Estimation of the Demand Responses to Ramp Metering

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Abstract

Ramp meters in the Twin Cities were turned off for 8 weeks in the Fall of 2000. Previous research has assumed demand to be fixed when analyzing ITS technologies, however analysis of this ramp metering shut down experiment, using traffic count data from freeway loop detectors, suggests otherwise: for discretionary trips (non-work trips), the presence of ramp meters encourages people to defer short non-work trips, which then take place during unmetered times. Similarly, the absence of ramp meters discourages long peak-period non-work trips, which are deferred to off-peak times. The effects of ramp metering on non-discretionary demand (work trips) are also reflected by the spreading of the peaks. The method of using freeway traffic count data to estimate demand shifts developed in this paper can also be applied to other freeway demand analyses. Key words: Ramp Meters, Elastic Demand, Non-work Trips, Twin Cities Ramp Meter Experiment

1. Introduction

Ramp meters improve the efficiency of freeway systems in terms of total trip travel time, a key factor in people's decision-making process about when, where, how and whether or not to make a trip (Cambridge Systematics, 2001). Our previous study (Levinson et al., 2001) on evaluating efficiency and equity of ramp meters shows that, in general, long distance trips save time at the expense of short trips. So, it is natural to believe that ramp meters can influence freeway travel demand and that the degree of influence varies for different trip types (short vs. long trips, work vs. non-work trips). However, previous research has assumed fixed demand when analyzing ramp meters. Ramp metering was first proposed as an Advanced Transportation Management System to reduce peak congestion on urban freeways by maximizing throughput at freeway bottlenecks, it was depicted as a short duration (one peak period) demand management device, so its long-term effects on travel demand were, in most cases, overlooked. Moreover, there is a lack of reliable demand data. In the Fall of 2000, MN/DOT Traffic Management Center shut off all 443 ramp meters in the Twin Cities freeway system for eight weeks to study the efficiency of ramp meters. This experiment also provides us data not previously available to explore the effects of ramp meters on freeway travel demand.

Some scholars noted the elasticity of freeway demand to ramp metering. Yoshii (Yoshii, 2001) identified two objectives of ramp metering: shifting freeway demand to alternative unsaturated routes and maximizing throughput at freeway bottlenecks. People may choose a less congested route based on individual experience and judgment. The new alternative can be a major arterial or another less congested freeway. However, travelers have a full set of possible behaviors in response to ramp metering, shown in Table 1. Changes in departure time, routes and

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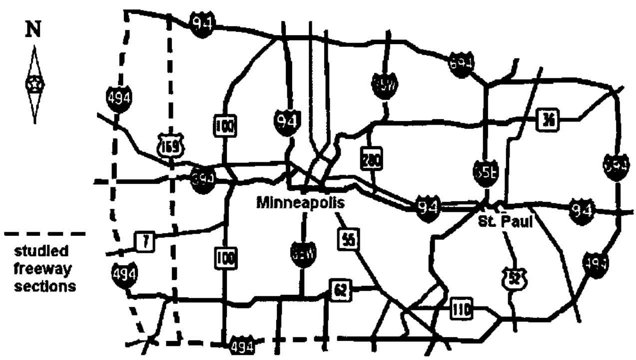
non-work destinations are shorter-term responses. Responses such as relocation are more drastic and hence are not likely to occur due to ramp meters in the short term and also are unlikely to be captured in the eight-week ramp metering shutdown experiment. There is no way to analyze those responses via direct freeway traffic counts. Therefore, this paper focuses on the previous three types of behaviors.

Table 1 Possible response to ramp metering

Response	Characteristics
Switch routes *(Short Term)*	Choose a less congested route, e.g. arterial, less congested freeways.
Change destinations *(Short Term)*	Discretionary trips only. e.g. switch destination for non-work trips.
Reschedule trips *(Short Term)*	Trips not characterized by specific arrival time requirements may be made during off-peak times or on weekends.
Others *(Long Term)*	New modes (Carpooling, Transit etc.); Cancel trips (Discretionary trips only); Change Activity Sequences; Relocation (Job location, House location.

Four representative freeway sections were chosen for this study: TH169 NB (from I494 to I94), TH169SB (from I94 to I494), I494 SB&EB (from I94 to TH5) and I494 WB&NB (from TH5 to I94). Figure 1 shows the locations of those freeway sections on the whole Twin Cities freeway network. The remainder of this paper is organized as follows. Section 2 introduces the data set we used in the analysis. Then the details of the methodology are described in section 3, followed by our main results in section 4. Conclusions are offered in section 5.

Figure 1 Location of the studied freeway sections



2. Data

Mn/DOT has installed more than four thousand loop detectors on the Twin Cities freeway system in order to provide input for various ITS systems, including 65 variable message signs and 443 ramp meters, as well as real time traffic information to its Advanced Traveler Information System. The loop detectors measure volume and occupancy in 30-sec intervals and have operated since 1994. The collected data then are electronically archived at the MN/DOT Traffic Management Center. Traffic counts used in this analysis are taken from this database. Freeway lengths, which are used to compute total Vehicle Kilometers Traveled (VKT), are obtained from Mn/DOT transportation information system.

The Twin Cites ramp meters shutdown experiment was from the third week of October to the first week of December, year 2000. It took a certain amount of time for the freeway network to achieve a new equilibrium after this shock. So, the last three weeks of the shutdown experiment (without ramp metering) and the corresponding weeks in year 1999 (with ramp metering control) were chosen as the study period of this paper. Besides the network equilibrium issue, there are several supply/demand side factors other than ramp meter control which can also lead to demand fluctuation. To cancel the demand effects from those factors from our analysis, we first apply appropriate controls for each factor (see table 2). In this process, special days, such as those with extreme bad weather conditions, are excluded from the analysis. Finally the median values of the remaining days with ramp metering control are calculated, as well as the days without ramp metering control, which will be discussed in more details in the next section.

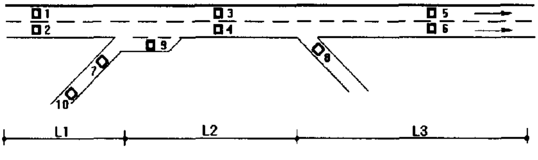
Table 2 Controls for other factors that can affect freeway demand

Factors	Control
Seasonal Demand Fluctuation	Comparable weeks (from the third week in Nov. to the first week in Dec.) were chosen for both year 1999 (with control) and year 2000 (without control).
Weather	Days with more than 0.4 inch hourly precipitation (rain, snow) in any peak period are excluded.
Crashes	Crashes are considered endogenous because ramp metering reduces freeways crashes. Days both with and without crashes are included.
Construction	No road construction work during the study periods and no capacity expansion between the two periods on all four freeway sections.

3. Methodology (estimate demand from traffic counts)

Figure 2 illustrates detector deployment in the Twin Cities freeway system. Mainline detectors (1 ~ 6) were installed at about 0.8-kilometer intervals. Each on-ramp has a queue detector (10), a departure detector (7) and a merge detector (9). Each off-ramp has an exit detector (8). Based on the 30 sec volume counts collected by each individual loop detectors, three freeway corridor level parameters can be derived: total trips, total vehicle kilometers traveled and average trip length.

Figure 2 Detector deployment



Total trips. Total trips entering a specific freeway in each time interval.

For the sample freeway segment in figure 2:

Total trips = vol(1) + vol(2) + vol(7)

in which vol(i) is the volume counts collected by detector i.

Total vehicle kilometers traveled. VKT on a specific freeway in each time interval.

The basic freeway units used to calculate total VKT are those freeway segments with uniform volume characteristic. For the sample freeway segment in figure 2, three segments are identified: L1, L2 and L3.

Total VKT = (vol(1) + vol(2))L1 + (vol(3) + vol(4))L2 + (vol(5) + vol(6))L3

Average trip length. Average trips length on a freeway in each time interval.

Ave. Trip Length = Total VKT / Total Trips

Note that this average trip length is not the actual average OD distance because trips starting from a studied freeway may not end on the same freeway and vice versa. So the absolute values of the average trip length can only be used to compare similar cases.

Then those 30-sec total trips, total VKT and average trip lengths are aggregated to seven longer time periods respectively: (1) AM peak: 6~9am; (2) PM peak: 3~ 7pm; (3) Peak total: 1 + 2; (4) Weekday off-peak: 0~6am + 9am~ 3pm + 7~24pm; (5) Early Morning: 4 to 6am; (6) Weekdays; (7) Weekend;

Remember the values we calculated are median values across the study period (the third week of November to the first week of December), so for each of the seven time period the results only contain one value for each one of the three parameters for both year 1999 (with ramp metering) and year 2000 (without ramp metering), e.g. the total trips measured for the P.M. peak periods are the median total trips of the fifteen P.M. peak periods. To illustrate, the sample results for time period (2) P.M. peak on TH 169 NB are shown in table 3.

Table 3 Sample results for the P.M. peak period on TH169 northbound

Parameters	Year 1999 Metered	Year 2000 Unmetered	Change (2000 - 1999)	% Change
Total Trips (# trips)	40927	42383	1456	3.6%
Total VKT (veh-km)	336430	311530	-24900	-7.4%
Ave. Trip Length (km)	8.22	7.35	-0.87	-10.6%

The "%Change" are percentage changes from values with ramp metering control to values without ramp metering control. This applies to all other results in this paper. By comparing results in different time periods, we are able to answer, not all, but many key questions about how travel demand responds to ramp metering.

4. Results

A comprehensive summary result table is attached in appendix 1, including total trips, total VKT and average trip length for all seven periods both with and without ramp control. Because the ramp meter shutdown experiment happened in 2000 and the chosen corresponding ramp-metering-on period is in 1999, our results will be people's response to the shutdown of ramp meters. There is no reason to believe that the results are not reversible, which means it is expected that people's response to the turning-on of ramp meters would simply be the opposite.

4.1 Spreading of the peak

In traditional transportation theory, the ratio of the peak 15-minute volume to the peak hour volume (or some other similar ratios) is used to represent the spreading of the peak. This can also be done using loop detector counts by aggregate traffic volumes at 15-minutes time intervals. However, this is only one way to look at peak spreading and some other ways are also useful. Here, we make two comparisons. First, we compare change of total traffic volumes (total trips) in the early morning period and those in the A.M. peak. It is obvious from Table 4 that people respond to the shutdown of ramp meters by departing earlier in the morning to avoid congestion in the morning peak periods. Secondly, we compare the total vehicle kilometers traveled in two peak periods with those in two off-peak periods in Table 5: weekday off-peak and weekends. When ramps are unmetered, relatively more travel is made during off-peak hours while less travel is made in the peak period. Many trips that occur in the peak periods with metering are pushed entirely to the off-peak periods without metering, generally weekday off-peak hours. The small increase in VKT on weekends is in tune with typical traffic growth.

Table 4 Early morning and A.M. Peak percentage change of total trips

Time Periods	TH 169 NB	TH169 SB	I494 WB&NB	I494 SB&EB
Early Morning	9.7%	14.0%	24.5%	8.7%
A.M. Peak	1.3%	-2.6%	1.4%	-1.0%

Table 5 Peak total and weekday off-peak percentage change in total VKT

Time Periods	TH 169 NB	TH169 SB	I494 WB&NB	I494 SB&EB
Peak Total	-2.5%	-5.8%	-5.8%	-6.4%
Weekday Off-peak	7.6%	2.6%	1.7%	2.0%
Weekends	0.6%	0.4%	-0.8%	0.3%

4.2 Non-work trips

While work trips which are characterized by a strongly desired arrival time and a fixed destination, non-work trips can more easily shift time and location. Research comparing the United States Nationwide Personal Transportation Survey reported a significant increase in discretionary travel. (Pisarski, 1992). Therefore, how non-work trips react to the shutdown of ramp meters is an important concern of this paper. Also given that previous work shows different effects of ramp meters on short trips and long trips, it is also of our high interest to separate out short non-work trips and long work trips and to see their different demand responses.

A direct traffic count can reflect trip purpose only if it's collected at certain locations, such as a street to a recreation center. However, discretion of travel or the ability to make a trip at some other time, is of high interest. Some inferences can be made based on the assumption that morning peak trips are dominated by work trips but afternoon peak trips consist of both work trips and non-work trips. Non-work trips, such as shopping and visiting are more likely happen in the afternoon than in the morning. Analysis in Montgomery County, MD also confirms this point (Levinson and Kumar 1994): about 80 percent of travel during the morning peak is classified as work trips while the afternoon peak period non-work travel constituting 50 percent of all trips.

Then the difference between the morning peak and the afternoon peak in terms of total trips and total vehicle kilometers traveled can be ascribed to a large extent to non-work trips that occur in the afternoon peak. For instance, the P.M. peak non-work trips on a northbound freeway will be the difference between the total

P.M. peak northbound trips and the total A.M. peak southbound trips, because work trips reverse directions between morning and afternoon.

As expected (see appendix 1), P.M. peak total trips and total VKT are always greater than those in the A.M. peak period, largely explained by the additional non-work travel during the P.M. peak period.

Table 6 P.M. peak non-work trips and weekday total trips

	TH 169 NB	TH169 SB	I494WB&NB	I494SB&EB
Total Non-work Trips	16.4%	-5.3%	10.3%	2.4%
Total Non-work trip VKT	6.0%	-14.5%	-10.5%	-15.1%
Ave Non-work Trip Length	-9.0%	-9.7%	-18.9%	-17.1%
Weekday Total Trips	0.9%	-0.9%	3.5%	-0.5%

There are more non-work trips in the P.M. peak period as a result of shutting off ramp meters (see table 6). The increase in P.M. non-work trips cannot be explained by the weekday trip growth rate, the last row in table 6. It is even more interesting to look at the change in total VKT. It decreases despite the increase in total trips. The only explanation is that as a result of absence of ramp meters, long peak-period non-work trips are discouraged while short non-work trips are encouraged. On average, people are making more but shorter non-work trips in peaks, exhibited by the decrease of average non-work trip length. Although this effect for all P.M. trips as a whole is mitigated to some extent by the inelasticity of work-trips, this trend of increasing total trips but decreasing total VKT still can be seen for all P.M. peak-period trips (see appendix 1).

People reschedule their short non-work trips to the peak period and defer their long non-work trips to off-peak times, when the ramp meters are shut down. There is no evidence that people change their weekend short non-work trips to weekday peaks. So, the additional short non-work trips in the P.M. peak without metering should occur during weekday off-peaks with metering. However, things are not so straightforward when we think about when those long non-work trips are rescheduled. They can then occur in weekday off-peak hours or weekends instead. Table 7 shows the changes in total VKT for these two time periods. Considering that the loss of short non-work trips should decrease the total VKT in the weekday off-peaks and that the increase of total VKT resulting from peak spreading (see appendix 1) only constitutes a small part of the total increase of VKT in the weekday off-peaks, we can draw conclusion that many long non-work trips are redistributed to weekday off-peak hours or varnish entirely.

Table 7 Changes in Total VKT of Weekday Off-peaks and Weekends

Change In Total VKT	TH 169 NB	TH169 SB	I494 WB&NB	I494 SB&EB
Weekday Off-peaks	40620	14377	20523	23497
Weekends	3978	2976	-13819	5073

4.3 Changing routes and destinations

Table 5 in section 4.1 shows that freeways carry less traffic in peak periods without metering and people reschedule their trips to weekday off-peak periods. If all trips pushed out from peak period are rescheduled and then occur during off-peak hours, the total change in VKT with/without ramp meters should be non-negative taking traffic growth into account. However, if we take a look at the change in total weekday travel (see table 8), the total weekday VKT decreases on most freeways. It's evident that travelers react to congestion without metering not only by rescheduling their trips but also changing routes and destinations. They may switch to a local arterial, a less congested freeway or even a less congested direction. Our results can not provide more details. In general, freeways take less travel, but not much less.

Table 8 Changes in Total Weekday VKT

Change In Total VKT	TH 169 NB	TH169 SB	I494 WB&NB	I494 SB&EB
Weekdays	27738	-15394	-42882	-43685

5. Conclusions

People react to the congestion resulting from the ramp metering shut-off by departing earlier in the morning and rescheduling their trips to weekday off-peaks, which shows a certain amount of peak spreading. Travelers also change routes and destinations and in general, freeways handle fewer vehicle kilometers when there is no ramp metering.

A unique demand response to ramp metering appears on non-work trips. Although there are more non-work trips during the PM peak period in general, total PM peak non-work trip VKT decreases when ramp meters are shut off. The absence of ramp meters discourages long peak-period non-work trips, which are deferred to weekday off-peak hours. On the other hand, short non-work trips are encouraged to occur in the peak period. On average, people make more but shorter non-work trips in the PM peak periods. This is because long distance trips save time at the expense of short trips when freeways are metered.

Besides providing real time volume and occupancy information to the Traffic Management Centers, loop detectors also shed lights on understanding freeway travel demand shifts which is of a key interest to transportation planners, researchers, engineers and policy analysts. Methodology developed in this paper can also be easily applied to other demand studies. Moreover, if combined with a methodology to estimate freeway OD tables from traffic counts, the actual freeway supply/demand curve can be estimated using traffic count data.

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Appendix 1: detailed results

Time Periods		TH169 NB				TH169 SB			
		1999	2000	Change	%chang	1999	2000	Change	%Chang
AM Peak	Total Trip	28857	29223	366	1.3%	27592	26861	-731	-2.6%
6:00~9:00am	Total VKT	178678	190695	12017	6.7%	255618	225889	-29729	-11.6%
	Trip Dist.	6.19	6.53	0.33	5.4%	9.26	8.41	-0.85	-9.2%
PM Peak	Total Trip	40927	42383	1456	3.6%	39672	39463	-210	-0.5%
3:00~7:00pm	Total VKT	336430	311530	-24900	-7.4%	262074	262032	-42	0.0%
	Trip Dist.	8.22	7.35	-0.87	-10.6%	6.61	6.64	0.03	0.5%
Peak Total	Total Trip	69784	71606	1822	2.6%	67264	66323	-941	-1.4%
AM + PM	Total VKT	515108	502225	-12883	-2.5%	517692	487921	-29771	-5.8%
	Trip Dist.	7.38	7.01	-0.37	-5.0%	7.70	7.36	-0.34	-4.4%
Early	Total Trip	3224	3537	313	9.7%	4912	5598	686	14.0%
Morning	Total VKT	20392	23614	3222	15.8%	44415	50270	5855	13.2%
4:00~6:00am	Trip Dist.	6.32	6.68	0.35	5.6%	9.04	8.98	-0.06	-0.7%
PM Peak	Total Trip	13336	15522	2187	16.4%	10815	10240	-576	-5.3%
-work Trips	Total VKT	80812	85641	4829	6.0%	83396	71337	-12059	-14.5%
	Trip Dist.	6.06	5.52	-0.54	-9.0%	7.71	6.97	-0.74	-9.7%
Weekday	Total Trip	82095	81713	-382	-0.5%	78576	78161	-415	-0.5%
Off Peaks	Total VKT	535461	576081	40620	7.6%	543842	558219	14377	2.6%
	Trip Dist.	6.52	7.05	0.53	8.1%	6.92	7.14	0.22	3.2%
Weekdays	Total Trip	151879	153318	1439	0.9%	145839	144484	-1356	-0.9%
	Total VKT	1050568	1078306	27738	2.6%	1061534	1046140	-15394	-1.5%
	Trip Dist.	6.92	7.03	0.12	1.7%	7.28	7.24	-0.04	-0.5%
Weekends	Total Trip	95687	94690	-997	-1.0%	91258	90077	-1181	-1.3%
	Total VKT	694001	697979	3978	0.6%	670975	673951	2976	0.4%
	Trip Dist.	7.25	7.37	0.12	1.6%	7.35	7.48	0.13	1.8%

Time Periods		I494 WB&NB				I494 SB&EB			
		1999	2000	Change	%Chang	1999	2000	Change	%Chang
AM Peak	Total Trip	49140	49847	707	1.4%	48680	48191	-489	-1.0%
6:00~9:00am	Total VKT	402688	385533	-17155	-4.3%	485065	459544	-25520	-5.3%
	Trip Dist.	8.19	7.73	-0.46	-5.6%	9.96	9.54	-0.43	-4.3%
PM Peak	Total Trip	78247	80817	2570	3.3%	70641	71874	1233	1.7%
3:00~7:00pm	Total VKT	682366	636116	-46250	-6.8%	565274	523612	-41661	-7.4%
	Trip Dist.	8.72	7.87	-0.85	-9.7%	8.00	7.29	-0.72	-9.0%
Peak Total	Total Trip	127387	130664	3277	2.6%	119321	120065	745	0.6%
AM + PM	Total VKT	1085053	1021648	-63405	-5.8%	1050338	983157	-67182	-6.4%
	Trip Dist.	8.52	7.82	-0.70	-8.2%	8.80	8.19	-0.61	-7.0%
Early	Total Trip	7820	9732	1913	24.5%	8755	9518	763	8.7%
Morning	Total VKT	56818	59709	2890	5.1%	86283	98356	12073	14.0%
4:00~6:00am	Trip Dist.	7.27	6.14	-1.13	-15.6%	9.86	10.33	0.48	4.9%
PM Peak	Total Trip	29567	32626	3059	10.3%	21501	22027	526	2.4%
-work Trips	Total VKT	197301	176572	-20730	-10.5%	162586	138080	-24506	-15.1%
	Trip Dist.	6.67	5.41	-1.26	-18.9%	7.56	6.27	-1.29	-17.1%
Weekday	Total Trip	166995	173964	6970	4.2%	149247	147073	-2174	-1.5%
Off Peaks	Total VKT	1188023	1208546	20523	1.7%	1149563	1173060	23497	2.0%
	Trip Dist.	7.11	6.95	-0.17	-2.3%	7.70	7.98	0.27	3.6%
Weekdays	Total Trip	294381	304628	10247	3.5%	268568	267138	-1430	-0.5%
	Total VKT	2273077	2230195	-42882	-1.9%	2199901	2156217	-43685	-2.0%
	Trip Dist.	7.72	7.32	-0.40	-5.2%	8.19	8.07	-0.12	-1.5%
Weekends	Total Trip	227502	234796	7295	3.2%	199413	196606	-2808	-1.4%
	Total VKT	1647835	1634017	-13819	-0.8%	1614102	1619175	5073	0.3%
	Trip Dist.	7.24	6.96	-0.28	-3.9%	8.09	8.24	0.14	1.7%