Trunk Highway 169

Dynamic Ramp Metering Evaluation

- Minnesota Department Of Transportation -

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MINNESOTA DEPARTMENT OF TRANSPORTATION
TRUNK HIGHWAY 169
DYNAMIC RAMP METERING EVALUATION

Minnesota Department of Transportation
Metropolitan Division
Office of Traffic and Maintenance Operations
Traffic Management Center

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Introduction

This report documents the impact of dynamic ramp metering on Trunk Highway 169 (TH 169) from Minnetonka Boulevard in Minnetonka to 77th Avenue in Brooklyn Park. The study examines changes in traffic performance with regard to traffic flow, congestion levels, travel times, and accident rates before and after implementation of dynamic ramp metering. Results from the data analysis answer the following three questions of interest:

- What happens when an in-place isolated ramp metering system is replaced with a dynamic ramp metering system (TH 169 southbound)?
- What happens to an existing dynamic ramp metering system when it is extended further downstream (TH 169 northbound)?
- What effect does Mn/DOT’s new ramp meter algorithm have on traffic flow (immediately after implementation compared to one year after implementation)?

Project Description

TH 169 (old Hennepin County State Aid Highway 18) is one of four major north/south freeways serving the western Twin Cities metropolitan area (See Figure 1). TH 169 connects the major east/west roadways I-494, TH 62, I-394, TH 55, and I-94. TH 169 is a four lane divided roadway designed to rural freeway standards of the early 1960’s. Today it functions as a major urban arterial roadway carrying from 45,000 vehicles per day at either end to 100,000 vehicles per day at I-394. The study area of TH 169 is an 11 mile stretch of four-lane road that extends from Minnetonka Boulevard on the south end to 77th Avenue North on the north end.

In 1991, seven isolated ramp meters were installed within the study area. Isolated meters are fixed rate, stand alone systems not remotely controlled by the Traffic Management Center (TMC) operators or computers. The isolated meters were located on the southbound entrance ramps at the interchanges of TH 169 and Bass Lake Road (County Road 10), 49th Avenue North, Rockford Road (County Road 9), 36th Avenue North, and Medicine Lake Road. In December 1992, fully
integrated, centrally controlled ramp metering was installed on TH 169 south of TH 55. In October 1996, all 36 ramps in the project section of TH 169 were brought on-line with the TMC and became part of the fully integrated FTMS. In 1997, a new ramp meter control algorithm was developed and implemented on the Twin Cities metro area freeways.

**Project Evaluation**

To answer the three questions of interest posed in the introduction, the goals and objectives of an FTMS were considered and four main expectations of ramp metering on TH 169 were identified. These expectations were to:

- Maximize the sustainable traffic flow at freeway bottleneck locations.
- Reduce the extent and duration of congestion on the freeway.
- Increase the average mainline speed on the freeway.
- Decrease the accident rate on the freeway.

Each expectation is stated as a proposed hypothesis and tested to see if the ramp metering system is performing as expected. The results from this analysis are then related to the specific questions of interest. The relationship is detailed in the conclusion of this report. The matrix in Table ES-1 shows the results from the evaluation.

**Conclusion**

This report documents the impact of dynamic ramp metering on TH 169 from Minnetonka Boulevard in Minnetonka to 77th Avenue North in Brooklyn Park. Results from the data analysis answer the three questions of interest posed in the introduction.

Based on the results of the analysis, the dynamic ramp metering system implemented on TH 169 has met three of the four expectations. It has increased the sustainable traffic flow at freeway bottleneck locations, reduced the extent and duration of congestion, and increased the average corridor speed. There was a slight increase in the accident rate after implementation in the southbound direction, and a slight decrease in the accident rate after implementation in the
### Table ES-1: Evaluation Summary Matrix

<table>
<thead>
<tr>
<th></th>
<th>Southbound (AM Peak)</th>
<th>Northbound (PM Peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone 3E</td>
<td>Zone 3F</td>
</tr>
<tr>
<td><strong>Sustainable Flow</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Month After</td>
<td>Major</td>
<td>Moderate</td>
</tr>
<tr>
<td>1 Year After</td>
<td>Major</td>
<td>Major</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Change (%)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Congestion</strong> (mile-minutes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>1 Month After</td>
<td>273</td>
<td>- 59 %</td>
</tr>
<tr>
<td>1 Year After</td>
<td>228</td>
<td>- 66 %</td>
</tr>
<tr>
<td><strong>Average Mainline Speed (mph)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>1 Month After</td>
<td>48</td>
<td>+ 20 %</td>
</tr>
<tr>
<td>1 Year After</td>
<td>45</td>
<td>+ 13 %</td>
</tr>
<tr>
<td><strong>Average Mainline Travel Time (minutes)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>1 Month After</td>
<td>14.8</td>
<td>- 17 %</td>
</tr>
<tr>
<td>1 Year After</td>
<td>15.5</td>
<td>- 13 %</td>
</tr>
<tr>
<td><strong>Accident Rates</strong> (accidents per million vehicle miles)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>1.39</td>
<td>+ 8 %</td>
</tr>
</tbody>
</table>

1. **Major Improvement**: Significant increase in volume and significant decrease in occupancy, with less variability in occupancy.

2. **Moderate Improvement**: Significant increase in volume and / or significant decrease in occupancy, with or without less variability in occupancy.

3. **Minor Improvement**: Minor increase in volume and / or minor decrease in occupancy, with or without less variability in occupancy.

4. **No Improvement**: No change or decrease in volume and / or no change or increase in occupancy.
northbound direction. There is not enough data to make any statistical inferences about the change in the accident rate on the freeway when the system is being metered. The change could be from random variation or some other confounding factor.

Changing the isolated ramp meters on southbound TH 169 to a dynamic system produced significant reductions in congestion. Extending the dynamic ramp metering system onto the previously un-managed section of northbound TH 169 also showed substantial improvements due to reduced congestion. With the introduction of the new ramp meter algorithm, these benefits were increased even more. One drawback of ramp metering is the added wait time at the ramp meter before entering the freeway. This increased wait time, however, is offset by the increases in safety and quality of travel on the freeway gained by the implementation of the ramp metering system. The results of this TH 169 ramp meter evaluation corroborate results from prior ramp metering studies that have been performed. Dynamic ramp metering has proven to be an effective tool for managing TH 169 and all of the Twin Cities urban freeways.
INTRODUCTION

Peak period travel demand has exceeded un-managed road capacity on most of the Twin Cities metropolitan area freeways for more than two decades. During this time the Minnesota Department of Transportation (Mn/DOT) has developed, implemented, and continues to expand its freeway traffic management system (FTMS). The primary goals of an FTMS are to enhance safety and to optimize traffic flow on the freeway. Specific objectives include minimizing the accident rate, minimizing the magnitude and duration of congestion, minimizing travel time on the freeway mainline, and maximizing the traffic volumes that can be accommodated at freeway bottleneck locations [1].

This report documents the impact of dynamic ramp metering on Trunk Highway 169 (TH 169) from Minnetonka Boulevard in Minnetonka to 77th Avenue North in Brooklyn Park. The study examines changes in traffic performance with regard to traffic flow, congestion levels, travel times, and accident rates before and after implementation of dynamic ramp metering. Results from the data analysis answer the following three questions of interest:

- What happens when an in-place isolated ramp metering system is replaced with a dynamic ramp metering system (TH 169 southbound)?

- What happens to an existing dynamic ramp metering system when it is extended further downstream (TH 169 northbound)?

- What effect does Mn/DOT’s new ramp meter algorithm have on traffic flow (immediately after implementation compared to one year after implementation)?
BACKGROUND

TH 169 (old Hennepin County State Aid Highway 18) is one of four major north/south freeways serving the western Twin Cities metropolitan area (see Figure 1). TH 169 connects the major east/west roadways I-494, TH 62, I-394, TH 55, and I-94. TH 169 is a four lane divided roadway designed to rural freeway standards of the early 1960's. Today it functions as a major urban arterial roadway carrying from 45,000 vehicles per day at either end to 100,000 vehicles per day at I-394.

Project Description

The study area of TH 169 is an 11 mile stretch of four-lane road that extends from Minnetonka Boulevard on the south end to 77th Avenue North on the north end. It flows through the communities of Minnetonka, St. Louis Park, Golden Valley, Plymouth, New Hope, Brooklyn Park, and Maple Grove. The actual project area where the new dynamic ramp metering system was implemented starts just south of Plymouth Avenue and ends at 77th Avenue North. The larger study area examined the extended affects of the project. There are 14 interchanges located within the study area. Nine of these interchanges are located in the project area. The other five interchanges are located to the south of Plymouth Avenue. Table 1 lists the location and types of interchanges as well as what components were present prior to implementation of the new ramp metering system.
Table 1: Trunk Highway 169 Study Area Interchanges

<table>
<thead>
<tr>
<th>Cross Road</th>
<th>Type of Interchange</th>
<th>FTMS Components Present</th>
</tr>
</thead>
<tbody>
<tr>
<td>77th Avenue North (County Road 130)</td>
<td>Diamond plus loop</td>
<td></td>
</tr>
<tr>
<td>Interstate 94</td>
<td>Clover leaf</td>
<td>None</td>
</tr>
<tr>
<td>63rd Avenue North</td>
<td>Modified folded diamond</td>
<td>None</td>
</tr>
<tr>
<td>Bass Lake Road (County Road 10)</td>
<td>Clover leaf</td>
<td>Isolated ramp meter control</td>
</tr>
<tr>
<td>49th Avenue North</td>
<td>Diamond</td>
<td>Isolated ramp meter control</td>
</tr>
<tr>
<td>Rockford Road (County Road 9)</td>
<td>Clover leaf</td>
<td>Isolated ramp meter control</td>
</tr>
<tr>
<td>36th Avenue North</td>
<td>Diamond</td>
<td>Isolated ramp meter control</td>
</tr>
<tr>
<td>Medicine Lake Road</td>
<td>Diamond</td>
<td>Isolated ramp meter control</td>
</tr>
<tr>
<td>Plymouth Avenue</td>
<td>Diamond</td>
<td>None</td>
</tr>
<tr>
<td>Trunk Highway 55</td>
<td>Clover leaf</td>
<td>Fully integrated FTMS</td>
</tr>
<tr>
<td>Betty Crocker Drive</td>
<td>Modified folded diamond</td>
<td>Fully integrated FTMS</td>
</tr>
<tr>
<td>Interstate 394</td>
<td>Clover leaf</td>
<td>Fully integrated FTMS</td>
</tr>
<tr>
<td>Cedar Lake Road</td>
<td>Modified folded diamond</td>
<td>Fully integrated FTMS</td>
</tr>
<tr>
<td>Minnetonka Boulevard</td>
<td>Diamond</td>
<td>Fully integrated FTMS</td>
</tr>
</tbody>
</table>

**TH 169 Freeway Traffic Management System**

There are four main components of an FTMS: traffic detection, traffic control, traffic surveillance, and traveler information. The following sections provide a description of each of the components of an FTMS as well as their use on TH 169. Figure 2 shows the components of the FTMS on TH 169 prior to implementation. Figure 3 shows the components of the FTMS after implementation.

**Traffic Detection**

The traffic detection system in use on TH 169 consists of a series of 6' x 6' inductive loop detectors that are embedded in each travel lane of the roadway and are spaced at approximately one-half mile increments. The detectors at each location are grouped together into a station. Loop detectors are also placed on all entrance and exit ramps to measure the amount of traffic entering and leaving the freeway.
Figure 2: Inplace FTMS Prior to Implementation

![Diagram of traffic systems]

**LEGEND**
- Camera
- Online Ramp Meter
- Isolated Ramp Meter
- Detector Station

*NOT TO SCALE*
Figure 3. FTMS Post Implementation

NORTHERN STUDY BOUNDARY & PROJECT BOUNDARY

ZONE 3E

ZONE 3D

ZONE 3F

ZONE 3G

ZONE 3H

ZONE 3B

ZONE 3C

SOUTHERN PROJECT BOUNDARY

LEGEND
- Changeable Message Sign
- Camera
- Online Ramp Meter
- Detector Station

NOT TO SCALE
Each loop detector collects two data types: volume and occupancy. The first data type, volume, is a measurement of the number of vehicles that pass over the detector. Each detector provides a lane volume, and a sum of all detectors in a station provides the station volume. The second data type, occupancy, is a measurement of the percentage of time that a vehicle is located over the detector. Again, each detector provides the lane occupancy of the roadway. The station occupancy, however, is the average of each detector in a station. The volume and occupancy data collected from the roadway are transmitted to the TMC over a fiber optic network for use in managing the freeway.

Traffic Control

Traffic control on the freeway is done through the use of ramp meters. Ramp meters are used to regulate traffic flow entering the freeway. A ramp meter location consists of four signal heads placed at a freeway entrance ramp (two on each side of the ramp) and a ramp meter signal controller. Each controller is connected to the TMC through a fiber optic network. From the TMC, the ramp meters can be automatically controlled by the central computer or manually controlled by TMC operators.

The primary benefit of ramp metering is that it reduces congestion and shockwaves by regulating the rate at which traffic enters the freeway. This diminishes the heavy surges or platoons of entering traffic and allows the freeway to carry substantially higher volumes at higher speeds. It also substantially reduces accidents, especially the rear-end type crashes that result from stop-and-go driving. This reduction in accidents and congestion also results in reductions in fuel consumption and air pollutant emissions.

A secondary benefit of ramp metering is that it smooths out flow where ramp traffic enters the freeway. This happens because freeway traffic is much more accommodating in permitting one vehicle at a time to enter (metered), as compared to when large platoons surge onto the freeway (un-metered). One result is a reduction in sideswipe-type and rear-end crashes in merging areas.

The effectiveness of ramp meters on the Twin Cities freeways is dependant on the Mn/DOT ramp meter algorithm. The algorithm is the mathematical model which determines the operating rates for each meter based on upstream and downstream conditions, highway capacity, and other factors affecting the flow of traffic. The freeway is split into zones defined by a free flowing section at
the beginning of the zone and a bottleneck at the end. Data from each zone is used to control the ramp meters in that particular zone. Further information on the Mn/DOT ramp meter algorithm can be found in the document, Ramp Metering by Zone—The Minnesota Algorithm (Minnesota Department of Transportation, March 1998. Unpublished Executive Summary).

The TH 169 study area is broken into six zones, three southbound and three northbound. The three southbound zones from north to south are: Zone 3E, Zone 3F, and Zone 3G. The three northbound zones from south to north are: Zone 3B, Zone 3C, and Zone 3D. The primary bottlenecks are located at the end of each of the six zones in the study area. Table 2 lists the zone boundaries, and the location and station of each of the freeway bottlenecks.

**Table 2: TH 169 Freeway Bottleneck Locations**

<table>
<thead>
<tr>
<th>Zone</th>
<th>Zone Start</th>
<th>Zone End</th>
<th>Bottleneck</th>
<th>Bottleneck</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 3B (NB)</td>
<td>South of Minnetonka</td>
<td>South of</td>
<td>South of Interstate</td>
<td>439</td>
</tr>
<tr>
<td>Zone 3C (NB)</td>
<td>South of Interstate</td>
<td>South of 36th</td>
<td>South of 36th</td>
<td>767</td>
</tr>
<tr>
<td>Zone 3D (NB)</td>
<td>South of 36th</td>
<td>North of 63rd</td>
<td>North of 63rd</td>
<td>759</td>
</tr>
<tr>
<td>Zone 3E (SB)</td>
<td>North of 77th</td>
<td>South of 63rd</td>
<td>South of 63rd</td>
<td>746</td>
</tr>
<tr>
<td>Zone 3F (SB)</td>
<td>South of 63rd</td>
<td>South of 36th</td>
<td>South of 36th</td>
<td>740</td>
</tr>
<tr>
<td>Zone 3G (SB)</td>
<td>South of 36th</td>
<td>South of</td>
<td>South of Interstate</td>
<td>451</td>
</tr>
</tbody>
</table>

In 1991, seven isolated ramp meters were installed within the study area. Isolated meters are fixed rate, stand alone systems not controlled by TMC operators or computers. The isolated meters were located on the southbound ramps at the interchanges of TH 169 and Bass Lake Road (County Road 10), 49th Avenue North, Rockford Road (County Road 9), 36th Avenue North, and Medicine Lake Road. In December 1992, fully integrated, centrally-controlled ramp metering was installed on TH
169 south of TH 55. In October 1996, all 36 ramps in the project section of TH 169 were brought on-line with the TMC and became part of the fully integrated FTMS. In 1997, a new ramp meter control algorithm was developed and implemented on the Twin Cities metro area freeways.

Traffic Surveillance

The traffic surveillance system in use on TH 169 consists of 13 remote controlled closed circuit television cameras (CCTV). Each camera installed in the study area is connected to the TMC through a fiber optic network. Operators at the TMC monitor the cameras to determine if the central computer is regulating the system appropriately. They also use the CCTV cameras to detect and verify freeway incidents, assist in the timely arrival of motorist aid, and help minimize traffic congestion. Images from the CCTV cameras are also broadcast through many of the traveler information components to allow travelers to see road conditions before beginning a trip.

Traveler Information

The components of the traveler information system available within the study area include changeable message signs, radio, the Internet, TV, and a Telephony Traffic Info System. These elements help to notify drivers of adverse traffic conditions, both en route and for pre-trip planning.

- Changeable message signs are positioned above the roadway at three locations and provide information about the location, nature, and severity of an incident.

- Traffic Radio provides live traffic reporting from the TMC for the entire metro area (including the TH 169 study area). Public radio station KBEM 88.5 FM broadcasts weekdays every ten minutes during peak traffic periods. During a major incident, traffic condition information is broadcast continuously. (Since 1989)

- The Internet provides real time traveler information about TH 169 as well as all area freeways at http://trafficview.twincities.sidewalk3.com/. (Since October 1997)

- Traffic TV, KVBM, broadcasts live accident and traffic information from 6:00 am to 8:30 am Monday through Friday. (Since October 1997)
The Telephony Traffic Info System (586-6000, code 8859) allows travelers to phone in and listen to up-to-the-minute recorded traffic information. (Since November 1997)

These traveler information systems rely extensively on the information collected by the other components of the freeway management system in order to provide detailed reports to the public.
PROJECT EVALUATION

Field observations were conducted on TH 169 prior to implementation of the FTMS. These initial observations of TH 169 found stop-and-go traffic southbound during the morning commute at all nine interchanges within the project area. Observations of the evening commute found similar conditions with heavily congested traffic flows from I-394 to Medicine Lake Road. Data was then collected before and after implementation and an evaluation was performed to measure the effectiveness of dynamic ramp metering on TH 169.

The evaluation of TH 169 answers the three main questions posed in the introduction:

- What happens when an in-place isolated ramp metering system is replaced with a dynamic ramp metering system (TH 169 southbound)?
- What happens to an existing FTMS when it is extended further downstream into a previously un-managed section of roadway (TH 169 northbound)?
- What effect does Mn/DOT’s new ramp meter algorithm have on traffic flow (immediately after implementation compared to one year after implementation)?

To answer these three questions, the goals and objectives of an FTMS were considered and four main expectations of ramp metering on TH 169 were identified. These expectations were to:

- Maximize the sustainable traffic flow at freeway bottleneck locations.
- Reduce the extent and duration of congestion on the freeway.
- Increase the average mainline speed on the freeway.
- Decrease the accident rate on the freeway.

Each expectation is stated as a proposed hypothesis and tested to see if the ramp metering system is performing as expected. The results from this analysis are then related to the specific questions of interest. The relationship is detailed in the conclusion of this report.
The data for the evaluation was collected from three separate time periods: before, one month after, and one year after implementation. The before data was collected between October 2nd and 17th, 1996. The one month after data was collected between November 13th and 20th, 1996. The one year after data was collected between October 7th and 23rd, 1997. Data from Tuesdays, Wednesdays, and Thursdays only was used from each of the three time periods. Any days with incidents or adverse weather conditions that may have affected the results were removed from the analysis. The data from each day was then averaged in each time period, and the average values were used for the analysis.

**Hypothesis I: The implementation of this system will maximize the sustainable traffic flow at freeway bottleneck locations.**

**Rationale**

A freeway bottleneck is a location where a condition exists that restricts the capacity of the freeway. Increases in road occupancy and reductions in speed at freeway bottleneck locations will cause areas of reduced traffic flow at and upstream of the bottleneck location. Effective control of a congested freeway includes the proper management of bottleneck locations. Controlling the amount of traffic that may enter a bottleneck should lead to an improvement in traffic flow at and upstream of the bottleneck location.

Maximum traffic flow on a freeway has been found to occur at an occupancy of about 18 percent. Because of the variability in traffic flow, maintaining an occupancy at this level could lead to a breakdown in traffic flow. The maximum sustainable traffic flow is defined through analysis of a particular roadway and is indicated by occupancies approaching but not exceeding 18 percent. The goal of the traffic management system is not to obtain the maximum traffic flow, but rather, to obtain the maximum sustainable traffic flow. The maximum sustainable traffic flow occurs when the occupancy is maintained at a consistent level at or below 18 percent with no dramatic variations.
Test Criteria

Improvements in traffic flow at freeway bottleneck locations can be tested by measuring the traffic flow at the freeway bottleneck location and at stations immediately upstream of the bottleneck location. A before and after comparison of traffic volume at and upstream of bottleneck locations during the am and pm peak periods (6 am - 9 am and 3 pm - 7 pm) should indicate the effects of ramp meter control on traffic flow at the bottleneck locations.

To determine if the sustainable traffic flow has been maximized, occupancy data for the bottleneck location and stations upstream of the bottleneck location must be analyzed. A before and after comparison of occupancies at and upstream of the bottleneck locations is an indicator of whether sustained traffic flow has been achieved.

Measure of Effectiveness

The MOE's for Hypothesis I are:

- Increase in volume at and upstream of the three bottleneck locations after system implementation.

- A smoothing of the occupancy curve at a level below 18 percent with the elimination of sharp peaks in occupancy.

Data Collection and Analysis

To determine if the traffic flow has been improved and has reached a maximum sustainable rate at the bottleneck locations, volume and occupancy data were collected for each bottleneck and for two stations upstream of the bottleneck. Five minute volume and occupancy data was collected before system start-up, after start-up, and one year after start-up. This data was analyzed and a before and after comparison study of the data was performed. The results of the comparison are given in the following section.
Findings

_Southbound (AM Peak)_

There was no ramp meter control at or upstream of the Zone 3E bottleneck prior to implementation. Isolated ramp meter control existed at and upstream of the Zone 3F bottleneck, and dynamic ramp meter control was in place at and upstream of the Zone 3G bottleneck prior to implementation. Dynamic ramp meter control was in place at and upstream of all bottlenecks after implementation.

_Zone 3E Bottleneck_

The bottleneck location, station 746, had a nine percent increase in total volume after the system was implemented. The two upstream stations, 747 and 748, had 12 and 13 percent increases in total volume respectively after system implementation. One year after system start-up, all three stations showed significant increases in total volume, ranging from 13 to 21 percent over the pre-implementation volumes (Figure 4).

The occupancies at all three stations before system start-up varied and peaked at levels above 18 percent. All three stations maintained steady occupancies at levels below 18 percent, both immediately after and one year after system start-up (Figure 5).

_Zone 3F Bottleneck_

The bottleneck location, station 740, had a seven percent increase in total volume after the system was implemented. The two upstream stations, 741 and 736, had five and nine percent increases in total volume respectively after system start-up. One year after implementation, all three stations showed significant increases in total volume, ranging from 10 to 14 percent over pre-implementation volumes (Figure 4).

The occupancies at stations 741 and 736, the two upstream stations, showed high levels of occupancy before system start-up. These stations peaked above 30 percent and maintained occupancies at or above 18 percent for the majority of the peak period. Station 740, the bottleneck
station, peaked at a lower level but still maintained occupancies above 18 percent for the majority of the peak period. Immediately after system implementation, all three stations peaked at lower levels but still had occupancies exceeding 18 percent. One year after system start-up, all three stations were maintaining consistent occupancies throughout the peak period with only minor peaks slightly above 18 percent (Figure 6).

Zone 3G Bottleneck

The bottleneck location, station 451, showed no change in total volume after implementation of the system. The two upstream stations, 450 and 448, had two and one percent decreases in total volume, respectively, after system start-up. All three stations showed increases in total volume one year after system implementation. The bottleneck station had a five percent increase and the two upstream stations had three and two percent increases in total volume, respectively. The changes in volume one year after implementation coincide with the introduction of the new ramp metering algorithm (Figure 4).

Stations 448 and 450 both maintained fairly steady occupancies with short peaks over 18 percent before the system was implemented. Station 451, the bottleneck station, maintained a consistent occupancy at a level below 18 percent before implementation. After implementation, the occupancies at all three stations showed very little change from the pre-implementation conditions (Figure 7).
Figure 5: AM Peak Occupancy

Zone 3E Bottleneck
Sta 748 - N of 63rd Ave

Sta 747 - 63rd Ave

Sta 746 - S of 63rd Ave (Bottleneck)

- Before
- After
- After - 1 yr After
Figure 6: AM Peak Occupancy

Zone 3F Bottleneck
Sta 736 - S of County Road 9

Sta 741 - 36th Ave

Sta 740 - S of 36th Ave (Bottleneck)

- Before
- After
- After - 1 yr After
Figure 7: AM Peak Occupancy
Zone 3G Bottleneck
Sta 448 - N of I-394

Sta 450 - S of I-394

Sta 451 - S of I-394 (Bottleneck)

- Before
- After
- After - 1 yr After
Northbound (PM Peak)

There was no ramp meter control at or upstream of the Zone 3C or 3D bottlenecks prior to implementation. Dynamic ramp meter control existed at and upstream of the Zone 3B bottleneck prior to implementation. Dynamic ramp meter control was in place at and upstream of all bottlenecks after implementation.

Zone 3B Bottleneck

The bottleneck location, station 439, and the two upstream stations, 438 and 437, had two percent increases in total volume after implementation. One year after implementation, all three stations showed a three percent increase in total volume over pre-implementation volume. The increases in volume one year after implementation coincide with the introduction of the new ramp metering algorithm (Figure 8).

The occupancies at all three stations before system start-up varied and peaked at levels above 18 percent. After implementation, the occupancies showed little variation and remained at a level less than 18 percent. One year after implementation, the occupancy remained consistent with the results that occurred immediately after implementation except for a sharp rise at the mid point of the peak hour. At this time the occupancy jumped up to about 20 percent and then dropped back off (Figure 9).

Zone 3C Bottleneck

The bottleneck location, station 767, and the first upstream station, 768, both had seven percent decreases in volume after implementation of the system. The second upstream station, 769, showed no change in total volume after system start-up. One year after implementation, results showed a one percent increase in total volume at the bottleneck station and a three percent increase in total volume at each of the two upstream stations (Figure 8).

Occupancies at all three stations maintained levels above 18 percent before the system was implemented. After implementation, there was still some variation in occupancy but remained at a level below 18 percent. One year after implementation, results showed the least amount of variation in occupancy and remained at a level less than 18 percent (Figure 10).
Zone 3D Bottleneck

The bottleneck location, station 759, had a one percent increase in total volume after system implementation. The two upstream stations, 760 and 761, both showed three percent increases in total volume after system start-up. One year after implementation, the bottleneck location had returned to the volume before implementation and the two upstream stations had dropped to just two percent above the pre-implementation volumes (Figure 8).

All three station showed occupancies at a level below 18 percent before, after, and one year after implementation. There was some variation in occupancy both before and immediately after implementation. The occupancy one year after implementation showed very little variation (Figure 11).

Summary of Analysis

In the southbound direction, Zone 3E and 3F showed the greatest improvement in sustainable flow. Volume increased through the bottleneck locations and occupancy dropped substantially and remained less variable after implementation. There was very little improvement in Zone 3G, due to the fact that traffic was already managed in this zone prior to implementing the new dynamic system to the north. Improvements that were seen in Zone 3G were mainly due to the management of flow upstream of the zone and the introduction of the new ramp meter control algorithm.

In the northbound direction, the improvements in sustainable flow were not as dramatic as those for the southbound direction. The most improvement was seen in Zone 3B, the section of Northbound TH 169 managed prior to the new system. This section was also determined to be the worst section based on field observations and data analysis. Neither Zone 3C or 3D showed any improvement immediately after implementation. In fact, Zone 3C had a reduction in volume through the bottleneck location. This reduction in volume is most likely due to over restrictive control of the ramps in the zone. One year after implementation and the introduction of the new ramp meter algorithm, both Zone 3C and 3D showed moderate improvements in sustainable flow through their bottleneck locations.

Based on the results of the analysis and MOE’s for Hypothesis I, it is true to say that the implementation of this system maximized the sustainable traffic flow at freeway bottleneck locations on TH 169.
Figure 8: PM Peak Volume

Zone 3B Bottleneck

Zone 3C Bottleneck

Zone 3D Bottleneck

Legend:
- Red: Before
- Green: After
- Blue: After - 1 yr After
Figure 9: PM Peak Occupancy

Zone 3B Bottleneck
Sta 437 - N of Minnetonka Blvd

Sta 438 - S of Cedar Lake

Sta 439 - N of Cedar Lake (Bottleneck)

Before  After  After - 1 yr After
Figure 10: PM Peak Occupancy

Zone 3C Bottleneck
Sta 769 - S of Medicine Lake Rd

Zone 3C Bottleneck
Sta 768 - N of Medicine Lake Rd

Zone 3C Bottleneck
Sta 767 - S of 39th Ave (Bottleneck)

Occupancy

25%
20%
15%
10%
5%
0%

Time

15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30

Before  After  After - 1 yr After

25
Figure 11: PM Peak Occupancy

Zone 3D Bottleneck

Sta 761 - N of County Road 10

Sta 760 - S of 63rd Ave

Sta 759 - N of 63rd Ave (Bottleneck)

- Before
- After
- After - 1 yr After
Hypothesis II: The implementation of this system will reduce the extent and duration of congestion on the freeway.

Rationale

Congestion occurs when a freeway is not properly managed, i.e. when the freeway traffic volume demand is greater than its capacity. Congestion is caused by freeway bottlenecks, incidents, and large platoons of traffic entering a freeway from entrance ramps. Effective use of ramp metering manages traffic through all segments of a controlled freeway system. Ramp metering eliminates large platoons of traffic from entrance ramps and controls the amount of traffic entering the freeway when an incident has occurred. Complete management of the freeway system will lead to a decrease in the extent and duration of congestion on the freeway.

Test Criteria

A freeway is considered congested when occupancies rise above 18 percent. A change in congestion can be tested by measuring the miles of roadway congested or length of time congestion exists. Traffic detectors regularly spaced along the freeway system allow the collection of volume and occupancy data for the freeway segment. Recording the time that a freeway is congested (occupancy above 18 percent) for each known segment length will provide a means of measuring congestion. This measurement is a mile-minute of congestion. A mile-minute of congestion represents one mile of roadway congested for one minute.

Measure of Effectiveness

The MOE for Hypothesis II is a reduction in mile-minutes of congestion over the entire project area.

Data Collection and Analysis

Five minute occupancy data from before, after, and one year after system implementation was collected for the 11-mile stretch of TH 169 under investigation. This data was used to determine how many minutes each station was congested. The number of minutes each station was congested was then multiplied by the length of road that the station represented (one-half mile, one-fourth mile before and one-fourth mile after station). This provided the number of mile-minutes of congestion at each station. The number of mile-minutes of congestion for each station was then summed together to provide the total number of mile-minutes of congestion for the entire stretch of TH 169.
Findings

Southbound (AM Peak)

There was no ramp meter control north of County Road 10 prior to implementation. Isolated ramp meter control existed between County Road 10 and Medicine Lake Road, and dynamic ramp meter control was in place south of Plymouth Avenue prior to implementation. Dynamic ramp meter control was in place on the entire stretch of TH 169 after implementation.

Before system implementation, the 11-mile section of TH 169 had a total of 660 mile-minutes of congestion. After system implementation, the number of mile-minutes of congestion dropped to 273, a 59 percent decrease from the before condition. One year after implementation, the number of mile-minutes of congestion dropped to 228, a 66 percent decrease from the before condition (Figure 12).

Northbound (PM Peak)

There was no ramp meter control north of TH 55 prior to implementation, and dynamic ramp meter control was in place from TH 55 south prior to implementation. Dynamic ramp meter control was in place on the entire stretch of TH 169 south of I-94 after implementation.

Before system implementation, the 11-mile section of TH 169 had a total of 585 mile-minutes of congestion. After system implementation, the number of mile-minutes of congestion dropped to 298, a 49 percent decrease from the before condition. One year after implementation, the number of mile-minutes of congestion dropped to 290, a 50 percent decrease from the before condition (Figure 13).

Summary of Analysis

There was a significant decrease in congestion on the 11-mile section of TH 169. This is shown by the dramatic reduction in the number of mile-minutes of congestion in both the AM and PM peaks. Based on the results of the analysis and MOE for Hypothesis II, it is true to say that the implementation of this system reduced the extent and duration of congestion on the freeway.
**Figure 12: Mile-Minutes of Congestion**

**AM Peak**

<table>
<thead>
<tr>
<th>Minutes of Congestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mile Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>139</td>
</tr>
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<td>138</td>
</tr>
<tr>
<td>137</td>
</tr>
<tr>
<td>136</td>
</tr>
<tr>
<td>135</td>
</tr>
<tr>
<td>134</td>
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<td>133</td>
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<td>132</td>
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<tr>
<td>131</td>
</tr>
<tr>
<td>130</td>
</tr>
<tr>
<td>129</td>
</tr>
<tr>
<td>128</td>
</tr>
</tbody>
</table>

Total Mile-Minutes of Congestion
Before = 660 : After = 273 : 1 Yr After = 228
Difference = 59% Decrease (After)
Difference = 66% Decrease (1 Yr After)
Figure 13: Mile-Minutes of Congestion

PM Peak

Total Mile-Minutes of Congestion
Before = 585 : After = 298 : 1 Yr After = 290
Difference = 49% Decrease (After)
Difference = 50% Decrease (1 Yr After)
Hypothesis III: The implementation of this system will increase the average mainline speed on the freeway.

Rationale

Congestion slows mainline freeway speeds and, as a result, increases the time to travel a given distance. Effective management of the freeway system, through the use of freeway ramp meters, traffic detection, CCTV, and motorist information will help to reduce congestion and will, in turn, increase the travel speed on the freeway. An increase in the travel speed correlates to a decrease in the travel time on the freeway.

Test Criteria

Traffic detectors located at regular intervals along the freeway can be used to collect volume and occupancy data. Analysis of the data from the detectors will determine the average corridor speed for each segment of the freeway. A comparison of the speed before and after implementation of the system will give an indication of the change in travel time.

Measure of Effectiveness

The MOE for Hypothesis III is an increase in the average mainline on TH 169.

Data Collection and Analysis

Five minute volume and occupancy data from before, after, and one year after system implementation was collected for each station along the 11-mile section of TH 169. This data was used to calculate the average speed at each station. The speed was assumed to be constant for the segment of road represented by the station (one-half mile, one-quarter mile before the station and one-quarter mile after the station). Using distance and speed, an average travel time was calculated for each segment of road. These travel times were then summed up to give a total travel time for the entire 11 mile stretch of TH 169 being studied. In addition to calculating the average speeds and travel times, field runs were performed before and immediately after system implementation. The average mainline speeds and travel times from the field runs were compared
with the calculated values. It is important to keep in mind that the calculated values take all travel
lanes of the roadway into account, and were averaged over the entire peak period. The field runs,
on the other hand, were taken from the left-most travel lane and only account for three to five time
periods during the peak period. Based on these facts, there were some inherent differences
between the values calculated and those measured. An exact match between the system data and
the field studies would be unreasonable, but there should be a direct coorelation between the two.
It was necessary to estimate some speed values because of invalid data collected at certain stations.
These values were interpolated using speeds upstream and downstream of the faulty stations. The
results of the analysis are shown in the following section.

Findings

Southbound (AM Peak)

There was no ramp meter control north of County Road 10 prior to implementation. Isolated ramp
meter control existed between County Road 10 and Medicine Lake Road, and dynamic ramp meter
control was in place south of Plymouth Avenue prior to implementation. Dynamic ramp meter
control was in place on the entire stretch of TH 169 after implementation.

Before system implementation, the calculated average mainline speed on TH 169 was 40 MPH.
After implementation, the speeds increased 20 percent to 48 MPH. One year after implementation
the average speed was 45 MPH, 13 percent higher than the pre-implementation speed. The field run results also indicated an increase in the average mainline speed. Before implementation the average speed was 41 MPH. After implementation the average speed increased 21 percent to 50 MPH (Figure 14).

Before system implementation, the calculated travel time on the 11 mile stretch of TH 169 was
17.8 minutes. After implementation, the travel time was reduced 17 percent to 14.8 minutes. One
year after implementation the calculated travel time was 15.5 minutes, 13 percent less than the pre-
implementation travel time. The field run results showed a 16.1 minute travel time before
implementation and a 13.3 minute travel time after implementation, a 17 percent decrease in travel
time (Figure 15).
Figure 14: Mainline Speeds
AM Peak

Average 5 Minute Speeds
Before = 40 : After = 48 : 1 Yr After = 45
Difference = 20% Increase (After)
Difference = 13% Increase (1 Yr After)
Figure 15: Mainline Travel Time
AM Peak

Total Travel Time (Minutes)
Before = 17.8 : After = 14.8 : 1 Yr After = 15.5
Difference = 17% Decrease (After)
Difference = 13% Decrease (1 Yr After)
Northbound (PM Peak)

There was no ramp meter control north of TH 55 prior to implementation, and dynamic ramp meter control was in place from TH 55 south prior to implementation. Dynamic ramp meter control was in place on the entire stretch of TH 169 south of I-94 after implementation.

Before system implementation, the calculated average mainline speed on TH 169 was 44 MPH. After implementation, the speeds increased six percent to 47 MPH. One year after implementation the average speed was 46 MPH, four percent higher than the pre-implementation speed. The field run results also indicated an increase in the average mainline speed. Before implementation the average speed was 44 MPH. After implementation the average speed increased nine percent to 49 MPH (Figure 16).

Before system implementation, the calculated travel time on 11 mile stretch of TH 169 was 16.5 minutes. After implementation the travel time was reduced nine percent to 15.0 minutes. One year after implementation, the calculated travel time was 15.4 minutes, seven percent less than the pre-implementation travel time. The field run results showed a 15.0 minute travel time before implementation and a 13.7 minute travel time after implementation, a nine percent decrease in travel time (Figure 17).

Summary of Analysis

The volume and occupancy data collected showed that there was an increase in the average mainline speed as well as a reduction in the average travel time on the 11 mile stretch of TH 169. These changes were also present in the field run data. Based on the results above and the MOE from Hypothesis III, it is true to say that the implementation of this system increased the average mainline speeds and decreased the travel time on TH 169.
Figure 16: Mainline Speeds
PM Peak

Average 5 Minute Speeds
Before = 44 : After = 47 : 1 Yr After = 46
Difference = 6% Increase (After)
Difference = 4% Increase (1 Yr After)
Figure 17: Mainline Travel Time
PM Peak

Travel Time (Seconds)

Total Travel Time (Minutes)
Before = 16.5 : After = 15.0 : 1 Yr After = 15.4
Difference = 9% Decrease (After)
Difference = 7% Decrease (1 Yr After)
Hypothesis IV: The implementation of this system will decrease the accident rate on the freeway.

Rationale

Benefits of dynamic ramp metering include the reduction in freeway shockwaves, or stop-and-go driving conditions, and the smoothing of ramp traffic merging onto the freeway. By minimizing freeway congestion and smoothing merge areas, the accident rate on the freeway will decrease.

Test Criteria

Accident records can be polled to find the number of accidents on TH 169. The accident rate can be calculated using the number of accidents and the vehicle miles traveled from the study area before and after implementation of the system.

Measure of Effectiveness

The MOE for Hypothesis IV is a decrease in the peak period accident rate on the section of TH 169 under investigation.

Data Collection and Analysis

Accident data was collected for 11 months before (November 1, 1995 to October 1, 1996) and 11 months after (November 1, 1996 to October 1, 1997) implementation of the ramp metering system. Accident data for October 1996 was not used because the ramp meters were turned on during this month. Accident data was obtained from the Department of Public Safety's accident record database and was processed through an accident analysis routine applied to the Transportation Information System. Traffic volume data was obtained from the TMC. Accident rates are expressed in units of accidents per million vehicle miles traveled (Acc./MVM) and are calculated as follows:

\[
\text{Peak Period Accident Rate} = \frac{\text{Total Annual Peak Period Accidents} \times 1,000,000}{\text{Peak Period Vehicle Miles Traveled} \times 260 \text{ (Days)}}
\]

\[
\text{Accident Rate} = \frac{\text{Total Annual Accidents} \times 1,000,000}{\text{Vehicle Miles Traveled} \times 365 \text{ (Days)}}
\]
Findings

Tables 3 and 4 show the number of accidents, broken down by type, time, and direction for TH-169 for the 11 months before implementation of the ramp metering system. Tables 5 and 6 show the same accident data for the 11 months following implementation of the ramp metering system. Accident rates were calculated from this data.

**Table 3: Southbound Accident Data Before Implementation**

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Number of Accidents</th>
<th>Vehicle Miles Traveled</th>
<th>Accident Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 Hr</td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Fatal</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-Capacitating</td>
<td>9</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Possible Injury</td>
<td>36</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>111</td>
<td>23</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
<td>35</td>
<td>26</td>
</tr>
</tbody>
</table>

**Table 4: Northbound Accident Data Before Implementation**

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Number of Accidents</th>
<th>Vehicle Miles Traveled</th>
<th>Accident Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 Hr</td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Fatal</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Non-Capacitating</td>
<td>9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Possible Injury</td>
<td>25</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>121</td>
<td>7</td>
<td>44</td>
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<tr>
<td>Total</td>
<td>157</td>
<td>10</td>
<td>54</td>
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Table 5: Southbound Accident Data After Implementation

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Number of Accidents</th>
<th>Vehicle Miles Traveled</th>
<th>Accident Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24 Hr</td>
<td>AM</td>
<td>PM</td>
</tr>
<tr>
<td>Fatal</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Non-Capacitating</td>
<td>16</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Possible Injury</td>
<td>36</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Property Damage Only</td>
<td>141</td>
<td>30</td>
<td>24</td>
</tr>
<tr>
<td>Total</td>
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<td>38</td>
<td>34</td>
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Table 6: Northbound Accident Data After Implementation

<table>
<thead>
<tr>
<th>Accident Type</th>
<th>Number of Accidents</th>
<th>Vehicle Miles Traveled</th>
<th>Accident Rate</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
<td>Fatal</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Incapacitating</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Non-Capacitating</td>
<td>9</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Possible Injury</td>
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<td>3</td>
<td>13</td>
</tr>
<tr>
<td>Property Damage Only</td>
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<td>33</td>
</tr>
<tr>
<td>Total</td>
<td>187</td>
<td>13</td>
<td>48</td>
</tr>
</tbody>
</table>

Summary of Analysis

There was very little change in the number of accidents on TH 169 after implementation of the dynamic ramp metering system. The accident rate during the AM peak increased slightly and the PM peak decreased slightly, but there is insufficient data to draw any statistical conclusions about the change in accident rates. The change could be from random variation or some other confounding factor not accounted for. It is also important to note the low accident rate prior to implementation of the ramp metering system. There is not much room to improve an accident rate around one accident per million vehicle miles traveled. It will take a larger data set than one years worth of accident data to determine if the changes in accident rates are statistically significant.

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For this reason, a more thorough study should be conducted in a few years once there is more data to compare. Based on the results, however, the implementation of the dynamic ramp metering system did not appear to have any adverse effects on the accident rates on the freeway.
DRAWBACKS OF RAMP METERING

There is one significant drawback to the dynamic ramp metering system in place on TH 169, as well as on most freeways. This drawback is the additional travel time incurred due to the wait time at the ramp meter. Field observations were made to study the wait times at ramps prior to the implementation of the new ramp metering system. These field studies showed that the wait time to enter the freeway was basically zero where there were no meters, and less than a minute at the isolated meters. A test was developed to measure the wait times incurred at the ramps due to the ramp metering system. Due to the small sample size, no statistical inferences could be made about the wait times. The data collected indicated that sustained queues were maintained at most ramps after the dynamic ramp metering system was turned on. Wait times at the ramp meters on TH 169 ranged from less than a minute at the beginning and the end of the peak period, to as much as 16 minutes during the heaviest part of the peak period. The average wait time at a ramp meter ranged from less than one minute to about six minutes during both the AM and PM peak periods.

The added wait time at the ramp meter must be incurred in order to achieve the increased performance on the freeway. This increased wait time is offset by the increases in safety, decreases in mainline travel time, and increases in overall quality of travel on the freeway gained by the implementation of the ramp metering system. Once on the freeway drivers will benefit from a reduction in mainline travel time. The benefits from the reduction in mainline travel time will be greatest for longer trips on the freeway. Short trips may actually increase the overall travel time because the driver will not be on the freeway long enough to experience any mainline time savings. Ramp metering has the effect of discouraging short trips that may be more beneficial being made on local arterial streets as opposed to the freeway.

Table 7 shows the impact of the ramp wait time on overall travel time for drivers traveling southbound on TH 169 from select ramps to Bren Road. The table also shows the effects for a driver entering TH 169 north of the study area where there are no ramp meters. The mainline travel times are based on average speeds and distance from the entrance ramp to Bren Road. The ramp meter wait times are the average wait time at each ramp. The mainline travel time and the ramp meter wait times were totaled and the percent difference between the before and after cases was calculated.

43
<table>
<thead>
<tr>
<th>Ramp</th>
<th>Distance to Bren Road</th>
<th>Before</th>
<th></th>
<th></th>
<th>After</th>
<th></th>
<th></th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Travel Time (Minutes)</td>
<td>Mainline</td>
<td>Ramp</td>
<td>Total</td>
<td>Mainline</td>
<td>Ramp</td>
<td>Total</td>
</tr>
<tr>
<td>No Ramp</td>
<td>14 miles</td>
<td>20.3</td>
<td>0.0</td>
<td>20.3</td>
<td>17.9</td>
<td>0.0</td>
<td>17.9</td>
<td>- 12 %</td>
</tr>
<tr>
<td>77th Avenue North</td>
<td>13.5 miles</td>
<td>19.5</td>
<td>0.0</td>
<td>19.5</td>
<td>17.3</td>
<td>2.0</td>
<td>16.3</td>
<td>- 1 %</td>
</tr>
<tr>
<td>Interstate 94</td>
<td>12.5 miles</td>
<td>18.0</td>
<td>0.0</td>
<td>18.0</td>
<td>16.0</td>
<td>0.9</td>
<td>16.9</td>
<td>- 6 %</td>
</tr>
<tr>
<td>63rd Avenue North</td>
<td>11.5 miles</td>
<td>16.5</td>
<td>0.0</td>
<td>16.5</td>
<td>14.8</td>
<td>1.3</td>
<td>16.1</td>
<td>- 3 %</td>
</tr>
<tr>
<td>County Road 10</td>
<td>10.5 miles</td>
<td>15.0</td>
<td>0.5</td>
<td>15.5</td>
<td>13.5</td>
<td>5.5</td>
<td>19.0</td>
<td>+ 23 %</td>
</tr>
<tr>
<td>49th Avenue North</td>
<td>10 miles</td>
<td>14.3</td>
<td>0.5</td>
<td>14.8</td>
<td>12.9</td>
<td>3.1</td>
<td>15.9</td>
<td>+ 8 %</td>
</tr>
<tr>
<td>County Road 9</td>
<td>9 miles</td>
<td>12.8</td>
<td>0.5</td>
<td>13.3</td>
<td>11.6</td>
<td>1.2</td>
<td>12.9</td>
<td>- 3 %</td>
</tr>
<tr>
<td>36th Avenue North</td>
<td>8 miles</td>
<td>11.3</td>
<td>0.5</td>
<td>11.8</td>
<td>10.4</td>
<td>2.3</td>
<td>12.7</td>
<td>+ 8 %</td>
</tr>
<tr>
<td>Medicine Lake Road</td>
<td>6.5 miles</td>
<td>9.0</td>
<td>0.5</td>
<td>9.5</td>
<td>8.5</td>
<td>2.7</td>
<td>11.2</td>
<td>+ 18 %</td>
</tr>
<tr>
<td>Plymouth Avenue</td>
<td>6 miles</td>
<td>8.3</td>
<td>0.0</td>
<td>8.3</td>
<td>7.9</td>
<td>1.3</td>
<td>9.1</td>
<td>+ 11 %</td>
</tr>
</tbody>
</table>

44
CONCLUSION

This report documents the impact of dynamic ramp metering on TH 169 from Minnetonka Boulevard in Minnetonka to 77th Avenue North in Brooklyn Park. The study examines changes in traffic performance with regard to traffic flow, congestion levels, travel times, and accident rates before and after implementation of ramp metering. Results from the data analysis answer the three questions of interest posed in the introduction. Table 8 shows a matrix of all results from the evaluation.

What happens when an in-place isolated ramp metering system is replaced with a dynamic ramp metering system (TH 169 southbound)?

Changing the isolated ramp metering system on Southbound TH 169 to a dynamic metering system had tremendous effects on traffic flow during the AM peak. Volume at the bottleneck locations rose by as much as 13 percent, while the occupancy dropped from between 30 and 35 percent to just over 20 percent. Congestion, measured in mile-minutes, on the mainline dropped 59 percent along the entire study area. Congestion dropped by 66 percent in the zone where isolated metering was used. The average mainline speed was increased by 20 percent from 40 to 48 mph.

What happens to an existing dynamic ramp metering system when it is extended further downstream (TH 169 northbound)?

The effects of extending the dynamic ramp metering system further downstream on northbound TH 169 are positive, but not as dramatic as those seen for the southbound direction. Volume increased in the previously managed Zone 3B by two percent. Volumes in Zone 3C dropped by as much as seven percent. This was probably due to an over restrictive metering rate, because the volumes rose above pre-implementation levels one year later after the new algorithm was introduced. Volume in Zone 3D rose by one to three percent. Occupancy, however, was reduced to levels below 18 percent and maintained a more consistent level. Congestion, measured in mile-minuted, was reduced by 49 percent in the study area. Congestion was reduced by 54 percent in the previously managed zone. The average mainline speed was increased six percent from 44 to 47 mph.
What effect does Mn/DOT's new ramp meter algorithm have on traffic flow (After implementation compared to one year after implementation)?

The introduction of the new ramp metering algorithm in 1997 had very positive effects on traffic flow on TH 169. Five of the six zone bottlenecks had an increase in volume. The volume increase ranged from two to 21 percent in the southbound direction, and from zero to three percent in the northbound direction. Occupancy at the bottleneck locations was maintained at a more consistent level, indicating a more sustained traffic flow. Congestion in mile-minutes was reduced an additional 17 percent southbound, and an additional three percent northbound. One to three mph decreases in mainline speed were experienced, but this reduction in speed allowed for improvements in traffic flow.

Based on the results of the analysis, the dynamic ramp metering system implemented on TH 169 has met three of the four expectations. It has increased the sustainable traffic flow at freeway bottleneck locations, minimized the extent and duration of congestion, and increased the average corridor speed. No statistical inference can be made about changes in the accident rate on TH 169. Changing the isolated ramp meters on south TH 169 to an integrated system produced significant reductions in congestion. Extending the integrated system onto the previously un-managed section of northbound TH 169 also showed tremendous savings due to reduced congestion. With the introduction of the new ramp meter algorithm, these benefits were increased even more. One drawback of ramp metering is the added wait time at the ramp meter before entering the freeway. This increased wait time, however, is offset by the increases in safety and quality of travel on the freeway gained by the implementation of the ramp metering system. The results of this TH 169 Ramp Meter Evaluation corroborate results from prior ramp metering studies that have been performed. Dynamic ramp metering has proven to be an effective tool for managing TH 169 and all of the Twin Cities freeways.
Table 8: Evaluation Summary Matrix

<table>
<thead>
<tr>
<th></th>
<th>Southbound (AM Peak)</th>
<th>Northbound (PM Peak)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zone 3E</td>
<td>Zone 3F</td>
</tr>
<tr>
<td><strong>Sustainable Flow (Improvement)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>Major</td>
<td>Moderate</td>
</tr>
<tr>
<td>1 Year After</td>
<td>Major</td>
<td>Major</td>
</tr>
<tr>
<td><strong>Congestion (mile-minutes)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>660</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>273</td>
<td>- 59%</td>
</tr>
<tr>
<td>1 Year After</td>
<td>228</td>
<td>- 66%</td>
</tr>
<tr>
<td><strong>Average Mainline Speed (mph)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>48</td>
<td>+ 20%</td>
</tr>
<tr>
<td>1 Year After</td>
<td>45</td>
<td>+ 13%</td>
</tr>
<tr>
<td><strong>Average Mainline Travel Time (minutes)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>17.8</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>14.8</td>
<td>- 17%</td>
</tr>
<tr>
<td>1 Year After</td>
<td>15.5</td>
<td>- 13%</td>
</tr>
<tr>
<td><strong>Accident Rates (accidents per million vehicle miles)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before</td>
<td>1.29</td>
<td></td>
</tr>
<tr>
<td>After</td>
<td>1.39</td>
<td>+ 8%</td>
</tr>
</tbody>
</table>

2. **Major Improvement**: Significant increase in volume and significant decrease in occupancy, with less variability in occupancy.

Moderate Improvement: Significant increase in volume and / or significant decrease in occupancy, with or without less variability in occupancy.

Minor Improvement: Minor increase in volume and / or minor decrease in occupancy, with or without less variability in occupancy.

No Improvement: No change or decrease in volume and / or no change or increase in occupancy.
REFERENCES