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Regularity and irreversibility of weekly travel behavior

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Abstract. Dynamic characteristics of travel behavior are analyzed in this paper using weekly travel diaries from two waves of panel surveys conducted six months apart. An analysis of activity engagement indicates the presence of significant regularity in weekly activity participation between the two waves. The analysis also shows a general lack of association between regularity in activity participation and change in person and household attributes, suggesting the presence of behavioral inertia or response lags. It is further shown that observed trip rates do not exhibit patterns that would be observed if travel behavior had no response lag and no history dependence. The results point to the needs for models that are capable of representing these aspects of travel behavior.

Introduction

Empirical studies of travel behavior have been based mostly on cross-sectional survey data. Underlying the use of cross-sectional observation as the sole source of information is the assumption that travel behavior can be explained by factors observed concurrently with the behavior. This implicit assumption of spontaneous correspondence between the travel behavior and travel environment has rarely been questioned in the effort of identifying behavioral relationship and building predictive models.

The assumption, however, does not hold true if the individual's response to a change in the travel environment involves a time lag, or if a habitual behavioral pattern prevails despite changes in contributing factors.[1] If this in fact is the case, accurate representation of travel behavior may not be accomplished through analysis based on cross-sectional observation. It has been shown elsewhere that a set of restrictive conditions must be satisfied for inferences based on a cross-sectional relationship to be valid (Kitamura 1986). Therefore it is critically important to examine whether travel behavior spontaneously responds to change in the travel environment and can be represented as a function of contributing factors whose values are observed concurrently with the behavior. If this is the case, the behavioral relation shall be called "contemporaneous."

Travel behavior may not be contemporaneous for several reasons. For example, individuals may not always be aware of changes in the travel environment

and continuously adjust their behavior, but they may remain to exhibit the same behavioral pattern until the cumulative magnitude of changes reaches a threshold. It may also be the case that responses are not reversible, i.e. travel behavior may not revert to its original pattern after a sequence of changes through which the contributing factors are reverted to their original values. Observed behavior, then, would depend on the past history of changes and responses. The trajectory of behavior will exhibit hysteresis. Cross-sectional observation, therefore, may not offer sufficient information for adequate explanation of travel behavior.[2]

Despite the pointed argument of Goodwin (1977), Clarke et al. (1982), and Goodwin & Layzell (1985), and despite the obviously far-reaching implications of the problem to data collection, model development, and forecasting, only a limited body of empirical evidence exists at this point on dynamic characteristics of travel behavior. Goodwin reports that changes in bus usage that followed changes in employment status are not symmetrical, e.g. the change from full-time employment to part-time employment is "associated with much smaller changes than part-time to full-time, a sign of resistance to change when things were getting worse, but not when they are getting better" (Goodwin 1986, p. 525). It is also reported that decreases in car ownership involve larger response delays than do increases.

A few additional examples in which non-contemporaneous properties of travel behavior were addressed in the past include the analysis of cohort and aging effects in travel and residential location behavior by Blanchard, Bunker & Wachs (1977) and Wachs (1979); the analysis of the impact of information diffusion on travel demand by Lerman & Manski (1982); and the study of departure time choice by commuters in learning processes by Mahmassani et al. (1986). The rare availability of data sets suited for such investigation has perhaps been a major reason for this scarcity of analyses.[3]

The hypothesis that travel behavior is contemporaneous is the subject of this study. The objective of this paper is to offer empirical results showing inertia and irreversibility in such fundamental aspects of travel behavior as trip generation. Using weekly travel diaries obtained from two waves of panel surveys from the Netherlands, we show that travel patterns exhibit strong regularity over time despite changes in socio-economic and other factors. It is also shown that changes in trip rates following changes in employment status are not symmetric, or reversible. This supports the conjecture that travel behavior is dependent upon the past history of contributing factors and behavior itself. The tabulations of this paper offer evidence that the relationship governing travel behavior is not contemporaneous and point to the needs to develop model structures that are capable of capturing non-contemporaneous aspects of travel behavior.

The question of regularity and inertia in travel behavior is first addressed. Following a brief exploration of changes in contributing factors, the regularity in trip rate and activity participation by day of the week is examined between the

two diary weeks of the panel survey. Changes in travel patterns between the two weeks are related to changes in person and household attributes. Irreversibility is next addressed by examining the relationship between the change in employment status and change in trip rates. The concept of "Markov response" is introduced to represent a hypothetical contemporaneous response pattern, and the discrepancy between this hypothetical pattern and observed pattern is examined. The study results and their implications are summarized in the last section.

Dutch mobility panel data

The Dutch National Mobility Panel was established in 1984 in order to evaluate longitudinal change in the mobility levels of the Dutch population. The households in the panel, selected by a stratified sampling method using household lifecycle, household income, and public transit service level as controlling factors, are spread over 20 municipalities across the Netherlands and are designed to represent the Dutch population. Details of the Dutch Panel survey can be found in Golob et al. (1985), Golob & Meurs (1986), and Kitamura & Bovy (1985).

One-week trip diaries were collected in each wave of the panel survey from all individuals of the household who were 12 years or older. As a result, the data set allows dynamic analysis of activity and travel scheduling for one-week periods. Diaries from the first two waves, collected in March 1984 and September to October 1984, respectively, are available for this study. The sample of this study consists of 1129 adult men and 1155 adult women (18 years old and over) who participated in both waves of the panel survey.[4]

Dynamics of household and person attributes

A sizable fraction of individuals in the panel sample experienced changes in factors that have traditionally been considered to influence travel behavior (see Table 1). The number of pre-school children (<6 yrs) in the household increased for slightly more than 5% of male and female adults in the sample.[5] The number of cars available to the household increased for 89 men (7.9%) and 82 women (7.1%), and decreased for 34 men (3.0%) and 24 women (2.1%).

Approximately 75% of those gaining cars already had a car available in the first wave. The increase in car ownership in the sample consists mainly of transitions from single-car to multi-car households. Also, about 65% of those with a decreased number of cars in wave two belonged to multi-car households in wave one. As a consequence, the number of male adults without access to a car slightly decreased from 190 (16.8%) to 180 (15.9%) and female adults from 237 (20.5%) to 225 (19.5%). The high level of car availability and the trend toward

Table 1. Changes in selected household and person attributes.

	Male adults				Female adults			
	Dec.	N.C.	Inc.	d(%)	Dec.	N.C.	Inc.	d(%)
No. of pre-schoolers	8	1066	55	5.6	9	1088	58	5.8
Household size	27	1052	50	6.8	30	1070	55	7.4
No. of cars	34	1006	89	10.9	24	1049	82	9.2

Dec. = decrease; N.C. = no change; Inc. = increase; d(%) = percent of individuals with changes.

Marital status

		Male adults				Female adults			
	Wave 2	No	Yes	Total	d(%)	No	Yes	Total	d(%)
Wave 1	No	83	3	86		130	8	138	
	Yes	2	1041	1043		3	1014	1017	
	Total	85	1044	1129	0.4	133	1022	1155	1.0

Employment status

		Male adults				Female adults			
	Wave 2	No	Yes	Total	d(%)	No	Yes	Total	d(%)
Wave 1	No	320	42	362		792	39	831	
	Yes	28	739	767		29	295	324	
	Total	348	781	1129	6.2	821	334	1155	5.9

No = not employed; Yes = employed.

Driver's license

		Male adults				Female adults			
	Wave 2	No	Yes	Total	d(%)	No	Yes	Total	d(%)
Wave 1	No	135	14	149		357	21	378	
	Yes	9	952	961		4	744	748	
	Total	144	966	1110	2.1	361	765	1126	2.2

an even higher level of car ownership indicated by these statistics are quite notable.

Only few individuals in the sample changed their marital status or obtained (or lost) a driver's license between the two waves.[6] A comparatively large number of individuals changed employment status; 70 men (6.2%) and 68 women (5.9%) either gained or lost employment during the six month period. Further examination indicated that younger individuals tended to undergo changes. Related to this is the hypothesis that a major change in a person's life, such as gaining employment, may be accompanied by other changes, e.g. getting a car. Although the available sample is too small to draw any definite conclusions on this hypothesis, our analysis suggests that some changes tend to follow each other, and others are isolated.[7]

Regularity at the aggregate level

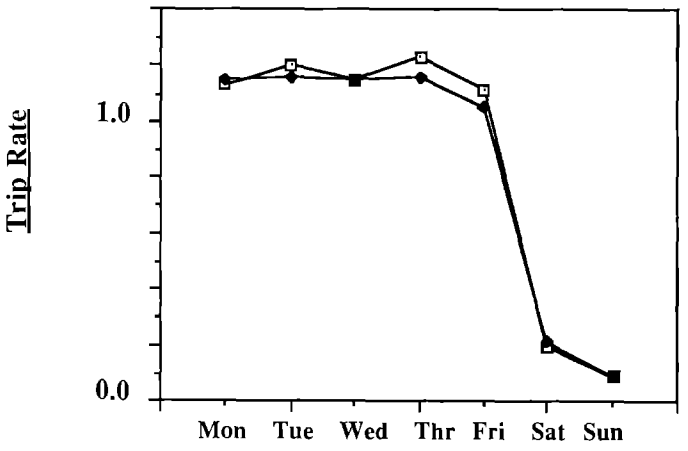
The regularity in trip making between the two diary weeks is examined in this section using aggregate trip rates obtained from those individuals who were employed in both waves of the panel survey. The trip purpose categories used are: work (including work-related business), shopping (including personal business and medical), social/recreation (including eating meals), and other activities. School trips and trips made to serve passengers or to accompany other persons are not included in the analysis of this study.

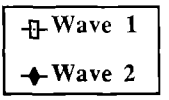
The same variation patterns prevail across days of the week in both waves (Fig. 1). In particular, differences in trip rates between weekdays and weekend are evident. As expected, social/recreation trips increase on Saturdays and Sundays and approximately 50% of social trips in the weekly diaries are made on these two days in both waves. The extremely small trip rate for shopping on Sunday is due to the fact that most stores are closed on Sundays in the Netherlands. The store hours during weekdays are also restrictive with most stores closing at 6:00 p.m. Accordingly Saturdays offer the most convenient shopping opportunities for many full-time workers, leading to the high shopping trip rate found on Saturday.

Note the gradual and clear increase in the shopping trip rate across weekdays toward Friday. This again reflects the store opening hours; most stores are closed on Monday mornings, while many communities have late opening hours (typically 7:00 to 9:00 p.m.) on Thursdays or Fridays. The variations in shopping trip rates across days of the week thus reflect the variations in the availability of shopping opportunities. Similar gradual increases toward the end of the week are also observed for social/recreation in both waves.

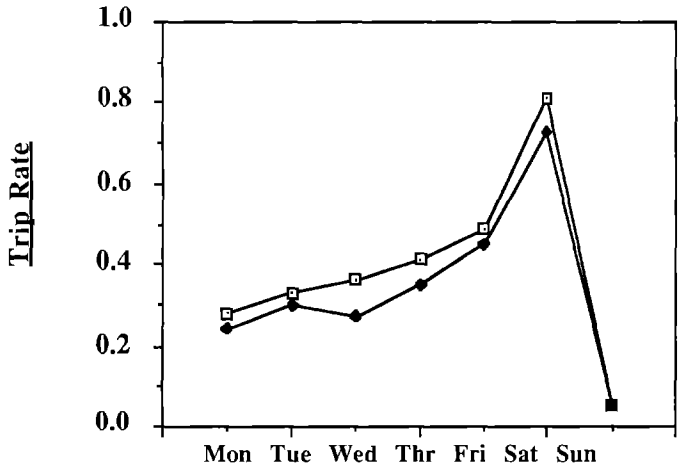
Increases in trip rates for discretionary activities during a week can also be found in a published tabulation of trip rates by day of the week using the 1983

Work Trip





Shopping Trips



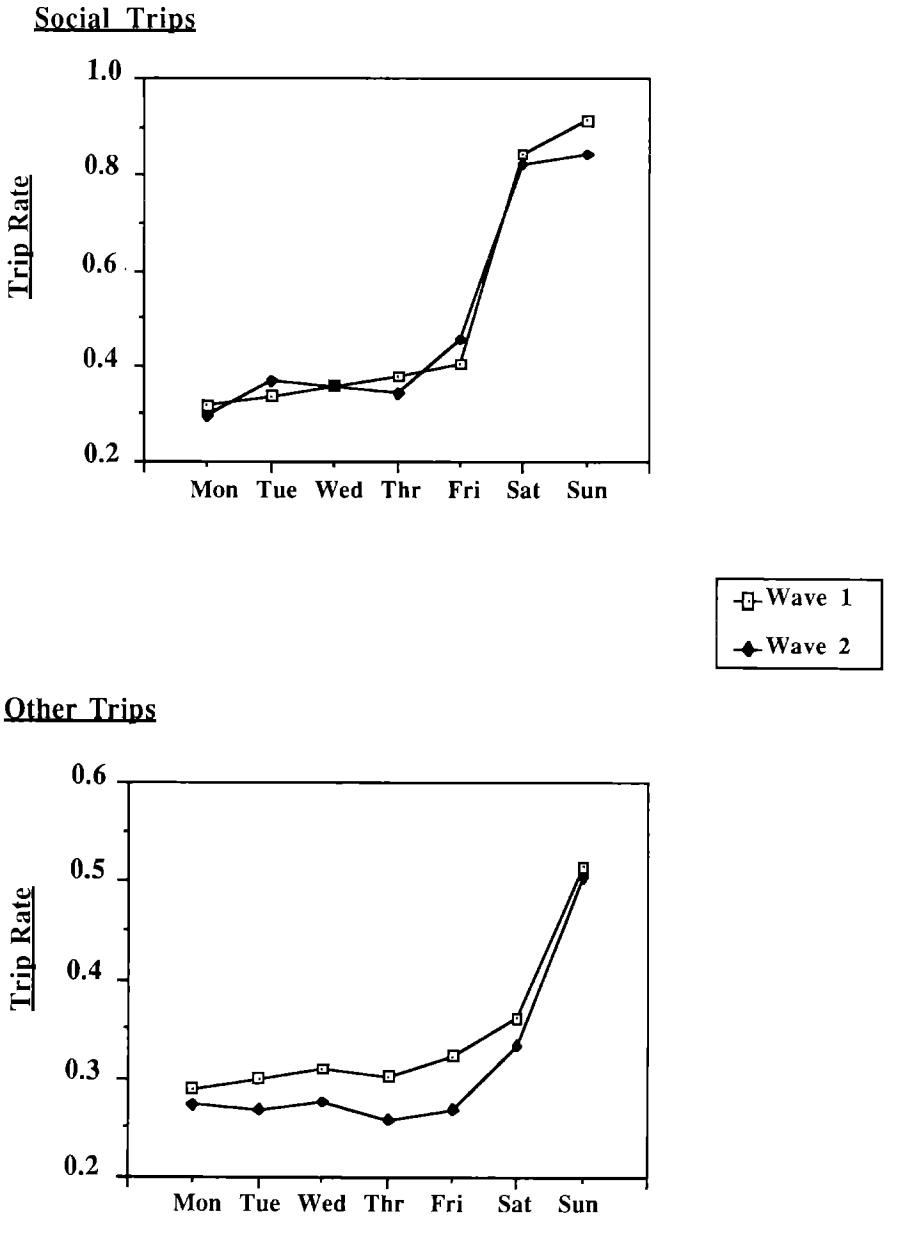
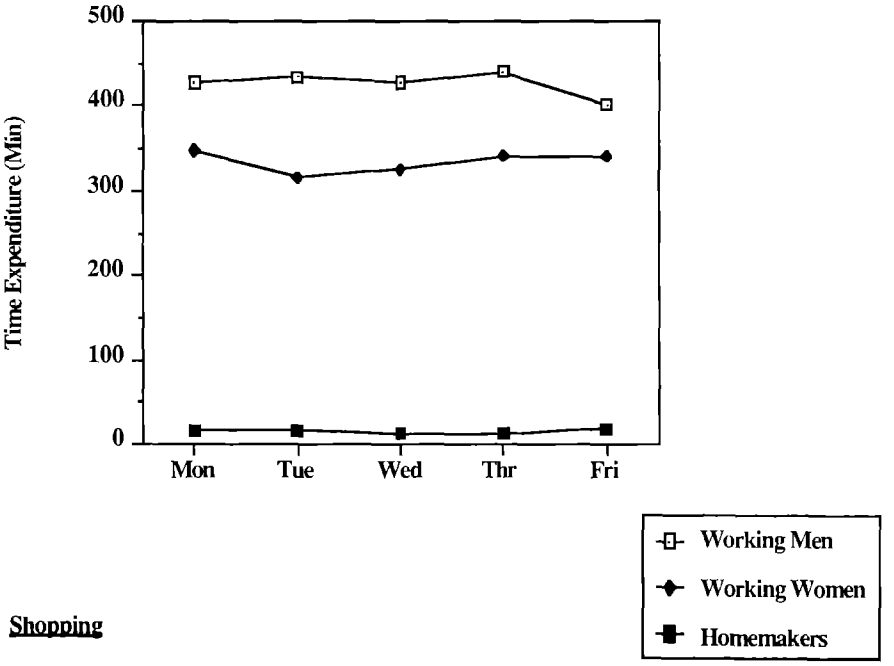
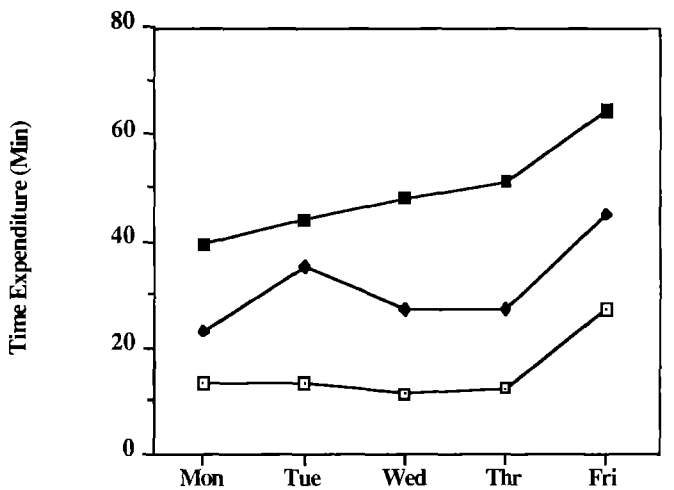


Fig. 1. Mean trip rate by activity type by day of the week.

Total Work



Shopping



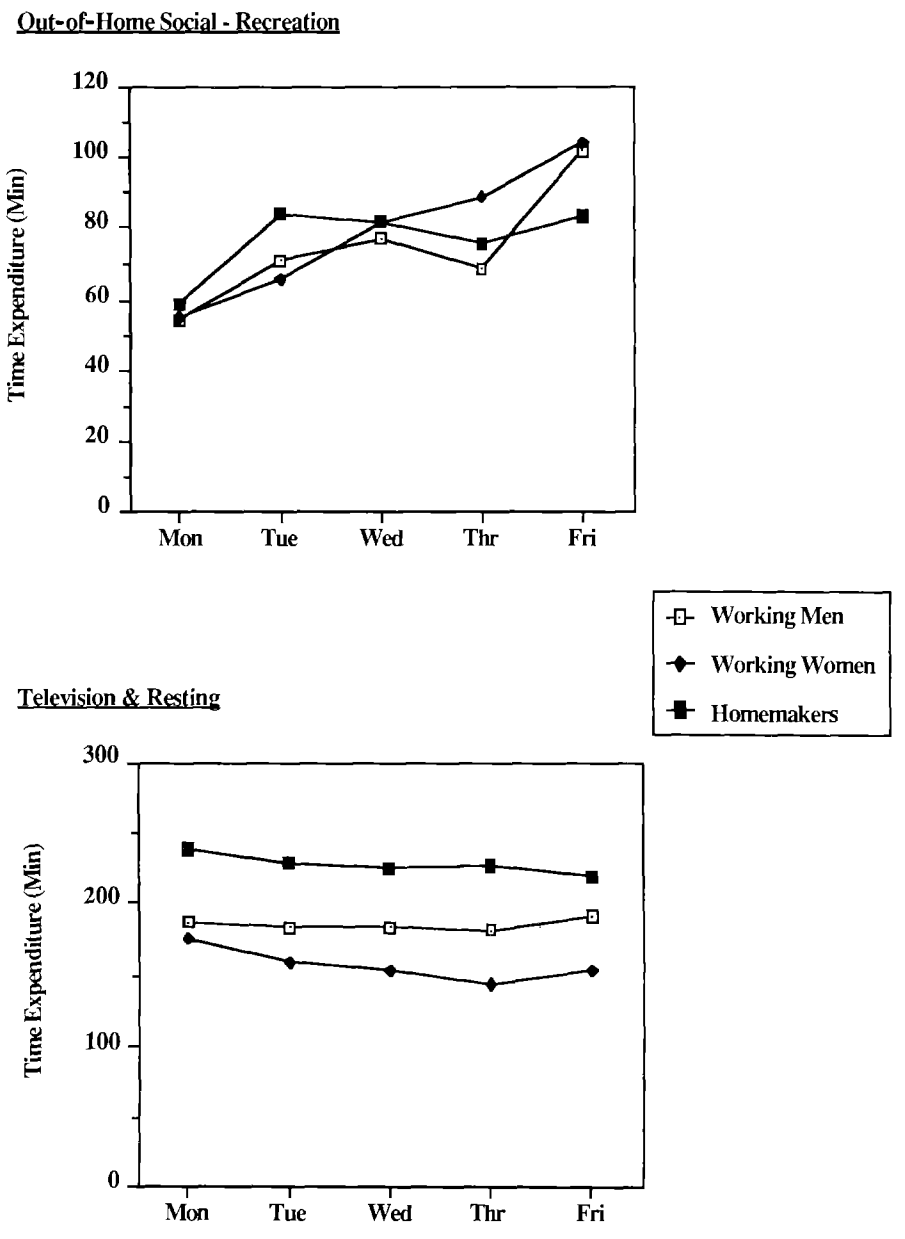


Fig. 2. Time expenditure by activity type by day of the week.

Dutch National Travel Survey data (Centraal Bureau voor de Statistiek 1984). An examination of daily time allocation using the Dutch Social and Cultural Planning Bureau (SCP) activity diary survey of 1975 (see van der Hoorn 1983) also indicates the same tendency. The amount of time spent for several types of activities obtained from SCP is presented in Fig. 2 for working men, working women and non-working adult women (the SCP survey does not contain data on weeked activities). The Figure shows similar increasing tendencies for the time allocated to out-of-home social/recreation and shopping. The time spend for in-home relaxation and passive recreation (resting and TV) decreases toward the end of the week; people appear to pursue more active discretionary activities towards the end of the week.

The tendencies found consistently in these three data sets constitute strong empirical evidence that the frequency of trips made for, and the amount of time allocated to, out-of-home discretionary activities increase during weekdays toward Friday. The tendency is in part due to institutional factors such as store opening hours. It may also be due to the same psychological factors that lead to the pattern of sequencing activities within a day or in a trip chain, where less flexible and less discretionary activities tend to be pursued first (Maw 1972; Kitamura 1983; Kostyniuk & Kitamura 1984). This analysis adds to the previous findings on daily variability of travel behavior (Hanson & Huff 1983; Koppelman & Pas 1984; Huff & Hanson 1986), and shows the systematic variations that exist across days of the week in time use as well as in trip generation. It is also found that aggregate trip rates show identical variation patterns between the two waves. The analysis suggests the presence of strong regularity over time and also across data sets in aggregate trip rates by day of the week.

Regularity of activity participation

In this section we examine whether the regularity observed in the previous section at the aggregate level can also be observed at the individual level. The analysis centers on the regularity in weekly activity engagement patterns between the two diary weeks.

Activity participation by day of the week

As a simple measure of regularity in activity participation on a given day of the week, consider the following categorical representation:

a) no participation in both waves,
b) participation in wave one, no participation in wave two,

c) no participation in wave one, participation in wave two,
d) participation in both waves.

These four cases are presented in Table 2 in the form of a matrix. Note that the analysis is concerned only with activity participation, i.e. whether or not the respondent engaged in a given type of out-of-home activity at all on a given day, but not with trip rates. Regularity of activity engagement can be inferred by comparing the observed frequencies across the four categories against expected frequencies obtained theoretically assuming the absence of regularity. Let

$p(t,d)$ = the probability of engaging in shopping on day of the week d in wave t, $d = 1, \ldots, 7$; $t = 1, 2$, and
$q(t,d) = 1 - p(t,d)$.

If shopping participation of N workers is entirely random and behavior is independent between the two waves, frequency observations of the above four categories will center around the expected values of

$$Nq(1,d)q(2,d),\ Np(1,d)q(2,d),\ Nq(1,d)p(2,d),\ \text{and}\ Np(1,d)p(2,d),$$

respectively. Expected values thus obtained are shown in Table 2 for shopping participation by male workers on Fridays. The hypothesis of independence between the two weeks, or no regularity, is tested using these expectations. The results are summarized in Table 3 in terms of chi-square statistics associated with transition matrices formulated, as in Table 2, by day of the week and by activity type.

The table offers strong statistical evidence that weekly activity engagement is repetitive. Further examination indicated that transitions with identical partic-

Table 2. Shopping participation by wave: male workers, Friday.

		Wave 2		
Wave 1		P	NP	Total
P	Obs.	96	127	223
	Exp.	61	162	
NP	Obs.	104	410	514
	Exp.	139	375	
Total		200	537	737

P = participation; NP = no participation; Obs. = observed frequency; Exp. = expected frequency; $x^2 = 40.95$, (df = 1).

Table 3. Significance of the correlation of activity participation by day of the week between the two waves (workers).*

Activity type	Day of the week						
	Mon.	Tue.	Wed.	Thur.	Fri.	Sat.	Sun.
Shopping							
Male workers	**8.60**	**19.22**	**34.68**	**11.56**	**40.95**	**35.91**	–
Female workers	**12.54**	**27.24**	**24.98**	2.40	**12.01**	4.13	–
Social/recreation							
Male workers	**28.57**	**63.51**	**36.21**	**25.36**	**20.50**	**30.09**	**33.96**
Female workers	**18.27**	**7.01**	**7.39**	**15.94**	6.07	3.39	**16.14**
Others							
Male workers	**13.28**	**13.19**	**12.14**	**10.50**	**6.70**	**24.47**	**25.33**
Female workers	**7.03**	1.82	1.56	**9.95**	0.63	4.07	**15.04**

–: Not shown because of small expected cell frequencies.

* The table shows chi-square statistics (df = 1) associated with the frequency matrix of activity participation by day of the week and activity type. The statistics significant at $\alpha = 1\%$ are indicated by bold-faced figures. The sample size is 737 for male workers and 293 for female workers.

ipation (types a and d as defined above) consistently have more-than-expected observations, and others (b and c) have less-than-expected observations. The difference between the observation and expectation is highly significant for any day of the week for male workers' activity participation. Female workers show in general less significant chi-square values. This, however, is in part due to the smaller sample size of female workers.

Similarity in weekly patterns between the waves

Additional evidence of regularity is given in Table 4 which presents the number of days in the week on which the same activity participation is observed between the two waves, i.e. participation in both waves, or no participation in both waves. The theoretical distribution is obtained using p(1,d) and p(2,d). Let r(d) = p(1,d)p(2,d) + q(1,d)q(2,d) be the probability of identical participation on day of the week d assuming participation is independent between the waves and also across days within each diary week. Then the expected frequency of individuals having 7 days of identical participation is given by the product, Nr(1)r(2)...r(7). Similarly, the expected frequency of individuals with 6 days of identical participation is given as

$$N \sum_{i=1}^{7} (1-r(i)) \times \prod_{j \neq i} r(j)$$

and that for 5 days as

$$N \sum_{\substack{i,\, j=1 \\ j>i}}^{7} (1-r(i))\,(1-r(j)) \times_{k \neq i,\, j} r(k)$$

etc. The theoretical frequencies thus obtained are presented in Table 4 together with the observed frequencies.

The result shows extremely significant difference between the observation and expectation. For example, 18.2% of male workers have completely identical shopping participation between the two weeks while the expected frequency is only 5.9%; nearly 60% of female workers have 5 or more days with identical participation in shopping while the expectation is below 40%. The same conclusion can be obtained for social/recreation and other activities. It is clear that individuals tended to maintain the same weekly pattern of activity participation between the two waves. This regularity is noteworthy especially because the two weeks are approximately 6 months apart and are in entirely different seasons of the year.

Persistence of activity participation

Does activity participation remain stable irrespective of changes in the travel environment, or is the regularity observed in the previous section merely a reflection of the stability in contributing factors? We now focus on the relation between the regularity in activity participation and changes in factors influencing the individual's travel. The sample is extended to include nonworkers and the significance of association is examined between the number of days with identical participation as a measure of regularity, and household size, number of preschool children, number of cars, driver's license, and employment status. As Table 1 shows, the fraction of individuals who experienced changes in these attributes varies from approximately 2% for driver's license to 10% for number of cars.

Two types of association are evaluated. The first measure is for the association between the regularity in activity participation (as measured by the number of days with identical activity participation) and a person or household attribute as reported in the wave-one survey. This association shall be called "cross-sectional" association between regularity and the person attribute. The second is concerned with the association between the regularity in activity participation and the change in a person attribute between the two waves. This shall be called "dynamic" association.

The first measure evaluates the correlation between the regularity in activity

Table 4. Number of days with identical activity participation between the two waves (workers).

No. of days with identical participation	Shopping			
	Male workers		Female workers	
	Observed	Expected	Observed	Expected
0 – 2	24	24.5	15	29.2
	(3.3)	(3.3)	(5.1)	(10.0)
3	77	85.2	44	63.2
	(10.4)	(11.6)	(15.0)	(21.6)
4	122	188.5	62	90.0
	(16.6)	(25.6)	(21.2)	(30.6)
5	187	237.1	95	73.0
	(25.4)	(32.1)	(32.4)	(24.9)
6	193	158.3	54	31.8
	(26.2)	(21.5)	(18.4)	(10.9)
7	134	43.4	23	5.8
	(18.2)	(5.9)	(7.8)	(2.0)
Total	737	737.0	293	293.0
	(100.0)	(100.0)	(100.0)	(100.0)
x^2 (df = 5)	231.6		94.6	

( ): percent of column total.

Table 4. (Continued).

No. of days with identical participation	Social/recreation				Other activities			
	Male workers		Female workers		Male workers		Female workers	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
0 – 2	44	85.6	30	48.7	81	56.6	25	17.6
	(6.0)	(11.6)	(10.2)	(16.6)	(11.0)	(7.7)	(8.5)	(6.0)
3	93	157.2	50	72.5	73	128.2	34	44.6
	(12.6)	(21.3)	(17.1)	(24.7)	(9.9)	(17.4)	(11.6)	(15.2)
4	188	217.5	78	84.9	139	210.6	61	80.6
	(25.5)	(29.6)	(26.6)	(29.0)	(18.9)	(28.6)	(20.8)	(27.5)
5	190	179.3	68	59.7	177	205.7	66	86.5
	(25.8)	(24.3)	(23.2)	(20.4)	(24.0)	(27.9)	(22.6)	(29.6)
6	158	81.6	48	23.3	184	110.7	63	51.0
	(21.4)	(11.1)	(16.4)	(8.0)	(25.0)	(15.0)	(21.5)	(17.4)
7	64	15.8	19	3.9	83	25.2	44	12.7
	(8.7)	(2.1)	(6.5)	(1.3)	(11.2)	(3.4)	(15.0)	(4.3)
Total	737	737.0	293	293.0	737	737.0	293	293.0
	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)	(100.0)
x^2 (df = 5)	269.6		100.5		243.7		95.2	

participation and a person attribute as observed at the beginning of the study period. Only cross-sectional variations in the person attribute are incorporated in this measure. The second measure, on the other hand, relates the regularity in behavior to the stability or change of the person attribute. Therefore this measure reflects longitudinal changes in the attribute, but not its absolute values or cross-sectional variations. The first measure will indicate what types of individuals tend to maintain stable activity participation patterns over time, while the second will reveal what types of change in person attributes tend to trigger a change in activity participation patterns. The two sets of association measures are summarized in Table 5 in terms of their significance.

The magnitude of associations between the regularity in activity participation and the person and household attributes varies considerably by the type of activity or between men and women. For example, the cross-sectional association between shopping participation and age is highly significant for male adults, but not for female adults. A similar observation can be made for the cross-sectional association between employment status and participation in shopping or social activities.

Furthermore, cross-sectional and dynamic associations do not share similar levels of significance. For example, car ownership shows significant (at $\alpha = 5\%$) cross-sectional associations with the regularity of male workers' shopping and social trips, but no dynamic association is evident. On the other hand, number of pre-school children shows significant (at $\alpha = 5\%$) dynamic association with

Table 5. Cross-sectional and dynamic associations of selected household and person attributes with the number of days with identical activity participation, expressed in terms of significance level, α.

		Male adults			Female adults		
		Shopping	Social	Others	Shopping	Social	Others
Age	X-Sect.	0.00	0.18	0.86	0.83	0.10	0.46
Household size	X-Sect.	0.10	0.05	0.05	0.57	0.38	0.14
	Dynamic	0.18	0.73	0.78	0.31	0.73	0.18
No of pre-schoolers	X-Sect.	0.34	0.92	0.46	0.25	0.46	0.28
	Dynamic	0.05	0.42	0.96	0.37	0.12	0.18
No. of cars	X-Sect.	0.05	0.01	0.57	0.85	0.89	0.28
	Dynamic	0.29	0.40	0.68	0.72	0.15	0.16
Driver's license*	X-Sect.	0.21	0.03	1.00	0.17	0.24	0.44
Employment status	X-Sect.	0.00	0.01	0.02	0.70	0.41	0.00
	Dynamic	0.77	0.45	0.02	0.09	0.15	0.90

X-Sect. = Cross-sectional association; Dynamic = dynamic association.

* No dynamic association is evaluated because of the small number of individuals with changes in license holding status.

male adults' shopping regularity, but no cross-sectional association. This discrepancy (Goodwin (1986) reports a similar discrepancy) is not surprising because these two measures represent different behavioral relations as noted above.

In a separate analysis, the association between the scheduled number of working hours per week and regularity in workers' activity participation was also examined. It was hypothesized that working hours are a major component of workers' time constraints that influence workers' weekly activity scheduling. However, no significant effect was identified in support of this hypothesis, despite the fact that the change in working hours was substantial with approximately 6 hours of increase or decrease when averaged over those workers who reported changes.[8] On the other hand, Table 5 shows that employment status is strongly associated with the regularity measure, especially for male adults. An inspection of the tabulation result indicated clearly that employed males' participation in shopping, social, and other activities possesses higher regularity. For this reason, the analysis of changes in travel behavior in the next section uses employment status as a key descriptor of the individual.

The dynamic associations evaluated here are in general not significant (at $\alpha = 5\%$). The only exceptions are the association between change in employment status and regularity in male adults' participation in other activities, and that between the number of pre-school children and shopping participation noted above. This is presumably due to the small fraction of individuals with changes (see Table 1) as a result of the slow-changing person attributes. At the same time, it is possible that the general low levels of dynamic association are due to habit persistence or to time lags in the individuals' responses to changes to these variables.[9]

In summary, the analysis thus far has indicated the presence of significant regularity in weekly activity participation, and shown the general lack of association between regularity in activity participation and change in person or household attributes. If activity participation tends to remain stable regardless of changes in household and person attributes, then adaptation to a change in these factors may be made without changing established weekly activity participation patterns. Or it may be the case that changes in these attributes are not substantial enough to overwhelm the inertia of habitual activity patterns.

Irreversibility of travel responses

We shall now turn our attention from activity participation by day of the week to the number of trips made during the diary weeks. This is an aggregate measure of weekly activity participation, but its change over time is easier to measure, making statistical analysis more sensitive to change. Employment status is used to classify individuals and change in the travel environment is represented in

terms of the transition in employment status.

The individual's response to a change is compared in this analysis against a hypothetical pattern termed here as "Markovian response." This response pattern is obtained under the conditions that:

- the individual's response to a change is instantaneous without any time lag,
- the response is reversible, and
- behavior is stationary.

A response is said to be reversible or symmetric if behavior reverts to its original pattern after a sequence of changes in the travel environment from condition A to condition B then back to condition A. One of the necessary conditions for reversibility is that the magnitude of response is independent of the initial condition. The term, stationarity, refers to the condition that the relationship governing behavior does not change over time.

If these conditions apply to trip generation and if variations across individuals can be effectively accounted for by classifying them into two categories at each time point (e.g. employed or not employed) then the change over time in trip rates can be illustrated by the transition diagram of Fig. 3 (the trip rate is expressed in terms of the difference from a reference value, e.g. sample mean). If either one of the above assumptions does not hold, the change in trip rates will divert from the Markovian pattern, and behavior will show hysteresis. The characteristics of the individual's responses to changes are examined below by comparing trip rates obtained from the panel sample with the Markovian pattern.

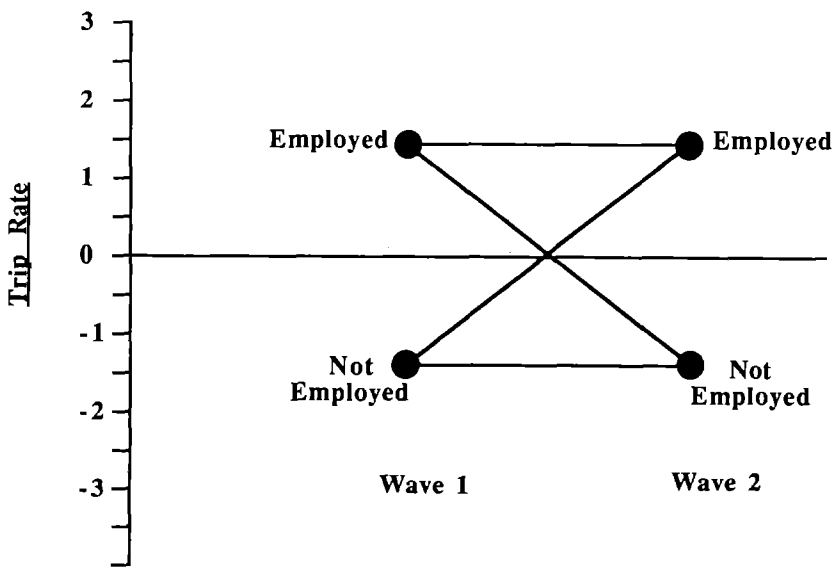


Fig. 3. Contemporaneous markov transition of trip rate.

Figure 4 presents the total number of trips by wave against change in employment status (the trip rate is normalized in Fig. 4 by taking the difference from the sample-wide mean in order to account for seasonal variation). The pattern shown in the Fig. 4 is by no means close to the idealized Markovian pattern. The origins and destinations of the four change vectors in Fig. 3 are respectively clustered at two points. This is not at all the case in Fig. 4, suggesting that the trip rate in wave two, given wave-two employment status, is not independent of the employment status in wave one. The wave-one trip rate given wave-one employment status also varies depending on wave-two employment status. For example, those who held employment in wave one but not in wave two show a smaller average trip rate than those who held employment in both waves. Possible reasons for this longitudinal dependence in trip generation are behavioral inertia and response lags.

The change vectors for work trip rates (Fig. 5) closely represent the pattern of the Markovia response. This is not surprising given that work trips are highly compulsory and have least degrees of temporal and spatial flexibility. Employment status will closely determine the work trip rate and the mandatory nature of work activity implies shorter (perhaps no) response lags following changes in employment status. The Figure, however, shows that the origin and destination points of the change vectors for the same employment status in each wave do not completely coincide. The discrepancy again suggests the dependence on past history and impact of anticipated changes. This, however, may be due to heterogeneity across individuals, i.e. those who lost or gained jobs between the waves are different in their characteristics from those individuals who remained in the same status.

Interestingly, changes in the shopping trips rates of male adults (Fig. 6) almost completely replicate the Markov pattern of Fig. 3. Male adults apparently adjust the number of weekly shopping trips without a lag following a change in employment status. Female adults, however, do not show this pattern, indicating that women's shopping activities do not immediately respond to a change in employment status. Examination of non-work, non-shopping trips also indicated that they do not exhibit the Markovian pattern.

Because the apparent divergence from the Markovian pattern seen here may be due to omitted variables, an attempt was made to quantify the inertia evident in Figs. 4 through 6 in a multi-variate context. The model used, formulated by Griliches (1967), assumes that two components control behavioral change over time: resistance to changing behavior and penalty for not adopting the optimal behavior determined by the factors prevailing in the environment (van der Hoorn & Kitamura 1987). The initial results, which should be considered to be tentative because of the limitations of the estimation procedure used, nonetheless offered another indication that response lags exist.

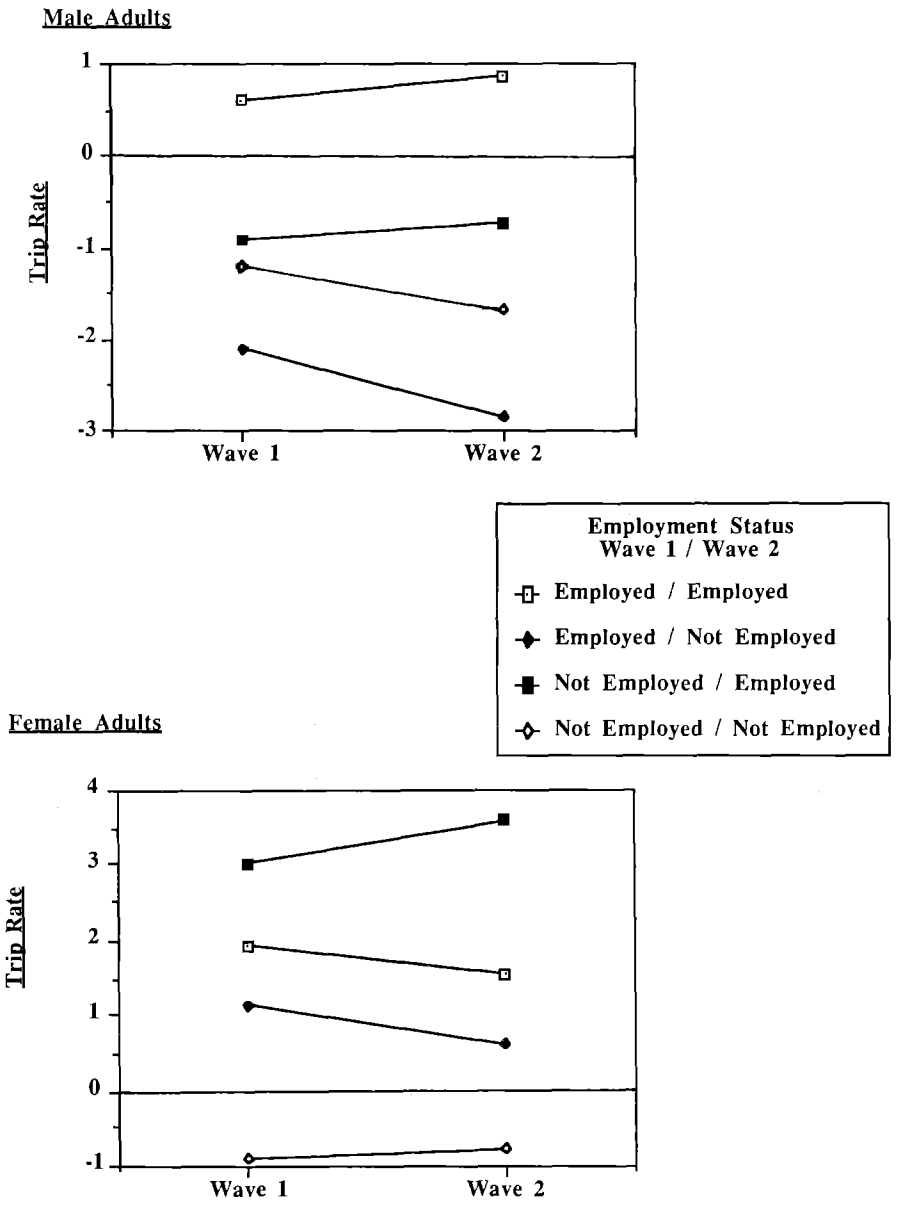


Fig. 4. Change in total trip rate.

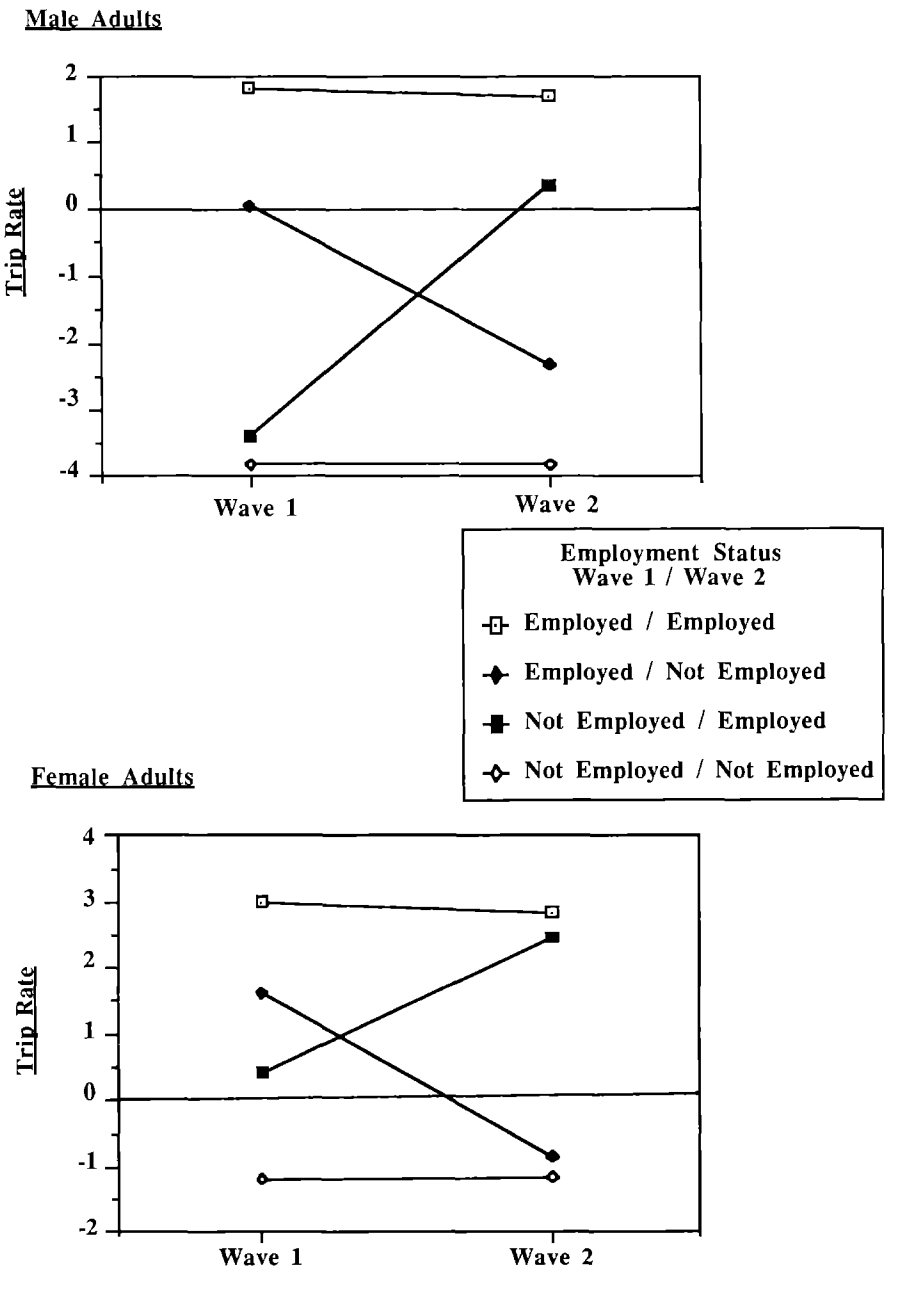


Fig. 5. Change in work trip rate.

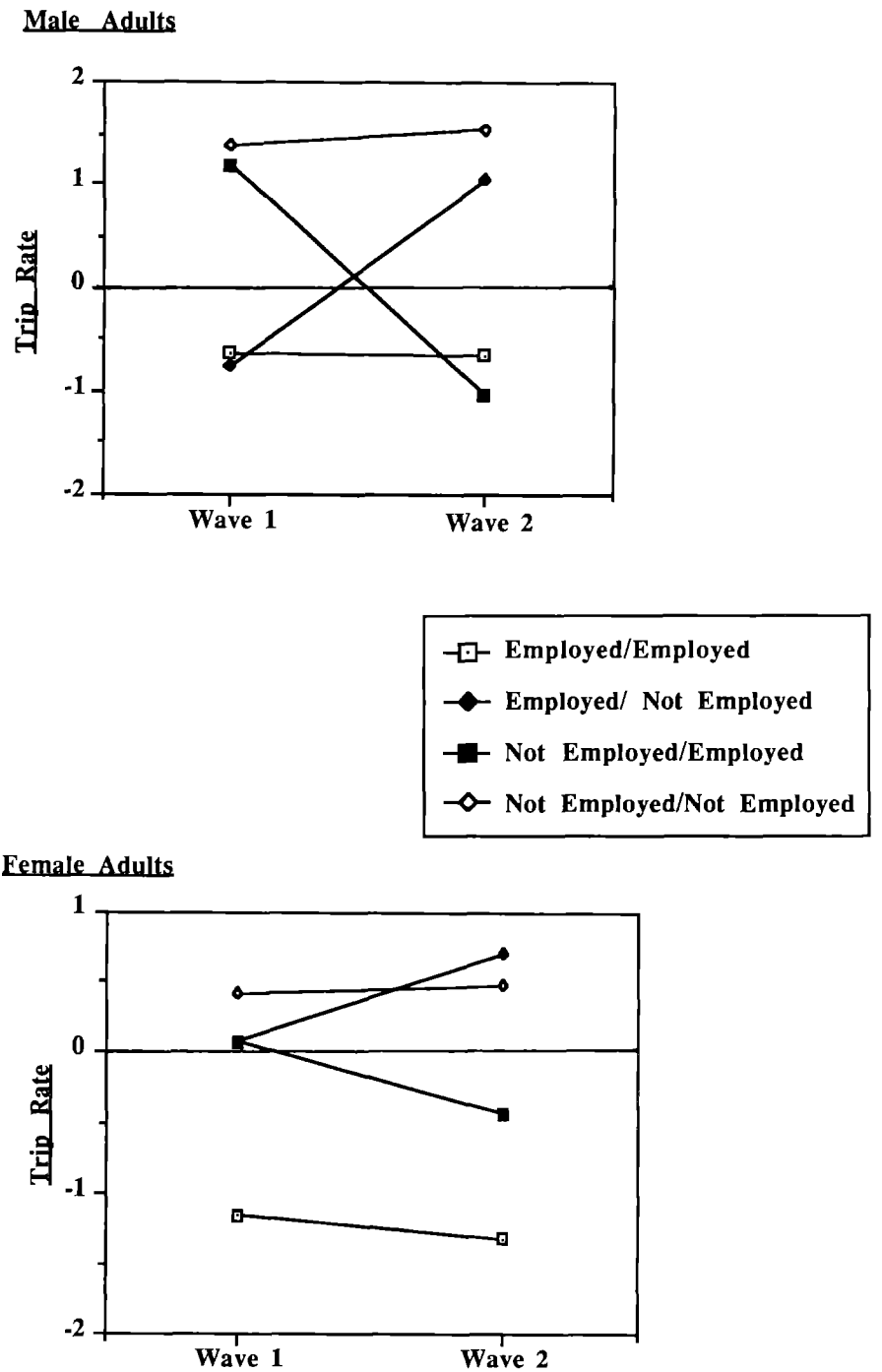


Fig. 6. Change in shopping trip rate.

Summarizing the findings of this section, changes in trip rates do not exhibit the Markovian response, the one that would be observed when response has no lag, no memory, and no hysteresis. The only exceptions found in the analysis are work trip rates by both male and female adults and shopping trip rates by male adults.

Conclusion

Dynamic characteristics of travel behavior are analyzed in this paper using weekly travel diaries from two waves of panel surveys conducted six months apart in the Netherlands. The analysis of activity engagement by day of the week has indicated the presence of significant regularity in weekly activity participation between the two waves. The analysis has also shown a general lack of association between regularity in activity participation and change in person and household attributes. This lack of correlation suggests the presence of behavioral inertia or response lags.

The analysis of trip generation has further shown that observed trip rates do not exhibit patterns that would be observed if travel behavior had no response lag, no history dependence, and therefore no hysteresis. The only exceptions are work trip rates by both male and female adults and shopping trip rates by male adults.

The conclusion consistently supported by the various types of analysis contained in this paper is that travel behavior is not contemporaneous. The results point to the presence of response lags, behavioral inertia, and hysteresis. Models of travel behavior that are capable of representing these non-contemporaneous aspects, which are virtually non-existent at present, are required for accurate depiction and prediction of travel behavior.

In light of the results of this study, it is critically important to further examine dynamic characteristics of travel behavior and test the validity of cross-sectional models, i.e. models based on observations from one cross-section. Although a cross-sectional model is unable to properly identify behavioral relationship if travel behavior is in fact not contemporaneous, it can still be applied for prediction when certain conditions are met (Kitamura 1986). Future effort to examine whether these conditions exist will be able to determine the extent to which cross-sectional models are applicable to prediction of travel demand.

Also important is the evaluation of the practical significance of the errors resulting from a failure to represent non-contemporaneous relations. It is conceivable that the magnitude of the errors of cross-sectional models are statistically significant but of little importance in practical contexts. Further effort needs to be made to assess the practical consequences of ignoring non-contemporaneous aspects in travel behavior.

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Notes

1. The assumption may also be violated by incomplete information and the variation in cognition levels of opportunities, noted in contexts different from ours by, e.g. Hanson (1976) and Burnett & Hanson (1979).
2. Huff & Hanson (1986) reached a similar conclusion as to the limitation of cross-sectional observation by analyzing day-to-day variations in travel patterns.
3. Another example is the frequent use of the length of residence as a surrogate for the individual's knowledge of the area.
4. The first-wave sample contains 1,764 households, of which less than 1,200 participated in the second-wave survey. This rather high attrition rate may make the comparison of the data from the two waves inappropriate. This study employs a sample weighting factor developed from a model system (Kitamura & Bovy 1987) in order to account for possible bias due to attrition between the two waves. For the tabulations of this study, however, attrition bias turned out not to be substantial.
5. The tabulation is by person, therefore may include more than one person from the same household. The statistics shown in Table 1 do not correctly reflect the distribution of households.
6. In this analysis the marital status is derived from the lifecycle stage provided in the data file, and is not based on the legal marital status of the individual.
7. Eight of the 42 men and 7 of the 39 women who gained employment in wave two also obtained cars between the waves. These are much larger than the expected frequencies of 3.31 and 2.17, respectively, obtained under the assumption that change in employment status and change in car ownership are statistically independent. Similarly, 5 of the 17 women who were employed in wave one and had new children between the two waves, stopped working in wave two; this is also much larger than the expected value of 1.46 (none of the 50 men who had new children changed their employment status). On the other hand, all of the 70 men with changes in employment status retained the same marital status, while of the 39 women who started working in wave two, one got married and one became single.
8. The regular work hours per week for wave one and wave two are respectively 41.4 and 41.6 h among male workers, and 28.4 and 27.8 h among female workers (the regular working hours per week reported by the respondent, rather than the number of working hours estimated from the diary, are used in this study). Approximately one-third of the workers in the sample reported different working hours between the two waves.
9. Dynamic effects of aging are not presented because they cannot be measured since there is no variation in aging which takes place uniformly across individuals. Dynamic association is also not shown for driver's license because of the small number of individuals who changed license holding status.

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