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**THE EFFECTS OF ROADWAY CAPACITY ON
PEAK NARROWING**

--- EVIDENCE FROM 1995 NPTS

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NPTS Data

Abstract

Spreading of the peak is one effect of increased peak-period congestion. Due to peak spreading, the travel-time impact of congestion is mitigated for some travelers, but the inconvenience of traveling at a less-preferred time also has a cost. Alternatively, increases in capacity have their impacts on peak-period congestion mitigated by a narrowing of the peak. This reduces the travel-time savings, but it generates a benefit for those traveling closer to their preferred times. This benefit from capacity improvements has largely been ignored, and one reason is the difficulty of quantifying the effect. This paper reports on some crude attempts to quantify the peak-narrowing effect of increased capacity. Using 1995 Nationwide Personal Transportation Survey (NPTS) data, this study investigates how workers in Metropolitan Statistical Areas (MSAs) in the US respond to roadway capacity differences in terms of changing their departure time to work. It is assumed that there is some distribution of travel times given by a mean and some measure of deviation from the mean. Peak narrowing is then measured by decreases in the deviation from the mean. The peak narrowing effects are modeled for both the morning commute and all departures from home for work at any time of the day. As expected, in urban areas with higher roadway capacity per capita, workers tend to depart from home closer to the peak time. For the morning commute, the model estimates that each one-percent increase in lane-miles per capita results in workers departing from home about 5.75 percent closer to the peak time. The effects of roadway capacity are found to be statistically significant in both models.

Introduction

Peak traffic is believed to be the core concern for congestion reduction. However, increasing roadway capacity reduces the generalized travel price and thus encourages people to travel. Capacity induced travel is believed to have important implications for infrastructure, land use, and environmental policy; it not only reduces the benefits of road capacity expansion in congestion reduction, but also potentially affects urban environments, land use, and urban development patterns.

Researchers are showing increasing interests in the study of induced travel. (e.g., Arnott and Small, 1994; Strathman et al. 2000). However, most studies focus on induced vehicle miles of travel (VMT) by testing the hypothesis that providing more roadways leads people to travel more (See DeCorla-Souza and Cohen, 1999; Marshall, 2000). In reality, travelers' potential response to highway capacity additions could result not only in additional travel, but also in the temporal, spatial and mode redistribution of existing and / or new trips. Route changes, departure time changes, mode shifts, destination changes, workplace and residential location changes are examples of such redistributions of trips. The final transportation outcome is the combination of all these changes. Each of these changes implies certain costs and benefits for the people making them. The purpose of this paper is to estimate the impact of road capacity improvements on the temporal redistribution of travel for workers commuting to work in the Metropolitan Statistical Areas (MSA) in the US. The temporal redistribution of travel is often referred to as rescheduling, which could result in peak narrowing (Mackie and Bonsall, 1989; Kroes et al. 1996). When roadway congestion is reduced because of roadway capacity improvements, those

who previously travel during off-peak times return to travel at the peak time, resulting in a “narrowed” peak period.

The basic assumption of peak narrowing is that people’s preferences to travel in the peak time are suppressed because of congestion. In other words, travelers presumably chose departure times that were different from their desired departure times due to peak congestion (Small, 1982; Gordon et al. 1990). When peak congestion is reduced by roadway capacity improvements, people return to their preferred travel time – the peak time. The hypothesis that increasing roadway capacity would induce people to travel closer to peak times seems intuitively reasonable, but few researchers have empirically demonstrated this. The goal of this paper is to provide empirical evidence of the relationship between roadway capacity changes and peak narrowing.

The rest of this paper is organized into four parts. The first part discusses the importance and impacts of peak narrowing. The second part provides a literature review that emphasizes the theoretical arguments, previous findings, and the methods used. The third part is the description and statistical analysis of data and methods employed in this analysis. The empirical regression results are then reported. The concluding section includes a discussion of the effect of peak narrowing and possible policy implications.

Literature Review

- **Theoretical arguments and the impacts of peak narrowing**

It is argued that travelers’ travel schedule is a part of their “time budget”, which organizes a variety of activities into a schedule (Small, 1982; Levinson and Kanchi, 2000). Given inelastic preferences, personal “time budgets” have appeared as empirical regularities in long-term examination of travel behavior (Levinson and Kanchi, 2000).

Small (1982) proposes that a consumer is assumed to choose the way that he/she can maximize the utility of activities (x), leisure time (l), working time (h), and consumption time (t) subject to a time budget, earning maximization, and so on. The time people depart for work is based on the value of time and a variety of other factors, in which congestion levels during the peak time and the peak shoulders play an essential role.

Peak narrowing or spreading involves a travel demand shift from one temporal market to another, while travel demands have different characteristics in different markets. For example, travel demand during the peak time is usually higher with lower elasticity than the demand during off-peak times. However, the two markets are so closely related to each other that the distinctions between them are often ignored. In the context of induced travel, the temporal redistribution of travel under the influence of roadway capacity improvements, known as peak narrowing, is the shift in demand from off-peak times to the peak time market. Dowling and Colman (1995) argue that peak narrowing is a key impact of new highway capacity. However, they do not provide empirical evidence, noting that “there is a strong need to develop better models to predict peak spreading / time of day of travel” (Dowling and Colman, 1995, page 147).

Rescheduling caused by roadway capacity improvements means that part of the additional traffic in the peak-time market is diverted or drawn from the off-peak travel market. Lee et al. (1999) argue that since the off-peak demand depends on the peak price, and vice versa, separating peak and off-peak travel is tricky in benefit-cost analysis. In fact, rescheduling is important in evaluating the effects of induced travel on congestion reduction, especially in the peak. If rescheduling is not controlled for in

induced travel analysis, the estimated induced travel is larger than it should be for those studies relying on traffic counts with Before-And-After methods.

By raising the congestion level at the peak time, peak narrowing reduces the travel-time benefits that the travelers who were not traveling during peak can get from roadway capacity improvements but the shift increases their non-monetary benefits such as convenience. Existing peak travelers do not gain such non-monetary benefits. On the other hand, the congestion reduction benefits that they can get from roadway capacity improvements are eroded by the traffic diverted from the off-peak times. This suggests that researchers need to identify a model evaluating the non-monetary benefits for the diverted travelers from off-peak periods.

Peak narrowing is also affected by the work schedules set by employers. With high congestion during the peak time, employers may cooperate with their employees to avoid “rush hour” by facilitating alternative work schedules (AWS) (Gordon et al. 1990). The AWS could be flexible scheduling, not requiring a fixed official starting time, or an afternoon / evening shift rather than only morning shifts. These and other responses to peak-period congestion should be analyzed with respect to their costs and benefits when evaluating alternatives to capacity improvements.

- **Empirical analysis**

Induced travel is multidimensional. Many researchers have identified at least the following behavioral responses – increased vehicle travel, route changes, trip frequency variation, mode shift, travel rescheduling, destination change, vehicle ownership change, and even residential and workplace location changes (see Mackie and Bonsal, 1989; Hills, 1996; Noland et al. 2000; Goodwin, 1996; Barr, 2000; Strathman et al. 2000).

However, the empirical analyses of induced travel appear to almost solely focus on the VMT resulting from roadway capacity improvements. Little attention has been placed on the other dimensions of induced travel. Table 1 summarizes the dimensions of induced travel analyzed in existing empirical studies.

In fact, even in the studies estimating induced VMT, peak narrowing and the other dimensions of induced travel play important roles in the accuracy of the estimation. The existing literature does not have a consistent conclusion on the magnitude of the estimated elasticity of VMT with respect to roadway capacity change, which varies greatly from 0.1 to 1.0 (Hansen and Huang, 1997). Many reasons, including the data, method, and model specification cause this problem. One distinct reason lies in the failure to account for the different dimensions of induced travel. The temporal, mode, and spatial redistribution of travel obviously affects induced VMT resulting from roadway capacity improvements. Without taking into account peak narrowing and the other dimensions of induced travel, the estimates of VMT elasticity with respect to capacity tend to be inconsistent.

Table 1 The Dimensions / Components of Induced Travel Covered in Selected Empirical Analysis

Author(s)	Year	More/ less driving	Reroute	Peak narrowing	Mode choice	Pub Tran LOS	Destination change	Driving frequency	vehicle ownership	Job / house loc change
Deakin	1991									Y
SACTRA	1994	Y								
Hansen	1995	Y								
Johnston and Ceerla	1996				Y					
Kroses et al.	1996	Y	Y	Y	Y		Y	Y		

Hansen and Huang	1997	Y								
Levinson	1996	Y								
Dowling and Colman	1998	Y								
Surface Transportation Policy Project	1998	Y								
Hartgen and Curley	1999	Y								
Litman	1999	Y								
Marshall	2000	Y								
Noland and Cowart	2000	Y								
Noland	2000				Y	Y				
Barr	2000	Y								
Strathman, Dueker, Sanchez, Zhang and Riis	2000	Y			Y					Y

One reason for ignoring travelers' rescheduling in the empirical analysis of induced travel is the misunderstanding that rescheduling does not result in greater VMT, and thus its impact on the congestion reduction benefit of roadway capacity improvements is little. Thus, rescheduling is conceptually excluded from induced travel in many studies. It is argued that peak narrowing may or may not be considered as induced travel, although it is a strategy that travelers might pick up in response to roadway capacity improvement distinguished from other behavioral responses (Hills, 1996; Bonsall, 1996). Barr (2000) defines induced travel as any increase in highway system use caused by a highway capacity addition or other transportation system change which results in reduced travel times and / or costs. Based on this definition, rescheduling is explicitly excluded from induced travel. "Induced travel does not include shifts in the time of day a trip is made because such changes generally do not result in a net increase in highway system use." (Barr, 2000, page 6). The exclusion of rescheduling from induced travel in Barr's (2000) analysis of induced travel imposes a restriction on

his modeling. He uses travel time saving in the empirical analysis with the hypothesis that adding highway capacity reduces travel times and thus induces additional VMT. The basic argument of the study is that roadway capacity improvements result in travel-time savings, which could be used to make more travel. Rescheduling obviously affects the time spent in travel since travelers have to suffer heavier congestion at peak times compared with that in off-peak times. Thus the time savings secured from congestion reduction, which is the time budget that is potentially spent in making the so-called “induced trip,” is obviously less in comparison with those who do not return to peak times.

In the empirical analysis of Noland and Cowart (2000), induced travel is conceptualized as corresponding to the traditional four-step travel demand model. Similarly, the peak narrowing effect is excluded from their definition of the framework of induced travel because it is argued that rescheduling of trips back to the peak period does not actually result in an increase in net VMT. The impact of rescheduling is hypothesized as the following: “if a capacity expansion reduces the duration of peak travel times, additional trips could be generated during the now relatively less congested shoulder periods.” (Noland and Cowart, 2000, Page 5)

The difficulty of obtaining relevant data is another possible reason for the lack of studies on peak narrowing. Unlike VMT data, which is collected and reported in many formats by many agencies, peak-narrowing data is not commonly collected and maintained. Researchers have to rely on surveys to study the phenomenon of rescheduling and peak narrowing. One excellent example of such a study is Kroes et al. (1996). They identify peak narrowing effects with a Before-And-After method in their

case study of the short-term effects of removing a bottleneck in the Amsterdam Ring road. They conducted surveys four months before and two months after the completion of roadway capacity improvements. They found that about 29% of all car users changed their departure time to some extent, leading to a net increase of 16% in the total number of trips by road users over the new roadway extension in both directions during the morning peak period (7-9 am), and an increase of 19% for commuters only. The total off-peak trips dropped about 8% while the commuter trips dropped 6% during the before-peak period. The after-peak period drops 11% for all trips and the commuter trips respectively. However, their study only reports the survey results by simple cross-tabulation. It also suffers the inherent limitations of Before-And-After methods (Hansen and Huang, 1997; Strathman et al. 2000).

Table 2 Peak Narrowing from Kroes et al. (1996)

Time Period	% change all purposes	% change commuter trips
0-7 am	-8%	-6%
7-9 am	+16%	+19%
9-12 am	-11%	-11%

Source: Kroes et al. (1996), page 75.

Beyond the context of induced travel, researchers have sought to understand travel demand in different temporal markets with utility theory. Traditional time-dependent demand functions rely on the appreciation of the value of time. A time-dependent demand function is estimated by Small (1982), who analyzes the reverse effect

of peak narrowing – peak spreading. Using a logit model, Small builds his model on the theory of time allocation proposed by Becker (1965) and Johnson (1966), adding scheduling considerations to both the utility function and the constraints. In Small's model, scheduling considerations are represented in three ways. First, he allows for preferences among schedule times. Second, he considers congestion and peak-load pricing phenomena. Third, he accounts for limitations imposed by the institutional setting within which employment opportunities are encountered. He finds that the marginal rate of substitution of minutes of travel time for minutes of early arrival is 0.61. Commuters living in households with more than one member place less value on travel time. Carpool commuters arrive early. White-collar workers are less averse to late arrival. Late arrival is less onerous for workers who report some flexibility. He finally concludes that, on average, urban commuters will shift their schedules by 1 to 2 minutes toward the early side, or by 1/3 to 1 minutes toward the late side, in order to save a minute of travel time. There is considerable variation depending on family status, occupation, transportation mode, and employer's policy toward work-hour flexibility. It is likely that many commuters, particularly single workers driving alone, are currently traveling at other than their preferred times of day in order to avoid traffic congestion. Commuters tend to respond to any improvement in congestion by shifting schedules toward the peak time. Small's study casts light on the analysis of peak narrowing in induced travel. But his arbitrary division of peak and off-peak periods imposes a limitation on the model.

With the 1977 and 1983 NPTS (the Nationwide Personal Transportation Study) data, Gordon et al. (1990) analyze the extent to which peak spreading had happened during that period. They find very little evidence of peak-travel-period elongation. The

peak spreading that occurred was limited to the smaller metropolitan areas, where the scope for locational adjustments by households and firms to relieve congestion was much less than in the larger polycentric metropolitan areas. Unsurprisingly, blue-collar and sales workers had more off-peak commutes than other occupations (e.g., professionals). The household and family restrictions on flexible working hours are found to have significant impacts on peak spreading. Based on their findings, they argue that institutionalized (i.e., compulsory) alternative work schedules (AWS) are more effective than voluntary spontaneous actions. Most of their findings, based on cross-tabulation methods, are weak relationships. Changing the threshold values of different variables would change the results. In addition, they arbitrarily define the peak period by time spans, although the NPTS data reports the departure time as continuous numbers.

The literature review indicates that the existing studies on peak narrowing in the context of induced travel are few and not conclusive. Kroes et al. (1996) is the only empirical study explicitly analyzing peak narrowing as a part of travelers' response to roadway capacity improvement, but it suffers the problems associated with the Before-And-After method that they employ. Related studies on time-dependent travel demand reveal the relationship between roadway demand, but typically do not take roadway capacity improvement into account.

Data and model specification

- Data

To study the relationship between roadway capacity and peak narrowing, the 1995 NPTS is used as the primary data source. Strathman et al. (2000), Barr (2000) and

Levinson and Kanchi (2000) use this data in modeling induced travel. The major advantage of the NPTS is that it provides the only source of disaggregate data on both work and non-work travel at the national level. Also, disaggregate data is argued to be preferable in induced travel analysis (Marshall, 2000). It is argued that the conventional procedures utilizing aggregate data on scheduling prevents the analyst from taking advantage of disaggregate techniques that have been found fruitful (Small, 1982).

The 1995 NPTS person and household files contain rich information on personal travel activity together with the socioeconomic and demographic status of each person of the sample households. The 1995 NPTS person and household data files also describe characteristics of the geographic area in which the household is located (such as the population density and bus service availability) and in which the job is located (such as the employment density and percentage of employees in different industries). Information on scheduling (departure time for work), time spent in travel, and so on is also reported in the person file. As a cross-sectional data source, the NPTS also avoids auto-correlation problems associated with time series data (Marshall, 2000).

The roadway capacity data is obtained from the TTI (Texas Transportation Institute) mobility study. We use the sum of major arterials and freeway lane-miles per capita. Strathman et al. (2000) discuss the limitations and benefits of the marriage of NPTS and TTI datasets.

- Model specification

The time dependent demand functions in existing literature are useful for analyzing the peak-narrowing effects in induced travel. In the fundamental work of Small (1982), a logit model is employed. One of the limitations is the omission of

congestion conditions. As indicated by other researchers, congestion plays a substantial role in people's travel rescheduling. In many peak traffic analyses, researchers arbitrarily define the peak times and off-peak times as a certain time period in the morning and / or in the evening. For example, Loudoun et al. (1988), in the analysis of peak traffic, defines the peak time travel as the trips made between 6:30 – 9:30 am, and then it is used as a dummy variable. Gordon et al. (1990) define the peak periods in three ways: 6-9 am and 4-7 pm, 8:00-8:30 am and 4:30-5:00 pm, and 5-10 am and 3-8 pm. Problems arise if too small a duration is set, since it would cut the actual peak period into pieces, while too large a duration would blur the distinction between the transportation attributes of the peak and off-peaks. Another limitation of this method is that the shoulder condition cannot be distinguished between peak and off-peak periods. The shoulder period plays an important role in the shift of travel between the peak and off-peak period. With the 1995 NPTS data, which reports the time that people leave for work, the peak, off-peak and shoulder can be treated in a continuous way without categorizing them into arbitrary segments.

The basic issue in peak narrowing is the interdependency between the travel markets of the peak time and off-peak times, particularly the peak-shoulder periods. Thus, we estimated a model including only the observations on people who commute to work between 5:30 am to 10:00 am (Model 1). This time span is assumed to include both the peak and the peak shoulder periods and thus is wider than the typical definition of the peak period mentioned above. We chose this time period based on the data distribution and the consideration of including the peak-shoulder periods.

However, another possible response to peak period congestion is that employers offer more flexible working schedules and employees tend to choose to work in a shift with less congestion (Downs, 1992; Gordon et al. 1990). Thus, we estimated another model with both morning and non-morning shift workers included (Model 2).

As for the definition of the peak time and the measurement of peak narrowing, we arbitrarily take the mean departure time of all worker samples in morning period (5:30-10:00am) in our dataset as the “preferred” time and look at deviation from that time as our measure of peak narrowing. The continuous departure time variable brings another benefit in modeling – the estimation can be made with a simple method – ordinary least squares (OLS). Thus, the absolute deviation of workers’ departure time for work from the peak time for all workers in all MSAs is used as the dependent variable. The peak time is defined as the mean of the departure time for work, 7:12 am in this case. We also tried using the mode of departure time, which is 7:00am, and median of departure time, which is 7:24am. The estimation results do not change much. The formula for departure time deviation is as follows:

$$Devn7 = \text{absolute} (\text{actual departure time} - 7:12\text{am})$$

The deviation from peak measures how close people’s departure is to the peak without distinguishing the direction of deviation. The smaller the deviation from the peak time, the closer the worker’s travel to the peak time and, consequently, the narrower the peak period would be. The omission of the direction from the peak time is consistent

with the empirical finding that peak narrowing is from both sides (Kroses et al. 1996) and that the willingness to deviate in each direction is roughly similar (Small et al. 1982).

The key independent variable used in measuring the roadway capacity is lane-miles per capita from the TTI mobility study. It is hypothesized that workers living in MSAs with more lane-miles per capita enjoy a higher level of roadway supply and will travel closer to the peak time.

Congestion has important effects on peak spreading (see Loudoun et al. 1988; Allen, 1991; Allen and Schultz, 1996). However, the 1995 NPTS only reports people's perception of congestion, not a measurement of the actual congestion status. The TTI roadway congestion index (RCI) is used as a proxy for congestion conditions.

Allen and Schultz (1996) consider congestion, trip purpose, and the distance of the trip. They find that trip distance strongly influences the peak-hour percentage for work trips. Actually, longer trips might be one of the reasons that some people tend to leave earlier. Commute distance is included in this analysis to capture this effect.

Income is assumed to be an important factor influencing departure time. People with higher incomes have a higher value of time and thus tend to avoid congestion. Household income is thus hypothesized to have a positive effect on people's departure time deviation from the peak.

The effects of occupation lie not only in the different time budgets for work and non-work activity, but also in differences in the flexibility of work schedules. Manufacturing industry employees, for example, have less flexibility in setting their working schedules, but may have choice of shifts. Our dataset does not contain occupation information, but the 1995 NPTS data provides the percentage of employees

working in different industries at the workplace. The percentage of workers in manufacturing (*manu*) is employed as the proxy for occupation. It is assumed that the higher the percentage of workers in manufacturing, the higher will be the probability that a given worker will have a job in manufacturing. Small (1982) and Gordon et al. (1990) find that family status has important effects on both the desirability of early arrival and the valuation of travel time. Household lifecycle variables are employed in the model to capture these effects on scheduling. Following De Palma et al. (1997), a gender dummy variable is included to estimate the difference between males and females in the deviation of departure time from the peak. It has been found that older people tend to leave home late (De Palma et al. 1997). To control the effects of geographical region on people's departure time to work, three census region dummy variables, North Central, South and West, with omitted category of Northeast Census Region, are included.

The final general specification of both models is as follows except that two dummy variables (BEFR530, which is one if departure time is earlier than 5:30am, zero otherwise, and AFTR10, which is one if departure time is later than 10:00am, zero otherwise) are used in the model 2, in which with both morning and non-morning commuters are included:

$$LN (DEVN7) = F (LN(INC), HHSIZ, LN(AGE), WKR_CNT, BY_BUS, LN(MANU), RCI, LN(CAP), LN(PDEN), EDEN15, SPRAWL, NC, SOUTH, WEST, JH7, JH40, FIXED, FULL, FSINGLE, M2, F2, M_1C_{0_5}, F_1C_{0_5}, M_2C_{0_5}, F_2C_{0_5}, M_1C_{6_21}, F_1C_{6_21}, M_2C_{6_21}, F_2C_{6_21}, RETIRED)$$

Where,

LN (DEVN7) = LN(| departure time – 7:12am |);

BY_BUS = Go to work by bus (1, 0);

EDEN15 = Jobs per square mile is less than 1,500 (1, 0);

FSINGLE = Single female (1, 0);

F₁C_{0_5} = Single female with children aged 0-5 (1, 0);

F₁C_{6_21} = Single female with children aged 6-21 (1, 0);

F2 = Female in a family of more than 1 adult with no children (1, 0);

F₂C_{0_5} = Female in a family of more than 1 adult with children aged 0-5 (1, 0);

F₂C_{6_21} = Female in a family of more than 1 adult with children aged 0-5 (1, 0);

FIXED = Working at a fixed working location, being one if respondents work at a fixed working place; zero otherwise.

Full = Full time job, being one if respondents have full time jobs; zero otherwise.

HHSIZ = Household size;

JH7 = Commuting distance is less than 7.8 miles (the mean) (1, 0);

JH40 = Commuting distance is larger than 25 miles (1, 0);

LN(AGE) = LN(age);

LN(INC) = LN(household income);

LN(CAP) = LN(lane-miles per capita);

LN(MANU) = LN(pct of 16+ workers in manufactory industry at workplace);

LN(RDEN) = LN(population density at living location);

M₁C_{0_5} = Single male with children aged 0-5 (1, 0);

M₁C_{6_21} = Single male with children aged 6-21 (1, 0);

M2 = Male in a family of more than 1 adult with no children (1, 0);
M₂C_{0_5} = Male in a family of more than 1 adult with children aged 0-5 (1, 0);
M₂C_{6_21} = Male in a family of more than 1 adult with children aged 6-21 (1, 0);
RCI = TTI Roadway congestion index, 1995;
NC = North Central Census Region (1, 0);
SOUTH = South Census Region (1, 0);
SPRAWL = Sprawl Development (being 1 if MSA population growth rate <
urban site area growth rate, 0 otherwise);
WEST = West Census Region (1, 0);
WKR_CNT = Household worker count.

Results

The results using OLS estimation are summarized in Table 3. The R squares of the two models are 0.0687 and 0.0890 respectively. The low explanatory powers are comparable to other analyses employing NPTS data (See Barr, 2000; Strathman et al. 2000). The performance associated with the use of micro data also contributes to the low R-square (Strathman et al. 2000).

With the double log specifications for the continuous variables, we can directly interpret the coefficients as elasticities. The positive sign of the household income coefficient in both models indicates that people with higher income try to avoid peak traffic hours. This is consistent with the hypothesis that household income plays a significant role in peak narrowing since people with higher incomes have a higher value

of time (Small, 1982). However, in the Model (2), household income is not statistically significant.

Table 3 The Regression Results of the Peak Narrowing Models

Independent Variables	Mean	Std. Dev	Model (1)	Model (2)
			Coefficient (t ratio)	Coefficient (t ratio)
LN(INC)	6.8933	5.0958	3.86E-04 (1.8211)	0.20183E-02 (1.064)
HHSIZ	2.449	1.6648	1.37E-02 (1.102)	0.26787E-01 (2.494)
LN(AGE)	3.0046	1.4207	-6.46E-02 (-2.076)	-0.14125 (-5.354)
FULL	0.70464	0.45622	-0.2976 (-10.99)	-0.22824 (-9.982)
FIXED	1.67E-04	1.29E-02	-0.12347 (-0.1915)	-1.0804 (-2.967)
WKR_CNT	1.6158	1.0438	5.53E-03 (0.3644)	0.36058E-02 (0.2713)
BY_BUS	3.98E-02	0.19551	-6.59E-02 (-1.496)	-0.86943E-01 (-2.181)
LN(MANU)	1.5817	1.2946	2.62E-04 (0.3237E-01)	0.13197E-01 (1.843)
RCI	0.88124	0.44398	0.49805 (6.125)	0.40250 (5.543)
LN(CAP)	5.9104	2.7986	-5.75E-02 (-2.908)	-0.55939E-01 (-3.117)
LN(PDEN)	6.9895	3.3194	2.26E-02 (1.839)	0.34297E-01 (3.145)
EMP15	0.43776	0.49613	-1.96E-02 (-1.929)	0.82557E-03 (1.3822)
SPRAWL	0.63228	0.48221	-5.93E-02 (-1.965)	-0.41245E-01 (-1.538)
NC	0.11308	0.31671	3.49E-03 (0.1168)	-0.12908E-01 (-0.4859)
SOUTH	0.27413	0.44609	-9.80E-02 (-4.032)	-0.93651E-01 (-4.333)
WEST	0.13074	0.33712	-0.15821 (-4.218)	-0.16096 (-4.858)
JH7	0.39437	0.48874	6.91E-02 (3.605)	-0.12217E-02 (-0.7148E-01)

JH40	2.86E-02	0.16681	0.15491 (3.032)	0.12406 (2.269)
FSINGLE	5.04E-02	0.21873	-8.30E-02 (-1.489)	-0.47199E-01 (-0.9416)
M2	0.14264	0.34972	-7.40E-02 (-1.477)	-0.87932E-01 (-1.987)
F2	0.14581	0.35293	-0.15814 (-3.152)	-0.15339 (-3.447)
M1C0_5	8.33E-04	2.88E-02	-0.11086 (-0.3808)	-0.39311E-01 (-0.1568)
F1C0_5	7.33E-03	8.53E-02	-0.15382 (-1.424)	-0.19362 (-1.989)
M2C0_5	8.59E-02	0.28016	-0.14918 (-2.386)	-0.17321 (-3.142)
F2C0_5	6.55E-02	0.24748	-0.19989 (-3.143)	-0.18750 (-3.356)
M1C6_21	4.66E-03	6.81E-02	-3.50E-02 (-0.2691)	-0.73549E-01 (-0.7309)
F1C6_21	2.24E-02	0.14799	-0.13544 (-1.891)	-0.11526 (-1.822)
M2C6_21	0.11008	0.31301	-7.61E-02 (-1.283)	-0.10055 (-1.933)
F2C6_21	0.11158	0.31487	-0.12762 (-2.165)	-0.14540 (-2.792)
RETIRED	3.63E-02	0.18706	-6.72E-02 (-1.051)	-0.30038E-01 (-0.5316)
BEFR530	0.2915E-01	0.16882		1.5932 (32.68)
AFTR10	0.15672	0.36355		2.0572 (86.40)
CONSTANT			-0.24024 (-1.191)	-0.10550 (-0.5892)

- Note: (1) Dependent variable: DEV72 (Deviation of departure time from peak time (7:12am)).
- (2) Mean and Standard Deviations are calculated from the morning peak commuters only (5:30-10:00am). Only BEFR530 and AFTR10 are calculated for all workers.
- (3) Model (1): Only morning commuters whose departure time falls between 5:30am - 10:00am are included.
Total observations: 9886.
R-Square = 0.0687.
- (4) Model (2): All commuters are included.
Total observations: 12,009
R-Square = 0.890.

Both population density at the residence location and employment density at the workplace are used to capture the effects of land use on peak narrowing. The regression results of the morning commuters indicate that people living in higher density areas have a greater departure time deviation from the peak. Each 1 percent increase in population density at the residential location is estimated to lead people to depart for work 2.26 percent further from the peak time. People working in an area with employment density higher than 1,500 jobs/mile² tend to schedule their departure time 1.96% farther away from the peak time compared with those who work in lower-density areas. In Model (2), only population density has statistically significant effect on departure time deviation from peak time.

The sprawl dummy variable, being one if the population growth rate is less than the area growth rate, is found to have a statistically significant effect on people's scheduling. According to Model (1), people in an MSA with "sprawl" tend to schedule their departure time 5.93% closer to the peak compared with those in MSAs with more compact development. This seems to be consistent with the arguments that the sprawl of jobs and residents actually helps reduce roadway congestion (Hartgen and Curley, 1999).

As expected, commute distance variables have a positive and statistically significant coefficient. Intuitively, people working farther away tend to depart earlier to go to work, while people living very close to their workplaces can depart later to work. Both tend to avoid leaving home at the peak time, but they may nevertheless be traveling at the peak. The regression result of Model (1) indicates that those who live within 7-miles and those who live 40+ miles away from their workplace tend to schedule their departure time 6.91% and 15.49% farther away from the peak time. This is one of the

largest elasticity among all the variables included in the model, but the interpretations are problematic.

Full-time worker status is found to be statistically significant in both models. According to Model (1), full-time workers tend to depart from home 29.76 percent closer to the peak time than part-time workers.

The percentage of workers in manufacturing at the workplace, bus mode choice, and having fixed working locations are not statistically significant in model (1) but are statistically significant in Model (2) for all workers, indicating that mode choice, fixed/unfixed work location, and the manufacturing worker ratio at the workplace, the proxy for occupation, play more important roles when the possibility of alternate shifts is taken into account.

Unsurprisingly, higher roadway congestion causes larger deviation from the peak time in both models. Note that the impact of congestion shows up even though we are treating capacity directly.

The regression results of both models support the hypothesis that providing more highway capacity induces people to return to peak travel times. The roadway capacity variable has a negative coefficient, suggesting that the higher roadway capacity per capita, the closer people tend to depart for work at the peak time. In model (1), each 1% increase in roadway lane-miles per capita induces people to depart from home for work 5.75% closer to the peak time.

Note that the data is cross-sectional, which is suitable for measuring long-term effects of changes in roadway capacity on travel scheduling (since it is assumed that travel and land use adjustments have been made in response to available levels of

services of the transportation system (Barr, 2000)). Temporal shifts are usually argued to be a short-run effect of roadway capacity change (see Dowling and Colman, 1998; Barr, 2000), but this finding is consistent with the argument that short-term effects of roadway capacity improvement do not go away in the long-term (Lee et al., 1999).

The result of the three census region dummy variables, North Central, South, and West (with Northeast as the reference), indicate that only the North Central census region has no statistically significant difference from the reference category – the Northeast region. The result of Model (1) indicates that workers living in the South and West census region depart for work 9.80% and 15.82% further away from the peak time compared with those in the Northeast census region.

Age is found to be statistically significant in both models. The regression results indicate that older workers tend to travel closer to the peak time. Family lifecycle dummy variables perform differently in the model. The single female actually does not differ much from the single male in terms of departure-time deviation from the peak. Female workers from households with more than one adult and no kids, female workers from households with more than one adult with kids of 6-21 years old, as well as other male and female workers from households with more than one adult and with kids aged 0-5 years old depart from home closer to the peak time compared with the reference category – single males. The results are statistically significant. However, most of the rest of the lifecycle dummy variables are not significantly different from the reference category.

Conclusions and Suggestions For Further Research

The relationship between roadway capacity and workers' travel behavior has generated a lot of discussion. Most previous studies have focused on induced VMT. In

this study, the workers' travel scheduling responses to roadway capacity changes in different MSAs in the US are analyzed by using the 1995 NPTS enriched by TTI roadway capacity data. The results indicate that higher levels of roadway capacity do result in peak narrowing. The relationship between roadway capacity and departure time deviation from the peak time is statistically significant. The existence of the peak-narrowing phenomenon confirms the argument that many commuters are currently traveling at other than their preferred times in order to avoid traffic congestion (Small, 1982). When roadway congestion is reduced as a result of roadway capacity improvements, they shift their travel schedules toward the peak time.

The results of this study show that newly added roadway capacity is not filled solely by induced trips. Peak-narrowing may reduce the apparent congestion reduction benefit from roadway capacity improvements. However, the convenience of traveling closer to their preferred times implies a non-travel-time benefit that is typically not included in analyses of capacity improvements. Further research on both the effect and its value is needed.

Our approach is clearly simplistic, but the findings support the need for further research. Some of the issues that could be addressed include: consideration of non-work trip scheduling, more direct analysis of the work trip distribution in areas with little congestion and comparison with congested areas, the direction of deviation from the peak, and the monetary value to workers of being able to travel closer to their preferred times.

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