Performance Measures

M-0446 Ramp Metering Feasibility Study for Durham and Wake Counties

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This document has 16 pages including the cover.

Document History

Job number: M-0446			**Document Ref: Typical Ramp Metering Design Criteria**			
Revision	**Purpose Description**	**Originated**	**Checked**	**Reviewed**	**Authorized**	**Date**
1.0	draft task report	Joe Castle	HAB	JLH	HAB	12/11/12
2.0	Submitted draft task report	Joe Castle	HAB	JLH	HAB	12/16/12
3.0	Submitted draft task report	HAB	Joe Castle	Joe Castle	HAB	12/18/12
4.0	Revised draft task report	HAB	BJS	BJS	HAB	01/09/13
5.0	Comments addressed	BJS	JG	JLH	HAB	2/11/13

Client Signoff

Client	NCDOT
Project	Ramp Metering Feasibility Study for Durham and Wake Counties
Document title	Performance Measures
Job no.	100026052
Copy no.	
Document reference	task 9 - performance measures - final draft complete.docx

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Introduction

This report outlines the process of establishing the likely performance of sites that were identified as "suitable for the introduction of ramp metering" during the Detailed Analysis Task of the NCDOT Ramp Metering Feasibility Study.

The identified sites have recurring significant congestion. Atkins reviewed their geometric characteristics and analyzed traffic volumes to confirm their suitability for ramp metering. After identifying that ramp metering will likely be effective at these sites, the next stage of the process is to determine whether ramp metering will provide sufficient benefits to make installation financially viable. This work involves the following tasks:

- Task 4, Screening and Data Analysis – summarizes the crash history per site
- Task 9, Performance Measures – identifies performance measures to be used and calculates the estimated benefits
- Task 10, Implementation Plan – summarizes the relative benefit-cost ratios of each site to prioritize them for implementation

Table 1 shows performance measures often used to justify transportation projects, and reasons for including/not including them in this analysis.

Table 1. Justification for Performance Measures

Measure	Used in Analysis?	Reasons
Reduction in Delay (Vehicle Hours)	Yes	This is the most significant benefit provided by ramp metering. Delays are estimated from existing traffic data and clear proof for reduction in delay is available from evaluation of previous ramp metering projects.
Travel Time Reliability	No	Ramp metering is likely to reduce congestion, which should improve travel time reliability (i.e., reduce the variability or range of travel speeds and travel time). Travel time reliability is frequently measured mathematically as the change in the standard deviation of travel speed or travel time. Quantifiable improvements in travel time strictly due to travel time reliability, however, are difficult to quantify since travel time reliability is, in itself, a ratio.
Crash Reduction	No	Evidence from before-and-after evaluations of other implementations shows that ramp metering significantly reduces accidents. However, crash reduction is not typically used as justification for implementing ramp metering without a detailed study of the crash history.

Measure	Used in Analysis?	Reasons
Air Emissions	No	Air emissions consist of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and hydro fluorocarbon (HFC). CO_2 is the major source of air emission and is approximately 95-99% of total air emissions from vehicles. CO, methane, and N_2O emissions are small relative to CO_2 emissions, but are more potent. HFC emissions occur largely from leaking air conditioners. CO_2 emission rates are based on gallons of fuel consumed. EPA estimates CO_2 emission rates of 8,887 grams/gallon of fuel. A ramp meter can change the average travel speed and reduce the fuel consumption rate. This, in turn, reduces CO_2 emissions. Methane and N_2O emission rates are based on vehicle miles travelled rather than fuel consumption. Similar to travel time reliability, reducing congestion should lead to reduced emissions. To estimate CO_2 emissions or vehicle miles travelled for the other emissions with and without improvements such as ramp meters requires a modeling process.

For the purposes of this project, only benefits due to reduced delays will be quantified. It is reasonable to assume other benefits can be achieved from the installation of ramp metering, such as crash reduction, improved travel time reliability, and reduced air emissions. However, reduction in delay is the only critical quantifiable measure for the justification of ramp metering.

As shown in Figure 1, this report covers the following:

- Method used to estimate delay at each site
- Method used to estimate delay reduction due to installation of ramp metering
- Calculation of financial benefits due to delay
- Summary results
- Conclusions

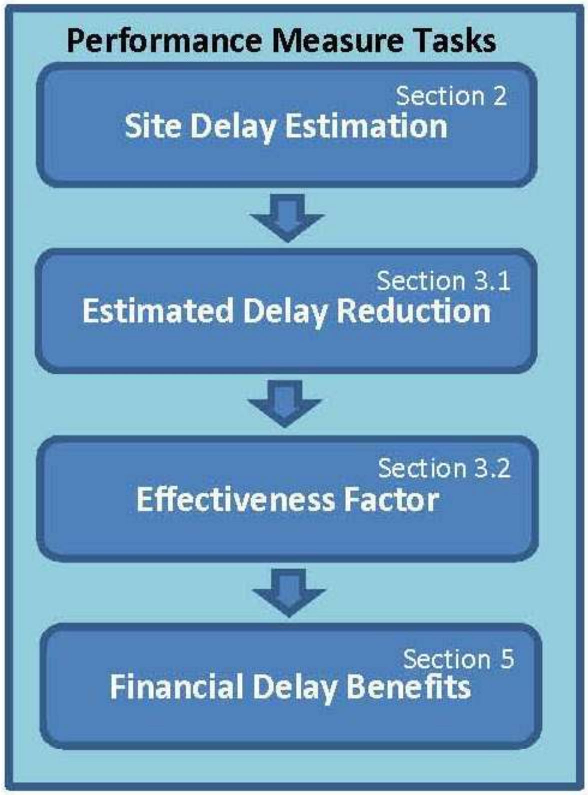

Figure 1: Flowchart of Performance Measure Methodology

1. Delay Estimation per Site

Task 4, Screening and Data Analysis Report, estimated delay using the congestion data from the VPP Suite administered by the University of Maryland CATT Lab. The VPP Suite consists of a number of congestion analysis tools based on probe vehicle data. The Bottleneck Ranking application identifies congestion in the study area.

Delay was estimated in the analysis of data from the bottleneck ranking tool was performed in Task 2.1. For each site, the following data were calculated:

- Average duration
- Average maximum queue length
- Number of occurrences per year

Hourly volumes for each site were collected and documented during the screening and data analysis (Task 4). Using these values in combination, it is possible to estimate the delay caused by congestion at each site during a single congested period:

1. The delay for each vehicle traveling through congestion is equal to the time it would take at free-flow speed minus the time it would take at congested speed. The free-flow speed is assumed to be 65 mph (all sites are on interstate roads) and congested speed of 30 mph, chosen as a cautiously high estimate of average speed in stop-start congestion.
2. The delay per vehicle, per mile is multiplied by the average maximum queue length to obtain the delay per vehicle.
3. The delay per vehicle is multiplied by the number of vehicles affected (based on average duration and volumes during hours of congestion) to obtain the total delay.

The resulting delay per congested period is then multiplied by the number of occurrences to obtain the total annual delay in vehicle hours.

While this calculation only results in an estimate, using data taken over a long period improves data robustness. By comparison, volumes where only two days are used are less robust. Therefore, the estimated benefits could be affected by the robustness of the volume data. The fact that the volumes from the two days were relatively similar for all sites provides the confidence that the data are sufficiently robust for use in this analysis.

2. Estimate of the Reduction in Delay

The reduction in delay achieved by ramp metering was estimated based on two factors:

1. An “Expected Delay Reduction” used results of evaluations of previous ramp metering installations and reduced it by a value described in Table 2.
2. Some sites with specific characteristics were identified for which the benefits achieved might be lower than previous evaluation averages.

Each of these factors is discussed in this section.

2.1. Expected Delay Reduction

In the National Research task, evaluation results of various ramp metering installations were obtained and reviewed to identify a likely reduction in delay percentage resulting from the use of ramp metering at a site. While not all of the evaluation results were in a useful format for this purpose, we have made the following assumptions:

Table 2. Evaluation Results for Delay Reductions

<table>
<tr><th>Evaluation Result</th><th>Notes</th><th>Delay Reduction Value Assumed for this Study</th></tr>
<tr><td>Atlanta, GA – 10% decrease in travel time</td><td rowspan="3">Travel time = free-flow travel time + delay time
Travel time reductions cannot be directly related to delay times but an approximation is that, if times are measured along the congested stretch,
Delay time reduction ≈ 2x travel time reduction</td><td>20%</td></tr>
<tr><td>Houston, TX – 22% decrease in travel time</td><td>44%</td></tr>
<tr><td>Arlington, VA – 10% decrease in travel time</td><td>20%</td></tr>
<tr><td>Minneapolis, MN 22%</td><td>Travel time = free-flow travel time + delay time</td><td>22%</td></tr>
<tr><td>Madison, WI 21%</td><td>Travel time = free-flow travel time + delay time</td><td>21%</td></tr>
<tr><td>Sacramento, CA – 50% decrease in driver hours</td><td>Driver hours is the same as travel time
This equates to 100% (i.e., delay reduced to zero); seems high, so ignored for this study</td><td>n/a</td></tr>
<tr><td>Los Angeles, CA – 8,470 hours saved per day</td><td>This is not a percentage reduction so cannot be related to our study</td><td>n/a</td></tr>
</table>

Based on the data shown above, the delay reductions of previous ramp metering alternatives range between approximately 16 and 50 percent. The modal (most common) and median (50^{th} percentile) averages of these results are 20 percent, while the mean is 28 percent.

Discussions among participants in the steering group meeting agreed that conservative benefit figures should be used for the reduction in delay. For the purpose of this study, we recommend assuming that delay reductions of approximately 20 percent could be obtained, but sensitivity analysis was performed by using a range of values. The analysis has therefore been carried out with low, medium, and high projections of "Expected Delay Reduction," which are 10, 15, and 20 percent, respectively.

2.2. Effectiveness Factor

There are some sites identified as suitable that might achieve lower than average benefits (e.g., some secondary sites and some sites with awkward geometry). While an average benefit of 20 percent has been identified, it is important to be realistic and not to overstate the potential benefits where a site has a characteristic that may risk a lower level of benefit. In order to be conservative in the level of benefits claimed, the effectiveness factor has been applied at this point. All sites were reviewed to identify an "Effectiveness Factor," which is the percentage of the "Expected Delay Reduction" they would be expected to achieve. Experience in the implementation and calibration of ramp metering has found that some sites are riskier in that they might not operate optimally for the following specific reasons:

- They are a "secondary" site within the congestion, meaning that there is another downstream "primary" site that is the main cause of the bottleneck. If the primary site cannot be metered, then the secondary site does not have as much effect in alleviating the congestion because it is not the cause. The secondary site can only assist once congestion from the downstream site has tailed back, and once the congestion is recovering. Therefore, an effectiveness factor of 50 percent is applied (it is estimated that the site will be effective for approximately 50 percent of the congested period).
- The site may have a short on-ramp, which means that the storage capacity for vehicles is low and, in turn, the site will operate in "queue management mode" for significant periods during congestion. Optimal operation is to reduce vehicles leaving the on-ramp during the worst congestion to help the main freeway. Queue management mode must allow more vehicles out of the on-ramp to avoid the queue spilling back onto the surface streets. Because there is a risk that the system will run sub-optimally as a result of limited storage, an effectiveness factor of between 50 and 75 percent is applied, depending on the judgement of an experienced ramp metering calibration engineer.
- Some sites meet the on-ramp flow thresholds to be suitable just for ramp metering implementation, but not for the entirety of the congested period. Ramp metering works partly by restricting flow from the on-ramp onto the main freeway, so low on-ramp flows could limit the system's ability to do this (if the flow is already low it cannot be reduced further). Where flows are outside of the recommended thresholds for a period of time during the congested period, the effectiveness factor can be adjusted to tailor the expected level of benefit proportionally. Where flows are very close to the threshold, an experienced ramp metering calibration engineer can determine how to slightly reduce the effectiveness factor, accounting for the fact that the site may occasionally run sub-optimally.

The majority of the sites have an effectiveness factor of 100 percent. Sites with a lower effectiveness factor are shown in Table 3, with their respective reasons. For each site, the expected delay reductions have been calculated by multiplying the Expected Delay Reduction and the Effectiveness Factor.

Table 3. Justification for Lower Effectiveness Factors

Log	Freeway	Cross Street	Exit	Direction	Effectiveness Factor	Reason
089	I-440	SR 1319 - Jones Franklin Rd	1C	NB	0.50	The downstream site is not suitable for ramp metering. This site would aid recovery, but not at onset of congestion. The site is only effective during the latter half of the congestion problem; therefore, the effectiveness factor has been reduced by 50%.
102	I-440	Lake Boone Trail	5	NB	0.50	The downstream site is not suitable for ramp metering. This site would aid recovery, but not onset of congestion. The site is only effective during the latter half of the congestion problem; therefore, the effectiveness factor has been reduced by 50%.
090	I-440	SR 1319 - Jones Franklin Rd	1C	SB	0.50	This site has low storage capacity (20 vehicles) on the entrance ramp, which will reduce benefits achievable during the most congested period. This site is only effective during the first part of the build-up to congestion and the last part of the recovery of congestion; therefore, the effectiveness factor has been reduced by 50%.
027	I-40	SR 1002 - Aviation Pkwy	285	EB-M1 (SB to EB)	0.75	The ramp is short and curved, and storage is approximately 47 vehicles. Therefore, benefits are expected to be slightly reduced. Due to this slight reduction in the site's ability to process entrance ramp traffic, the effectiveness factor has been reduced by 25%.
028	I-40	SR 1002 - Aviation Pkwy	285	EB-M2 (NB to EB)	0.50	This site has lower than threshold on-ramp volumes during part of the congested period, which may limit the amount of benefits achievable by ramp metering at this location. Ramp metering will only be effective during the worst part of the congestion, not during build-up or recovery; consequently, the effectiveness factor has been reduced by 50%.

Log	Freeway	Cross Street	Exit	Direction	Effectiveness Factor	Reason
095	I-440	SR 1012 - Western Blvd	2	SB-M2 (EB to SB)	0.75	This site has low on-ramp volumes, but within thresholds, which may limit the amount of benefits achievable by ramp metering at this location. Due to this slight reduction in the site's ability to process on-ramp traffic, the effectiveness factor has been reduced by 25%.

3. Financial Benefits

The steering committee agreed the appropriate value of time due to delay should be $22 per hour based on discussions with both CAMPO and DCHC MPO staff. This rate is based on Texas Transportation Institute's (TTI) 2011 Urban Mobility Report. In that report, the monetary delay per person was calculated as $16.81 per hour. That rate can be converted by applying an average vehicle occupancy rate of 1.3, which rounds to $22 per hour. This value converts the expected reduction in passenger vehicle delay into financial terms. The same TTI report estimated the average cost of delay per truck for all types of commercial vehicles to be $88.12 per hour.

From historical traffic classification counts, one can weigh the delay based upon the distribution of passenger and commercial vehicles. As an example, if the count data shows that 90 percent of the traffic volume is passenger vehicles, then the weighted delay per vehicle would be:

$$\text{Weighted Delay per Vehicle} = .90 \times \$22.00 + .10 \times \$88.12$$

$$= \$28.61 \text{ per hour}$$

The results are presented per site showing reduction in delay and monetary benefit for the low, medium, and high projections.

The reduction in delay at each of the sites, sorted by log number, is shown in Table 4. The monetary value of the reduction in delay at each of the sites, sorted by log number, is shown in Table 5.

Table 4. Reduction in Vehicle Hours Delayed

Log	Freeway	Cross Street	Exit	Direction	County	Annual Delay (veh-hours)	Effective-ness Factor	Annual Reduction in Delay		
								10% Delay Reduction	15% Delay Reduction	20% Delay Reduction
002	I-40	US-15 / US-501	270	WB	Durham	$9,877	1.00	988	1,482	1,975
009	I-40	NC-55 / Apex Hwy	278	EB	Durham	$23,462	1.00	2,346	3,519	4,692
010	I-40	NC-55 / Apex Hwy	278	WB	Durham	$25,147	1.00	2,515	3,772	5,029
012*	I-40	NC-147 / Durham Fwy - SBD	279	EB-M2 (SB to EB)	Durham	$18,732	1.00	1,873	2,810	3,746
014*	I-40	NC-147 / Durham Fwy - SBD	279	WB-M2 (SB to WB)	Durham	$30,084	1.00	3,008	4,513	6,017
015	I-40	Davis Dr	280	EB	Durham	$28,501	1.00	2,850	4,275	5,700
017	I-40	S Miami Blvd	281	EB	Durham	$70,641	1.00	7,064	10,596	14,128
019	I-40	Page Rd	282	EB	Durham	$80,410	1.00	8,041	12,061	16,082
025	I-40	SR 3015 - Airport Blvd	284	EB	Wake	$4,699	1.00	470	705	940
027	I-40	SR 1002 - Aviation Pkwy	285	EB-M1 (SB to EB)	Wake	$19,768	0.75	1,977	2,965	3,954
028	I-40	SR 1002 - Aviation Pkwy	285	EB-M2 (NB to EB)	Wake	$29,078	0.50	2,908	4,362	5,816
030	I-40	SR 1652 - N Harrison Ave	287	EB	Wake	$29,845	1.00	2,985	4,477	5,969
043	I-40	SR 1571 - Gorman St	295	WB	Wake	$26,213	1.00	2,621	3,932	5,243
056	I-40	SR 5220 - Jones Sausage Rd	303	WB	Wake	$26,518	1.00	2,652	3,978	5,304
089	I-440	SR 1319 - Jones Franklin Rd	1C	NB	Wake	$9,275	0.50	928	1,391	1,855
090	I-440	SR 1319 - Jones Franklin Rd	1C	SB	Wake	$11,569	0.50	1,157	1,735	2,314
095	I-440	SR 1012 - Western Blvd	2	SB-M2 (EB to SB)	Wake	$64,648	0.75	6,465	9,697	12,930
102	I-440	Lake Boone Trail	5	NB	Wake	$57,237	0.50	5,724	8,586	11,447
108	I-440	US-70 / NC-50 / Glenwood Ave	7	WB-M2 (SB to WB)	Wake	$29,672	1.00	2,967	4,451	5,934
133*	I-540	US-70	4	EB	Wake	$9,770	1.00	977	1,466	1,954
135	I-540	SR 1829 - Leesville Rd	7	EB	Wake	$25,010	1.00	2,501	3,752	5,002

*F2F site

Table 5. Financial Benefits Due to Delay Reduction

Log	Freeway	Cross Street	Exit	Direction	County	Annual Delay (veh-hours)	Effective-ness Factor	Percent Trucks	Annual Financial Benefit 10% Delay Reduction	15% Delay Reduction	20% Delay Reduction
002	I-40	US-15 / US-501	270	WB	Durham	10,482	1.00	8.5%	$ 25,818	$ 38,726	$ 51,635
009	I-40	NC-55 / Apex Hwy	278	EB	Durham	24,898	1.00	6.4%	$ 57,986	$ 86,980	$ 115,973
010	I-40	NC-55 / Apex Hwy	278	WB	Durham	26,687	1.00	8.2%	$ 65,218	$ 97,827	$ 130,436
012*	I-40	NC-147 / Durham Fwy - SBD	279	EB-M2 (SB to EB)	Durham	19,879	1.00	9.6%	$ 50,357	$ 75,535	$ 100,713
014*	I-40	NC-147 / Durham Fwy - SBD	279	WB-M2 (SB to WB)	Durham	31,926	1.00	8.4%	$ 78,429	$ 117,644	$ 156,859
015	I-40	Davis Dr	280	EB	Durham	30,246	1.00	9.6%	$ 76,619	$ 114,928	$ 153,237
017	I-40	S Miami Blvd	281	EB	Durham	74,966	1.00	8.3%	$ 183,685	$ 275,527	$ 367,370
019	I-40	Page Rd	282	EB	Durham	85,333	1.00	7.1%	$ 202,548	$ 303,822	$ 405,096
025	I-40	SR 3015 - Airport Blvd	284	EB	Wake	4,986	1.00	5.5%	$ 11,327	$ 16,990	$ 22,653
027	I-40	SR 1002 - Aviation Pkwy	285	EB-M1 (SB to EB)	Wake	20,979	0.75	5.5%	$ 35,740	$ 53,610	$ 71,480
028	I-40	SR 1002 - Aviation Pkwy	285	EB-M2 (NB to EB)	Wake	30,859	0.50	5.5%	$ 35,048	$ 52,571	$ 70,095
030	I-40	SR 1652 - N Harrison Ave	287	EB	Wake	31,673	1.00	5.9%	$ 72,753	$ 109,129	$ 145,506
043	I-40	SR 1571 - Gorman St	295	WB	Wake	27,817	1.00	5.3%	$ 62,832	$ 94,248	$ 125,664
056	I-40	SR 5220 - Jones Sausage Rd	303	WB	Wake	28,141	1.00	9.4%	$ 70,928	$ 106,392	$ 141,856
089	I-440	SR 1319 - Jones Franklin Rd	1C	NB	Wake	9,843	0.50	5.2%	$ 11,085	$ 16,627	$ 22,170
090	I-440	SR 1319 - Jones Franklin Rd	1C	SB	Wake	12,277	0.50	4.6%	$ 13,591	$ 20,387	$ 27,183
095	I-440	SR 1012 - Western Blvd	2	SB-M2 (EB to SB)	Wake	68,606	0.75	4.6%	$ 113,922	$ 170,884	$ 227,845
102	I-440	Lake Boone Trail	5	NB	Wake	60,741	0.50	5.6%	$ 69,181	$ 103,771	$ 138,361
108	I-440	US-70 / NC-50 / Glenwood Ave	7	WB-M2 (SB to WB)	Wake	31,488	1.00	7.3%	$ 75,144	$ 112,715	$ 150,287
133*	I-540	US-70	4	EB	Wake	10,368	1.00	6.3%	$ 24,081	$ 36,122	$ 48,162
135	I-540	SR 1829 - Leesville Rd	7	EB	Wake	26,542	1.00	5.6%	$ 60,458	$ 90,688	$ 120,917

*F2F site

4. Conclusions

The results of this analysis indicate a wide range of estimated annual financial savings due to delay across the sites, from $1,828 to $405,098 per year for the 20 percent reduction scenario (see Table 5). This demonstrates the importance of focusing on congestion and the potential benefits of reducing it when selecting sites for ramp metering.

While the analysis has focused on reduction in delays (vehicle hours), there will be other subjective and more minor quantitative benefits as a result of ramp metering installation, including more reliable trips, reduction in fuel consumption, reduction in vehicle emissions, and reduction in crashes.

These results show that a number of sites could have the ability to gain significant monetized benefits that would offset the cost of implementing ramp metering within a relatively short period.

Each site's results will now be compared with the cost of implementing ramp metering. The costs for each individual site will be estimated in a separate task, and the benefit-cost analysis will be developed in the "Implementation Plan" task.

In the Implementation Plan task report, the benefits and costs will be used to calculate the benefit-cost ratios to determine their financial feasibility.

Alf Badgett, PE
Atkins
5200 Seventy Seven Center Drive, Suite 500
Charlotte, NC 28217

Alf.badgett@atkinsglobal.com
704.665.4403