Washington State Department of Transportation

Maximizing Highway System Capacity:

Measuring and Communicating System Performance in an Evolving Field

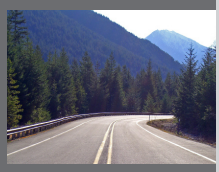
Abstract

The Washington State Department of Transportation (WSDOT) has been publishing congestion performance measurement data for six years. The annual congestion update, published in WSDOT's Measures, Markers, and Mileposts (also known as the Gray Notebook), draws attention from a wide spectrum of information consumers both within the State of Washington and nationally. Over the years, congestion performance measurements and methods to communicate capacity management results have evolved. As performance measurements become more sophisticated, their communication becomes increasingly challenging. Effective communication of performance information is also complicated by the diversity of audiences that these measures are designed to inform.

WSDOT's experience shows that despite this increasingly complex environment, there are guiding principles that agencies can use to effectively communicate performance results. These principles include: 1) use real-time data (rather than computer models) whenever possible; 2) use "Plain-English" to describe results; 3) measure congestion due to incidents (non-recurrent) as distinct from congestion due to inadequate capacity (recurrent); 4) measure travel time and travel time reliability; 5) communicate congestion fixes using an "apples-to-apples" comparison with the current situation; and, 6) use maximum throughput as a basis for congestion measurement.

WSDOT continuously looks to its peers nationally and internationally to identify methods to further enhance effective performance communication. This includes a recent effort to engage the public and the press to find better ways to communicate maximum throughput and system efficiency: The Doug McDonald Challenge, which received national attention. With SAFETEA-LU's focus on congestion performance measurement and its effective communication, this is likely to receive continued emphasis during the next highway reauthorization. This paper demonstrates how WSDOT has applied its congestion measurement principles to better communicate system performance and engage the public to explain complex concepts like maximum throughput benefits and the benefits of congestion pricing strategies.

Full document: http://www.wsdot.wa.gov/Accountability/Publications/PerformanceDocuments.htm#reports



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ABSTRACT
The Washington State Department of Transportation (WSDOT) has been publishing congestion performance measurement data for six years. The annual congestion update, published in WSDOT's Measures, Markers, and Mileposts (also known as the *Gray Notebook*), draws attention from a wide spectrum of information consumers both within the State of Washington and nationally. Over the years, congestion performance measurements and methods to communicate capacity management results have evolved. As performance measurements become more sophisticated, their communication becomes increasingly challenging. Effective communication of performance information is also complicated by the diversity of audiences that these measures are designed to inform.

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INTRODUCTION

Efforts to measure congestion have been the subject of increased attention as the congestion "problem" has become more acute and highway users have become more frustrated with travel time variability. Congress recognized the congestion problem during the last highway funding package, the Safe Accountable Flexible Efficient Transportation Act: A Legacy for Users (SAFETEA-LU 2005). Section 5502 of SAFETEA-LU directs the Secretary of Transportation to establish research initiatives that examine congestion. More specifically, the Surface Transportation Congestion Solutions Research Program is charged with a responsibility to identify local methods for reporting congestion and to develop "national models and methods to monitor, measure, and report surface transportation congestion information" (Section 5502(b)(1)(C)), as well as analyze the effectiveness of these measurements in the assessment of congestion problems and communication of these problems to decision-makers (Section 5502(b)(2)(A)). Congress validated the importance of the measurement and communication of these measures by appropriating a total of $9 million per year over four fiscal years to fund this research. It is significant that Congress not only requested that measurements be developed, but also that the effective communication of these measures be studied.

Over the years, congestion performance measures and methods to communicate capacity management results have evolved. Complexity of measures has accompanied their evolution. The Washington State Department of Transportation's experience shows that despite this increasingly complex environment, there are guiding principles that agencies can use to effectively communicate performance results. These principles include: 1) use real-time data (rather than computer models) whenever possible; 2) use "Plain-English" to describe results; 3) measure congestion due to incidents (non-recurrent) as distinct from congestion due to inadequate capacity (recurrent), 4) measure travel time and travel time reliability; 5) communicate congestion fixes using an "apples-to-apples" comparison with the current situation; and, 6) use maximum throughput as a basis for congestion measurement. WSDOT uses these principles to report congestion measures in its annual congestion report, published in *Measures, Markers, and Mileposts*, also known as the *Gray Notebook*.

Effective communication of the latest generation of congestion performance measures, which are based on efficient utilization of highway capacity, presents a particularly difficult challenge. This challenge is in part due to the technical nature of the concepts and in part because the public is asked to accept congestion thresholds and strategies that do not manage the system at free flow or posted speeds. Rather, these thresholds and strategies manage the system to lesser speeds that yield higher vehicle throughputs. This paper also describes how WSDOT solicited nationwide input to develop an effective strategy for communicating to the public the concept of maximum throughput to accept that travel at less than posted speeds may mean that the freeway system is functioning at maximum capacity.

WSDOT's PRINCIPLES FOR MEASURING AND REPORTING CONGESTION PERFORMANCE MEASURES

Use Real-Time Data Whenever Possible

Data collection is a necessity for system performance monitoring. Traditional congestion measurements are for the most part based on modeled speed estimates generated from capacity and volume information based on the physical design of highway systems.

These types of measurements can be difficult to communicate to the public. Perhaps most important, measures that use modeled data do not allow for accountability and transparency because they are inadequate for tracking system performance and evaluating and communicating the impacts of specific projects and strategies aimed at reducing congestion. These measures are important both for the transportation agency to assess its efforts and for the public to know how effective an agency's efforts are in mitigating congestion.

The use of field sensors is one approach for collecting system performance data and includes loop detectors (magnetic loops embedded in roadways which collect vehicle count and speed data), automated license plate recognition cameras (which can track individual vehicles between various points on highway segment), and the infra-red traffic logger (which classifies and counts vehicles by beaming lights across the road at axle height to measures axle spacing). These data collection methods are often done in real-time, yielding data that are more readily accessible to traffic engineers and the public. Another method of data collection in system performance is to utilize existing labor resources on the highway system, such as incident response vehicles and highway patrol officers responding to incidents. These types of data can be especially useful in collecting information on incidents which may cause non-recurrent congestion on the highway system. Additionally, data can be collected through customer satisfaction surveys and Before and After studies, though these data are limited by their qualitative (survey data) and selective (Before and After studies) nature.

Cell phone technology and probe based data collection methods hold promise for collecting real time data. However, these data collection methods are still fairly unreliable during heavily congested conditions, and the resulting poor data quality allows for very limited applicability in system monitoring and performance measurement.

Leveraging Operational Data to Monitor System Performance: WSDOT makes extensive use of existing magnetic induction loop sensors in its congestion measurement program and is leveraging its Intelligent Transportation System (ITS) investments and infrastructure to the maximum extent possible (Bremmer, Cotton, and Cotey 2004). The magnetic loop detectors are embedded in the roadway lanes regularly spaced along highway segments. Much of WSDOT's real-time operational data are collected using a network of 4,000 induction loops embedded in the highway. This system of loop detectors has been in place for decades and is a primary source of data for the region's operation of traffic signals and the freeway management system. These data have been collected 24 hours a day, 365 days a year over the past few decades. The loop detectors work by running an electrical current through a wire embedded in the pavement which creates a magnetic field. As a vehicle passes over the loop, the magnetic field is disrupted and the presence of the vehicle is logged in a database. The loop detectors provide WSDOT with data on vehicle count and length of time each vehicle occupies the loop.

Apply Strict Standards for Quality Control: As with any system that is decades old, maintenance and data quality control are important. Data collected from loops must undergo strict quality controls to ensure that WSDOT uses reliable data to monitor and evaluate system performance. Data quality control is an issue that many states are struggling with, thus preventing the full deployment of operational data for performance measurement purposes. WSDOT's loop data are archived by the University of Washington's Transportation Center (TRAC), which uses multiple quality control procedures to exclude erroneous or inaccurate data from the loop detectors. In addition to

maintenance and loop failure issues, error in measurements can also occur when: 1) gaps between vehicles are very small, 2) there is excessive lane changing over the loops, and 3) when traffic remains stopped over the loop for a long period of time. WSDOT compensates for this variability by installing "speed stations" (double loops) at approximately 100 locations in the highway system, which provide accuracy of speed data to within 1 or 2 mph at ordinary driving speeds. In addition, WSDOT performs periodic checks of the data accuracy by comparing the real-time loop data at certain points with direct observation and measurement of driving speeds.

Raw data from the loop detection system undergo a software-based quality control procedure using the Washington State Transportation Center's TRACFLOW software. This is a three-step process that begins with an automated scanning process which identifies data that are questionable and then replaces them with values that are consistent with loop detectors that are nearby. In this first step, data are validated on the loop-day level. The second step for data validation is a manual process. Data for individual loops, at the five-minute level, are flagged by the software to indicate the level of reliability. A table that summarizes data quality is produced. A manual review process is then conducted to determine if data should be discarded, kept, or replaced with historical data based on nearby sensor values. In the final step, an automated process reviews the data from an individual sensor on a day level. Data are checked for unusual patterns. If unusual patterns exist, the automated process replaces the entire day's data with historical data based on values from nearby sensors (Wright and Ishimaru 2007).

Overall data quality for a loop sensor system is enhanced with an increase in the number of sensors. The increased number of sensors allows a cross-check between sensors to be performed. The additional sensors also provide a closer level of detail with respect to the system (NCHRP 2006). The ITS system is an integral part of WSDOT's management of congestion on the state highway systems as nearly all of the congestion performance measurements reported by WSDOT, such as travel time and delay measures, use the loop data in their calculations. Moreover, the size, completeness, and detail of the data archive allow statistical inferences to be drawn with reasonable confidence levels.

Applications for Real-time Data: Collection of real-time data allows WSDOT to publish timely information that is useful for travelers. For example, *travel time* is one of the more easily understood congestion measures for the public. In its broadest sense, travel time measures include average speed or delay and have been used in the transportation literature since the 1920s (Lomax, Turner, and Shunk 1997).

More recently, travel time measures are used to quantify the time required to get between two points on the transportation system. It is easy for the public to understand this measure because it relates information that the public wants to know. Citizens want to know how long it takes to get from their origin to destination, and increases or decreases in this length of time are relevant and important to their every-day lives.

In May of 2002, recognizing the broad appeal and importance that live and real-time travel time information has for the general public, WSDOT launched a travel-time website that provides these data for the public in five minute, real-time intervals. These actual travel times, updated every five minutes, are available for over 30 of the most traveled commute routes in the Puget Sound area.

Figure 1: Example of Scrolling Real-Time Data on Television News

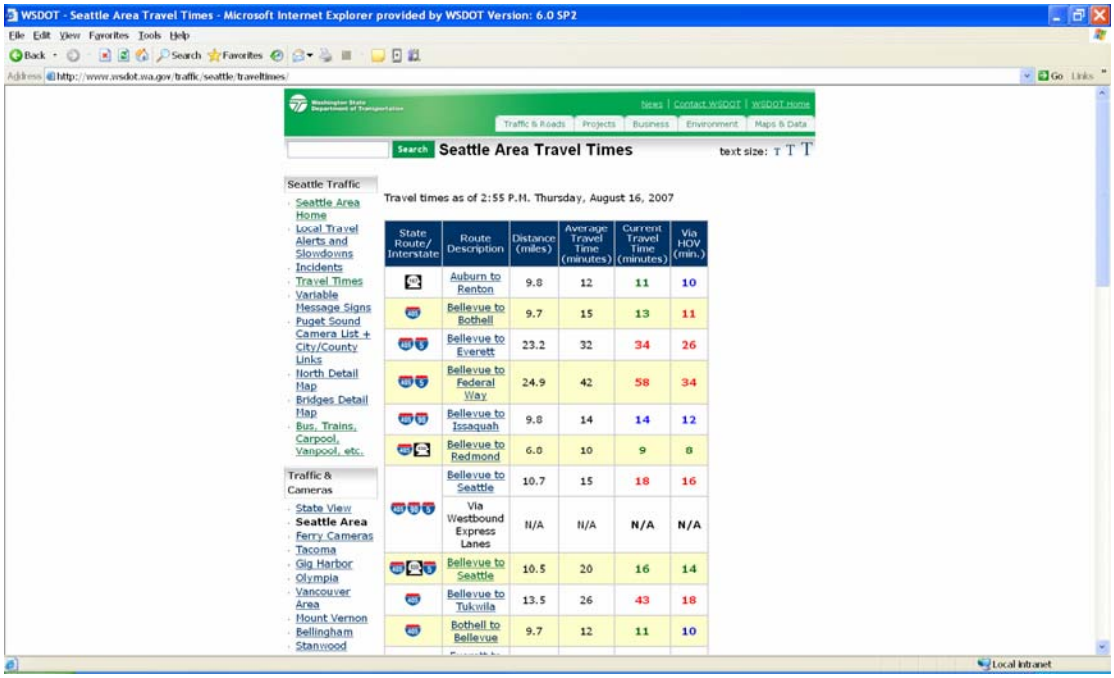


Figure 2: Puget Sound Region Travel Times Website

Average travel times as well as current travel conditions via general purpose and HOV lanes are available. These data are streamed to the media via a link to WSDOT's servers, and are scrolled across the bottom of TV newscasts as well as used in radio traffic report updates. Figure 1 shows how these real-time data are displayed to Puget Sound area commuters. WSDOT's traffic website is another source of travel time information for

Seattle-area commuters, averaging about three to four million page views per day. Figure 2 shows an excerpt of this page that is available at http://www.wsdot.wa.gov/traffic/seattle/traveltimes/.

***MORNING*: Key Commute Routes: Changes in Travel Time Performance, 2003 to 2005**

				Travel Time (in min.)	Average Peak Travel Time, Based on Peak Time (in minutes)			95% Reliable Travel Time (in minutes)			Ratio of Peak Travel Time to Maximum Through-put Travel Time MT³I		Traffic Volume Peak Hour	Duration of Peak Period (hours and minutes that average speed falls below 70% of posted speeds)[1]		
Route	Route Description	Peak time	Length (Miles)	At Posted Speeds	2003	2005	Change (%)	2003	2005	Change (%)	2003	2005	Change (%)	2003	2005	change (in minutes)
To Seattle																
I-5	Everett to Seattle	7:30 AM	23.7	24	47	48	2%	70	68	-3%	1.7	1.7	-1%	2:30	2:35	5
I-5	Federal Way to Seattle	7:40 AM	21.8	22	40	44	10%	54	59	9%	1.6	1.7	-1%	2:30	2:45	15
I-90/I-5	Issaquah to Seattle	8:10 AM	15.5	15	23	26	13%	32	38	19%	1.2	1.3	3%	0:10	1:10	60
SR 520/I-5	Redmond to Seattle	8:40 AM	14.8	16	22	24	9%	29	33	14%	1.3	1.4	0%	0:20	1:00	40
I-5	SeaTac to Seattle	7:40 AM	12.9	13	23	25	9%	29	38	31%	1.5	1.6	-1%	2:25	3:15	50
I-405/I-90/I-5	Bellevue to Seattle	8:40 AM	10.7	11	15	16	7%	23	25	9%	1.2	1.3	1%	*	0:20	*
I-405/SR 520/I-5	Bellevue to Seattle	8:40 AM	10.5	11	18	19	6%	24	28	17%	1.4	1.4	-3%	1:15	1:30	15
To Bellevue																
I-5/I-405	Everett to Bellevue	7:25 AM	23.4	23	n/a	52	n/a	n/a	80	n/a	n/a	1.9	-1%	n/a	2:35	n/a
I-405	Bothell to Bellevue	7:30 AM	16.0	16	35	42	20%	61	66	8%	1.9	2.2	-1%	2:25	2:40	15
1-405	Tukwila to Bellevue	7:35 AM	13.5	13	31	39	26%	42	55	31%	2.0	2.5	4%	3:25	3:45	20
I-5/I-90/I-405	Seattle to Bellevue	7:50 AM	10.6	11	16	17	6%	20	26	30%	1.3	1.4	-2%	0:15	1:20	65
I-5/SR 520/I-405	Seattle to Bellevue	7:50 AM	10.1	11	18	23	28%	26	35	35%	1.4	1.8	-2%	2:05	2:40	35
I-90/I-405	Issaquah to Bellevue	7:45 AM	9.5	9	17	19	12%	24	26	8%	1.5	1.7	3%	1:25	2:05	40
SR 520/I-405	Redmond to Bellevue	9:00 AM	7.1	8	10	9	-10%	12	12	0%	1.1	1.0	1%	*	*	*
To Other Locations																
I-5/SR 520	Seattle to Redmond	7:50 AM	14.7	16	24	29	21%	31	40	29%	1.3	1.6	-1%	1:35	2:20	45
SR 167	Auburn to Renton	7:40 AM	9.8	10	16	17	6%	24	26	8%	1.4	1.5	-2%	1:10	2:35	85
I-5/I-90	Seattle to Issaquah	7:45 AM	15.5	16	19	21	11%	23	26	13%	1.0	1.2	5%	*	n/a	*

Overall MT³I Ratio (average)		
morning commutes	1.25	1.44

Source: WSDOT Traffic Operations and Washington State Transportation Center (TRAC) at the University of Washington
Note: An asterisk (*) indicates that speeds did not fall below 70% of posted speed on a route; and n/a means that no information is available for a route.
[1]SR 520 contains a four-mile stretch that has a posted speed limit of 50mph. In that location, duration is measured as beginning at 84% of the posted speed, which is equal to 70% of 60 mph.

Figure 3: Key Performance Metrics Published in the September, 2006, edition of the Gray Notebook

While these data are extremely popular with the public and the media, they also provide important performance metrics for WSDOT in analyzing system performance. Figure 3 shows a combination of several of WSDOT's real -travel time data based performance measures that are provided to the public, transportation planners and traffic engineers. This information is published in the annual congestion report that is part of WSDOT's *Gray Notebook* (WSDOT *Gray Notebook* September 2006). This annual report is available at http://www.wsdot.wa.gov/NR/rdonlyres/3E501E2B-6E0A-4FD9-8801-2400A9194A45/0/WSDOTCongestionReport.pdf.

Communicating Delay: Delay is reported in WSDOT's annual congestion report in tabular and graphical form. Figure 3 shows delay reported in tabular form, with the economic cost of delay reported along with vehicle hours of delay. In order to make this measure more readily understandable and visual, WSDOT has tried and evaluated various approaches over the years. During an information and best practice exchange with the Japanese Road Bureau, Ministry of Land, Infrastructure, and Transport, WSDOT staff received a three dimensional representation of delay in the Tokyo region and subsequently applied a similar approach. This has proven very effective and has become a main component of WSDOT's annual congestion report. Figure 4 shows delay in three

dimensional graphical form, designed to give the reader an idea of the intensity of delay that is experienced in different parts of the state.

WSDOT uses the *duration of peak period* measure to describe the duration of congestion, and reports these data by commute corridors. WSDOT defines this measure as the period in which average weekday speed on a roadway segment falls below 70% of the posted speed (the minimum threshold of maximum throughput). By measuring the duration of peak period, the public is able to evaluate periods in the morning and afternoon when they should expect congestion on certain routes, and transportation planners can evaluate the duration of time where the system is operating at below maximum efficiency or throughput. In addition, the public is able to evaluate periods in the morning and afternoon when they should expect congestion on certain routes when making commuting decisions. In recent years, WSDOT has noted that the duration of the peak period is spreading, with many morning commutes seeing significant increases in volume and drops in average travel speeds as early as 5 am on a weekday, and lasting as late as 10:30 am.

WSDOT measures and reports the duration of the peak period for select routes in the Puget Sound area. These data are presented in the *Gray Notebook* as well as on the internet at http://www.wsdot.wa.gov/Accountability/Congestion/Default.htm. Figure 3 above is an excerpt from the September 30, 2006, congestion report and includes a column where the "Duration of Peak Period" is listed for each route. Data for additional routes are available at the website listed above.

Use "Plain English and Good Graphs" to Describe Results

WSDOT uses the principles of what it calls "Performance Journalism" to communicate all performance reporting information. Performance Journalism was developed over a six-year period internally at WSDOT and emphasizes making performance information understandable and interesting to a variety of target audiences. *Effective communication* is emphasized as opposed to merely publishing data that may be difficult for citizens to understand. The key elements of clear writing and story telling, effective graphic presentation of data, and rigorous data analysis and data quality control are the foundation for the following seven principles of Performance Journalism and for all subsequent agency performance reporting:

- Good stories combined with good graphics – Use narrative reporting to make it real and tell the story
- Good writing – Use a reader-friendly approach
- Good data – Every graph tells a story – every graph asks a question
- Good graphics
- Good format/presentation
- Quality Control – It's your credibility
- Good timing – Lead, don't follow

Examples of Performance Journalism Approach to Communicating Congestion Data: The sum of vehicle delay across an average twenty-four hour day is in WSDOT's view a basic and easily understood measure for describing congestion. It is the composite of the extent, severity and duration of congestion. WSDOT uses various approaches to communicate delay data and concepts. This has proven very effective and has become a main component of WSDOT's annual congestion report. The 3-D graph in figure 4 is an example of visualizing the data in a way that can be easily and quickly understood by multiple audiences. This visual graph is used to demonstrate magnitude of congestion

across the state. The table in figure 5 complements this graph and provides the cumulative delay data in another form.

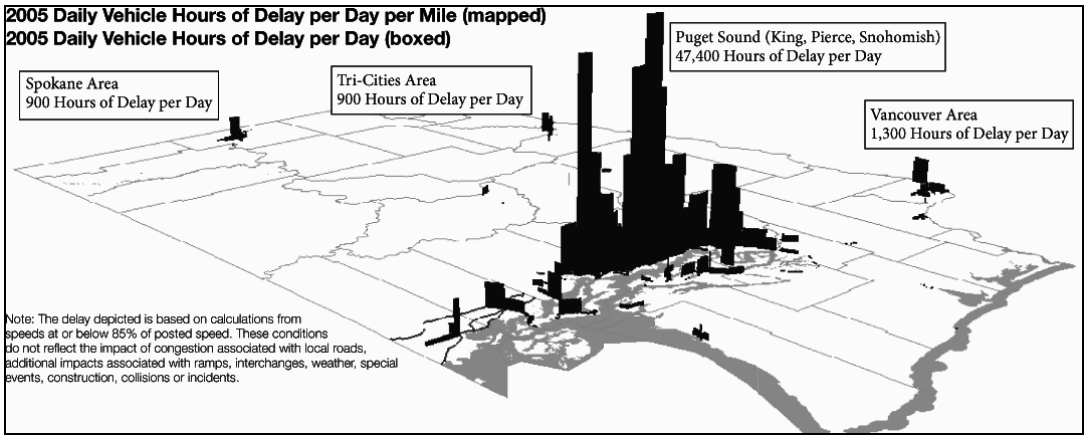


Figure 4: Graphical Representation of Delay Data

All State Highways: Average Weekday Delay Comparison (Daily and Annual) and Estimated Cost of Delay on State Highways (Annual), 2003 and 2005

	DAILY Average Vehicle Hours of Delay (Weekdays)			ANNUAL Average Weekday Hours of Vehicle Delay (in thousands)			ANNUAL Cost of Delay on State Highways (in Millions of 2005 dollars)		
Actual Travel Compared to	**2003**	**2005**	**Change**	**2003**	**2005**	**Change**	**2003**	**2005**	**Change**
Optimal Flow Speeds (Approx 51 mph)	82,200	99,400	21%	20,550	24,850	21%	$486	$598	23%
Posted Speeds	156,300	173,800	11%	39,075	43,450	11%	$920	$1,043	13%

Source: WSDOT Urban Planning Office

Figure 5: Tabular Representation of Delay Data

Stamp graphs –Providing clear explanations: The "stamp graph" in figure 6 is an example of the type of graph used to show severe congestion on each of the 35 Central Puget Sound routes that are tracked by WSDOT for performance reporting. These graphs compare multi year data and communicate the percent of days on each route when traffic speeds fell below 35 mph, or when the traveler experiences "severe congestion." While the graphs are easy to follow, WSDOT still provides an illustrative example and brief explanation on how these graphs should be read (see Figure 7). The graphs are all grouped onto two pages and apply the same scale, using performance journalism graphing principles that allow the reader a quick, side by side visual scan of otherwise pretty complex congestion data.

Measure Congestion Due to Incidents (Non-Recurrent) as Distinct From Congestion Due to Inadequate Capacity (Recurrent)

The reliability of the system is often significantly impacted by congestion caused by incidents such as accidents, weather, or special events (non-recurrent congestion). This is especially true if the system is suffering from insufficient system capacity due to regular heavy demand (recurrent congestion) versus congestion caused by incidents (non-recurrent congestion) such as accidents, weather, or special events.

A decade ago, Lomax, Turner, and Shunk (1997) recognized the relationship between non-recurrent congestion and travel time: "Daily congestion delay caused by excessive traffic volume is relatively stable and somewhat predictable. Non-recurrent (due to accidents, vehicle breakdown, weather, etc.) delay causes much greater variation

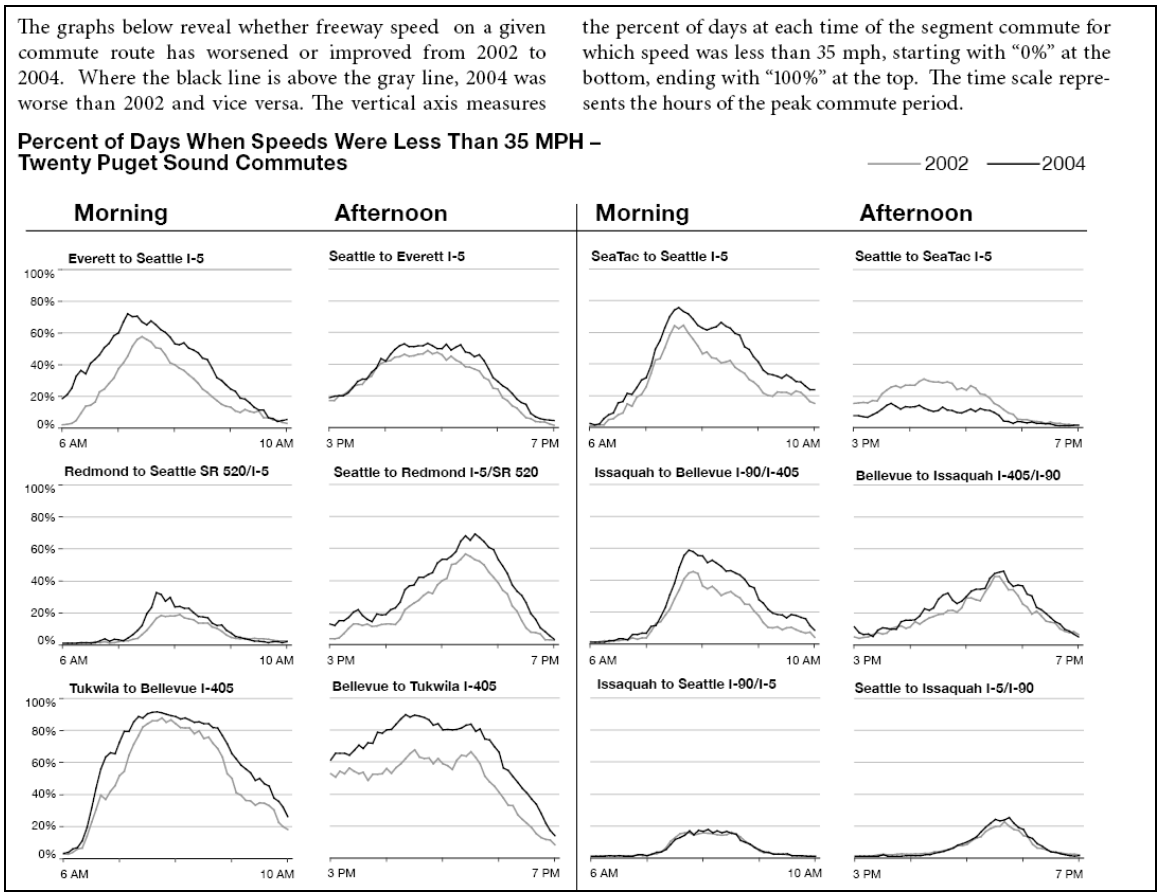


Figure 6: Stamp Graph Representing Severe Congestion

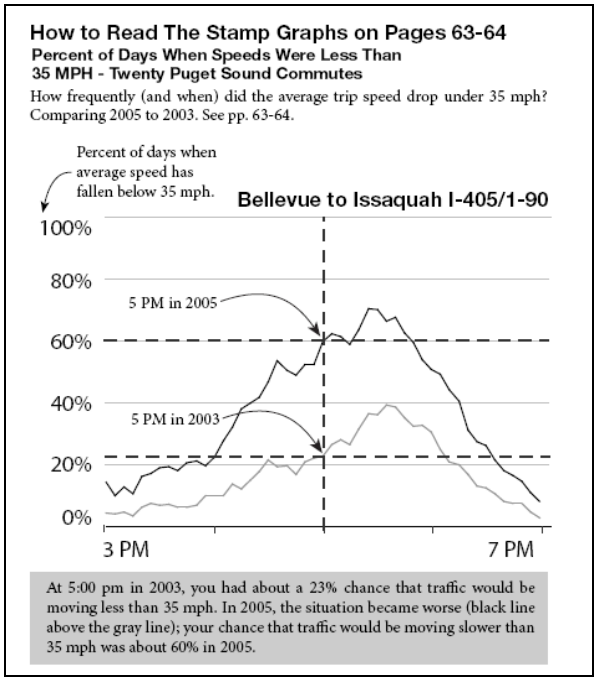


Figure 7: How to Interpret a Stamp Graph

in the amount of congestion and is much less easily predicted. Reliability is the impact of non-recurrent congestion on the transportation system" (p. 3). The authors suggested the use of standard deviations of average travel rates and/or delay measures to study

reliability (p. 7). Differences in standard deviations may be appropriate to compare a singe corridor across time periods (for example, Corridor A in 2003 versus 2005), but it is not useful for comparing two corridors in a single period or across time periods. Rather, the use of the coefficient of variation is appropriate to make comparisons.

The need to measure the effectiveness of operational strategies drives the effort to isolate and quantify non-recurrent congestion. WSDOT recognized this need when trying to measure the results of its expanded Incident Response (IR) program in 2002. Initially, due to the lack of viable alternatives, WSDOT chose to use two times free flow speed as a threshold to define when incident-related congestion was taking place while research continued that could better identify recurrent versus non-recurrent congestion. In other words, WSDOT defined incident-related congestion as occurring when the time to complete a trip takes more than two times the amount of time to complete the trip under free-flow conditions.

WSDOT used this definition to examine historical data from 2001 and 2002 for 11 routes in the Puget Sound area but then abandoned this approach because the precision was inadequate. The study did yield some significant results including the conclusion that non-recurring delay is responsible for between 30 and 50 percent of all peak period delay, and lane blocking incidents are responsible for approximately 10 to 35 percent of non-recurring delay. Unfortunately, efforts to be more specific in these percentages have been unsuccessful due to the complexity of parsing out recurrent versus non-recurrent congestion from available data.

Measure Travel Time Reliability and Variability

Travel time communication was discussed above in the section about the use of real-time data to communicate congestion. Again, travel time is one of the more easily understood congestion measures for the public and policy makers because this measure is easy for commuters to relate to their real-life experiences. At the same time, travel time reliability and predictability is important to the public. It allows travelers to budget sufficient time for commuting while at the same time preventing commuters from arriving at their destination too early and thus, losing the opportunity cost of the time reserved for commuting. Reliability measures the variability in travel times for specific commutes. Increased travel time reliability is often associated with non-recurrent congestion as mentioned above. Variability in travel times leads to frustrating and costly uncertainty for commuters and freight haulers.

Not only are travel time reliability measures useful for the public, they are also useful to the transportation agency to assess freeway performance. Recent work by the National Cooperative Highway Research Program advocates the development and application of these measures to assess freeway performance (NCHRP 2006). WSDOT has been using this metric for over five years to assess system performance. Travel time reliability is important to the public.

Some organizations use the Buffer Index, a number expressed in percentage terms to indicate the additional amount of time “that travelers must add to their average travel time when planning trips to ensure on-time arrival” (FHWA 2006)**.** While widely applied, the buffer index is less user-friendly than other reliability measures in communicating with the public. First, the index is unitless. Second, it requires a user to first know one’s average commute time, then perform a computation to derive the time required to make it to a commute destination on time. Thus the buffer index is not a good communication tool for the public and policy makers.

Rather than report the buffer index (FHWA 2006, TTI 2007), WSDOT chose to report the *95% reliable travel time*, which is the basis of one of WSDOT's principles for communicating congestion measures. Whereas an index is a ratio and more abstract and difficult to communicate, a specific travel time gives the user tangible and easily understood information (Bertini 2006). This measure, like travel time, is both a performance metric and important traveler information service.

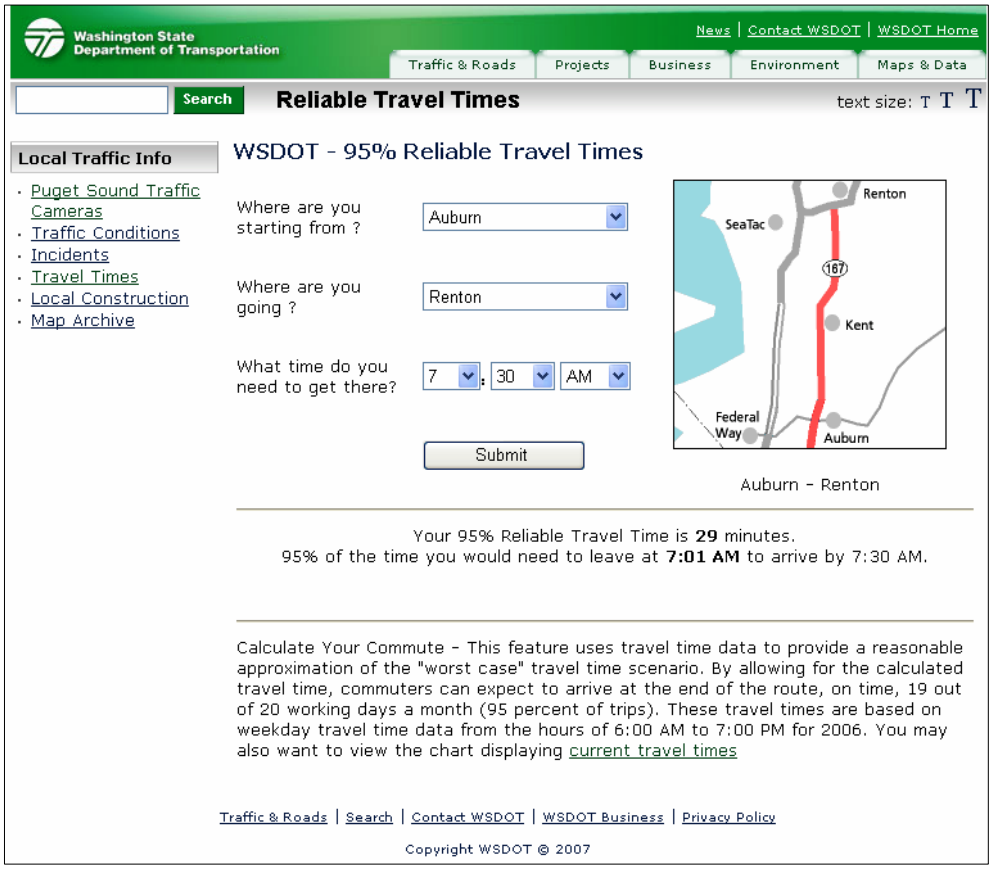


Figure 8: Screen Shot of WSDOT's Interactive, 95% Reliable Travel Time Public Information Website, http://www.wsdot.wa.gov/Traffic/Seattle/TravelTimes/95reliable.html

The 95% reliable travel time measure has limitations when trying to define one system-wide reliability performance metric in a roll-up fashion. For this particular purpose, an index may be more appropriate. With the 95% reliable travel time measure, a commuter is able to predict, with 95 percent certainty, the amount of travel time they will need to set aside in order to make it to their destination on time 95 percent of the time. For example, if a commuter travels during peak travel periods five days a week for a four-week period (20 weekdays), using the 95% reliable travel time, the commuter will arrive on-time on 19 out of those 20 days. WSDOT believes this measure is important to commuters, as they plan trips based on the worst days, not the average day.

WDOT uses this metric to compare system performance from year to year based on each corridor (see figure 3). This measure, as reported in the GNB, is computed by taking the peak five minute travel time for the year, then rank ordering the travel times for all weekdays in that year during that peak five minute period, and then choosing the first travel time that is the greater than 95% of the travel times. In addition, similar to the travel time table in the GNB, WSDOT provides an interactive website that the public and

media can use to determine the 95% most reliable travel time for a particular highway corridor and route based on the previous year, weekday travel times (6 am to 7 pm), an excerpt of which is shown in figure 8.

Communicate Congestion Fixes Using an "Apples-to-Apples" Comparison with the Current Situation

WSDOT also informs the public about the results of capital improvement programs with respect to mitigating congestion. Specific projects are used to illustrate these results using Before and After studies that compare congestion performance measures in an area after an improvement is completed to the same measures before the improvement. For example, figure 9 illustrates the effect of ramp metering in alleviating congestion using throughput and travel speeds as the measures. In this case, the use of real-time data was very useful for the Before and After analysis.

Use Maximum Throughput as a Basis for Congestion Measurement

Recently, WSDOT has emphasized *system efficiency* in its management of congestion on state highways in Washington State. Throughput is one of the most important aspects of this system efficiency goal. Maximum throughput is the maximum number of vehicles that can pass through an individual lane every hour, which is approximately 2000 vehicles per lane per hour on highways, and is achieved when traffic on a roadway is traveling at 70%-85% of the posted speed limit. Maximum throughput differs from other measures of system efficiency that are based on posted speed. Moving traffic at the posted speed in modern urban areas at peak times is unrealistic, but more importantly it ignores the potential cost savings of adequately using existing highway infrastructure over the long term. One of the most important goals of WSDOT is to manage the current highway system to achieve maximum throughput and productivity. This is part of balanced system management approach that examines and evaluates capacity utilization of the existing highway system as well as new capacity requirements.

As congestion increases and traffic begins to move slower than 70% of the posted speed limit, overall productivity declines and the highway supports fewer vehicles, as highways are engineered to move specific volumes of vehicles. In addition, highways do not operate at their maximum efficiency when moving at 60 MPH (the most common highway speed limit in Washington State) because of the need for increased spacing between vehicles.

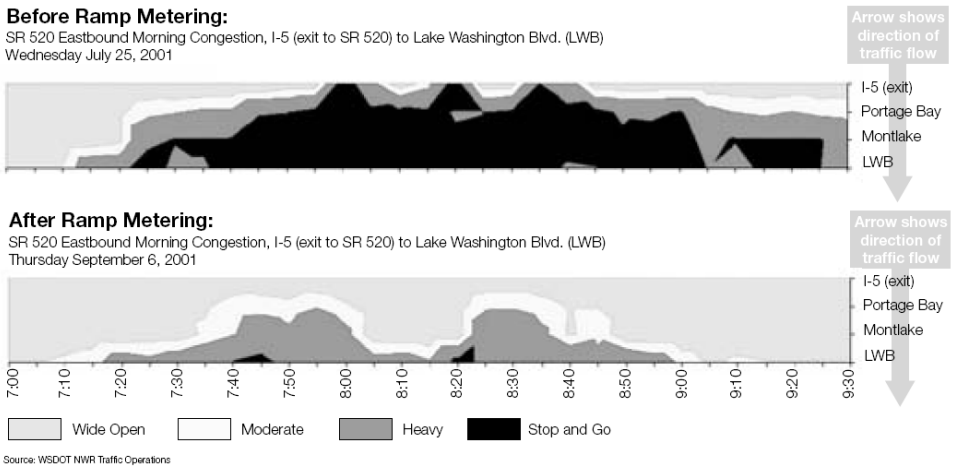
Maximum throughput (optimal flow) speed is not a static number for all highways, and can vary from facility to facility and from segment to segment depending on conditions such as lane width, slope, shoulder width, pavement conditions, traffic composition, and presence or lack of a median barrier for example. It should be noted that, as cars are equipped with more sophisticated devices and become easier to maneuver, maximum throughput speed should increase. Currently, maximum throughput speed on a typical freeway segment in the Central Puget Sound region is about 51 mph (roughly 85% of the posted speed). For surface arterials, maximum throughput speed is even more difficult to determine, as it is heavily influenced by conflicting traffic movements at intersections. Ideally, maximum throughput speeds for each highway segment would be determined through comprehensive traffic studies and validated based on field surveys. Due to resource constraints and for simplicity, 85% of posted speed is used as a surrogate for the true optimal flow speed for the purpose of performance analysis.

Case Studies – Before and After Results

Case Study 1 - Ramp Metering

Smoother Merging, More Throughput, and Higher Speeds
Reducing highway traffic congestion is the primary goal of ramp metering. Ramp meters respond to actual traffic conditions, linking computers with sensors embedded in the ramps and on the freeways near the ramps. These act as metal detectors, registering when a car or motorcycle passes over the sensor. This information is fed to a central computer, that in turn adjusts the rate at which the ramp meter signal releases drivers to enter the mainline. If cars start to back up onto the city street, the ramp meter automatically speeds up to clear the queue. If traffic is light on the highway, the meter also speeds up to allow more cars to merge. If traffic is heavy everywhere, which is often the case during peak hours, the computer optimizes the flow. Ramp meters help smooth traffic flow. The Transportation Management Center in Seattle monitors over 150 freeway ramp meters, and one in Vancouver, during congested hours on all days. Ramp metering reduces congestion while increasing throughput and freeway speeds.

How do we know ramp meters reduce congestion?
The following chart shows traffic conditions on SR 520 between I-5 and the floating bridge on a typical morning (July 25, 2001) without ramp metering.



Before
Reading the top graph, the black shading shows stop-and-go traffic from 7:30 a.m. to 9:30 a.m., extending back to I-5 at different times. At 8:00 a.m. on this day, traffic flow on SR 520 eastbound was at a rate of 2,780 vehicles per hour.

After
The bottom graph shows a typical morning (Sept. 6, 2001) after ramp metering was activated along the corridor. Stop-and-go traffic was limited to a total duration of about 15 minutes and never extended west of Montlake Blvd. NE. At 8:00 a.m. on this day, traffic flow on SR 520 was at a rate of 3,265 vehicles per hour.

Figure 9: Before and After Analysis of Congestion Strategy

By emphasizing maximum throughput in its congestion mitigation policy, WSDOT is able to utilize existing assets in an efficient manner, while simultaneously moving passengers and freight on highways in the most cost-effective way. Figure 10, from the September 30, 2006, edition of the *Gray Notebook* depicts the relationship between speed and throughput.

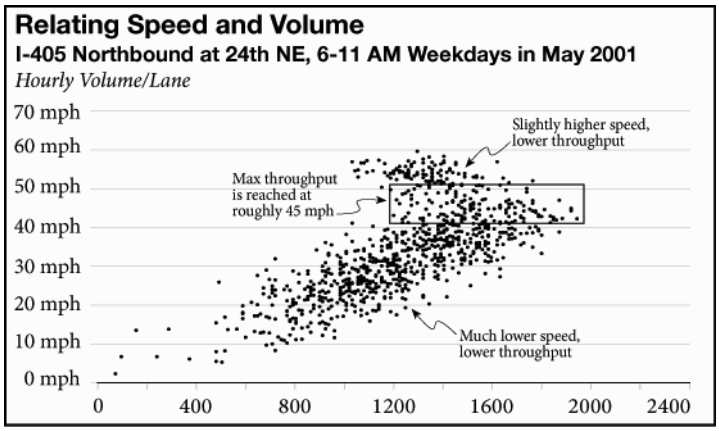


Figure 10: Relationship of Speed and Throughput

It is also important to communicate to the public and others, particularly legislators, the effect that lost productivity or throughput has on highway efficiency. At the same time, the principle of communicating non-recurrent versus recurrent congestion is important. WSDOT has used graphs to communicate these two concepts. Figure 11 depicts the percent of lost throughput as a result of lane or shoulder blocking incidents (non-recurrent congestion) at one point in the Puget Sound freeway system. Figure 12 shows total lost throughput for another point in the system.

The Maximum Throughput Travel Time Index (MT³I): Many transportation agencies use the Texas Transportation Institute's Travel Time Index (TTI) for performance reporting. TTI is defined as the ratio of peak travel time to the travel time for a given roadway segment based on travel at the posted speed limit. WSDOT has not used the TTI because it is based on posted speed. This violates a key congestion management principle and

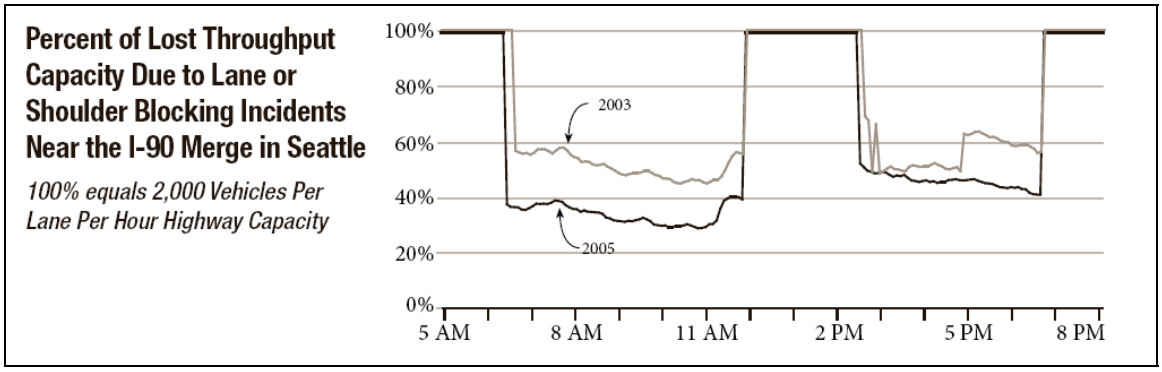


Figure 11: Graphical Representation of Lost Throughput from Non-Recurrent Congestion

indices are difficult to communicate as discussed previously. WSDOT challenged the Texas Transportation Institute's methodology for computing congestion measures based on free-flow speeds as opposed to maximum throughput speeds. Using free-flow speeds as the benchmark for defining when congestion begins implied that congestion was getting worse even when the system was carrying more vehicles per hour at maximum throughput speeds. WSDOT was not able to convince the institute to change its measurement basis for the index in its annual *Urban Mobility Report* and on May 14, 2002, WSDOT temporarily ended its sponsorship of the report.

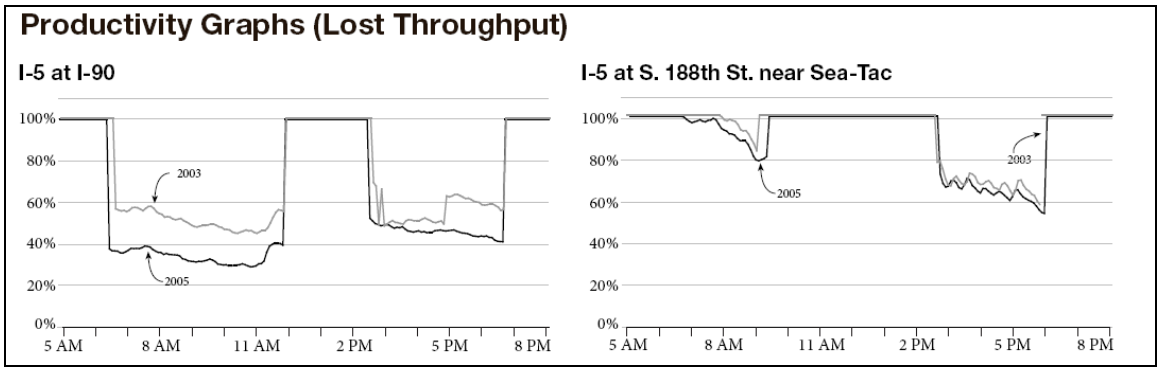


Figure 12: Total Lost Throughput Due to Recurrent and Non-Recurrent Congestion

This raised national attention and began an active, public dialogue about maximizing system efficiency and the measurement and application of operational strategies to address congestion (The Urban Transportation Monitor 2002). More recently, WSDOT

has further expanded its set of congestion measures and has included a customized TTI version, the "Maximum Travel Time Index, or MT³I (see figure 3). The MT³I is based on maximum throughput thresholds to illustrate viable alternatives to the current TTI approach

Unlike the TTI, the MT³I assess congestions in terms of productivity of the highway systems. It is the ratio of peak travel time to the theoretical maximum throughput travel time for a given roadway segment based on the time it takes to travel the segment at speeds where the system is operating at maximum throughput (70%-85% of the posted speed limit). This measure is directly proportional to delay and inversely proportional to the ideal level of service (which is reached during maximum throughput). For example, if a commute route has an MT³I value of 1.7, on average the travel time during the peak travel period for that commute is 70% longer than the ideal travel time at maximum throughput. The closer the MT³I value is to 1.0, the more efficient (closer to the ideal level of service or maximum throughput) the average commute is for that particular route.

The delay and cost measure, seen in Figure 5, is another congestion performance report example that illustrates the difference in managing and measuring to maximum throughput (optimal flow) speed versus posted speed. Figure 5, seen previously, compares average weekday delay between 2003 and 2005 on all state highways, estimated from traffic counts collected on state highways. Congestion is worse based on either threshold but the table demonstrates that system performance in relationship to maximum throughput speed has deteriorated more and many congested highways got even more congested from 2003 to 2005, possibly requiring a different response and management approach.

ENGAGING THE PUBLIC TO EFFECTIVELY COMMUNICATE CONGESTION SOLUTIONS: THE DOUG MACDONALD CHALLENGE

Background

Congestion measurement and analysis remains a complex issue and many of the previous concepts are difficult to convey to the public and policy makers. Highway system performance measurement and reporting is an ongoing challenge and WSDOT continuously seeks innovative ideas and better methods to communicate key concepts and results. While managing the system to maximize and fully leverage existing public infrastructure investments seems a given, how can these principles be effectively and compellingly communicated to the public and decision makers? This is particularly difficult because the public is asked to accept congestion thresholds and strategies that do not manage the system to free flow or posted speeds - a perceived standard. Rather, these thresholds and strategies manage the system to lesser speeds that yield higher vehicle throughputs. In addition, this requires the deployment of operational strategies, which are often difficult to measure, and strategies such as variable pricing and tolling that can become highly contentious issues. Hence the importance of effective performance communication becomes even more critical.

In response to this dilemma WSDOT Secretary Doug MacDonald announced a contest entitled "The Doug MacDonald Challenge," to create the most effective communication tool for conveying the concept of "maximum throughput" to the general public and the media. The winner would receive a $1000 prize donated by MacDonald himself. The contest was sponsored by the Transportation Research Board's (TRB) Congestion Pricing Committee (ABE25), who helped to advertise the contest to a

national audience at a wide variety of institutions. The objective of this contest was to help convey the importance of WSDOT's goal of system efficiency on state highways, as opinion research had shown that the public was unaware or not educated about this strategy for managing congestion, as well as to help make the case for congestion pricing on state highways in the future. Each entry could submit a 175 word submission, with an additional chart, graph or graph to supplement the written explanation. (See http://www.trb-pricing.org/challenge for original call for papers).

Soon after announcing the contest at TRB's 2006 Summer Conference in La Jolla, California, the *Seattle Times* picked up the story, but misreported the details of the contest as the best idea for "relieving traffic," in the title of the article, "Got any bright ideas to relieve traffic? State roads official offers $1,000 prize" (*The Seattle Times*, September 2006). Subsequently, over 250 enthusiastic members of the public sent in congestion mitigation ideas to WSDOT before the details of the contest were corrected by the *Seattle Times*.

While surprised about the volume of responses, WSDOT was very interested in this unsolicited, public opinion poll. Many submissions were very thoughtful and detailed and demonstrated interesting insights into perspective and understanding of the congestion problem. WSDOT analyzed these unsolicited submissions in detail to gain a better understanding of the publics' knowledge of and feelings about transportation issues related to congestion. As such they proved to be a very valuable resource. Based on submission information, approximately 80% of entrants were men, and 20% were women. Seven suggestions came from Bainbridge Island, 10 from Bellevue, and 61 from Seattle. Two Californians, one Canadian, and one Briton) supplied entries. A writer from Nigeria and one from Sierra Leone each promised riches for Secretary MacDonald if he would help get their bank accounts safely to America. The suggestions for relieving congestion were wide-ranging and included ideas such as eliminating HOV lanes, teaching drivers how to merge, lowering the speed limits, raising the speed limits, tolling of highways, and 16 entries suggested building more roadways.

The Actual Challenge

Once the *Seattle Times* corrected the nature of the Challenge and TRB distributed details via e-mail to committees and website, the "real" contest drew 90 separate submissions from 24 states, three countries, and a variety of institutions. Of the 90 submittals 28% were consultants, 22% public-sector transportation professionals, 27% academics, 22% from the general public, and two projects from non-profit groups.

In January, 2007 Secretary Doug McDonald announced and presented the winning entry at the TRB's 2007 Annual Meeting in Washington to a standing room only crowd of hundreds congestion pricing workshop attendees and transportation professionals. Paul Hasse of Sammamish, Washington was the winner of the Doug MacDonald Challenge. His winning entry explained the concept of maximum throughput through a demonstration of pouring a bag of dry rice through a funnel. In this demonstration, pouring all the rice at one time into the funnel causes a clog in the funnel spout, and very little rice makes it out the bottom. Yet, by pouring the rice slowly through the funnel, the rice organizes itself in a more efficient manner, and the rice flows out the spout at a rate roughly one-third faster than if poured in all at once. Figure 14 shows Doug MacDonald demonstrating this concept on a Seattle television station morning show.

Other runners up (see figure 15) had similar concepts for explaining maximum throughput. A few entries explained the "clogging" concept through examples using

bricks on a worksite and grass clippings in a lawn mower. Other entries were more theoretical, and demonstrated the physics and logic behind the concept of maximum throughput in terms of speed and volume on the highways. Others suggested more practical solutions for achieving maximum throughput, such as adding toll lanes adjacent to existing highways to lower the overall volume on the highway, and using video games to help explain the concept of maximum throughput to the general public.

Figure 14: Doug MacDonald Displays Winning Entry Concept on Local News Broadcast

This example can be applied to real-world conditions, where the volume on a highway system can become so great at one time (i.e. rush-hour), that the average number of vehicles traveling per lane per mile begins to rapidly fall as the peak period progresses. By controlling the flow and volume of vehicles on the roadway, more vehicles are able to move per lane per mile, thus increasing system efficiency and reducing the need to build more costly infrastructure. This project demonstrated to the general public and the media how practices such as ramp metering, HOV lanes, HOT lanes, and specifically congestion pricing can help to relieve congestion and efficiently use existing roadways by controlling the volume and flow of vehicles on the roadway, especially during morning and afternoon peak periods. Pouring the rice through the funnel shows this perfectly because almost everybody knows from experience and intuition exactly what will happen even before they see it done. They can even do it themselves in their own kitchen and when they see the demonstration, they recognize a highway in the stuck rice. The winning approach to the challenge says ”it’s all about organizing the particle flow in contrast to letting the unorganized particle flow jam itself up.

What WSDOT Learned

This demonstration of public participation and education in conveying maximum throughput issues resulted in a few, but critical takeaway messages and lessons learned that were quickly applied and yielded results.

First, communicating difficult to understand (maximum throughput) and politically sensitive subjects (tolling and congestion pricing) to the general public and the media is best done in an engaging, humorous, and disarming manner. And second, engaging a wide variety of audiences, such as engineers and the general public, with a visually pleasing and hands-on presentation is useful in implementing new and complex transportation concepts.

WSDOT quickly deployed this communication approach in various settings including a presentation in the White House, with the state governor and legislators, at national transportation conferences, local chambers of commerce meetings, and on local television news broadcasts.

While pricing remains a challenging and controversial subject, WSDOT was able to effectively communicate maximum throughput concepts and benefits locally and nationally. Subsequently WSDOT was successful in partnering with the City of Seattle, Puget Sound Regional Council, and King County to develop and submit an Urban Partnership Agreement proposal that included a pricing component for S.R. 520 (floating bridge across Lake Washington) to USDOT that was ultimately selected as one of the 5 finalist for the multi-million dollar grant.

CONCLUSION

Communicating congestion performance measures to a diverse audience is challenging. The complex nature of these measures makes them difficult to communicate, while their constant evolution exacerbates the communication problem. Nevertheless, there are principles that can be followed in a congestion performance measurement and communication program which the WSDOT experience has shown to be helpful in meeting this challenge. These principles include 1) use real-time data (rather than computer models) whenever possible; 2) Use “Plain-English” to describe results; 3) measure congestion due to incidents (non-recurrent) as distinct from congestion due to inadequate capacity (recurrent); 4) measure travel time and travel time reliability; 5) communicate congestion fixes using an “apples-to-apples” comparison with the current situation; and, 6) use maximum throughput as a basis for congestion measurement.

Even when these principles for effective communication of congestion performance measurement are followed, the evolution of the measures sometimes forces transportation agencies to find new and innovative methods for communication. The *Doug MacDonald Challenge* exemplifies how public input can be used to solicit ideas for communicating complex congestion and system operations performance measures. This collaborative and innovative approach can yield successful and compelling strategies for communicating highway system performance and capacity management results.

Figure 15: The Winning Entry and Three Runners Up

REFERENCES

Bertini, R L. You Are the Traffic Jam: An Examination of Congestion Measures. Transportation Research Board, Washington D.C., January 2006, text file, TRB CD-ROM.

Bremmer, D. The Changing Role of Transportation Performance Measures. www.ntoctalks.com/icdn/perfmeas_bremmer.php, 2005. Accessed August 10, 2007.

Bremmer D., Cotton, K., and Cotey, D. Measuring Congestion: Learning From Operational Data. *Transportation Research Record: Journal of the Transportation Research Board, No. 1895*, TRB, National Research Council, Washington, D.C., 2004, pp. 188-196.

Bremmer, D., Cotton, K., and Hamilton, B. Emerging Performance Measurement Responses to Changing Political Pressures at State DOTs: A Practitioners' Perspective. *Transportation Research Record: Journal of the Transportation Research Board, No. 1924*, TRB, National Research Council, Washington, D.C., 2005, pp. 175-183.

Gilmore, S. "Got any bright ideas to relieve traffic? State road official offers $1000 prize," *The Seattle Times*, 2 September 2006.

Lomax, T., Turner, S., Shunk G., Levinson, H S., Pratt, R H., Bay, P N., and Douglas, G B. Quantifying Congestion: Volume 1, Final Report. *Transportation Research Board: NCHRP Report*, TRB, National Research Council, Washington, D.C., 1997.

National Cooperative Highway Research Program. Guide to Effective Freeway Performance Measurement: Final Report and Guidebook 2006. http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w97.pdf. Accessed August 15, 2007.

Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), U.S. Code volume 23, section 5502 (2005).

Texas Transportation Institute. *2007 Urban Mobility Report*. Texas A&M University Press, College Station, TX, September 2007.

Tufte, E.R. *The Visual Display of Quantitative Information*. Graphics Press, Cheshire, CT, 1983.

U.S. Department of Transportation, Federal Highway Administration. Travel Time Reliability: Making It There On Time, All the Time. http://ops.fhwa.dot.gov/publications/tt_reliability/index.htm. Accessed August 15, 2007.

Washington State Department of Transportation. Reader Friendly Document Toolkit. www.wsdot.wa.gov/TA/T2Center/ToolKitDocument.pdf Accessed August 15, 2007.

Washington State Department of Transportation, Strategic Planning and Programming Division. *Measures Markers and Mileposts: The Gray Notebook for the Quarter Ending September 30th, 2006*

Wright, D R., and Ishimaru, J M. Data Quality Approach of Tracflow Software. *University of Washington, Washington State Transportation Center-Seattle (TRAC).* 2007.

Author Unknown "TTI Annual Report Documents Increased Congestion: WSDOT Withdraws Its Support" for TTI Study, Citing Lack of Recognition of Operational Improvements, *The Urban Transportation Monitor,* Vol. 16, No.12, 28 June 2002.