Traffic Equilibration: The Case of the Twin Cities Ramp Meter Shut Off

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Abstract

In Fall 2000, more than 430 ramp meters in the Twin Cities metropolitan area were shut down in order to evaluate the effectiveness of the metering system. This shutdown disturbed normal traffic patterns and thus traffic equilibrium. This paper examines how long it takes to establish a new equilibrium after a shock to the system, and thus establishes the basis for how long traffic studies should be carried out, as transportation analysts are generally concerned with comparing two equilibrium conditions. While traffic seems to be tending toward an equilibrium by the end of the 8 week shut-down, it has not yet converged to one. More research is needed to examine the question of whether and how equilibria form, and we need to examine longer time periods for analysis.

Introduction

Intelligent Transportation System (ITS) technology to manage freeways is becoming widespread due to claims that it reduces congestion; however, there are still issues related to its best use. Ramp meters, an ITS technology in the Minneapolis-St. Paul Metropolitan area (the Twin Cities), deployed at nearly every freeway entrance ramp, have been criticized for creating unnecessary delays. In Spring 2000, the Minnesota Legislature passed a bill requiring the Minnesota Department of Transportation to study the effectiveness of ramp meters in the Twin Cities region. This study involved shutting off the ramp meters for a 2-month period (Oct 16, 2000 – Dec 08, 2000). The shut down, a widely publicized and heavily monitored event, significantly disturbed travel speeds and traffic flows.

Drivers rely on previous experience when making travel decisions. The ramp meter study, which turned off meters at all the ramps, invalidated much previous experience. Thus travel decisions after the beginning of the study were based on especially imperfect and incomplete information until a new traffic equilibrium was established. This paper examines how within day and day-to-day variations affect the equilibrium process when Minnesota's ramp meters were shutdown. This study employs loop detector data (volume and occupancies) to understand equilibrium.

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Traffic fluctuates from one day to another and also within the day. Today's travel is not identical to yesterday's. There are many factors (weather, construction, accidents etc.) that affect a driver's perception of travel. It is believed that it doesn't take the system long to return to equilibrium due to small shocks. However the ramp meter shutdown radically altered travel times on the network. The disturbed flow might take one week, two weeks or 3 months to settle down to new conditions, or it might not settle at all.

This research investigates whether, and how quickly, traffic returns to an equilibrium after a major shock such as removing ramp meter controls. The research objectives are to: (1) define traffic equilibrium, (2) develop a methodology to estimate network flow equilibration, and (3) apply the methodology to determine from the empirical data how soon an equilibrium is re-established.

This fundamental research will aid in understanding short-term traffic responses to significant changes in capacity such as road construction or new traffic control policies, and thereby assess their effects. In particular, it is important to know whether and how quickly equilibrium is restored to determine how long traffic studies, such as this one, need to be carried out. For instance, if a new equilibrium is established in one week, the ramp meter experiment could have been much shorter; on the other hand, if a new equilibrium takes longer than eight weeks, the experiment was too short.

Site Selection And Data

The data for this study has been provided by Minnesota Department of Transportation Traffic Management Center as part of their routine data collection (TMC 2002). Two study sites are selected for this project: TH-169 and I-35W, both commonly used for traffic research in the Twin Cities based on the availability and quality of data.

To achieve the objective of the study, data was compiled from various sources. Pre- and post-shut down data, and data from a year previous are also considered in the model. In addition to loop detector data, weather data for Minnesota was obtained from National Climatic Data Center (NCDC). The data used in this study consists of freeway volumes counts, hourly precipitation data, and temperature data. The raw data contained detector errors, which were corrected before the analysis (Sheikh 2002). Table 1 shows the months and years taken into consideration for this study.

Table 1: Data Summary

	September	October	November
Pre Shutdown	04, 2000	15, 2000	
Previous year	06, 1999	17, 1999	
Shutdown		16, 2000	26, 2000
Previous year		18, 1999	28, 1999

Methodology

A new approach is developed to find traffic equilibria based on loop detector data. The model takes into account various explanatory variables to predict flow. Ordinary Least Squares (OLS) regression is used to estimate the parameters of the model.

We can measure equilibrium by comparing the week-to-week flow at the same hour of the day and day of the week. If the difference in flow remains smaller than some threshold, we can say that traffic is at equilibrium. We use the pre-shutdown data to give us that threshold. The dummy variable indicating weeks since the start of the experiment (W_n) is used to measure equilibrium by examining the week-to-week change in this indicator.

We can define the pre-shutdown equilibrium as the average week-to-week change before the shutdown ($e_{pre-shutdown}$).

$$e_{pre-shutdown} = \frac{\sum_{n=1}^N |W_n - W_{n+1}|}{N}$$

Then we can establish that a new equilibrium has been established if for all weeks after a certain date ($n > x$), that the average of the week to week change during the shutdown is the same as or less than that obtained in the pre-shutdown.

$$e_{shutdown} = \frac{\sum_{n=x}^N |W_n - W_{n+1}|}{N - x} \leq e_{pre-shutdown}$$

This is tested by predicting today's flow based on flows in the previous hour, previous day, previous week and previous year as well as the week since shutdown dummy variable. The seasonal variation was taken into account by including temperature and snow variables (as well as previous year flows on the comparable day and hour). Day of the week is also an important factor. A trip on Monday is not the same as a trip on Tuesday and so on. This is taken into account by defining a day of the week dummy. In addition, the hourly dummies control for time-of-day effects. These variables allow us to test the hypothesis that flow on each day of the week or hour of the day differs from flows on other days or hours. Detailed descriptions of these variables are given in Sheikh (2002).

$$Q_{ij,h,d,w,y} = f(Q_{ij,h-1,d,w,y}, Q_{ij,h,d-1,w,y}, Q_{ij,h,d,w-1,y}, Q_{ij,h,d,w,y-1}, H_1, H_2, D_{mon}, D_{tues}, D_{wed}, D_{thurs}, D_{fri}, D_{sat}, D_{sun}, S_x, W_n, P_{2000}, P_{1999}, S_f, S_c, \Delta F_{max}, \Delta F_{min})$$

Where,

$Q_{ij,h,d,w,y}$ = Today's flow

$Q_{ij,h-1,d,w,y}$ = previous hour volume

$Q_{ij,h,d-1,w,y}$ = previous day volume

$Q_{ij,h,d,w-1,y}$ = previous week volume

$Q_{ij,h,d,w,y-1}$ = previous year volume (adjusted to day of the week accordingly)

h = hour

d = day

w = week

y = year

ij = section

n = weeks since shut down

H_m = hour of day dummy

D_{week} = day of week dummy

S_x = section dummy

P_{year} = Precipitation dummy in year 2000 & 1999 respectively

$W_1 \dots W_n$ = Weekly dummy (Calculated from Oct 16, 2000) Onwards for Shutdown period and backward for pre-shutdown.

S_f = Amount of snow fall on that day in year 2000

S_c = amount of snow coverage on that day in year 2000

ΔF_{max} = difference of maximum temperature (2000-1999)

ΔF_{min} = difference of minimum temperature (2000-1999)

Analysis and Results

The model predicts today's flow as a function of flow on the previous hour, day, week and year. It tells us how changes to flow on the network affect drivers' decisions to take trips. The model was tested for eight different cases and on two facilities. Table 2 shows the R-squared values obtained for eight different cases. Flow is well described by the explanatory variables.

Table 2: R-Squared values for 8 cases

Cases	Facility	Period	Time of day	R-Squared
1	TH-169 NB	Pre Shutdown	Morning	0.9889
2			Evening	0.8916
3		Shutdown	Morning	0.9746
4			Evening	0.8975
5	35W NB	Pre Shutdown	Morning	0.9871
6			Evening	0.9664
7		Shutdown	Morning	0.9839
8			Evening	0.9519

Table 3 shows results obtained from the above model. There is enormous significance of these results as it explains the flow trends. Dummies for Sunday and H_4 (H_3 in case of morning peak) are suppressed to take into account the effect of these variables. The dummy for Sunday is chosen as there is less traffic than compared to other days of the week. Similarly in the case of the hour dummy, the last hour of the peak period is suppressed.

The results obtained explain much of the daily variation in drivers' behavior. The previous day's, week's and year's flows are significant in most cases, suggesting that drivers' decision to take trips are based on historical experience and continuing behavior. If trip makers are not satisfied with their previous selections, they will seek a new route or adjust their departure time or both.

Table 3 represents the results obtained for eight cases for both TH-169 and I-35W. All the eight cases are statistically significant and corroborate the hypothesis that travel is explained by historical parameters. Analysis of results is done in two ways: across the period (pre-shutdown and shutdown) and time of the day (morning or evening peak). Previous hour volume seems to be significant in all cases but explains more in the shutdown period. During the shutdown, drivers may have relied heavily on reports of previous hour volume to plan their trip, adjusted their departure time, or canceled the trip entirely (particularly for non-work trips). Alternatively, drivers in different hours may all be responding to the same factors. Previous day and week volumes are somewhat more explanatory in the shutdown period compared to the pre-shutdown. Drivers rely heavily on previous experience to make a trip but after the shutdown this pattern is disturbed because no historical data was available. This empirical analysis shows that previous year volume during the same time interval is significant for all the cases. By comparing the results for morning and evening peak for previous year volume, it seems that today's travel is more easily explained in the morning period than the evening peak period. One reason might be that there are fewer discretionary trips in the morning, so travelers are less flexible.

Week dummies explain week-to-week variations. This variable allows us to compare traffic with the previous week after controlling for seasonal and climatological factors. Week-to-week variation is one of the important variables that explains how traffic reacts to the shutdown. In the pre-shutdown period, this variation is small from one week to the other but in case of shutdown it increases as expected (shown in Figure 1 and 2) for TH-169. In addition, week-to-week variations decreases in the shutdown period with the passage of time, suggesting that traffic is forming a new equilibrium. Still is larger at the end of the study than the pre-shutdown average in both cases.

Temperature is another important constraint in decision making. During snow days, travelers are less likely to make non-work trips than on clear days. Results obtained indicate that travel decreases if it rains or snows. Winter in 2000 was considered severe and it is evident from the results that travel decreases due to snow and rain in 2000 as compared to 1999, especially during the morning commute. Also drivers are more likely to travel on warm days (a natural behavior).

Figures 3 and 4 shows that the weekly change in volume in the pre-shutdown period for I-35W was much smaller than the shutdown period. It is expected due to the relative equilibrium of traffic before the ramp meter shutdown occurred. However, during the last weeks of the shutdown period, this change in volume is small also, indicating that traffic is finding a new equilibrium point, rather than returning back to the previous equilibrium. In addition, change in volume from one week to the next decreases as the study progressed in both the morning and evening commute, validating the hypothesis.

Conclusion

A new methodology to estimate traffic equilibrium was developed and tested on two major freeways in the Twin Cities. This new methodology questions the assumption of traffic equilibrium.

In a nutshell, it is hard to unequivocally state that a new equilibrium was established, but we can say that traffic appears to be converging. Traffic will not return to its initial equilibrium but should settle to a new equilibrium because shutdown conditions affected both travel time and travel time reliability. The inconclusive evidence has a number of consequences, and raises many questions, as strongly held traffic theory requires drivers to be at equilibrium.

Were there other events (weather, holidays, etc.) that would affect the result in this way? Our examination of the weather logs suggests not. There was more rain and snow in fall 2000 during the experiment than the previous year (or the previous 8 weeks), however it was still minor for the winter-adapted Minnesotans, and should have little effect on AM freeway traffic, largely commutes and work-related trips.

A second possibility is that 8 weeks is insufficient to fully account for short-term shifts. A longer experiment may have eventually reached equilibrium. Perhaps people were simply still adjusting to determine the best departure time within a larger peak period window. This is the first time such kind of method is used to establish equilibrium. Further research is necessary to confirm the methodology.

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Figure 1. Difference of week's variation for AM peak period on TH-169

Figure 2. Difference of week's variation for PM peak period on TH-169

Figure 3. Difference of week's variation for AM peak period on I-35W

Figure 4. Difference of week's variation for PM peak period on I-35W

Table 3: Results summary

Independent Variable	Hypothesis	Dependent variable - Q_{ijkdev}				Pre-shutdown TH-169 NB				Shutdown TH-169 NB				Pre-shutdown I-35W NB				Shutdown I-35W NB			
		Evening		Morning		Evening		Morning		Evening		Morning		Evening		Morning		Evening		Morning	
		Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS	Sign	S or NS
Q_{ijkdev}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
Q_{jkldev}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
Q_{jkldev}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
$Q_{ijkldev}$	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
H_1	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
H_2	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
H_3	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{1noon}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{2noon}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{3wed}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{4thurs}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{5fri}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
D_{6sat}	+	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S	+	S
W_2	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
W_3	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
W_4	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
W_5	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
W_6	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
wetter	-	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS
drier	+	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS
snowfall	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
snowcove	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
ditempna	+	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS	+	NS
ditempni	-	-	S	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS	-	NS

Note: no snowfall in pre-shutdown period, S – Significant at 90% confidence interval on two-tailed T-test, NS – Non significant, NA – Not Applicable