Development of a Methodology to Evaluate Potential Ramp Management Projects, Including a Benefit/Cost Tool

The purpose of this research was to develop a travel demand/simulation forecasting and benefit/cost analysis tool to evaluate ramp management projects. The research developed these planning tools and applied them to a candidate project on I-376 in Pennsylvania.

BY MARK J. MAGALOTTI, P.E. AND JAMES CULLISON, P.E.

Introduction

Overview of Ramp Management

The Federal Highway Administration (FHWA) publication *The Freeway Management & Operations Handbook*[1] defines ramp management as "the application of control devices, such as traffic signals, signing, and gates to regulate the number of vehicles entering or leaving the freeway, in order to achieve operational objectives." This handbook has a chapter devoted entirely to ramp management and control, discussing ramp metering, ramp closures, special use treatments, and ramp terminal treatments. This reference generally describes how ramp management fits into the larger umbrella of overall freeway management, describes the current state of the practice regarding ramp management, and lists some implementation and operational considerations. Two case studies are also discussed.

In January 2006, FHWA published the *Ramp Management and Control Handbook*.[2] This handbook promotes ramp management as a lower-cost solution for common operational problems that traditionally required major freeway re-construction, such as improper ramp spacing, inadequate acceleration distances, and/or recurring traffic congestion. The handbook stresses the importance of multiagency communication/collaboration when implementing ramp management strategies, and highlights the fact that this approach can help break down the existing barriers between these agencies.

Other recent research that was reviewed included *Transportation Research Record Journal* numbers 2012[3] and 2047,[4] which covered topics on ramp metering and its traffic diversion effects. In addition, the report *A Synthesis of Ramp Metering Practices for the Maryland State Highway Administration*[5] from October 2007, issued by Kittelson & Associates, Inc. was reviewed. This report documents the benefits and impacts of ramp meters.

Potential Impacts of Ramp Management

Although ramp management strategies can impact the overall freeway transportation program positively, some potential impacts can hinder the success of the overall system. According to the literature, these potential impacts include diversion, queue spillback, equity, emissions on ramps, and public opposition.

Diversion occurs when a portion of the traffic finds alternate routes around the queues that form at ramp meters. This can cause increased traffic on arterials. Queue spillback can also cause congestion on adjacent arterials when the storage capacity of the ramp cannot accommodate the queues at the ramp meter. The argument of equity arises because ramp management strategies can be perceived to favor one group over another (that is, although the mainline traffic sees less delay, the ramp traffic sees much more delay). This can also lead to public opposition.

Finally, although the emissions on the mainline may be reduced by ramp management strategies, this can be partially offset by an increase in emissions from the queued ramp traffic.

Integration of Traffic Management Centers and Arterial Traffic Signals

The topic of integrating ramp management with arterial signals and traffic management centers is briefly mentioned in the literature; however, it is not discussed at length in any of the FHWA handbooks. The handbooks stress the importance of integrating the strategies into the overall traffic management program, but little

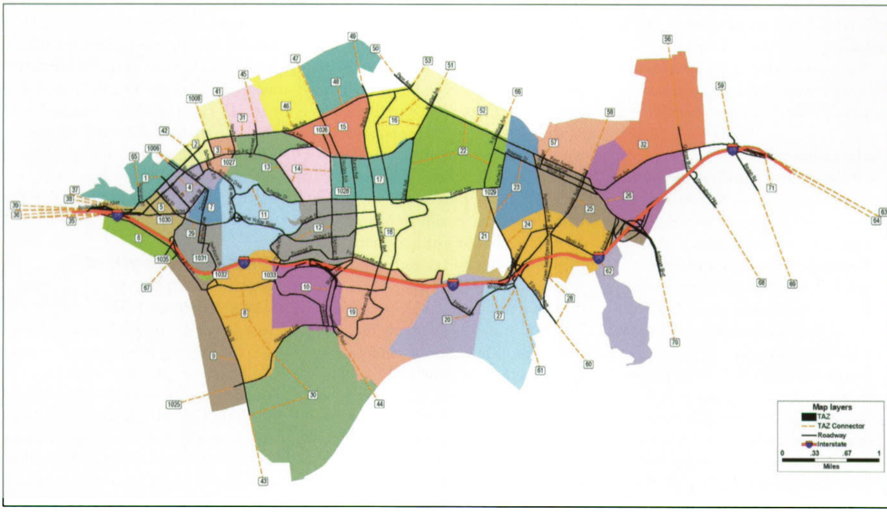


Figure 1. Ramp management study area.

detail is given on traffic management centers or arterial signals.

According to the FHWA's *Highway Traffic Operations and Freeway Management State-of-the-Practice Final Report*,[6] the current state of the practice is to "manage the freeway and arterial systems separately and to coordinate the operation through the operators of the two separate systems." Since then, some states seem to have shifted toward integrating the systems. According to a contact at Washington State Department of Transportation (WSDOT), Seattle is set to launch an integrated corridor management project. WSDOT considers the ramp terminal signal a part of the freeway management system. This allows the state to maintain control of this signal, and provide interconnect between the ramp meter cabinet and the ramp terminal signal cabinet.

Evaluation of Ramp Management for I-376

Interstate 376 in Pittsburgh, Pennsylvania (from Downtown Pittsburgh to Monroeville), was selected by the Pennsylvania Department of Transportation (PennDOT) and the research team as a demonstration corridor. Figure 1 delineates the model area for the I-376 ramp management evaluation. The Squirrel Hill Tunnel represents a significant bottleneck on this corridor, creating excessive delays and queues during the AM and PM peak travel periods.

Model Options

Three ramp management options were analyzed for the study area. The analysis was conducted for both the AM and the PM peak hours. The options that were studied evolved as follows:

- Option 1—ramp metering for all interchanges in the corridor. This was the first option studied; however, it was demonstrated that metering alone did not produce optimum operations.
- Option 2—ramp metering and ramp closures at selected ramps. This option converted meters to peak-hour closures at ramps that were redundant ramps and disrupted merging operations.
- Option 3—ramp closure at one on-ramp directly upstream from the tunnel. This option was developed as a potential first phase of implementation.

Areawide Simulation Model of Ramp Management Techniques on I-376

To quantify area-wide impacts of ramp management on I-376, a multi-resolution modeling platform was developed to combine a travel demand forecasting model with a micro-simulation model. This modeling approach provided a comprehensive planning tool capable of forecasting the volume and location of traffic diversions while estimating operational performance measures on both the freeway and the adjoining urban street system.

Travel demand forecasting can be described as the process of estimating traffic volume conditions for a set of transportation features from mathematical models of actual travel behavior. Such models typically include four major components; trip generation, trip distribution, mode choice, and traffic assignment. By implementing these four components, travel demand models can be calibrated to evaluate a multitude of scenarios such as alternative land development patterns, alternative demographic forecasts, major highway and transit initiatives such as the construction of new roadways, or even minor transportation improvements such as the addition of new travel lanes. The models are typically calibrated to match travel activity from an observed baseline (existing) condition. This ensures the validity of future travel estimates when evaluating alternative scenarios.

The travel demand model developed for the ramp management study area was implemented in the software package VISUM.

Model Calibration

The following steps provide an overview of the travel demand model calibration process for the ramp management study area:

- Establish a baseline roadway network;
- Establish transportation analysis zones (TAZ) to allow aggregation of land-use information for individual parcels into common points of origin and destination;
- Document origin-destination patterns within the local study area from the large-scale regional travel demand model maintained by the Southwestern Pennsylvania Commission (SPC);
- Estimate existing zonal trip generation totals within the local study area from the large-scale model maintained by SPC;
- Adjust the origin-destination patterns implemented in the SPC model to better replicate existing traffic counts taken within the study area and existing trip generation estimates by TAZ;
- Initiate existing year traffic assignment through the model;
- Validate the existing year model with observed traffic counts; and
- Export origin-destination routing patterns to the traffic simulation model to identify measures of effectiveness.

A hybrid static/dynamic traffic assignment algorithm known as the blocking-back method was incorporated into the travel demand model for the ramp management study area. Rather than assigning a volume that exceeds link capacity like traditional static assignment procedures, the blocking-back method will estimate the queue lengths and queue waiting times that form at a bottleneck and spill back onto upstream links. Together with incremental traffic assignment to simulate the build-up of queues over time, the blocking back method provided the most efficient procedure to incorporate the impact of the Squirrel Hill tunnel on route choice behavior.

Areawide Traffic Simulation Model

Traffic simulation models were prepared for the ramp management study area to provide visualization of traffic conditions and identify measures of effectiveness for various ramp management options. These types of models are based on driver behavior at an individual-vehicle level of detail. Driver behavior is defined stochastically based on vehicle type/performance, car-following behavior, gap acceptance, lane-change behavior, and motorist reaction to traffic control devices.

The areawide simulation models for the ramp management study area were developed using the software package VISSIM 5.1, published by PTV America. VISSIM is a microscopic, time-step, and behavior-based simulation program that provides modeling functionality for both motor vehicle and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stop, and tolling operations. The program provides multiple measures of effectiveness for evaluating transportation engineering/planning alternatives, including number of stops, travel speeds, travel times, queue time, queue length, lane change maneuvers, and traffic control delay.

Calibration for the baseline VISSIM models was aimed primarily at replicating the morning and afternoon queue lengths on I-376 Parkway East as the Squirrel Hill Tunnel. The model was reviewed by an expert panel of local transportation officials and adjusted, as necessary, based on panel comments. Default values suggested by PTV America were generally incorporated into the model for driving conditions on the local street network. Merging behavior for traffic on I-376 was adjusted to provide a more aggressive distribution of acceleration and gap acceptance. Car-following characteristics for traffic within the Squirrel Hill Tunnel were adjusted to replicate the increased headway spacing/variations within the narrow tunnel cross-section.

Origin-destination traffic patterns established in the VISUM travel demand model were imported directly into the corresponding VISSIM simulation model. The simulation model was executed a total of five times, each with a unique random number seed, to incorporate the statistical variability inherent to traffic simulation modeling. Measures of effectiveness were reported based on the average and standard deviation of the traffic simulation runs. Comparison of ramp management alternatives to baseline conditions followed a one-sided paired Student's t-Test at a 95 percent confidence interval.

Benefit/Cost Analysis of Implementing Ramp Management on I-376

To perform the benefit/cost analysis for each ramp management option, the methodology in the September 2010 American Association of State Highway and Transportation Officials (AASHTO) publication *User and Non-User Benefit Analysis for Highways*[7] was followed. This analysis applied only to the freeway, not the local roadway system. Three main user benefits were examined for each option: (1) value of time, (2) operating and ownership cost, and (3) crash cost. Once these benefits were determined for both the AM and PM peak hours for each option, the benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours. Yearly capital and operating costs were also estimated. Both the user benefits and the capital and operating costs for each year of the expected ramp management project were entered into a basic present value formula (using a riskless real discount rate and a risk premia) to bring values back to present day dollars. A real rate was used (compared with a nominal rate) because the net benefit calculations were in real terms (that is, uninflated). A risk premia was used to obtain a risk-adjusted discount rate. The total present value benefit to present value cost ratio was then calculated for each ramp management option.

User Benefit Costs

Value of Time

Value of time calculations followed the methodology presented in the AASHTO *User and Non-User Benefit Analysis for Highways.* Because of the type of data from the simulation model, the "value of time saved due to change in delay" equation was used to determine the costs sav-

Table 1. Types of crashes by option.			
	Prop Damage Only	Injury	Fatal
Option 1	178	146	2
Option 2	178	146	2
Option 3	66	52	0

Table 2. Yearly user benefits by option.			
	Option 1	Option 2	Option 3
Value of Time Savings	$515,675.73	$5,733,075.56	$1,357,006.49
Operating and Ownership Cost Savings	$840,170.72	$9,790,094.65	$2,252,690.43
Crash Cost Savings	$3,349,229.13	$3,349,229.13	$812,301.36
Total Yearly Savings	$4,705,075.58	$18,872,399.34	$4,421,998.29

Table 3. Capital and yearly operating and maintenance costs by option.			
	Option 1	Option 2	Option 3
Capital Cost	$3,253,500	$4,588,500	$632,750
Yearly Operations and Maintenance Cost	$40,000	$40,000	$5,000

Table 4. Net present value and benefit/cost ratios per option.			
	Option 1	Option 2	Option 3
Net Present Value	$35,614,275	$151,805,506	$36,021,779
Benefit/Cost Ratio	12:1	34:1	15:1

ings for both the AM and PM peak hours. The benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours.

Operating and Ownership Costs
Operating and ownership cost calculations followed the methodology presented in the AASHTO *User and Non-User Benefit Analysis for Highways.* Three main elements were evaluated: (1) fuel cost savings, (2) truck inventory savings, and (3) capital cost savings. Because of the type of data from the simulation model, the "change in fuel costs due to delay" equation was used to determine the fuel cost savings for both the AM and PM peak hours. Similarly, the "change in inventory costs due to delay" equation was used to determine the inventory cost savings for both the AM and PM peak hours. Finally, the "change in capital costs due to delay" equation was used to determine the capital cost savings for both the AM and PM peak hours. The benefits were then extrapolated to a yearly value based on assumed ramp meter/closure operating hours.

Crash Costs
Crash cost calculations followed the methodology presented in AASHTO.[4] Crash data were obtained from PennDOT for 2006, 2007, and 2008. The data were used to determine the average number of fatal, injury, and property-damage only crashes per year within the study area on I-376. The reduction factors were applied to the sections of the freeway where the metering was proposed. Individual crash analysis was not conducted but overall reduction rates applied. Only crashes occurring on the eastbound lanes from the Bates Street Interchange to the Squirrel Hill Tunnel and on the westbound lanes from the Squirrel Hill Tunnel to the Greensburg Pike Interchange were considered relevant crashes for Options 1 and 2. The relevant crashes for Option 3 included those on the eastbound lanes from the Beechwood Boulevard on ramp to the Squirrel Hill Tunnel. Table 1 presents the total number and type of relevant crashes.

The national average of crash reduction percentage due to ramp metering from AASHTO *Intelligent Transportation Systems Benefits: 2001 Report*[8] was determined to be 33 percent and was used for expected crash reduction in all options. Net perceived user cost information per crash was taken from *User and Non-User Benefit Analysis for Highways.* The values provided in the handbook were given in year 2000 dollars, so an inflation rate was applied to the data to bring these costs to today's value. Table 2 summarizes the yearly user benefits for each option.

Capital and Operating Costs
Capital costs for each option were estimated. Table 3 summarizes the total capital and yearly operating and maintenance costs.

Benefit/Cost Ratio
To determine the benefit/cost ratio for each option, the user benefit cost, capital cost, and operating cost for each year of the expected ramp management project life were entered into a basic present value formula to convert the values to present-day dollars. The total present value benefit to total present value cost ratio was then calculated. A riskless real discount rate of 3.5 percent was used, as was an assumed risk premia of 3 percent. A real rate was used (vs. a nominal rate) because the net benefit calculations were in real terms (that is, uninflated). A risk premia was used to obtain a risk-adjusted discount rate. It was also assumed that the service life of the project would be 15 years and that the terminal asset value would be $0. The valuation year of the calculation was assumed to be 2011, while the implementation date was assumed to be 2014. Table 4 summarizes the net present value as defined in AASHTO[8] as well as the benefit/cost ratios for each option.

Conclusion
Ramp management can be used to help reduce congestion along freeways, without

the high costs of capacity improvements. Congested freeways that are eligible for ramp metering or ramp closure are likely to see decreases in mainline congestion, emissions, and crash rates.

The final recommended criterion requires an analysis of the benefits of a ramp management plan, which involves the use of both travel demand and traffic simulation models. This level of evaluation can be much more involved compared with data collection and analysis, but it is necessary to determine the feasibility and benefit of the potential project. The use of a travel demand model is unique when comparing this methodology with models in other states, and involves evaluating the off-freeway effects of the project.

In addition, this analysis will set the framework for discussion with local municipalities about how the ramp management project may impact the local roadway network and plan for these impacts. One of the challenges of this effort is creating an integrated operations system that responds to changes in the freeway and local roadway network conditions. The operation of local traffic signal systems in conjunction with the ramp meters or closures can be critical to the success of a ramp management system because of the changes in both daily travel patterns and incident induced pattern.

Each ramp management option reviewed for I-376 for this study showed positive net benefits. Option 2 had the highest benefit/cost ratio of 34:1. Option 1 had the lowest benefit/cost ratio, 12:1. Although it had the lowest ratio of the three options, Option 1 still showed a significant amount of user benefits compared with its capital and operating costs.

In summary, the relatively low cost of each ramp management option, combined with the relatively large expected user benefits, resulted in high benefit/cost ratios for each option. This method to measure the benefits and costs of a ramp management project was recommended for adoption by planning and design agencies to rank or evaluate projection options. ■

References

1. *Freeway Management and Operations Handbook*, FHWA, Publication FHWA-OP-04-003, 2003.

2. *Ramp Management and Control Handbook*, FHWA, Publication FHWA-HOP-06-001, 2006.

3. *Freeway Operations and High-Occupancy Vehicle Systems 2007*, Transportation Research Record: *Journal of the Transportation Research Board 2012*, 2007.

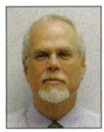
4. *Guidelines for Selection of Ramp Control Systems*, Transportation Research Board, National Cooperative Highway Research Program Report 232, 1981.

5. *A Synthesis of Ramp Metering Practices*, Kittelson & Associates, Inc., Project No. 7673.00, 2007.

6. *Highway Traffic Operations and Freeway Management: State-of-the-Practice Final Report*, FHWA, Publication FHWA-OP-03-076, 2003

7. *User and Non-User Benefit Analysis for Highways*, AASHTO, September 2010 (3rd edition).

8. *Intelligent Transportation Systems Benefits*, AASHTO, 2001.



MARK J. MAGALOTTI, *P.E. is the co-director of the University of Pittsburgh's Center for Sustainable Transportation Infrastructure (CSTI). He is also the coordinator of the Graduate Program for Transportation Engineering and a senior lecturer for the university in the program for transportation engineering. Formerly, Mr. Magalotti was the CEO of Trans Associates. Trans Associates is a civil engineering consultant firm that specializes in transportation planning and design, headquartered in Pittsburgh, PA, USA. He is a member of ITE.*

JAMES T. CULLISON, *P.E., PTOE is a project manager with Larson Design Group in Williamsport, PA, USA. His experience includes traditional transportation engineering services, travel demand forecasting, simulation, geographic information systems, research, and custom software development. He holds both a bachelor's degree and master's degree from the Pennsylvania State University. He is a member of ITE.*