TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 0-4629-S
URL: http://tti.tamu.edu/documents/0-4629-S.pdf

Project 0-4629: Evaluation of Ramp Metering Algorithms

Author: Nadeem A. Chaudhary, P.E.

PROJECT SUMMARY REPORT

Recommendations for Ramp Metering Operations in Texas

Ramp metering was reintroduced in Texas in the 1990s. The Texas Department of Transportation (TxDOT) is currently using ramp metering in two metropolitan areas: Houston and Arlington. Early in the process, the TxDOT Houston District made a policy decision to not allow more than two minutes of delay on any on-ramp. To implement this policy, TxDOT decided to meter all ramps using the fastest metering rate possible. In addition, detectors were installed at all ramps to detect and flush excessive ramp queues. This strategy, in conjunction with a successful media campaign, resulted in a favorable response from drivers and politicians alike.

The Arlington system, which consists of only five metered ramps, has remained unchanged since its initial operation. However, the Houston District of TxDOT has proactively expanded the ramp metering operation to include all major freeways. Furthermore, the district has added a dual-lane meter and changed the operation at several ramps from single-lane one-car-per-green to platoon or bulk metering. Platoon metering allows two or three cars to enter the freeway during each signal cycle, and slightly increases the capacity of a single-lane meter.

During the last decade, the Houston metropolitan area has experienced a steady growth of traffic. As a result, most freeways in Houston currently face severe congestion during a significant part, if not all, of the morning and evening peak periods. Furthermore, traffic demand at many ramps is above the capacity of a single-lane meter. Many of these meters experience frequent queue flushing, resulting in ineffective metering operation. TxDOT initiated this research project to investigate alternate algorithms and strategies that could be used to improve the current metering operations, especially in Houston.

The research team for this project consisted of researchers from the Texas Transportation Institute (TTI) and the University of Houston (UH).

What We Did . . .

The research team was responsible for collecting and analyzing data from several sites in Houston. In consultation with TxDOT staff, researchers selected a several-mile section of U.S. Highway 59 for this data collection effort. The selected freeway section consisted of both travel directions from Kirby Drive to Fondren Road. Data collected by researchers included the following 15-minute data:

- entrance ramp volumes,
- exit ramp volumes,
- freeway volumes, and
- frontage road volumes.

In addition, researchers gathered existing data for a section of U.S. 290 that included freeway and ramp volumes for a two-hour period in 15-minute increments. The research team conducted a number of additional tasks.

The team developed an enhanced version of TTI's Ramp Adaptive Metering Bottleneck Optimization (RAMBO) II program for system-level analysis and optimization. Researchers also provided a copy of the software to TxDOT staff and demonstrated how to apply the software using data for U.S. 290. Researchers used feedback from TxDOT staff to improve the software.

Researchers provided a one-day controller training session to TxDOT staff. The researchers used hardware-in-the-loop (HITL) simulation for this purpose. HITL simulation uses a real controller to respond to simulated traffic.

Researchers compared the existing ramp metering strategy used in Texas with ALINEA. ALINEA is a closed-loop traffic-responsive algorithm whose objective is to maintain specified flow conditions on the freeway. For this purpose, researchers decided to use the VISSIM simulation program and performed various associated sub-tasks.

What We Found . . .

Data Collection and Analysis

Preliminary analysis of data collected by researchers provided the following insights:

- Ramp demand at several sections is much higher (in some cases 1500 vehicles per hour) than the capacity of a single-lane meter.
- There are significant differences in statistical characteristics of data from different locations on the same highway.
- Several ramps need to be either closed during portions of peak times or metered using extremely restrictive rates in order to keep freeway traffic flowing smoothly. However, the impacts on other ramps and upstream intersections were not analyzed.

Simulation Studies of Metering Strategies

Simulation studies conducted by the TTI team provided the following insights:

- ALINEA does not operate well under high freeway and ramp demand scenarios such as those encountered in Houston. This is because the algorithm's logic of restricting metering rate to maintain specified freeway occupancy results in fast queue growth at the ramp, which causes frequent flushing detrimental to freeway operation.
- Among the three ALINEA strategies, the one with the 22 percent occupancy threshold performed the best in terms of keeping the meter from flushing frequently.
- A fixed metering strategy using the fastest metering rate is the best strategy for congested facilities such as those observed in Houston. This strategy works best with a 600-ft storage space because it results in the highest meter availability. A 400-ft storage space provides acceptable operation. Meter availability is the percentage of total time that a meter is cycling as intended (that is, the meter is not flushing).
- Ramp metering using the fastest rate improves freeway operation only under the following conditions:
  - freeway volumes (freeway demand) just upstream of the meter are high,
  - freeway demand plus ramp demand is less than 95 percent of downstream freeway capacity, and
  - meter availability is 90 percent or higher.
- Under medium or low freeway demand scenarios, ramp metering does not provide any reduction in delay or travel time for freeway traffic in the vicinity of the meter, even when the meter availability is high. However, under these conditions metering may improve freeway conditions at downstream freeway sections. Furthermore, a frequently flushing meter may hurt freeway flow because such an operation can cause the release of more dense platoons than no metering. Figure 1 illustrates the effects of frequent queue flushing. Under these conditions, there is no point in causing delay at the meter unless metering benefits downstream sections of the freeway.

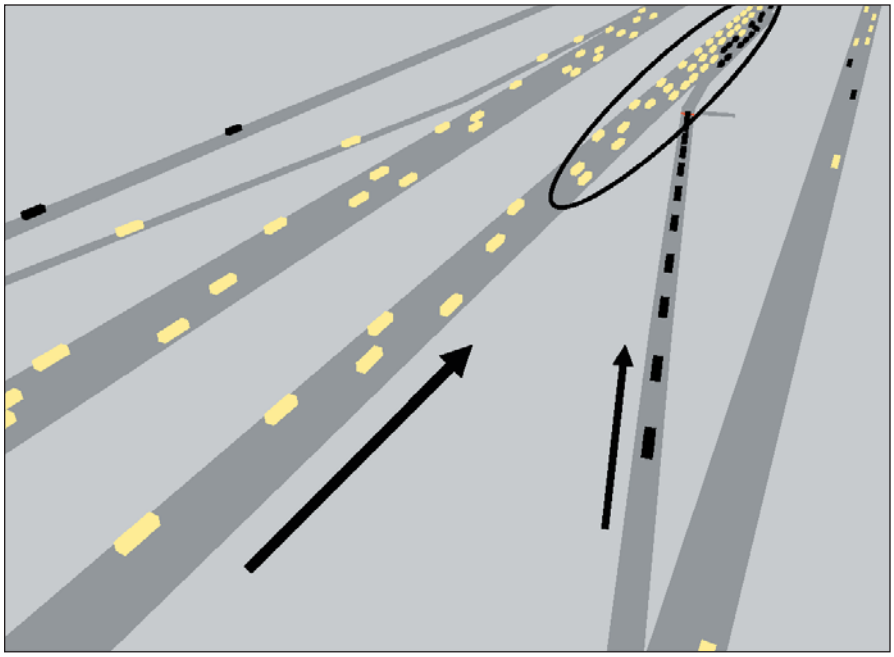


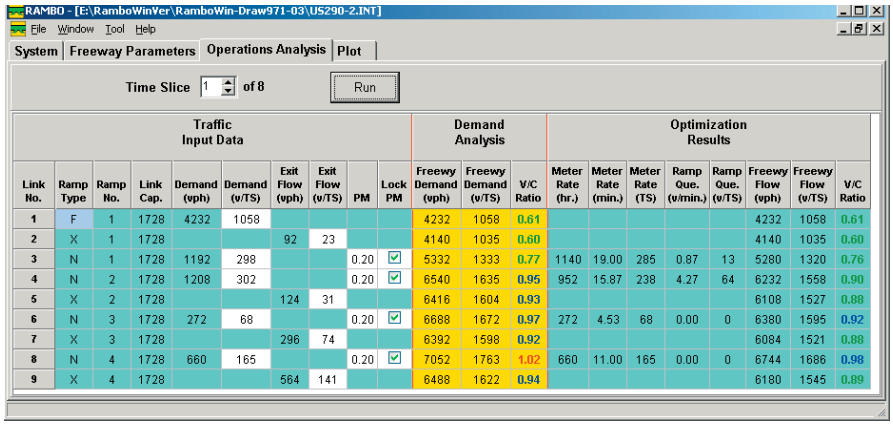
Figure 1. Queue Buildup while Freeway Recovering from the Last Flush.

Controller Training

HITL using an actual ramp controller is a useful tool for providing controller training. However, TTI researchers found that a single training session is not sufficient to familiarize a technician with all of its aspects and programming features.

Usefulness of RAMBO II

The enhanced version of RAMBO II (Figure 2) developed in this project is easy to use and provides for the analysis and optimization of larger freeway segments than the previous version. In addition, it can accommodate more time slices than the previous version. RAMBO II can be used by TxDOT to develop metering rates based on freeway- and merge-capacity constraints. Graphical displays in the software provide better insights about the locations of problems (Figure 3). For instance, incremental queue at a ramp during a time slice can be used in conjunction with the available storage space to determine the expected number of queue flushes during that time slice. Additionally, the program's capability to export outputs from multiple scenarios to a single comma-separate-value (CSV) data



Link No.	Ramp Type	Ramp No.	Link Cap.	Demand (vph)	Demand (v/TS)	Exit Flow (vph)	Exit Flow (v/TS)	PM	Lock PM	Freewy Demand (vph)	Freewy Demand (v/TS)	V/C Ratio	Meter Rate (hr.)	Meter Rate (min.)	Meter Rate (TS)	Ramp Que. (v/min.)	Ramp Que. (v/TS)	Freewy Flow (vph)	Freewy Flow (v/TS)	V/C Ratio
	Traffic Input Data									Demand Analysis			Optimization Results							
1	F	1	1728	4232	1058					4232	1058	0.61						4232	1058	0.61
2	X	1	1728			92	23			4140	1035	0.60						4140	1035	0.60
3	N	1	1728	1192	298			0.20	☑	5332	1333	0.77	1140	19.00	285	0.87	13	5280	1320	0.76
4	N	2	1728	1208	302			0.20	☑	6540	1635	0.95	952	15.87	238	4.27	64	6232	1558	0.90
5	X	2	1728			124	31			6416	1604	0.93						6108	1527	0.88
6	N	3	1728	272	68			0.20	☑	6688	1672	0.97	272	4.53	68	0.00	0	6380	1595	0.92
7	X	3	1728			296	74			6392	1598	0.92						6084	1521	0.88
8	N	4	1728	660	165			0.20	☑	7052	1763	1.02	660	11.00	165	0.00	0	6744	1686	0.98
9	X	4	1728			564	141			6488	1622	0.94						6180	1545	0.89

Figure 2. Operations Analysis Screen of RAMBO II.

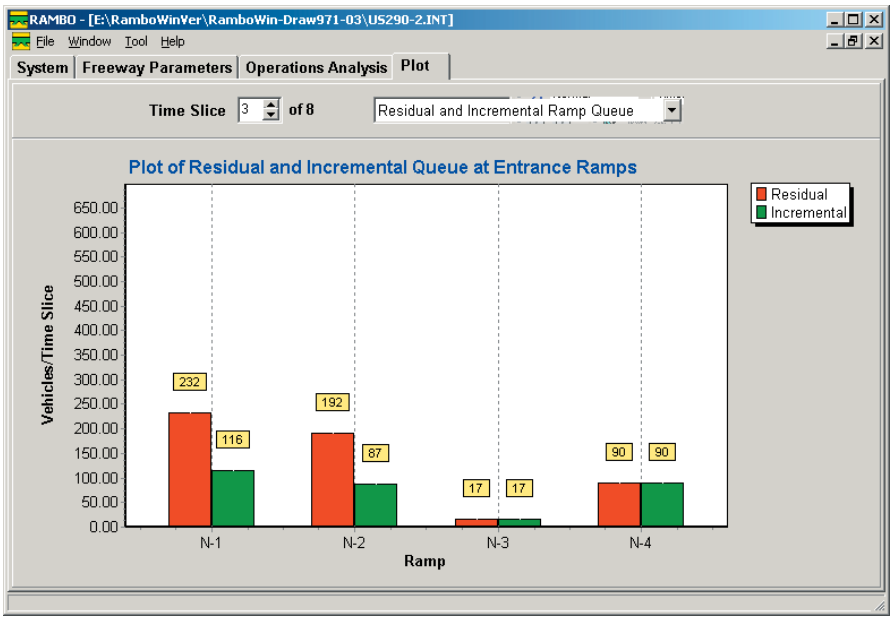


Figure 3. Graphic Output in RAMBO II.

file allows an easy way for the user to compare various alternatives.

The Researchers Recommend . . .

As suggested by the preliminary analysis, closing an on-ramp to keep freeway traffic flowing is not a practical option for most locations. Therefore, we have the following recommendations.

Use a System-Based Approach

A system-based approach should be taken to develop and implement more restrictive metering rates with equity between adjacent on-ramps. A centralized control system with a real-time feedback loop is preferable. However, Houston currently does not have detector and communication infrastructure for providing such control. The newer version of the ramp controller being used in Texas contains features (i.e., direct communication capability with a central computer over a party line) to support such operation without the use of local and system control units. Until such infrastructure is in place, we recommend the use of RAMBO II for developing system-based metering rates and implementing these rates at the local level.

Be More Restrictive at the Local Level

The current ramp metering strategy in Texas does not help reduce freeway demand because it services all ramp vehicles (during metering and any queue-flush periods). Therefore, in most cases, ramp metering does not significantly improve freeway travel times or delay in the vicinity of the ramp. A significant local benefit of metering is to improve freeway merge operation by breaking up the platoons of vehicles arriving from the upstream signal. Even this local benefit is lost when a meter starts to flush queues frequently. Nonetheless, metering a group of ramps can benefit the downstream freeway operation.

Based on research conducted in this project and findings of previous research, researchers offer the following recommendations:

1. Use fastest metering with queue flush only when the freeway volume-to-capacity ratio upstream of the entrance ramp ratio is above 0.8, and only if storage space of 400 ft or more is available to contain the platoons arriving from the upstream signal. Additionally, we recommend that the one-car-per green (single-lane or dual-lane) strategy be used with metering rates that can be accommodated by the downstream freeway section. However, when ramp demand is higher than 900 vehicles per hour and it is not practical to provide a dual-lane meter, platoon metering with two- or three-cars-per-green can be used with caution.
2. When feasible, provide a storage space of at least 600 ft.
3. Start shifting toward a more restrictive metering strategy that eliminates queue flushing. In this scheme, the queue detector can be used to provide metering rates responsive to ramp demand with a cap on maximum metering rates. This can be done by configuring the existing queue detector to be the intermediate detector in the controller. This scheme may also require coordination with the upstream signal to minimize the adverse effects of ramp queues on the upstream intersection/ interchange.

For More Details...

The research is documented in Report 0-4629-1, *Ramp Metering Algorithms and Approaches for Texas.*

Research Supervisor: Nadeem A. Chaudhary, Ph.D., P.E., Texas Transportation Institute, n-chaudhary@tamu.edu, (979) 845-9890

Researchers: Carroll J. Messer, Ph.D., P.E., Texas Transportation Institute
Zongzhong Tian, Ph.D., P.E., Texas Transportation Institute
Chi-Leung Chu, Texas Transportation Institute
Lawrence Schulze, Ph.D., P.E., University of Houston, ljhs@uh.edu, (713) 743-4196
Jason Lajeune, University of Houston, jlej@uh.edu

TxDOT Project Director: John Gaynor, P.E., jgaynor@dot.state.tx.us, (713) 881-3028

To obtain copies of reports, contact Nancy Pippin, Texas Transportation Institute, TTI Communications, at (979) 458-0481 or n-pippin@ttimail.tamu.edu. See our online catalog at http://tti.tamu.edu.

TxDOT Implementation Status—March 2005

The objective of this research project was to compare ramp metering algorithms and develop guidelines for improving ramp metering operations in Texas. Two products were required for this project: 1) guidelines for improving ramp metering operations and 2) all code developed by the researchers in this project for the simulation testbed. The first product has been incorporated in Chapter 6 of Technical Report 0-4629-1, *Ramp Metering Algorithms and Approaches for Texas*. The second product is a CD which contains the RAMBO II program (Version 1.1.2). This program is capable of developing metering rates based on freeway-capacity and merge-capacity constraints. Both of these products are available for immediate implementation in locations with freeways where ramp meters exist.

For more information, contact Mr. Wade Odell, P.E., RTI Research Engineer, at (512) 465-7403 or email wodell@dot.state.tx.us.

YOUR INVOLVEMENT IS WELCOME!

TTI.PSR0501.0505.580 PSR 0-4629-S

Disclaimer

Texas Transportation Institute/TTI Communications
The Texas A&M University System
3135 TAMU
College Station, TX 77843-3135