		Portland[1]		The Netherlands[2]	
	Frequency	%	Frequency	%	Frequency	%
			Simple Chains			
Home-work-home	1384	43.2	2000	25.1	5277	15.3
Home-school-home	531	16.6	1289	16.2	1834	8.2
Home-shop-home	468	14.6	761	9.6	5211	15.1
Home-social/recreation-home	372	11.6	737	9.3	8971	26.0
Other simple chain	109	3.4	1276	16.0	4755	13.8
Total simple chains	2864	89.4	6063	76.1	27048	78.4
			Complex Chains			
Home-work-work-home	34	1.1	125	1.6	616	1.8
Home-work-shop-home	16	0.5	88	1.1	241	0.7
Home-work-other-home	29	0.9	298	3.7	585	1.7
Home-school-other-home	115	3.6	135	1.7	514	1.5
Home-shop-other-home	14	0.4	158	2.0	804	2.3
Home-social/rec.-other-home	53	1.7	100	1.3	1451	4.2
Home-other-other-home	77	2.4	1000	12.6	3237	9.4
Total complex chains	338	10.6	1904	23.9	7448	21.6
Total trip chains	**3202**	**100.0**	**7967**	**100.0**	**34496**	**100.0**

[1]Strathman *et al.* (1994).
[2]Golob (1986).

in the West are made by single-parent households with one car. Single parent households with school-going children are, at the present time, very rare in Kuwait (Koushki *et al.* 1998).

The economic characteristics of households in Kuwait also play a significant role in reducing their percentage of complex chains. Family car ownership for Kuwaiti households is among the highest in the world. The employment of drivers by Kuwaiti households, and the presence of a considerable number of driver's license holders in the family, allows households to undertake a large number of simple-chain trips. Moreover, Kuwaitis are generally not concerned about the economical use of autos due to the extremely low price of fuel (30% of the US fuel cost, and one-sixth that of Europe). All these factors encourage the repetition of simple chains by households in Kuwait in order to meet their travel needs. Another important contributing factor is the rather low level of awareness on the part of the majority of the population in Kuwait about the adverse environmental impact of excessive automobile use. In addition, the work culture in Kuwait allows the population plenty of leisure time, and the effect of this amount of free time on daily travel behavior further contributes to the discrepancy in trip chaining.

Simple work chains constituted 43% of all trip chains reported in the Kuwaiti data, compared to 25% in Portland and 15% in the Netherlands study. Simple work chains accounted for 48% of the simple chains in Kuwait, corresponding to 33% in Portland and 20% in the Netherlands. The lower percentage of work chains and higher percentage of social/recreation and shopping chains in the Dutch data

could be due to the fact that the data was collected over a span of one week, including a weekend, while the Kuwait and Portland data were collected on a single, normal working day.

Nevertheless, the percentage of simple work chains was significantly higher in Kuwait compared to the other two locations. The presence of large numbers of expatriates in the State of Kuwait, where they constitute the majority of the population and whose main role is to engage in work, could be one of the possible reasons for this. Many expatriates work in two sessions, with a lunch break during which most of them visit their homes. The percentage of school chains reported in Kuwait (16.6% of all trip chains and 18.5% of simple chains) compared well with that of Portland (16.2% of all trip chains and 21.2% of simple chains).

The percentage of simple shopping chains reported in Kuwait was higher (Table 7) than that of the Portland study. This is justified by the fact that most of the shopping obligations in Kuwait are met by making separate single-purpose shopping trips. The availability of cars and employed drivers in Kuwaiti households, abundant leisure time for most of the inhabitants, and lack of other social activities (pubs, night clubs, etc.) are factors that encourage separate shopping trips whenever a need arises. In addition, shopping is considered a form of social entertainment for both Kuwaitis and expatriates.

Considerable differences were observed between Kuwait and the two other areas in the category of complex trip chains as well. The first three types of complex chains listed in Table 7 can be considered work-commute complex chains. Together, they account for just 2.5% of all trip chains (23% of complex trip chains) in Kuwait, compared to 6.4% of all trip chains (27% of complex trip chains) in Portland and 4.2% of all trip chains (19% of complex chains) in the Netherlands. The predominance of single-occupant auto use during commuting hours in Kuwait should encourage linking non-work activities to work-commute trips. However, the need for linking a shopping or other trip to the regular commute trips is very limited in Kuwait, as discussed above.

The home-school-other-home complex chain type was found to be more common in Kuwait than in Portland and the Netherlands. These complex trip chains, arranged by some Kuwaiti households, are made possible by the presence of employed drivers and high car ownership. Sometimes shopping trips, visits, laundry stops etc., are linked to school trips to generate complex chains of this nature. It is presumed natural that families in the West with much smaller family sizes undertake few such trips.

The home-social/recreation-other-home complex chains occurred at almost the same frequency in Kuwait and Portland. Again, since the Dutch data included weekend trips also, the percentage of trip chains of this type was higher for the Netherlands. The last category of complex chains, namely, home-other-other-home chains, accounted for only 2.4% of trips reported in Kuwait, compared to 12.6% in Portland and 9.4% in the Netherlands. With limited information regarding the 'other' purposes mentioned in the Portland and Dutch data sets, further conclusions cannot be drawn about this significant difference.

LOGISTIC MODELS FOR COMPLEX TRIP CHAINS

The model structure

Policy-makers in charge of managing daily traffic congestion are in need of tools/methods to predict trip generation and trip-chaining, especially those made during the daily peak periods, for use in the development of effective TSM measures. The logistic regression technique was thus employed to model the probability of a household making a complex chain (Goulias *et al.* 1990, Strathman *et al.* 1994). A logistic regression model is a special type of generalized linear model specifically suited for binary response variables. In generalized linear models, the mean of the response variable is assumed to be related in a linear format to the explanatory variables through a link function. In other words, the generalized linear models have a random or stochastic component which identifies the probability distribution of the response variable, a systematic or deterministic component which specified a linear function of explanatory variables used as predictors, and a link function describing the functional relationship of stochastic and deterministic components (Agresti 1990).

In the model system proposed here, the probability of a household making a complex chain is assumed to be a binary random variable (Y) which follows the Bernoulli distribution. The possible outcomes of this binary variable are denoted as 1, if at least one complex chain is made by the household, or 0 if no complex chain is made. The Bernoulli distribution for binary random variables specifies probabilities:

$$P(Y = 1) = p \quad \text{and} \quad P(Y = 0) = 1 - p$$

for the two outcomes discussed above, where, $p = E(Y)$, the mean response of Y.

It is assumed that the response variable, namely the probability of a household making at least one complex chain, is dependent on a set of travel and socioeconomic explanatory variables. Specifically, the response probability modeled is $p = P(Y = 1 \mid x)$, where x represents the vectors of explanatory variables. Since a monotonic relationship is expected between p and the predictor variables, conventional S-shaped curves which have asymptotes at 0 and 1 (corresponding to the probability values of 0 and 1) are considered to be natural shapes for the regression curves. A function with this S-shape is called the logistic regression model expressed as:

$$p = \frac{\exp\left(\alpha + \sum_i \beta_i x_i\right)}{1 + \exp\left(\alpha + \sum_i \beta_i x_i\right)}$$

where

α = the intercept parameter, and
β_i = slope parameter corresponding to the ith predictor (explanatory) variable.

For this function, the odds of making response 1 are

$$\frac{p}{1-p} = \exp\left(\alpha + \sum_i \beta_i x_i\right)$$

the log odds of p, which is also called the logit of p and has a linear relationship with the predictor variables which can be expressed as follows:

$$\text{logit}(p) = \log\left(\frac{p}{1-p}\right) = \left(\alpha + \sum_i \beta_i x_i\right).$$

This is the link function for the assumed logistic regression model. The parameters of the explanatory variables are now estimated using the method of maximum likelihood estimation. If the value of $\text{logit}(p^m) = \alpha^m + \sum_i \beta_i^m x_i^m$ for the mth household, the probability of mth household making at least one complex chain is given by

$$p^m = \frac{\exp\left[\alpha m + \sum_i \beta_i^m x_i^m\right]}{1 + \exp\left[\alpha m + \sum_i \beta_i^m x_i^m\right]}.$$

It is assumed that the probability of households making complex trip chains depends on the total number of daily family trips, socioeconomic variables, and the number of trips for various purposes. The inclusion of the last set of variables, namely, the numbers of trips of various purposes, is due to the possible interaction between them in the generation of complex chains.

The calibrated models

Since the socioeconomic and, consequently, the travel behavior of the Kuwaiti sample population differed significantly from those of the sample expatriate households, two logistic models were calibrated, using respective data.

Table 8 shows the results of the maximum likelihood estimation when all variables are included in the model. The significance of each variable is tested using the Wald chi-squared statistic, computed as the square of a parameter estimate divided by its standard error. The p-value of this statistic with respect to a chi-square distribution with one degree of freedom was also determined. It was interesting to observe that most of the socioeconomic characteristics that contributed to daily family trips were not significant (due to colinearity with car ownership: with income, $r_{xy} = 0.763$ and with employed drivers, $r_{xy} = 0.689$), in this model at the $\alpha = 0.05$ significance level. The number of daily family trips was significant for both of the nationality groups; however, the negative sign of the parameter is an indication of multicolinearity with other trips by purpose, as was expected. Also, most of the trips by purpose had significant parameters at $\alpha = 0.05$. The number of daily

Table 8. Maximum likelihood parameter estimates for the complex chain models

Variable	Kuwaiti		Expatriate	
	Parameter	p-value[a]	Parameter	p-value[a]
Constant	−4.258	0.001	−1.643	0.063*
Daily work trips	1.405	0.001	2.161	0.001
Daily school trips	2.101	0.001	2.161	0.001
Daily shopping trips	2.675	0.001	1.927	0.001
Daily recreational trips	2.424	0.001	2.581	0.001
Daily other trips	1.894	0.001	2.581	0.001
Distance from CBD	0.086	0.046	−0.028	0.447*
Daily family trips	−0.592	0.001	−1.005	0.001
Age of head of household	−0.026	0.106*	−0.023	0.235*
Family size	−0.115	0.141*	−0.177	0.118*
Family income	0.0002	0.632*	0.0002	0.959*
Family car ownership	−0.922	0.001	0.826	0.001
Family license holders	0.149	0.441*	−0.514	0.095*
Family employment	0.375	0.231*	−0.287	0.317*
Employed drivers	0.676	0.155*	—	
Weekly trips for social visit	0.223	0.044	−0.139	0.359*
Weekly trips for recreation	0.329	0.051*	0.429	0.026
Weekly trips for shopping	−0.033	0.835	0.031	0.861
−2 Log Likelihood (Chi-square)	198	<0.0001	186	<0.0001
degrees of freedom	15		15	

* not significant at $\alpha = 0.05$.

[a] p-value of the Wald chi-square statistic=(Parameter estimate/Standard error)^2, with respect to chi-square distribution with one degree of freedom.

Table 9. Maximum likelihood parameter estimates for Kuwaiti households making complex chains

Variable	Parameter	Wald χ^2	p-value[a]
Constant	−3.686	24.45	<0.0001
Daily work trips	1.516	28.42	<0.0001
Daily school trips	1.969	47.07	<0.0001
Daily shopping trips	2.624	41.67	<0.0001
Daily recreational trips	2.552	50.28	<0.0001
Daily other trips	1.729	9.66	0.0019
Family car ownership	−0.919	26.86	<0.0001
Weekly trips for social visit	−0.239	5.83	0.0158
Weekly trips for recreation	−0.393	6.43	0.0113
−2 Log Likelihood (Chi-square)	187		<0.0001
Degrees of freedom	8		

[a] p-value of the Wald chi-square statistic=(Parameter estimate/Standard error)^2, with respect to chi-square distribution with one degree of freedom.

Table 10. Maximum likelihood parameter estimates for expatriate households making complex chains

Variable	Parameter	Wald χ^2	p-value[a]
Constant	−2.595	18.1	<0.0001
Daily work trips	2.053	60.8	<0.0001
Daily school trips	1.967	72.3	<0.0001
Daily shopping trips	1.824	27.6	<0.0001
Daily recreational trips	2.374	27.1	<0.0001
Daily other trips	3.848	43.5	0.0019
Family size	−0.235	4.4	0.0358
Family car ownership	0.807	10.6	<0.0001
Family license holders	−0.607	4.8	0.0288
Weekly trips for recreation	−0.397	5.0	0.0253
−2 Log Likelihood (Chi-square)	182		<0.0001
Degrees of freedom	9		

[a]p-value of the Wald chi-square statistic= '(parameter estimate/Standard error)^2, with respect to chi-square distribution with one degree of freedom.

family trips was, therefore, eliminated from the final model in order to avoid the problem of multicolinearity, given the relatively strong positive correlations between the daily family trips and the trips for various purposes.

The final models were, again, calibrated utilizing a stepwise selection procedure so as to allow only those variables significant at $\alpha = 0.05$ to remain in the models. Table 9 shows the parameter estimates for the Kuwaiti households. Car ownership was the only socioeconomic variable that entered into the model at the specified significance level. It is also important to note the negative sign of this variable in the model. Naturally, as the number of cars increases in a given family, the probability of making complex trip chains would decrease. The model produced a chi-square −2 Log Likelihood = 187 with 8 degrees of freedom. This value of the statistic shows that the combined effect of all the explanatory variables on the response variables is highly significant.

The values of the parameter estimates for the expatriate sample households are given in Table 10. Three socioeconomic variables appeared in the model at the significance level of $\alpha = 0.05$. This suggested that for expatriates the probability of making complex chains was explained more by household socioeconomic characteristics. The −2 Log Likelihood statistic is 182 with 9 degrees of freedom which, again, suggests that the combined effect of the explanatory variables in the model is highly significant.

CONCLUSIONS

Evidence exists to indicate that traffic congestion during daily commuting hours has become a concern for the traveling public in Kuwait, and for responsible policymakers as well. In a recent study, time delay due to traffic congestion during morning peak hours was identified by the commuting public as the most critical urban transport-related problem in Kuwait. This research project was initiated

to determine the composition of trips (by purpose and mode), trips during peak hours, to examine trip chaining, and to calibrate logistic predictive models for Kuwait.

The characteristics of the daily trips and trip chaining behavior of Kuwaiti and non-Kuwaiti individual households have been presented. A comparative analysis of trip chaining behavior data for Kuwait with that available for other locations has also been made. Findings indicate that nearly 1/3 of the morning peak hour trips were for school transport purpose and that over 92 percent of these utilized the private auto mode. Results also indicated that the Kuwaiti and the expatriate sample households behaved significantly different with respect to the generation of simple and complex trip chains. The Kuwaiti households produced a large number of simple chains and a few complex chain trips daily. The opposite was true for the non-Kuwaiti households.

The study also revealed that simple school chains accounted for nearly a quarter of all simple chains made by the Kuwaiti sample households and about five percent of those undertaken by the non-Kuwaitis. The availability of autos and personal drivers to the Kuwaiti households explain this variation in simple chain trip making behavior.

The most striking feature of the trip-chaining comparison was the difference in the split of trip chains into simple and complex categories between Kuwait, the Netherlands and Oregon, USA. The Kuwaiti sample households generated complex chains less than one half of those produced by the Western households.

Logistic models were fitted to the data and sorted by Kuwaiti and non-Kuwaiti nationalities. The calibrated models will assist responsible policy-makers in the development of both short-range TSM measures to curb traffic congestion and long range plans to meet future demand for travel in metropolitan Kuwait.

The study results also showed that the post-invasion time-staggering of work and school trips—implemented to reduce peak hour traffic congestion—has in fact brought about the opposite result. Working parents chain work and school trips, and personal drivers make simple chains to drive children to schools, thereby intensifying both the magnitude and the duration of peak hour traffic congestion. This finding points to the ineffectiveness of the time-staggering Transport System Management (TSM) measures to reduce congestion when applied without regard for socioeconomic traits, cultural preference, and the need for other supporting measures. Rather than spreading trips over the commuting period, the staggered work hour has provided parents with the opportunity to transport their children to school prior to their journey to work, and/or generate simple school-trip chains using personal drivers.

The study findings have also pointed to the importance of the interrelationships between the socioeconomic traits of households and their travel behavior. It is both logical and understandable that when the resources of money (indicated by high auto ownership, cheap fuel, tax-free incomes and other government allowances), as well as time (working from 7.30 am to 1.30 pm), are available to individual households, they generate more daily trips, mostly by private auto, and practically all in the form of simple trip chains. Measures taken to reduce the simple auto chain trips must be designed with full awareness of the socio-economic and cultural (social prestige) traits of the travelling public. Only then, will a well coordinated set of policy measures produce the desired results.

ACKNOWLEDGEMENTS

This research project (EPV-068), was funded by the Research Administration, Kuwait University. Their support is greatly acknowledged. The authors also wish to thank Mrs. Alison M. Koushki for editing the manuscript. Thanks are also due to Mrs. Daisy and Mrs. Mini for typing the manuscript.

REFERENCES

Adler, R. & Ben Akiva, M. 1979. A theoretical and empirical model of trip chaining behavior. Transportation Research-B **13B:** 243–257.

Agresti, A. 1990. Categorical data analysis. John Wiley & Sons Inc, New York, NY, USA.

Clarke, M.I., Dix, M.C., Jones, P.M. & Heggie, I.G. 1981. Some recent developments in activity-travel analysis. Transportation Research Record **794:** 1–8.

Feng-Chia, J. & Mahmassani, H.S. 1997. Comparative analysis of day-to-day trip chaining behavior of urban commuters in two cities. Transportation Research Board, 76th Annual Meeting, Paper No. 970215. Washington, D.C, USA.

Golob, T.F. 1986. A nonlinear canonical correlation analysis of weekly trip chaining behavior. Transportation Research **20A:** 385–399.

Gordon, P.K. & Richardson, H.W. 1988. Beyond the journey to work. Transportation Research-A **22A:** 419–426.

Goulias, K.G. & Kitamura, R. 1989. Recursive model system for trip generation and trip chaining. Transportation Research Record **1236:** 59–66.

Goulias, KG, Pendyala, R.M. & Kitamura, R. 1990. Practical method for the trip generation and trip chaining. Transportation Research Record **1285:** 47–56.

Hamburgh, M. 1977. Statistical analysis for decision making, 2nd Ed. Harcourt, Brace & Jovanovich, New York, NY, USA.

Horowitz, J. 1979. A disaggregate demand model for nonwork travel. Transportation Research Board 673: 65–71.

KEO, 1989. The traffic models—base year data, development of traffic models and public transport corridors study, Final Report. Kuwait Municipality, Kuwait.

Kostynuik, L.P. & Kitamura, R. 1984. Trip chains and activity sequences: Test of temporal stability. Transportation Research Record **987:** 29–39.

Koushki, P.A., Al-Saleh, O. & Aljassar, A. 2000. School transportation in Kuwait. Proceedings of the 2nd Asian Pacific Conference on Transportation and the Environment. Beijing, China, April 10–13.

Koushki, P.A., Yaseen, S. & Mohammad, B. 1998. Post-invasion household socio-economic and travel analysis in Kuwait. Kuwait Journal of Science & Engineering **25:** 307–324.

Lathrop, G. 1970. Characteristics of urban activity patterns. Highway Research Record **322:** 232–244.

Metaxatos, P. & Sen, A. 1997. Trip chaining models: Theoretical framework and empirical analysis. Transportation Research Board, 76th Annual Meeting, Paper No. 970080. Washington, D.C., USA

Oster, C. 1973. Household trip making to multiple destinations: The overlooked urban travel pattern. Traffic Quarterly **32:** 511–529.

Strathman, J.G., Dueker, K.J. & Davis, J.S. 1994. Effects of household structure and selected travel characteristics on trip chaining. Transportation **21:** 23–45.

Thill, J.-C. & Thomas, I. 1987. Toward conceptualizing trip chaining behaviour: A review. Geographical Analysis **19:** 1–17.

(Accepted 20 May 2000)

دراسة مقارنة الرحلات المتسلسلة وتطبيق نموذج اللوجستك على الرحلات المتسلسلة المركبة في الكويت

أ.د. بارفيز كوشكي ، د. عمر الصالح ، د. صالح ياسين و م. بشير محمد
قسم الهندسة المدنية – كلية الهندسة والبترول – جامعة الكويت
ص.ب. 5969 الصفاة – الكويت 13060

خلاصة

نظراً لتفاقم الازدحام المروري ووصوله لمستويات غير طبيعية خلال ساعات الذروة في الأعوام القليلة الماضية ، تم عمل هذه الدراسة لمعرفة تأثير ظاهرة تسلسل الرحلات على الاختناقات والازدحام المروري المنتشر على شوارع الكويت الرئيسية . ولقد تم رصد توزيع الرحلات اليومية حسب الغاية ، الوسيلة وحمولة المركبات وكذلك مدة وميقات الرحلة . كما تم عمل تحليل مقارن لظاهرة تسلسل الرحلات في الكويت . ولقد تبين بأنه رغماً عن تطبيق اختلاف مواعيد بدء المدارس والمؤسسات والوزارات والهيئات الحكومية لتخفيف الازدحام إلا أن 31% من الرحلات اليومية بفترة الذروة الصباحية كانت لتوصيل الأبناء للمدارس قبل الذهاب للعمل والغالبية العظمى منها كان باستخدام السيارات الخاصة. كما تبين بأن الرحلات اليومية المتسلسلة من النوع المركب (أكثر من رحلتين متتابعتين للسائق الواحد) وذلك بفترة الذروة الصباحية في الكويت تقل كثيراً جداً عن مثيلها في أوربا وأمريكا. ومن الأسباب الرئيسية التي تؤدي إلى قلة تسلسل الرحلات (كثرة الرحلات الفردية) في الكويت هو ارتفاع معدل ملكية السيارات الخاصة للعائلة الواحدة وازدياد استخدام العائلات وبالخصوص الكويتية للسائقين الخاصين. مما يؤدي إلى انخفاض الحاجة لقضاء عدة احتياجات (رحلات متسلسلة) في الرحلة الرئيسية الواحدة ويزيد من العدد الإجمالي للرحلات كما تبين بوضوح الحاجة الماسة لإعادة تفعيل النقل الجماعي لطلبة المدارس . ولقد تم تحضير نماذج من نوعية لوحستيك لتقدير احتمالات وأعدا الرحلات المتسلسلة الاعتيادية والمركبة في الكويت للكويتيين والوافدين . وعليه سيكون بإمكان متخذي القرار التخطيط لإعداد الرحلات المتوقعة (الحجم المروري والازدحام ، وذلك على المدى القصير (لإدارة شبكات النقل) والمدى البعيد (للتخطيط للمدن الحضرية).