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Effects of household structure and selected travel characteristics on trip chaining

JAMES G. STRATHMAN, KENNETH J. DUEKER, & JUDY S. DAVIS
Center for Urban Studies, School of Urban and Public Affairs, Portland State University, Portland, OR 97207, USA

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Abstract. This paper analyzes trip chaining, focusing on how households organize non-work travel. A trip chaining typology is developed using household survey data from Portland, Oregon. Households are organized according to demographic structure, allowing analysis of trip chaining differences among household types. A logit model of the propensity to link non-work trips to the work commute is estimated. A more general model of household allocation of non-work travel among three alternative chain types – work commutes, multi-stop non-work journeys, and unlinked trips – is also developed and estimated. Empirical results indicate that the likelihood of linking work and non-work travel, and the more general organization of non-work travel, varies with respect to household structure and other factors which previous studies have found to be important. The effects of two congestion indicators on trip chaining were mixed: workers who commuted in peak periods were found to have lower propensity to form work/non-work chains, while a more general congestion indicator had no effect on the allocation of non-work trips among alternative chains.

Introduction

With urban traffic congestion becoming a more pressing concern, transportation researchers have begun to pay closer attention to non-work trips, especially those made in peak commuting periods. Gordon et al.'s (1988) examination of Nationwide Personal Transportation Survey (NTPS) data for 1983, for example, showed that non-work travel accounted for just over half of all person-trips in the AM peak and two-thirds of PM peak person-trips in

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metropolitan areas with more than three million people. Moreover, they observed that between 1977 and 1983 non-work trips grew considerably faster than work trips, and they also grew faster in peak than off-peak periods. This latter increase is puzzling on the surface because, unlike work travel, non-work travel is considered to be less constrained by fixed time schedules. Thus, congestion during peak commuting periods ought to act as an incentive to shift non-work travel toward off-peak periods. The fact that the relative growth of non-work travel has been greater in peak periods signals that other factors, which tend to favor the peaks for non-work travel, are offsetting congestion's rescheduling incentives.

Gordon et al. (1988) hypothesized that the growth of peak non-work trips might be attributable to increases in two-worker households. While plausible, this explanation relates to only one dimension of the structural changes experienced by U.S. households over the past several decades. Alternatively, Oster (1979) emphasized the importance of functional linkages between work and non-work travel, and he estimated the effects of various household structural characteristics on the propensity to add non-work travel to the work commute. Oster found significant propensity differentials among households, and he concluded that future changes in the mix of the household types would thus have a noticeable impact on the relationship between work and non-work travel. Specifically, he suggested that continuing reductions in household size coupled with further expansion of the percentage of multiple worker households would result in a greater tendency for non-work trips to be linked to work trips. One consequence of a growing propensity to link work and non-work travel would be a relative shift of non-work trips to peak commuting periods, which is clearly consistent with what Gordon et al. (1988) observed.

The purpose of this paper is to analyze the potential trade-offs, principally between household mix and congestion effects, on the organization of non-work travel. Using data from a household travel survey in Portland, Oregon, we estimate two models of trip chaining behavior. The first model addresses the propensity of households to add non-work trips to the work commute. It represents an extension of Oster's (1979) analysis in that it considers congestion and also depicts household structure in greater detail. The second model focuses more generally on household allocation of non-work trips to alternative chaining options, which include the work commute, multi-stop non-work journeys, and independent (unlinked) trips.

The remainder of the paper is organized as follows. In the next section we review related trip chaining and activity analysis research, focusing mainly on empirical studies. The trip chaining patterns and household characteristics of the surveyed population are then described, followed by the empirical analysis. Our findings are summarized in the final section, and several of their research and policy implications are discussed.

Related travel activity and trip chaining research

Activity analysis depicts travel behavior as a derived consequence of the production and consumption decisions of households. These decisions, in turn, reflect the collective welfare maximizing allocation of household members' time and resources among alternative activities. The basic theoretical foundation for analysis of travel activity can be traced to Becker's (1965) pioneering work in "new home economics" and Hagerstrand's (1970) conceptualization of space-time travel "prisms."

Travel activity researchers have sought to relax behavioral constraints of travel demand models which, according to Heggie and Jones (1978: 120) "ignore or oversimplify most temporal and spatial linkages and pay no attention to social interactions . . . between household members." In the work of Heggie and Jones (1978), for example, travel activity domains of increasingly complex inter-personal and space-time character are outlined. In the first and simplest domain, trip-making decisions are assumed to be unaffected by other travel decisions of the household. In the second domain an individual's travel decisions become functionally integrated into activity sequences, but remain independent of the activity decisions of other household members. Their third domain is concerned with the scheduling of individual trips in the context of other household activity needs. Interest in this domain has grown as a result of research indicating a resistance of work commuters to altering their schedules to avoid congestion (Small 1982; Wilson 1989). In the fourth domain the linkages among trips and the relationships between travel decisions and other household activities are fully integrated.

A considerable effort has been devoted to characterizing the functional dimensions of household travel (Kansky 1967; Oppenheim 1975; Hanson & Hanson 1981; Neale & Hutchinson 1981; Pas 1982; Prevedouros & Schofer 1989). In this research, distinct activity patterns are usually generated by cluster or factor analysis of household socioeconomic and travel data. Such segmentation of travel activity has been found to be related to travel frequency and purpose, household composition and life cycle status, and household economic factors.

Individual travel activities are organized into trip chains, which are defined as home-based n-stop, n-purpose journeys. Trip chains thus represent the full range of travel possibilities, from single purpose unlinked trips to sojourns involving numerous stops and purposes. The basic theoretical properties governing the formation of trip chains have been derived by Adler and Ben-Akiva (1979). In their analysis, time and income constraints limit both the coordination of trips and the choices of destinations. A key condition derived by Adler and Ben-Akiva equates the marginal rate of substitution between linked and unlinked trips with the ratio of their respective generalized time and travel costs. An increase in income, for example, would thus result in higher time opportunity costs and a greater propensity to form trip chains.

Clarke et al. (1981) provide important empirical insights on the linkages between trip chaining and household characteristics. They found that households comprised of young working adults without children developed chains around the work trip to satisfy a greater proportion of their travel activity needs. Households with preschool children had a higher proportion of simple home-destination-home shopping trips and correspondingly fewer complicated work commute chains. Households with school age children experienced increasingly complex passenger and household needs-serving chains. At the mature stage of the life cycle, household trip chains became relatively simple again and, at retirement, the work commuting anchor was lost. Clarke et al. (1981) simulated a change in school hours and found that small changes had little effect on household travel activity patterns, while larger changes led to noticeable rescheduling of household activities and alteration of trip chains.

Pas (1984) developed a similarity index of travel activity to identify trip chain types distinguished by complexity, purpose and time of day. Pas identified five underlying types of trip chains using cluster analysis. The first was mainly comprised of single stop mid-day shopping trips, and accounted for 14 percent of the sampled journeys. Single stop evening leisure trips characterized the second chain type. The third type, accounting for 20 percent, was comprised of mixed purpose travel organized around the AM and PM work commutes. The fourth type represented "random" complex chaining comprised of multi-stop travel for all purposes throughout the day. The final category contained the AM and PM peak work commutes with no other stops. With 34 percent of the trip chains, it was also the largest cluster.

Pas (1984) also performed a multi-way contingency analysis to determine whether trip chain types could be associated with various individual and household attributes. Factors which proved to be significant discriminators among trip chain types included life cycle stage, marital status, gender, employment status, education, income, the presence of children, and residential density.

Recker et al.'s (1987) analysis of household travel activity patterns indicates that the propensity to form trip chains is positively related to the number of trips undertaken and negatively related to activity duration, employment status, and age. Williams (1988) found that accessibility to destinations was a key determinant of households' propensity to trip chain. He found that suburbanites had higher trip frequencies, lower accessibility, and a resultant higher propensity to form trip chains. Golob (1986) defined 20 trip chain types reflecting different travel activity sequences, and then performed a non-linear canonical correlation analysis between the chain types and variables covering household life cycle, income, residential location, auto ownership, and the age, gender and work status of the individual trip-makers. He found that life cycle, income and age had the greatest collective explanatory effects on the trip chain variates. He also found that car ownership had little explanatory power, possibly because of the high levels of transit and bicycle use in the surveyed population.

Although unlinked work trips constitute a fairly small proportion of household trip-making, their importance as an organizing element for other travel activity has been emphasized in a number of trip chaining studies (Oster 1978; Hanson 1980; Damm 1982; Pas 1984; Golob 1986; Hodge 1991). Work commutes and non-work trips functionally linked to them have been found to account for a third to over half of all household trips in the studies just cited.

Among other implications, the linking of non-work trips with the journey to work clouds our understanding of commute responses to changing traffic conditions. Our ability to assess programs which seek to increase ride-sharing or to shift work travel away from congested periods may be limited if we focus only on the work trip. The varying complexity of work commute chains may explain why research on work trip departure times has estimated varying tendencies of commuters to reschedule their journey to work (Abkowitz 1981; Small 1982; Hendrickson & Plank 1984; Wilson 1989; Chin 1990; Mannering & Hamed 1990). Also, too little attention has been devoted to empirically analyzing congestion's influence on the propensity to link non-work travel with the work commute.

Because non-work travel is thought to be more flexibly scheduled, one would expect that increases in congestion would encourage a de-coupling of non-work trips from work commute chains. Nishii et al. (1988), for example, show analytically that the propensity to link non-work travel to the work commute is positively related to the distance of the commute, travel cost, and the attractiveness of the non-work opportunities, while the propensity to undertake non-work trips independently is positively related to travel speed and the utility of scheduling the trip at a more preferred time. Thus, if congestion reduces travel speed, Nishii et al.'s (1988) work indicates that this should result in non-work trips shifting from peak to off-peak periods.

It should be emphasized that increasing congestion does not necessarily lead to reductions in speed and greater travel times. For example, Gordon et al. (1989) contend that the decentralization of employment in metropolitan areas has had a mitigating effect on travel times because suburban speeds tend to be higher and suburban jobs tend to be more accessible to metropolitan residents. Alternatively, Pisarski (1992) found that while congestion has apparently become worse and work trip lengths have grown, average work trip travel times have changed little. He believes that this may be explained by a shift from shared-ride modes to private occupant vehicles. Pisarski found that the vehicle occupancy rate for work trips in the 1990 NTPS was 1.14, down from 1.30 in 1977.

Increasing reliance on single occupant auto mode for the journey to work, moreover, may also be facilitating the scheduling of non-work travel in the commuting periods. The related congestion management implications of this latter effect have not been widely recognized. For example, policies promoting higher vehicle occupancy for work commutes seek a reduction of vehicle miles relative to person miles of travel in peak periods. While the policy focus is on vehicle miles, higher occupancy levels should also lead to fewer non-work trips scheduled in the peaks.

Changes in household structure provide another possible explanation for the growth of non-work trips in the peak commuting periods. There has been a rapid increase of multiple worker households since the early 1970s (Hayghe 1990). Changes in household composition have also been dramatic. Between 1970 and 1990, the share of family households declined from 81 to about 70 percent, while single person households increased form 17 to 25 percent and households comprised of unrelated individuals increased from 2 to 5 percent. The mix of family household types also changed, with the proportion of families headed by a married couple declining from 87 to 79 percent, and families headed by a single adult growing from 13 to 21 percent (U.S. Bureau of Census, 1991). The Oster (1979), Clarke et al. (1981) and Pas (1984) studies collectively indicate that the household types which have higher propensities to link non-work travel to the work commute are also the ones which have been growing most rapidly over the past two decades.

Despite considerable development, travel activity models are still fairly far from the point of generating estimates which could replace those of the four-step models in urban transportation planning. Kitamura (1988: 24) concedes that "(a)pplications of activity based methods with specific planning or policy objectives . . . are few and far appart," while Horowitz (1985) contends that limited understanding of non-work travel behavior is a particular barrier to the development of travel activity models.

Composition of trip chains

Travel data for this study were obtained from the Metropolitan Service District (METRO), the Metropolitan Planning Organization for the Portland, Oregon, region. The data cover weekday travel of 2,718 households who were surveyed in 1985. The survey recovered information on trips made by each household member over the age of five, as well as information on household characteristics. Trips were geocoded by origin and destination coordinates within approximately 400 traffic zones in the metropolitan region. Estimates of trip lengths were generated according to the shortest origin-destination path on the existing street network, while travel time estimates were generated at the zonal level using Metro's EMME/2 transportation planning model.

The household sample consists of 3,443 persons over the age of five, who made 19,112 trips in the preceding 24 hour period. These trips were organized into 7,967 chains wherein the home constituted the starting and ending location. Another 196 chains were identified in which an individual either began or ended the survey period away from home, and these were not included in subsequent analysis.

Table 1 compares the distribution of trip chain types in Portland with Golob's (1986) detailed typology from the Dutch National Mobility Panel. Despite the difference in settings, such a comparison is useful because of the detailed nature of Golob's typology and the broader geographic coverage of his data. Given our interest in chains which combine work and non-work travel, we added an additional category for Portland identifying chains which included a stop made on the way to work for any non-work purpose. This category is part of "anything else" in The Netherlands column. The chains are also divided into simple and complex categories. Consistent with Golob's approach, chain types are defined by the first two destinations.

In both regions, about three-fourths of the chains are comprised of simple home-destination-home journeys. The most notable differences include a higher proportion of work, school, and personal business travel and a lower proportion of shopping and social/recreational journeys in Portland. These dissimilarities may be explained by differences in the data sets. The Portland travel data was collected for weekday travel while The Netherlands data included weekends, when more shopping and social/recreational activities and less work, school, and personal business are likely to occur. The Portland survey also included trips made by children ages 6 to 11, while the Dutch panel did not. Considering these differences, the proportion of chains of each type are remarkably similar in the two regions.

For subsequent analysis we designed a simplified typology, which is illustrated in Table 2. Chains including a work trip were classified as work chains and all others as non-work journeys. Simple chains involved only one stop away from home while complex chains had multiple stops. Table 2 shows that about one-third of the chains were work-based. About 80 percent of these work chains were simple journeys to and from places of employment, which is slightly higher than the comparable split (74 % simple) for non-work journeys.

Regarding household structure, we defined a twelve category classification that considered household composition (number of adults and children) and number of workers. A worker was defined as a person age 18 or older who made a work trip on the recorded day. Individuals who worked at home, were ill, or had the day off were missed by this definition. Households without

Table 1. Trip chain breakdown: Portland v. The Netherlands.

Chain type	Portland[a] No.	Portland[a] %	The Netherlands[b] No.	The Netherlands[b] %
Simple chains				
Home-work-home	2,000	25.1%	5,277	15.3%
Home-school-home	1,289	16.2%	2,834	8.2%
Home-shop-home	761	9.6%	5,211	15.1%
Home-social/recreational-home	737	9.3%	8,971	26.0%
Home-personal business-home	733	9.2%	1,205	3.5%
Home-serve passenger-home	353	4.4%	1,935	5.6%
Home-other-home	190	2.4%	1,615	4.7%
Total simple chains	6,063	76.1%	27,048	78.4%
Complex chains				
Home-work-work-	125	1.6%	616	1.8%
Home-work-shop-	88	1.1%	241	0.7%
Home-work-other than shop, work, home-	298	3.7%	585	1.7%
Home-school-other than home-	135	1.7%	514	1.5%
Home-personal business/serve passenger-shop-	122	1.5%	333	1.0%
Home-personal business/serve passenger-social/recreational-	55	0.7%	351	1.0%
Home-personal business/serve passenger-other than shop or social/recreational-	296	3.7%	432	1.3%
Home-shop-shop-	129	1.6%	474	1.4%
Home-shop-social/recreational-	29	0.4%	330	1.0%
Home-social/recreational-social/recreational-	67	0.9%	1,100	3.2%
Home-social/recreational-shop-	33	0.4%	351	1.0%
Home-other-other-	222	2.8%	1,003	2.9%
Home-other than work-work-	172	2.2%	–	–
Anything else	133	1.7%	1,118	3.2%
Total complex chains	1,904	23.9%	7,448	21.7%
Total complete chains	7,967	100.0%	34,496	100.1%

[a] Compiled by the authors from Metro travel survey.
[b] From Golob (1986).

workers were divided into two categories based on age in an attempt to sort retirees from others. Households with a single working head, a traditional family structure, and dual workers were subdivided into three categories each based on dependency status: a) no children; b) preschoolers (under age six); and c) children age six or older. The final category contained household units with three or more adult workers.

Table 2. Breakdown of trip chains by purpose and complexity.

	Work	Non-work	Total
Simple	2000 25.1%	4063 51.0%	6063 76.1%
Complex	511 6.4%	1393 17.5%	1904 23.9%
Total	2511 31.5%	5456 68.5%	7967 100.0%

Table 3. Distribution of trip chains by household type.

Household types	Households (%)	Trip chains (%)	Trip chain %/ household%
Zero workers, all persons age 60+	15	9	0.60
Zero workers, some under age 60	14	12	0.86
Single working person	8	4	0.50
Single working person w/child < 6	1	0	–
Single working person w/ child > 5	2	2	1.00
Traditional couple	16	13	0.81
Traditional family w/ child < 6	11	12	1.09
Traditional family w/ child > 5	10	17	1.70
Dual income, no children	12	11	0.92
Dual income w/ child < 6	3	4	1.33
Dual income w/ child > 5	7	12	1.71
Multiple adult workers	2	5	2.50

Table 3 presents a breakdown of household types and their relative sample and trip chaining frequencies. A ratio of the percentage of total trip chains to the percentage of households is also given in the right-hand column. This provides a comparative chaining indicator for each of the household types. These ratio values indicate that retiree, zero worker, individual worker, dual income without children, and traditional households without children all tended to make relatively fewer journeys, while the remaining groups accounted for a proportionately greater number. The presence of children is clearly an important factor in distinguishing higher relative journey frequencies, with the exception being single adult-headed families. It is also noteworthy that households with school age children account for proportionately more travel than households with preschool age children. Lastly, while multiple adult worker households represent two percent of the sample, they accounted for five percent of all trip chains, a comparative frequency which is five time greater than that of single worker households without children.

Empirical analysis of trip chaining

A twofold modeling approach is employed in analyzing trip chaining activity. First, we focus on work commutes, and assess whether the likelihood of linking work and non-work trips can be related to a set of household, travel and traffic variables. Work commute chains are classified into the discrete alternatives "simple" and "complex." Similar to Oster's (1979) analysis, the commuter's choice between these alternatives is estimated by a binary logit model. Our application differs from Oster's in that household structure in the present analysis is more detailed, and the commute chaining effects associated with gender, travel mode, locational factors and a proxy for congestion are also addressed. In a second analysis, we focus on non-work travel in terms of its organization at the household level, where the concern is with factors influencing households' allocation of non-work trips among three alternative chain types, including the *work commute, multi-stop non-work journeys* and *unlinked non-work trips*. Specifically, we develop a simultaneous equations model to estimate the shares of non-work trips contained in each of the three above-mentioned chain types.

The journey to work can consist of a simple home-work-home commute, or it can also include trips to satisfy non-work needs and obligations. The commuter's choice between these alternatives is hypothesized to be affected by household composition, travel activity level, locational factors, mode of travel and traffic conditions. In general form, the model is specified as follows (a full listing of variables is presented in the Appendix):

$$\log (P_c/1 - P_c) = f(M, G, L, D, C, NWT, HS, Y), \text{ where} \qquad (1)$$

P_c = the probability of an individual engaging in a complex work commute
M = travel mode
G = gender
L = a vector of variables representing residential location and place of employment
D = distance between residence and place of employment
C = traffic congestion
NWT = total non-work trips made by the household
HS = a vector of household structure variables
Y = household income

One would expect that the complexity of the work chain would be related to the mode of travel chosen. Single occupant auto commuters have substantially more flexibility to schedule non-work activities in conjunction with their journey to work. Alternatively, transit commuters and carpoolers have less control over travel schedules and routes, which makes coordination of work and non-work activities more difficult for them.

Some households may be compelled to coordinate non-work activity with the work commute, as in the case of obtaining child care. Women have traditionally held greater responsibility for child care and household maintenance, and the inertia of tradition may carry such responsibilities forward despite their shift from work in the home to market work. Consistent with this view, we hypothesize that women's propensity to form complex commute chains will be greater than men's.

Work place location may have an important bearing on commute chain complexity. Accessibility to non-work activities from suburban employment centers is limited according to Cervero (1988). This leads to greater auto dependency and, relative to CBD workers, decreases the likelihood that suburban workers will walk from their job site to non-work activity sites. The respondents to the survey used in this study were instructed to report walking trips only if they were work-related, and thus we expect that individuals who work in the suburbs would have a greater tendency to report complex commute chains.

Regarding residential location, suburbanites are hypothesized to be less accessible to non work activity locations as a result of lower development density. One consequence of lesser accessibility is that suburbanites ought to be more likely to consolidate travel activities. This consolidation could occur in the journey to work, or it could be reflected in a greater tendency to form complex non-work chains (Williams 1988). The former possibility is tested here while the latter is addressed later in the paper.

Distance to work is expected to have a positive effect on the propensity to form complex commute chains. Longer commutes imply exposure to potentially more non-work activity sites, and they also offer potentially larger travel savings from linking work and non-work activities (Nishii et al. 1988).

Higher congestion levels are expected to increase the likelihood of choosing the simple home-work-home commuting option. To proxy congestion, a simple distinction is made regarding whether the commuter begins his or her trips to and from work during the morning and evening peak period.

The assignment of non-work activities among household members is influenced by time availability and access to vehicles. Work trips have traditionally had priority access to household vehicles, but with the number of vehicles now approaching the number of licensed drivers, time availability has probably become a more important criterion for non-work travel activity assignment. Non-work travel frequency of the household derives from their activity demand levels. Higher levels of demand for non-work activity can be satisfied by coordinating these activities with the work commute. Thus Oster (1979) estimated that the probability of adding non-work trips to the commute increased with the household's total number of non-work destinations.

The alternative household types are defined by dummy variables to capture the differential effects of demographic structure on the propensity to form complex work commute chains. Since the model is concerned with work commuting, two household categories ("retirees" and "no working adults") are not included. Traditional households (i.e., two adults, one worker) with school-age children are the designated reference category.

Household income has been found to be positively related to workers' propensity to schedule non-work activities during the work day (Damm 1982) and, by correspondence, their propensity to form complex commute chains (Oster 1979; Goulias & Kitamura 1989). The present analysis is limited to specifying dummy variables identifying high and low income households due to a design problem in the survey.

The observations employed in the model are 2,468 adult household members who reported making work trips. Parameter estimates are presented in Table 4. The likelihood of forming a complex commuting chain is estimated to be significantly greater for women, people who drive alone to work, workers from high income households, and as the number of non-work trips made by the household increases. Commuting during both the AM and PM peaks significantly reduces the probability of adding non-work trips to the work chain, which is consistent with our expectation that congestion induces a shift of non-work travel away from the work commute.

Regarding the various household types, it is not surprising that single working adults with preschool children are estimated to have the greatest propensity to form complex work commute chains. In decreasing order, they are followed by single adult workers, single heads with school-age children, dual income couples, dual income families with preschool children, and traditional couples. The chaining propensities of the remaining households cannot be distinguished from traditional households with school-age children.

The coefficient for the low income dummy variable is not significant. Also, home-to-work distance, and work place and residential location variables are insignificant, indicating that in assessing chain formation propensity, how workers commute may be more relevant than how far they travel or where they travel to and from. However, there may be confounding effects involving distance, location and travel mode. For example, downtown workers have better access to transit access and face higher parking costs than their suburban counterparts, and are thus more likely to choose transit for commuting. Hence, work place location influences their mode choice which, in turn, influences their propensity to form complex commute chains. In addition, individuals are more likely to commute by auto as home-to-work distance increases. The correlations between the single occupant auto mode variable and the commuting

Table 4. Parameter estimates for the work commute chain model.

Variable	Coefficient	T-statistic
Gender	0.323	3.23
Total Non-work trips	0.057	5.69
CBD work	–0.015	–0.11
Suburban work	–0.179	–1.56
Peak commute	–1.212	–9.52
Drives alone	0.438	3.62
Suburban residence	0.002	0.02
Distance to work	–0.0001	–0.06
Low Income	–0.273	–1.69
High Income	0.346	2.54
Single Person	1.099	4.59
Single/Preschoolers	2.374	4.11
Single/School age	0.802	2.23
Traditional Couple	0.420	2.03
Traditional/Preschoolers	0.289	1.32
Dual Income Couple	0.733	3.74
Dual Income/Preschoolers	0.664	2.62
Dual Income/School age	0.167	0.80
Multiple Workers	0.358	1.54
Constant	–1.945	–8.20
Log-likelihood Function (0)	–1418	
Log-likelihood Function (β)	–1314	
Likelihood Ratio Statistic	208 (18 D.F.)	
n	2468	

Dependent variable = probability of a complex commute

distance, CBD and suburban work location variables (0.12, –0.38 and 0.18, respectively) are consistent with the hypothesis regarding confounding effects among these variables.

Household trip chaining

While the analysis of commute chains provides insight of factors affecting the coordination of non-work trips with the journey to work, we are also interested in the more general organization of non-work travel within the household. In this regard, we posit that a household's allocation of non-work travel to alternative trip chain types will be influenced by a similar set of factors as those employed above in modeling the work commute. Three alternative chaining options are defined: a) the work commute; b) simple unlinked trips; c) multi-stop non-work journeys. Our objective is to specify a model which can assess the effects of household structure and travel conditions on the relative importances of each chain alternative in satisfying non-work travel needs.

The model corresponding with this objective is comprised of three linear equations, one for each chain type; its general specification is as follows (see the Appendix for a detailed description of the variables):

$$S_i = f(M, L, D, V, C, NWT, HS, Y) \quad (2)$$

The variable S_i on the left hand side of the equation represents the share of household non-work trips contained in a type i chain. The mode and distance variables refer to the work commute of the household's principal wage earner. A more general proxy for congestion is also employed in place of the peak period dummy used in the work commute model. It is the ratio of estimated PM peak to mid-day auto travel time between the zone of residence and the work zone of the principal wage earner. The specification also includes the number of household vehicles (V). The breakdown of household types follows the previous approach, except that single parent households are now represented by one dummy variable rather than two. This reduction was necessary because few of the single parent with preschooler households reported both work and non-work trips. In all other respects the variables on the right hand side of the three share equations are the same as those used in the work commute model.

Given that the sum of the proportions of non-work trips across the three chaining alternatives is equal to one, the trip share equations can be estimated simultaneously by iterative three stage least squares, subject to the following parameter restrictions:

$$\Sigma_i\alpha_i = 1; \quad \Sigma_i\beta_{ij} = 0,$$

where α's represent the intercept terms and the β's are the estimated coefficients for each of the variables. As a result of these restrictions, the coefficients for a give variable can be interpreted in direct trade-off form across the three equations. For example, a marginal increase in the proportion of non-work trips linked to work commute chains associated with the principal wage earner's choice to drive alone would have to be offset by an equivalent new marginal decline in the proportion of non-work trips linked to the other two chain types. Finally, the reader is cautioned that the parameter restrictions make interpretation of goodness-of-fit statistics ambiguous.

The sample consists of 1472 households who made both work and non-work trips. The parameter estimates are reported in Table 5. As indicated by the coefficients among the respective equations, when the principal wage earner commutes alone by car there is a significant re-allocation of the household's

Table 5. Parameter estimates for the non–work trip allocation model.

Variable	Complex work Eq.	Simple non–work Eq.	Complex non–work Eq.
Constant	0.060	0.939	0.001
	(0.84)	(9.48)*	(0.01)
Drives alone to work	0.084	–0.112	0.028
	(3.56)*	(–3.40)*	(1.02)
Suburban residence	–0.021	0.071	–0.050
	(–1.29)	(3.14)*	(–2.65)*
CBD work place	0.024	–.069	0.044
	(1.13)	(–2.26)*	(1.74)
Suburban work place	0.013	–0.044	0.031
	(0.78)	(–1.82)	(1.52)
No. of HH Vehicles	–0.015	0.007	0.008
	(–1.84)	(0.61)	(0.84)
Distance to Work	0.001	–0.001	–0.0005
	(0.78)	(–0.34)	(–0.26)
Congestion	0.022	0.003	–0.024
	(0.40)	(0.03)	(–0.38)
Total Non–work Trips	–0.011	–0.010	0.021
	(–6.79)*	(–4.72)*	(11.54)*
Single Person	0.298	–0.433	0.135
	(8.91)*	(–9.24)*	(3.45)*
Single/Children	0.056	–0.128	0.072
	(1.40)	(–2.28)*	(1.53)
Traditional Couple	0.027	–0.186	0.158
	(1.15)	(–5.57)*	(5.67)*
Traditional/Preschoolers	–0.013	–0.105	0.118
	(–0.54)	(–2.98)*	(4.02)*
Dual Income Couple	0.206	–0.322	0.116
	(7.73)*	(–8.62)*	(3.71)*
Dual Income/Preschoolers	0.171	–0.241	0.071
	(4.38)*	(–4.42)*	(1.55)
Dual Income/School age Ch.	0.022	–0.17	–.005
	(0.83)	(–0.46)	(–0.16)
Multiple Workers	0.185	–0.184	–0.001
	(4.60)*	(–3.27)*	(–0.01)
High Income	0.021	–0.018	–0.002
	(0.90)	(–0.57)	(–0.09)
Low Income	–0.016	0.043	–0.028
	(–0.66)	(1.30)	(–0.99)
R^2	0.19	0.11	0.11
n	1472	1472	1472

* Significant at α 0.025, two-tailed test.
(Asymptotic t-ratios in parentheses)

non-work trips from simple non-work chains to the work commute. The proportion of non-work trips organized into complex journeys is not significantly affected by the principal wage earner's mode choice decision. Specifically, the estimated consequences of the principal wage earner's decision to commute alone by car on the household's organization of non-work travel are as follows: an eight point increase in the percentage of non-work trips linked to the work commute, an eleven point decline in the percentage of trips in simple non-work chains, and a three point increase in the percentage of non-work trips comprising complex non-work journeys. This finding is consistent with the earlier-stated hypothesis of an inverse relationship between vehicle occupancy and the propensity of households to schedule non-work trips in conjunction with the work commute.

Suburban residents tend to allocate a significantly larger share of their non-work trips to simple chains than the referent city residents do. This is contrary to Williams' (1988) results, but consistent with Richardson and Gordon's (1989) conclusion that the dispersion of commercial activities has reduced suburbanites' tendency to form complex chains.

When the household head works in the central business district, a smaller proportion of non-work travel is conducted in simple non-work chains and more in both the work commute and in complex non-work chains.

The number of vehicles, the distance to work of the principal wage earner, and congestion have insignificant effects on households' allocation of non-work trips. It may be that the number of vehicles has reached a saturation point (households in the sample averaged just over one vehicle per licensed driver). Both distance to work and congestion were estimated by EMME2, a traditional four-step transportation planning package used by METRO. As Talvitie and Dehghani (1979) found, measurement errors in these packages can be considerable. From an estimation perspective, this leaves us unable to distinguish whether the absence of statistical significance is a result of measurement error or a consequence of the fact that the organization of non-work travel is not influenced by congestion levels and commuting distances.

As the number of non-work destinations visited by the household increases, there is a significant reallocation involving comparable reductions in the share of non-work trips linked to the work commute and simple non-work chains, and a corresponding increase in the share associated with complex non-work journeys. In other works, when households experience growth of non-work trip making, they tend to organize their travel into more complex purposeful journeys.

Relative to the traditional family benchmark, all the specified household groups in the model tend to allocate a smaller share of their non-work trips to simple chains. As Oster (1978) demonstrated, this contributes to aggregate travel time and cost savings. However, it may also contribute to congestion if non-work trips, which presumably are more amenable to off-peak scheduling, are shifted to the work commute. In this regard, there are several distinct patterns among the household groups. The first is characterized by trip shifting from simple to complex non-work chains, and is most pronounced for traditional couples and traditional households with preschoolers. Their trip reallocations potentially result in personal time and cost efficiencies and are less likely to contribute to peak period congestion. The second pattern involves shifts from simple non-work to complex work chains by dual income families with preschoolers and multiple adult worker households. The travel economies achieved by these households are more likely to have negative congestion implications. A third group of households, comprised of single workers, dual income couples and single heads with children, shift their non-work trips from simple chains to both work and complex non-work chains. For the former two groups the shift to the work commute is about twice as large as the shift to complex non-work chains.

The trip chain equation estimates for the various household types reinforce Oster's (1979) findings, and provide a possible explanation for the rapid growth of non-work trips during peak commuting periods observed by Gordon et al. (1988). First, the household types which coordinate the largest shares of non-work trips with the work commute – single persons, dual income couples, dual income families with preschoolers, and multiple workers – are the same types which grew most rapidly between 1970 and 1990. Second, single occupant auto commuters were estimated to have a higher propensity to add non-work trips to their work commute. The declines in auto occupancy levels reported by Pisarski (1992) thus facilitated scheduling of a larger proportion of households' non-work travel within work commute chains.

Considering other results of both models, there are clear similarities between the factors which influence the probability that an individual will make a complex work commute and the factors which affect the share of non-work travel a household allocates to commute chains. For example, driving alone was associated with a greater likelihood of a complex commute and a higher proportion of non-work trips linked to the work commute. Likewise, households without children tend to shift more none-work activities to the commute, while households with school-age children link proportionately fewer non-work activities to the commute. The number of non-work trips made by the household affected the estimations in opposite ways, but this is not necessarily contradictory. As the number of non-work trips grows it is likely that some of them will be added to the work commute. Relative to other chaining options, however, work commute chains do not proportionately absorb increases in non-work travel of households.

Conclusions

In this paper we have empirically analyzed factors influencing trip chaining, focusing first on the work commute and then more generally on the household allocation of non-work trips to alternative work and non-work chains. In the concluding section we will discuss several implications of the results for congestion management and, more generally, urban transportation planning.

In the model addressing the work commute, we found that the probability of forming simple work chains was significantly greater when individuals scheduled their journey to work in peak congestion periods. This finding is consistent with previous conceptual analyses of trip chain formation, which indicated that increasing congestion should lead to rescheduling of non-work travel to off-peak periods. However, this rescheduling effect needs to be more carefully evaluated in light of past growth of non-work travel in peak commuting periods. Our findings suggest that increases in single occupant auto commutes and changes in the mix of households tended to mitigate rescheduling effects associated with congestion.

In the more general analysis focusing on household allocation of non-work travel, we found that a travel time-based indicator of congestion did not influence the distribution of non-work trips among alternative types of trip chains. This may have been due to measurement problems stemming from attempting to relate zonal congestion estimates to micro-level behavior. Notwithstanding this issue, the more general model provided additional evidence of substantial household structural differences among trip chains involving non-work travel. These structural effects have both positive and negative congestion implications, depending on household type. On the positive side, the faster growing household types show a greater tendency to organize non-work trips into chains, which produces travel economies for them and, when their non-work journeys are off-peak, for others as well. On the negative side, while the fastest growing household groups showed the greatest tendency to chain non-work trips, they also showed the greatest tendency to add non-work travel to the work commute.

The importance of household composition in explaining trip chaining differences also has travel demand and congestion management implications. It should be emphasized that while household structural factors affect travel demand, trip chain formation and congestion, transportation policies clearly have little impact on household composition. Given that the mix of households is essentially exogenous, the effects of travel demand and congestion management policies will be either magnified or muted by demographic trends. Policy makers will need to consider more carefully how such trends are likely to affect transportation management programs. Moreover, given that the complexity of work commute chains varies considerably among household groups, the distributional consequences of alternative congestion management policies will probably warrant closer attention.

Research on work trip scheduling usually focuses on the commuter in isolation from his or her household. Our results suggest that household structure has an important influence on the complexity of work journeys, and that trend changes in the mix of households have led to increasingly complex work commutes that are more resistant to peak spreading programs (e.g., flex-time and staggered work hours).

Our findings also suggest that policies which seek to increase vehicle occupancy (e.g., see Downs 1992) may provide more effective congestion relief than previously thought because, in addition to reducing vehicle trips directly, higher occupancy levels would encourage rescheduling of non-work trips presently linked to the work commute.

The beneficial consequences of uncoupling non-work trips from peak congestion periods, however, may be offset to an unknown extent by negative air quality effects if separate non-work trips were to include cold starts or contribute additional vehicle miles. At a minimum it is important to recognize that complex trade-offs will be encountered in efforts to both manage traffic congestion and improve urban air quality.

The exploratory nature of our analysis should not be forgotten. Clearly, the travel patterns of one metropolitan area's residents may not represent travel elsewhere. Ideally, national sample data ought to be used, and beginning with the 1990 NPTS this will be possible. Second, the logit and share models employed simplifying assumptions regarding the trip chaining options facing commuters and households. The logit model could be extended to address more specifically defined travel purposes. The share model would probably benefit form lengthening the survey period, which would increase the number of trips per household. It turn, this would contribute to more stable parameter estimates and minimize observations with share values at zero or one. Also with regard to the share model, the limitations of the estimation procedures need to be further assessed.

In contrast with the dramatic changes in household structure in the 1970s and 1980s, the outlook for the 1990s points to a slowing down of household formation rates, particularly for several of the groups which we found to have a greater tendency to organize travel around the work commute. Exter (1992a, b) projects that the number of single person households aged 18-to-34 will decline 8 percent between 1990 and 2000, reflecting the assimilation of the "baby bust" cohort into the adult population. He also projects that family households will grow slightly faster than non-family households, another reversal of past trends. In addition, after two decades of rapid increase, there has been a leveling off of female labor force participation rates, and it is widely believed that future increases will be modest at best. Collectively, these changes should contribute to a slowdown in the growth of peak period travel, in which case transportation policies would need only provide reinforcing rather than off-setting incentives in managing congestion.

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Appendix

Variables in the work commute model.

Variable	Definition	Mean	Standard deviation
Gender	1 if female, 0 if male	0.44	0.50
Non-work trips	Total number of non-work trips made by household	4.64	5.17
CBD work	1 if works in the central business district, 0 otherwise	0.20	0.40
Suburban work	1 if works outside the central city, 0 otherwise	0.39	0.49
Peak commute	1 if both a.m. and p.m. commutes occur during rush hours (7–9 a.m. and 4–6 p.m.), 0 otherwise	0.29	0.46
Drives alone	1 if drives alone, 0 otherwise	0.71	0.45
Suburban residence	1 if lives outside the central city	0.55	0.50
Low income	Household income < $15,000	0.12	0.33
High income	Household income > $50,000	0.14	0.34
Distance to work	Minimum path distance (in miles) between zone of residence and zone of work	6.56	4.67
Single person	1 if single working person household, 0 otherwise	0.08	0.28
Single/preschoolers	1 if single, working person with child under 6, 0 otherwise	0.01	0.07
Single/school age	1 if single, working person with all children age 6 and older, 0 otherwise	0.02	0.14
Traditional couple	1 if two-adult household with one worker, 0 otherwise	0.16	0.37
Traditional/ preschoolers	1 if two-adult household with one worker and a child under 6, 0 otherwise	0.12	0.32
Dual income couple	1 if two working adults and no children, 0 otherwise	0.24	0.43
Dual income/ preschoolers	1 if two working adults and child under 6, 0 otherwise	0.06	0.23
Dual income/ school age	1 if two working adults and all children 6 and other, 0 otherwise	0.13	0.34
Multiple workers	1 if 3 or more workers in household, 0 otherwise	0.08	0.27

Variables in the non-work trip allocation model.

Variable	Definition	Mean	Standard deviation
Commutes by car	1 if commutes by car, 0 otherwise	0.859	0.348
Suburban residence	1 if lives outside the cental city, 0 otherwise	0.566	0.496
CBD work	1 if household head works in the central business district, 0 otherwise	0.200	0.400
Suburban work	1 if household head works outside the central city, 0 otherwise	0.398	0.490
No. of vehicles	Number of vehicles owned by household	2.059	0.996
Distance to work	Estimated distance to work of household head	5.59	4.70
Congestion	Ratio of estimated peak to non-peak travel times	1.20	0.15
Non-work trips	Total number of non-work trips made by household	6.04	5.02
Single person	1 if single, working person with no children, 0 otherwise	0.077	0.266
Single/children	1 if single, working person with child(ren), 0 otherwise	0.041	0.199
Traditional couple	1 if two-adult household with one adult in work force and no children, O otherwise	0.214	0.410
Traditional/ preschoolers	1 if two-adult household with one adult in work force and child under 6, 0 otherwise	0.154	0.361
Dual income couple	1 if two working adults and no children, 0 otherwise	0.178	0.346
Dual income/ preschoolers	1 if two working adults and child under 6, 0 otherwise	0.041	0.199
Dual income/ school age	1 if two working adults and all children 6 and older, 0 otherwise	0.116	0.320
Multiple workers	1 if 3 or more workers in household, 0 otherwise	0.039	0.195
Low income	1 if household income < \$15,000, 0 otherwise	0.12	0.32
High income	1 if household income > \$50,000, 0 otherwise	0.12	0.32