**Final Research Report**
Agreement T2695, Task 63
Delay Causes WSDOT

# MEASUREMENT OF RECURRING AND NON-RECURRING CONGESTION: PHASE 2

by

Jaime M. Kopf
Research Engineer

Jennifer Nee
Research Engineer

John M. Ishimaru
Senior Research Engineer

Mark E. Hallenbeck
Director

**Washington State Transportation Center (TRAC)**
University of Washington, Box 354802
University District Building
1107 NE 45th Street, Suite 535
Seattle, Washington 98105-4631

Washington State Department of Transportation Technical Monitor
Daniela Bremmer, Director of Strategic Assessment
WSDOT Transportation Planning Office

Prepared for
**Washington State Transportation Commission**
Department of Transportation
and in cooperation with
**U.S. Department of Transportation**
Federal Highway Administration

July 2005

# TECHNICAL REPORT STANDARD TITLE PAGE

| 1. REPORT NO. | 2. GOVERNMENT ACCESSION NO. | 3. RECIPIENT'S CATALOG NO. |
|---|---|---|
| WA-RD 619.1 | | |

| 4. TITLE AND SUBTITLE | 5. REPORT DATE |
|---|---|
| MEASUREMENT OF RECURRING AND NON-RECURRING CONGESTION: PHASE 2 | July 2005 |
| | 6. PERFORMING ORGANIZATION CODE |
| 7. AUTHOR(S) | 8. PERFORMING ORGANIZATION REPORT NO. |
| Jaime M. Kopf, Jennifer Nee, John M. Ishimaru, Mark E. Hallenbeck | |
| 9. PERFORMING ORGANIZATION NAME AND ADDRESS | 10. WORK UNIT NO. |
| Washington State Transportation Center (TRAC)<br>University of Washington, Box 354802<br>University District Building; 1107 NE 45th Street, Suite 535<br>Seattle, Washington 98105-4631 | 11. CONTRACT OR GRANT NO.<br>Agreement T2695, Task 63 |
| 12. SPONSORING AGENCY NAME AND ADDRESS | 13. TYPE OF REPORT AND PERIOD COVERED |
| Research Office<br>Washington State Department of Transportation<br>Transportation Building, MS 47372<br>Olympia, Washington 98504-7372<br>Doug Brodin, Project Manager, 360-705-7972 | Final Research Report<br><br>14. SPONSORING AGENCY CODE |

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

In 2003, the Washington State Department of Transportation (WSDOT) initiated a research effort to develop and test a methodology for estimating congestion delay on Seattle area freeways. The initial phase of the research developed a preliminary methodology for both measuring congestion and assigning that congestion to specific lane blocking incidents. In Phase 2 of this study, that methodology was automated and extended to include an examination of the effects of incidents occurring on the shoulders of the freeway, spillback from incident-caused congestion on one freeway that affects a second freeway that feeds traffic onto the initially congested facility, special events, and weather.

Because funding for this effort was extremely limited, only three corridors (with both directions analyzed independently) and two months of data were analyzed. The project found that the Phase 1 methodology works well in assigning traffic congestion that occurs in the immediate time frame and geographic location of incidents to those incidents. It also showed that this process can be automated, making the data preparation effort now the primary determinant of the cost of additional work of this kind.

Unfortunately, even with the addition of shoulder incidents, special events, and weather to lane blocking events, the automated process is unable to assign a significant proportion of the non-recurring delay occurring on Seattle freeways. The detailed analysis of freeway performance showed that much of the delay caused by specific incidents occurs in places or at times removed from the incident itself. The result is that much of the observed non-recurring delay can not be assigned to specific causes by the current analytical process. New analytical procedures will need to be developed in Phase 3 of this work.

The Phase 2 analysis also confirmed that the congestion effects of specific incidents and other traffic disruptions are highly dependent on the background traffic conditions at the time of the disruption. While the Phase 2 analysis did not produce all of the results desired, the additional analyses showed that the summary statistics output from the Phase 2 software are useful as input to other analytical procedures.

| 17. KEY WORDS | 18. DISTRIBUTION STATEMENT |
|---|---|
| Traffic congestion, freeway performance, congestion causes | No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616 |

| 19. SECURITY CLASSIF. (of this report) | 20. SECURITY CLASSIF. (of this page) | 21. NO. OF PAGES | 22. PRICE |
|---|---|---|---|
| None | None | | |

## DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Washington State Transportation Commission, Washington State Department of Transportation, or Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

# CONTENTS

## FIGURES



## TABLES

# EXECUTIVE SUMMARY

In 2003, the Washington State Department of Transportation (WSDOT) initiated a research effort to develop and test a methodology for estimating congestion delay on Seattle area freeways. Of particular interest was the development of methods for estimating the extent to which congestion delay on Seattle area freeways is related to non-recurring events and for determining the relative importance of the different causes of non-recurring congestion. The first phase of the project examined the effects of lane blocking incidents on congestion. Among the primary conclusions from that effort were the following:

- The percentage of congestion associated with non-recurring events varied greatly from freeway to freeway, due in large part to the level of routine congestion each facility experienced.
- A large percentage of non-recurring delay could not be directly associated with specific lane blocking incidents.

This report presents the results of the second phase of this research. Phase 2 extended the analysis to include an examination of the effects of

- incidents occurring on the shoulders of freeways
- spillback from incident-caused congestion on one freeway that affects a second freeway that feeds traffic onto the initially congested facility
- special events
- weather.

It also included a detailed manual examination of measured freeway performance information against recorded event data to detect limitations in the Phase 1 analytical process. Because funding

for this effort was extremely limited, only three corridors (with both directions analyzed independently) were analyzed.

The project found that the Phase 1 methodology works well in assigning traffic congestion that occurs in the immediate time frame and geographic location of incidents to those incidents. Unfortunately the detailed analysis of freeway performance showed that much of the delay caused by specific incidents occurs in places or at times removed from the incident itself. The result is that even with the addition of shoulder incidents, special events, and weather to lane blocking events, the Phase 1 analytical process is unable to assign a cause to a significant proportion of the non-recurring delay on Seattle freeways. New analytical procedures will need to be developed in Phase 3 of this work.

The Phase 2 analysis did confirm that the congestion effects of specific incidents and other traffic disruptions are highly dependent on the background traffic conditions at the time of the disruption. Therefore, the findings presented in this report apply primarily to the specific facilities studied. Additional work is needed in Phase 3 to generalize the results presented in this report so that they are more applicable to elsewhere in the state and/or country. Until that generalization takes place, the findings in this report can be applied only with caution to other facilities, cities, or regions.

While the Phase 2 analysis did not produce all of the results desired, several interesting findings were produced. Key findings include the following:

- Incidents confined to the shoulder can have a significant impact on freeway performance, but the vast majority of incidents confined to the shoulder had little or no impact on congestion relative to normal volume-induced conditions.

- Rain was not frequently a direct cause of congestion (at least in Seattle). However, the presence of rain increased the likelihood of congestion, and it could worsen congestion that was already present. This was likely due to increases in incident rates, which in turn affected levels of congestion.
- Special events (cultural and sporting events with more than 10,000 attendees) were determined to have a significant impact on corridor-wide levels of delay on specific freeways, but not all freeways. These delays were not always experienced near the special event venue itself, but were more frequently seen as an increase in congestion at bottleneck locations. Freeways not directly affected by the special events showed no change in congestion levels (i.e., they did <u>not</u> have decreased congestion levels because travelers that would normally have used them were going to the special event).
- Incidents and events cause changes in traffic patterns that create congestion at times and locations that at first glance might appear to be unrelated to that incident or event. (For example, a traffic volume surge, formed by vehicles queuing at an incident scene and released by the clearance of that incident, can cause new congestion several miles downstream from the location of that incident and forming only after the incident has been completely removed.)
- A lower percentage of non-recurring congestion occurred during the morning commute period than during either the mid-day or evening commute periods.
- A higher percentage of congestion caused by lane blocking occurred during the midday time period than during either the morning or afternoon commute periods.

- A higher percentage of non-recurring congestion caused by both special events and incidents confined to the shoulder occurred during the afternoon commute period than during either the morning or midday periods.
- There were significant day-of-week variations in expected recurring and non-recurring delay. Not surprisingly, the least congested commute period was Friday morning. Friday afternoon could be either good or bad, depending on whether a corridor and direction served a recreational movement.

Each of these findings is discussed in more detail in the main body of this report. All of these findings must be viewed with regard to the specific facilities being studied, the time periods being studied, and the types of special events and weather events that were used for this analysis.

# INTRODUCTION

## BACKGROUND

In 2003, the Washington State Department of Transportation (WSDOT) initiated a research effort to develop and test a methodology for estimating congestion delay on Seattle area freeways. That effort was prompted by a need for more accurate information about the magnitude and causes of congestion delay, information that could have a direct impact on the prioritization and allocation of the state's limited resources for congestion management. Of particular interest was the development of methods for estimating the extent to which congestion delay on Seattle area freeways is related to non-recurring events and for determining the relative importance of the different causes of non-recurring congestion. Better knowledge about the causes, extent, and locations of non-recurring delay is valuable as input into the policy making process associated with strategies such as incident response programs that are designed to reduce non-recurring delay.

The initial phase of the research developed a preliminary methodology for both measuring congestion and assigning that congestion to specific lane blocking incidents. It examined two months of lane blocking incident and freeway performance data on all corridors of the Seattle metropolitan freeway system. Among the primary conclusions from that effort were the following:

- The percentage of congestion associated with non-recurring events varied greatly from freeway to freeway, due in large part to the level of routine congestion each facility experienced.
- A large percentage of non-recurring delay could not be directly associated with specific lane blocking incidents.

In response to those findings, and as additional research funding became available, the project team undertook to expand the Phase 1 research. In Phase 2 of the study, the methodology developed in Phase 1 was automated and extended to include an examination of the effects of

- incidents occurring on the shoulders of freeways
- spillback from incident-caused congestion on one freeway that affects a second freeway that feeds traffic onto the initially congested facility
- special events
- weather.

It was anticipated that the investigation of these “causes” of traffic congestion would greatly increase the percentage of delay that could be associated with specific traffic disruptions.

Because funding for this effort was extremely limited, only three corridors (with both directions analyzed independently) and two months of data were analyzed. A supplementary analysis of two additional months of data was conducted to further explore the effects of special events, but these supplemental analyses were only completed for one direction of each of the three corridors, and only for the evening peak period.

Finally, because some of the results of the initial Phase 2 analysis provided counter-intuitive results, the project team also performed a detailed manual examination of specific days of performance information to compare measured freeway performance with recorded event data in order to detect limitations in the Phase 1 analytical process. This detailed review of facility performance provided significant insight into the limitations of the current analytical process. These insights are presented later in this document as part of suggestions for continued research into the relative importance of different causes of traffic congestion.

## REPORT ORGANIZATION

This report is organized into five sections. This first section presents an introduction to the project. The second section summarizes the major project findings. The third section presents the detailed analytical results. The fourth section presents observations for shaping the next phase of research into the causes of urban freeway congestion. The last section contains technical appendices that provide a detailed description of the methodologies used in the analysis, as well as information on the key analytical assumptions used to apply those methodologies.

## SUMMARY PROJECT FINDINGS

The project found that the Phase 1 methodology works well in assigning traffic congestion that occurs in the immediate time frame and geographic location of incidents to those incidents. It also showed that this process can be automated, making the data preparation effort now the primary determinant of the cost of additional work of this kind.

Unfortunately, even with the addition of shoulder incidents, special events, and weather to lane blocking events, the automated process is unable to assign a significant proportion of the non-recurring delay occurring on Seattle freeways. The detailed analysis of freeway performance showed that much of the delay caused by specific incidents occurs in places or at times removed from the incident itself. The result is that much of the observed non-recurring delay can not be assigned to specific causes by the current analytical process. New analytical procedures will need to be developed in Phase 3 of this work.

The Phase 2 analysis also confirmed that the congestion effects of specific incidents and other traffic disruptions are highly dependent on the background traffic conditions at the time of the disruption. Therefore, the findings presented in this report apply primarily to the specific facilities studied. Additional work is needed in Phase 3 to generalize the results presented in this report so that they are more applicable to elsewhere in the state and/or country. Until that generalization takes place, the findings in this report can be applied only with caution to other facilities, cities, or regions.

While the Phase 2 analysis did not produce all of the results desired, the output from the automated software did allow a variety of useful analyses. The additional analyses conducted as part of this effort also showed that the summary statistics output from the Phase 2 software are also quite useful as inputs to other analytical procedures.

Key findings from the analyses performed under the Phase 2 effort include the following:

- Incidents confined to the shoulder can have a significant impact on freeway performance, but the vast majority of incidents confined to the shoulder had little or no impact on congestion relative to normal volume-induced conditions.
- Rain was not frequently a direct cause of congestion (at least in Seattle). However, the presence of rain increased the likelihood of congestion, and it could worsen congestion that was already present. This was likely due to increases in incident rates, which in turn affected levels of congestion.
- Special events (cultural and sporting events with more than 10,000 attendees) were determined to have a significant impact on corridor-wide levels of delay on specific freeways, but not all freeways. These delays were not always experienced near the special event venue itself, but were more frequently seen as an increase in congestion at bottleneck locations. Freeways not directly affected by the special events showed no change in congestion levels (i.e., they did not have decreased congestion levels because travelers that would normally have used them were going to the special event).
- A lower percentage of non-recurring congestion occurred during the morning commute period than during either the mid-day or evening commute periods.
- A higher percentage of congestion caused by lane blocking occurred during the midday time period than during either the morning or afternoon commute periods.

- A higher percentage of non-recurring congestion caused by both special events and incidents confined to the shoulder occurred during the afternoon commute period than during either the morning or midday periods.
- There were significant day-of-week variations in expected recurring and non-recurring delay. Not surprisingly, the least congested commute period was Friday morning. Friday afternoon could be either good or bad, depending on whether a corridor and direction served a recreational movement.

Each of these findings is discussed in more detail later in this report. All of these findings must be viewed with regard to the specific facilities being studied, the time periods being studied, and the types of special events and weather events that were used for this analysis.

## DETAILED ANALYTICAL RESULTS

### CORRIDOR DESCRIPTIONS

For Phase 2, three freeways with distinctly different geometric and traffic characteristics were chosen to allow examination of the effects of those characteristics on delay and the interaction of delay with specific causes of congestion. The facilities selected were

- SR 520
- I-90
- the southern half of I-405 (from downtown Bellevue to its southern interchange with I-5).

All analyses were done directionally. (That is, eastbound I-90 was always analyzed separately from westbound I-90.) The reversible roadway on I-90 was not included in the analysis. Neither were the HOV lanes on any of the routes.

SR 520 was selected because it has long stretches of road with little or no available roadway shoulder. It is thus subject to a larger number of lane blocking incidents than either I-90 or I-405. It also experiences heavy, routine congestion, as it is among the most routinely congested freeway segments in the metropolitan region. Routine congestion forms in both directions across Lake Washington in both the morning and evening peak periods. In addition, traffic is routinely congested eastbound in the evening at the eastern-most end of the freeway. SR 520 is also well known for experiencing special event-related congestion, especially during evening peak periods when professional sports events take place in downtown Seattle.

Because of these conditions, WSDOT operates incident response teams throughout much of the length of SR 520, with specific emphasis on the Evergreen Point Floating Bridge, a 2-mile-long segment of road with no shoulders and no exits. Thus, while SR 520 experiences a greater number of lane blocking incidents than the other roadways selected in this analysis, the duration of most of those lane blocking incidents is shorter.

I-90, the other freeway that crosses Lake Washington, was also selected for this analysis. Like SR 520, I-90 experiences heavy peak period congestion in both directions across Lake Washington, although the congestion levels experienced are not quite as heavy as those on SR 520. I-90 also experiences directional peak period congestion between Issaquah and I-405. I-90 westbound is also known to be affected by special event traffic. As on SR 520, tow truck equipped incident response teams are stationed near the floating bridge to limit the effects of peak period incidents.

One major difference between I-90 and SR 520 is that I-90 was built to modern Interstate standards. Consequently, it has full-width shoulders for most of its length. It also has one additional lane of traffic and has the reversible lanes between I-405 and I-5. All of these factors combine to lower the intensity of routine congestion on I-90 in comparison to that experienced on SR 520. There are relatively few lane blocking incidents (because disabled vehicles can move off the roadway), and the extra lanes allow greater freedom of movement during mid-day, thus limiting the effects of midday incidents. As a result, I-90 is among the least congested of the region's freeways.

The last freeway selected for this analysis was the southern half of I-405 (from downtown Bellevue to its southern terminus). This stretch of I-405, along with SR 520, is among the most heavily congestion roadways in the state. However, unlike SR 520, the vast majority of I-405 does have shoulders onto which vehicles can pull over if they need to stop, although some of those shoulders are not full width. I-405 also experiences congestion in both directions during peak periods, but the southbound AM/northbound PM movements are not as congested as the reverse movements.

## THE EFFECTS OF LANE BLOCKING INCIDENTS

The Phase 1 analysis showed that relatively little of the delay occurring in these corridors was the result of lane blocking incidents. (I-5 and SR 167 had higher percentages of lane blocking delay than I-90, SR 520, or southern I-405.) However, much of the delay measured on these three corridors was not recurring congestion (i.e., not routine), and therefore, they were good choices to determine whether shoulder incidents, special events, and weather were significant causes of that non-recurring congestion.

### Methodology

The relative effect of lane blocking incidents on delay was the primary subject of Phase 1 of this study. The primary analytical approach for defining and measuring congestion related to lane blocking incidents was developed for that project and is described in detail in the report for that effort.[1] Phase 2 simply automated and expanded on that effort with an additional two months of freeway incident and performance information. Because no change was made to the basic analytical methodology, no major differences in outcome were anticipated in the congestion associated with lane blocking incidents.[2]

The approach used for assigning delay to specific lane blocking incidents computes the routine congestion condition for roadways during days that do not contain lane blocking incidents. A confidence interval is then placed around that "routine" condition. When the roadway operates

---

1 *Measurement of Recurring versus Non-recurring Congestion, Technical Report*, Hallenbeck, M. E., J. M. Ishimaru, and J. Nee. 2003, WA-RD 566.2

2 In Phase 1, two different methods were used to allocate non-recurring congestion to lane blocking incidents. The method chosen for automation in Phase 2 was the most conservative (that is, it allocated the <u>least</u> amount of delay to a specific incident).

within those routine conditions, all delay is defined as "recurring" congestion. When delay exceeds the confidence interval boundaries, the delay is defined as "non-recurring" congestion. Non-recurring congestion is assigned to specific lane blocking incidents whenever it occurs at a location where a lane blocking incident occurs, as long as the non-recurring congestion begins at some point between the beginning and end of the actual lane blocking incident. All contiguous (in time and space) non-recurring delay is then assigned to that incident.

This approach does an excellent job of assigning delay in the immediate vicinity to specific lane blocking incidents. However, the Phase 1 analysis showed that it is a very conservative approach to assigning non-recurring delay to specific incidents.

## Results

As expected, Phase 2 results were similar to Phase 1 results. On specific days, lane blocking incidents significantly increased delays on all corridors. However, as a fraction of total delay, the delay occurring at the location of a lane blocking incident was only a modest portion of the total delay experienced along a corridor. Table 1 lists the percentage of all delay (all travel less than 60 mph) that could be directly correlated with the effects from lane blocking incidents, by time of day for each corridor and direction for January and February of 2003. The results shown in Table 1 are consistent with the results from the Phase 1 analysis, given the expected variation in the number and size of lane blocking incidents from month to month.

Corridors with 0.0 percent delay in a given time period either had no lane blocking events during that time period for the two month study (I-90 WB, PM), or the few blocking incidents that took place were minor, given available capacity at the time of the incident (I-90 EB, midday). The lack of lane blocking incidents was partly due to luck (no accidents occurred) and partly due to the roadway geometry on I-90.

**Table 1: Percentage of All Delay Caused by Lane Blocking Incidents January-February 2003**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 4.8% | 7.3% | 3.3% |
| SR 520 EB | 1.7% | 5.2% | 4.6% |
| I-405 NB | 2.5% | 6.4% | 2.5% |
| I-405 SB | .9% | 1.9% | 3.1% |
| I-90 WB | 0.7% | 2.2% | 0% |
| I-90 EB | 2.5% | 0% | 0.2% |

Table 2 shows both the total number of lane blocking incidents that occurred during the two-month study and the rate of lane blocking incidents per vehicle-mile-traveled on that corridor. I-90 had a very low percentage of lane blocking incidents in large part because it had relatively few lane blocking incidents. On the other hand, the effects of the lack of shoulders on SR 520 is clearly apparent in Table 2. The higher number and rate of lane blocking incidents explain why SR 520 had a much higher percentage of delay related to those incidents. Of interest to WSDOT is the relatively high percentage of lane blocking incidents on I-405, which unlike SR 520 has shoulders along the majority of the corridor.

These findings also suggest that if shoulders are removed or significantly reduced on I-90 as part of an effort to provide an HOV lane in the direction not served by the Express lanes, WSDOT can expect additional non-recurring delay at rates that could approach those found on SR 520.

**Table 2: Frequency of Lane Blocking Incidents**
**January – February 2003**

| Corridor | Number of Lane Blocking Incidents (43 days) | Approximate Daily Corridor VMT (6 AM – 7 PM) | Blocking Incidents Per 10,000,000 VMT |
|---|---|---|---|
| SR 520 | 124 | 870,000 | 33 |
| I-405 | 114 | 1,256,000 | 21 |
| I-90 | 45 | 1,220,000 | 9 |

Even though the percentage of delay directly attributable to lane blocking incidents was fairly small, in the cases of SR 520 and I-405 the total delay experienced by travelers was still substantial. Table 3 presents the total number of vehicle-hours lost to delay directly associated with lane blocking incidents in January and February of 2003. During that time, more than 12,000 vehicle hours were lost because of the delay on just these three corridors. An assumed time value of $15 per vehicle-hour[3] would make the delay for this two-month period worth over $180,000, or roughly one million dollars a year.

The analysis of lane blocking delay produced several non-intuitive results that required further exploration. One of those non-intuitive results was the fact that eastbound I-90 had 10 midday lane blocking incidents, but the Phase 2 software identified no directly attributable lane blocking delay for the eastbound direction of I-90 in the middle of the day. An in-depth review of those days of performance data showed that the conditions prior to the incident were essentially sufficiently free flow at the time of incident, the lane blocking incidents were fairly small, and as a

[3] The $15 per hour value comes from a recent Oregon DOT study, *the Value of Travel-Time: Estimates of the Hourly Value of Time for Vehicles in Oregon in 2003*, by the Oregon DOT Policy and Economic Analysis Unit, May 2004. It does not include the value of time for commercial trucks and is thus a very conservative estimate of the value of time associated with this delay statistic.

result, while congestion occurs, the resulting congestion did not exceed our “recurring” threshold values. As a result, there was delay, but the delay was not assigned to “lane blocking” as a cause. Analyses of other non-intuitive results often found significant increases in nonrecurring delay on days and in time-periods when lane blocking events occurred, but these delays were often not contiguous with the location and time of the incident.

**Table 3: Total Vehicle-Hours of Delay Lost to Lane Blocking Incidents for January-February 2003**

| Corridor | Vehicle Hours Lost |
|---|---|
| SR 520 WB | 2650 |
| SR 520 EB | 1900 |
| I-405 NB | 4750 |
| I-405 SB | 3080 |
| I-90 WB | 200 |
| I-90 EB | 210 |

These findings led the project team to explore other ways to examine the effects of lane blocking incidents. Unfortunately, budget constraints limited what could be performed under this analysis. The one additional effort undertaken was to examine the total delay experienced on a corridor as a function of whether a lane blocking event had occurred. A simple T-test was performed to examine the delay (by corridor, direction, and time period) experienced on days with and without lane blocking incidents. Table 4 shows the expected increase in vehicle hours of delay when a lane blocking incident occurs.[4] Changes in expected delay that are statistically significant with 90 percent confidence or better are shown in **bold.**

**Table 4: Average Change in Vehicle-Hours of Delay When a Lane Blocking Incident Occurred**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | **216** | **201** | **324** |
| SR 520 EB | **141** | **154** | **275** |
| I-405 NB | **363** | -17 | 294 |
| I-405 SB | **512** | 243 | **780** |
| I-90 WB | -149 | 40 | -100 |
| I-90 EB | **174** | 18 | 174 |

Table 4 shows, not surprisingly, that lane blocking events on SR 520 tended both to have significant impacts and to be statistically significant. I-90, on the other hand, experienced lane blocking events with relatively little added delay, and I-405 fell somewhere in between. These results are consistent with expectations.

On I-90, the combination of extra roadway width, wider shoulders (onto which lane blocking vehicles can be quickly moved by WSDOT incident response teams and WSP troopers with push bumper-equipped vehicles), and lower volume to capacity ratio for much of the day made the impacts of an average lane blocking incident far less significant. Conversely, on SR 520, many lane blocking incidents occurred on the floating bridge, where no shoulders exist and the

[4] This analysis did not take into account the severity or duration of the lane blocking incident. One likely Phase 3 analysis will be to explore the use of more sophisticated analyses that would allow the incorporation of these factors.

volume/capacity ratio is already high. The result was significant delay whenever such an event occurred.

I-405, once again, fell somewhere in between I-90 and SR 520. Half of the I-405 time period / directional cells in Table 4 show a significant increase in delay whenever a lane blocking incident occurred. Two of the remaining three cells show a substantial increase in average delay, but that increase was not statistically significant. (This result is consistent with a facility where delay is highly variable during that time period.) Only northbound during midday did I-405 not appear to be significantly affected by lane blocking incidents. A more detailed analysis of the lane blocking incidents on northbound I-405 showed that a number of other types of incidents (e.g., shoulder incidents, spillback from delays on SR 167) could create considerable midday delay that was equal to or greater in size than the delay created by the lane blocking incidents that occurred during the study period.

## THE EFFECTS OF SPECIAL EVENTS

### Methodology

There is no doubt that very large public events create congestion in the vicinity of the event. However, little work has been done to quantify the effects of these events on regional congestion levels or on commute period traffic congestion. This project undertook to start this review.

The first tasks in the analysis were to define “special event” and to determine where and when those events took place. For this project, “special events” were initially defined as events of greater than 3,000 attendees that took place on weekdays at Key Arena, Safeco Field, Qwest Field, or the University of Washington campus.[5]

The initial analyses related to special events used data for January and February of 2003. During these two months, several moderately large events took place at Key Arena in downtown Seattle and at Hec Edmundson pavilion on the University of Washington campus. The project team documented 32 events at these two venues ranging in size from 1,300 to 15,500 people. To supplement these results, the project team also examined two additional months of data (March and April of 2003) for westbound I-90, westbound SR 520, and southbound I-405 to allow analysis of the effects of Seattle Mariners games on PM congestion. Twelve Mariners games took place in April on weekday evenings, all with attendance figures above 30,000 people. In addition eight Sonics games took place during March 2003 and were included in the analysis.

Special event analyses were conducted only for the evening commute period.

The initial analysis effort assigned an "incident time and location" to the off-ramp nearest to the special event location. (For downtown Seattle events, this was the western end of the I-90 and SR 520 freeways.) The time of the "incident" related to the special event was assumed to be one hour long, starting one hour before the event was scheduled to begin. Non-recurring congestion was then assigned to these "special event incidents" by using the same criteria that were used for assigning congestion to lane blocking incidents. [6]

This analytical approach did not prove to be successful. While ramp congestion did indeed occur in a manner that might be captured by the above method, analysis of the congestion data proved that the selected analytical process was omitting a considerable amount of delay related to

---

[5] Note that one reason Friday evenings tend to have greater congestion than other evening commutes is that a large number of people travel at that time to attend "small events." Thus, the increase in congestion found on any given Friday evening is in large part "special event" related, even though it is not necessarily attributable to a single event.

[6] In other words, a "virtual incident" was created that allowed use of the Phase 2 software. The virtual incident occurred one hour before the event started, lasted one hour, and "occurred" at the ramp nearest the event location.

special events.  A manual review of daily congestion data determined that the geometric configurations of both I-90 and SR 520 resulted in the formation of congestion forming at bottlenecks far upstream from the event's associated off-ramp, and that congestion often formed several hours before the event's scheduled start time.  For example, on SR 520, the worst of the westbound congestion likely related to these events took place on the eastern (far) approach to the Evergreen Point floating bridge.  For both I-90 and SR 520, the added event traffic caused the existing bottleneck locations to reach breakdown conditions earlier and more strongly than would otherwise have been expected.  These bottleneck situations limited the number of vehicles reaching the "event ramps" and thus limited the congestion occurring there.  The end result was that the analytical approach was unable to find congestion specifically related to these events.

This led the project team to use the simple T-test comparison employed to study the lane blocking incidents.  In this technique, corridor-wide delays were computed for each time period during each day.  The mean and standard deviation of vehicle-hours of delay for each corridor and time period were then computed for days during which special events took place and for days without special events.

This technique allowed the application of a simple statistical test to determine the differences expected in levels of congestion with and without special events.  To further test the impacts of special events additional tests were performed by removing days with lane blocking incidents during the PM period from the analysis so that the effects of special events could be compared without the results being affected by delays caused by lane blocking incidents.

**Results**

For January and February of 2003, three of the six corridor/directions studied showed an increase of more than 10 percent in average traffic delay when an event with more than 10,000 attendees took place in central Seattle.[7] But only one of those increases (westbound I-90) was statistically significant with 90 percent confidence, and a second (westbound SR 520) was statistically significant at the 80th percentile level. Two of the corridor/directions showed no increase in delay on special event days.

To test these findings, an analysis of March and April special event data was performed for the three directional movements that were most heavily influenced by January-February special events. The two cross-lake routes both showed statistically significant increases in PM peak period traffic delay during March and April events. (Note that the April events were Mariners games, which have larger attendance figures than Sonics games.) Table 5 shows the delays with and without special events. Changes in delay that were statistically significant at or above the 90th percentile level of confidence are shown in **Bold** type.

The fact that the two westbound bridges and southbound I-405 were the only routes significantly affected makes intuitive sense. The fact that many of the changes were not statistically significant was surprising.

A further examination of the data showed that the major reason that increases in delay on special event evenings were not statistically significant was that the amount of delay experienced on any given day varied considerably. Because previous analyses showed that lane blocking incidents were a considerable source of delay, the researchers decided to remove days from the analysis during which lane blocking events occurred in the afternoon or evening along these three corridors and directions.[8]

---

7 Events with attendance of less than 10,000 people did not have a statistically significant impact on delay on any of the tested corridors.

8 Because I-90 and SR 520 serve as alternative routes for each other, delays on both bridges tend to be affected by blocking incidents on either bridge as a result of traffic diversion. So for this analysis, a day with a lane blocking incident on either bridge in the afternoon or evening commute period was removed from the analysis of both corridors.

**Table 5: Effects of Special Events Larger Than 10,000 People on Evening Delay**

| Corridor | Mean Vehicle-Hours of Delay Per PM Peak Period For Days Without A Special Event | Standard Deviation of Delay Per PM Peak Period | Change in Vehicle Hours of Delay on Special Event Days | Percent Difference |
|---|---|---|---|---|
| **January – February Events** | | | | |
| SR 520 WB | 887 | 451 | 165 | 19% |
| SR 520 EB | 484 | 262 | 27 | 5% |
| I-405 NB | 789 | 445 | -64 | -8% |
| I-405 SB | 1655 | 701 | 189 | 11% |
| I-90 WB | 140 | 264 | **369** | **164%** |
| I-90 EB | 391 | 363 | 4 | 1% |
| **March – April Events** | | | | |
| SR 520 WB | 872 | 415 | **441** | **51%** |
| I-405 SB | 1734 | 851 | 188 | 11% |
| I-90 WB | 163 | 235 | **453** | **277%** |

Table 6 shows the average level of delay expected in the evening peak period when no lane blocking incident took place, as well as the average change in that delay when a special event of greater than 10,000 people occurred. Once again, changes in delay that were statistically significant at or above the 90$^{th}$ percentile level of confidence are shown in **Bold** type. By removing the effect of lane blocking incidents on travel delay variability, the effects of special events in

January and February became statistically significant at the 90th percentile confidence level for all three of the movements expected to be affected by these events.

**Table 6: Effects of Special Events on Evening Delay When No Lane Blocking Incidents Occurred**

| Corridor | Mean Vehicle-Hours of Delay Per PM Peak Period For Days Without A Special Event | Standard Deviation of Delay Per PM Peak Period | Change in Vehicle Hours of Delay on Special Event Days | Percent Difference |
|---|---|---|---|---|
| **January – February Events** | | | | |
| SR 520 WB | 677 | 413 | **337** | **50%** |
| SR 520 EB | 440 | 261 | 39 | 9% |
| I-405 NB | 751 | 407 | -42 | -6% |
| I-405 SB | 1531 | 762 | **285** | **19%** |
| I-90 WB | 115 | 135 | **209** | **181%** |
| I-90 EB | 384 | 383 | -12 | -3% |
| **March – April Events** | | | | |
| SR 520 WB | 761 | 360 | **472** | **62%** |
| I-405 SB | 1491 | 861 | 305 | 20% |
| I-90 WB | 192 | 259 | **404** | **211%** |

Interestingly, the March-April change in delay on southbound I-405 due to special events was not statistically significant, again because of very high levels of variability in delay experienced on this route. In fact, the standard deviation of vehicle delay actually increased slightly when days with lane blocking incidents were removed from the March-April analysis.

Functionally, the increase in congestion on southbound I-405 when special events occurred in Seattle was caused primarily by increased congestion between downtown Bellevue and I-90 as vehicles attempted to reach I-90 to cross the lake. The delay on this segment of the corridor probably increased in a statistically significant manner during Mariners games.[9] But delay over the remainder of the southbound I-405 corridor was probably 1) not significantly affected by event traffic, and 2) quite variable because of a number of other significant congestion factors. The result of these other congestion causing factors was that the variability in delay along the entire corridor was high enough that it affected the statistical significance of the special event delay.

Not surprisingly, the Mariners and Sonics games in March and April appear to have had a somewhat greater effect than the smaller special events included in this analysis during January and February. This was most likely due to the size of the Mariners events, which made up roughly half of the March-April special events and tended to be bigger than the Sonics and UW events that made up the majority of the January-February events.

Both tables 5 and 6 show that the absolute increases in delay due to special events were roughly similar in size on I-90 and SR 520. However, in percentage terms, westbound I-90 experienced a far greater increase in delay as a result of these special events than westbound SR 520. This is primarily because westbound SR 520 tended to experience far greater routine congestion than westbound I-90.

---

[9] Insufficient resources were available in this project to test these hypotheses. These computations should be considered for Phase 3.

## THE EFFECTS OF WEATHER

### Methodology

Extreme weather conditions (snow, ice, very heavy rain fall) have obvious effects on roadway performance. Less severe weather (e.g., light rainfall) also affects driving conditions by reducing visibility and decreasing pavement friction, but the direct effects of these factors on traffic performance were less obvious.

To begin to examine the effects of Seattle's moderate weather conditions on traffic congestion, the project team gathered weather data for January and February 2003 and examined vehicle delay in relation to those weather conditions. Weather conditions during the two-month study period were quite mild for winter, even by Seattle standards. No snow fell during the study period. The vast majority of the rainfall observed was defined as "light" (less than 0.1 inches per hour) by the University of Washington's Atmospheric Sciences Department. Therefore, the results from this study's analysis should not be considered representative of congestion caused by severe weather conditions. The project team did not attempt to determine the existence of other weather effects such as "sunshine slowdowns."

Rainfall was determined by corridor and time of day. During the two-month analysis period, I-405 experienced more rainfall than either I-90 or SR 520, but even I-405 experienced rain on only 20 of the 41 weekdays in the study period. In addition, on the days when rain did fall, it rarely fell throughout the day. Thus, rain occurred on individual corridors during individual analysis time periods on no more than 15 days during the two-month study period.

Two different approaches were used to determine the effects of bad weather on traffic congestion. The initial approach started by computing recurring and non-recurring delay as described earlier in this report. An overlay indicating whether or not rain was falling (by location and time of day) was then placed over the matrix containing recurring and non-recurring delays. This allowed allocation of those delays to “poor weather” and “good weather” conditions. This approach assumed that rain had to be currently falling for delays to be attributed (at least in part) to rainfall. Summarization of the data developed with this technique did not yield useful results. Additional work will be performed in this area in the next phase of this analysis.

To supplement this initial approach, a broader definition of “weather” was used. In this second approach, a commute trip (corridor by time period) was considered “affected” by weather if rain occurred at any time during the analysis time period for that day. A simple statistical test was then applied to determine whether differences in expected delay existed for days that experienced rain versus those that did not experience rain. While this approach did not yield a direct correlation between a specific rain storm and specific delay, it did account for the fact that many weather effects remain (slick pavement, reduced visibility due to spray from other vehicles) long after rain has stopped falling.

**Results**

In general, the presence of rain at some point during the day increased the average delay experienced on each corridor. However, the measured increases were not statistically significant on all corridors and during all time periods. This was not terribly surprising, given the following:

- On many days in the analysis time period rainfall was quite light and Seattle drivers tend to be accustomed to driving in light rain.
- The amount of delay experienced on any corridor/time period tends to be quite variable.
- Thus, even fairly large average changes in delay experienced are not always statistically significant.

Table 7 shows the percentage increase in delay (by time period) measured on each corridor when rain occurred during that time period. Increases in congestion that are statistically significant when compared to days with no rain are shown in **Bold** letters.

**Table 7: Percentage Increase in Delay on Days with Rain**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 42.4% | 8.6% | 26.9% |
| SR 520 EB | 17.7% | **61.8%** | 21.4% |
| I-405 NB | **58.7%** | 43.6% | 0.8% |
| I-405 SB | **96.3%** | **154.9%** | -3.7% |
| I-90 WB | **62.8%** | **121.6%** | **283.3%** |
| I-90 EB | **78.3%** | **143.0%** | **154.7%** |

For the two months studied, I-90 was much more heavily affected by rain than either I-405 or SR 520. It is not clear why this occurred, although the research team offers the following speculation: I-90 has much lower routine traffic congestion levels than either SR 520 or the southern half of I-405. This results in two specific effects. One is that the same absolute change in delay results in a much higher percentage increase on I-90 than on SR 520 and I-405. Thus, an absolute increase in delay that is equal on all corridors results in a much higher percentage increase on I-90 than on SR 520 or I-405. For that same reason, the I-90 increase is more likely to be statistically significant. Table 8 shows the absolute increases in average delay associated with days on which rain falls.

A second factor to consider is that vehicles are often already moving slowly on SR 520 and I-405, and consequently the effects of rain may be more modest on those roads than on I-90, where the slower traffic speeds caused by slick conditions may create congestion in places where it does not otherwise routinely occur. (That is, rain "tips the balance" from conditions on I-90 that are close to being congested but not yet congested.)

**Table 8: Absolute Increases in Average Vehicle-Hours of Delay Due to Rain**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 165 | 15 | 249 |
| SR 520 EB | 74 | **165** | 106 |
| I-405 NB | **269** | 173 | 7 |
| I-405 SB | **205** | **319** | -66 |
| I-90 WB | **323** | **42** | **763** |
| I-90 EB | **119** | **75** | **494** |

On all facilities, the mere presence of rain, by itself, was not an accurate predictor of heavy congestion. On many occasions, rain was present, but very little congestion occurred. This caused the standard deviation of the corridor delay statistic to be quite high and resulted in the lack of statistical confidence in these measured differences. For example, on I-90 westbound in the evening, rain occurred on only seven weekdays during January and February of 2003. Two of those seven days had extremely high congestion delays. (They were the worst two evening commute periods of the entire two-month analysis period.) However, on the other five days when it rained, travelers experienced fairly modest delays. For the two extremely congested days, neither day featured major accidents or lane blocking events. Both experienced extreme back-ups starting at the eastern end of the Mercer Island floating bridge at about 4:00 PM. No detailed cause of the congestion existed in the event records used in this analysis, so it is unclear what caused these slow downs. (That is, they did not appear to be caused by an incident of any kind, and while a Sonics game with an attendance of ~13,000 took place on one day, no major event took place on the other.)

Table 7 shows that rain had a more statistically significant effect on congestion during the AM and midday time periods than on the afternoon commute. The project team is reluctant to offer speculation as to why this might be the case, although the facilities that appeared to be the most severely effected by rain were those with the least recurring congestion (I-90 and midday travel on I-405 and SR 520). More detailed analysis of the interaction of rainfall and delay is needed in Phase 3 of this effort.

## THE EFFECTS OF INCIDENTS CONFINED TO THE SHOULDER

### Methodology

Shoulder incidents were defined for this study as any disabled vehicle incident that was located on the shoulder and reported by the WSDOT incident response teams. The Washington Incident Tracking System (WITS) database was used to provide start time and clearance times for these events. In general, these times were the amount of time spent at the scene by the incident response team staff. This served as a reasonable estimate of the amount of time a visual distraction was present at the scene. Although this time can be quite brief, in several cases it lasted for more than an hour.

Non-recurring congestion was computed and assigned to shoulder incidents in the same manner described earlier for blocking incidents. Shoulder incidents were placed in time and space on each time-distance matrix of non-recurring congestion. Increases in non-recurring congestion associated with the time and location of the shoulder incident were then categorized as being related to that shoulder incident.

## Results

Delays that could be directly attributed to incidents on the shoulder of the roadway were relatively small. Less than 1 percent of measured daily delay could be directly assigned to shoulder incidents in this manner.

In other words, the delay directly attributable to shoulder incidents was roughly equal to 20 percent of the delay that lane blocking incidents directly created, even though the number of "shoulder incidents" reported within the WITS was roughly equal to the number of "lane blocking incidents." The delay was also roughly equivalent to the spillback delay that lane blocking incidents caused on secondary freeways.

Two reasons are suggested for such a small amount of delay being directly attributable to shoulder incidents. The first is that a relatively modest number of shoulder incidents were recorded by incident response team personnel during the two-month study period. Table 9 shows the distribution of incidents by corridor during the study period.

**Table 9: Number of Reported Incidents by Type in January and February 2003**

| Corridor | Shoulder | Lane Blocking |
|---|---|---|
| SR 520 | 81 | 124 |
| I-405 | 96 | 114 |
| I-90 | 77 | 43 |

The second reason for the modest impact of shoulder incidents is that these disruptions frequently do not cause immediate congestion. Instead, shoulder incidents appear to simply be a negative factor that, when combined with the right level of volume and other traffic conditions, can create traffic congestion where it otherwise would not exist.

While incident response team personnel reported an average of roughly two shoulder incidents per day per facility, few of those days exhibited direct measurable congestion caused by those incidents. In the AM peak period, of the six directional movements, three experienced no delays directly attributable to shoulder incidents, while the remaining three all experienced one or two days (out of 43) during which delays could be tied directly to shoulder incidents. More delays due to shoulder blocking incidents were identified in the PM peak period. Both westbound SR 520 and southbound I-405 experienced such delays on multiple occasions. Table 10 shows the number of days that each directional movement experienced delays that could be directly attributed to shoulder incidents.

**Table 10: Number of Days That Shoulder Incidents Caused Congestion**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 0 | 3 | 8 |
| SR 520 EB | 0 | 2 | 3 |
| I-405 NB | 2 | 2 | 3 |
| I-405 SB | 1 | 1 | 7 |
| I-90 WB | 0 | 0 | 3 |
| I-90 EB | 1 | 0 | 1 |

The midday and evening commute periods appeared to be much more susceptible to shoulder related incident delays. It is not clear why this is the case.

Of the three corridors studied, I-90 was the least affected by shoulder incidents. The majority of I-90 has shoulder widths that meet federal design standards, while I-405 and SR 520 have more limited shoulder configurations, resulting in more shoulder incidents and bigger impacts when those incidents occur. Table 11 shows the percentage of measured congestion that can be directly attributed to shoulder incidents.

**Table 11: Percentage of All Congestion Related to Incidents on the Shoulder**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 0% | 0.76% | 1.72% |
| SR 520 EB | 0.04% | 0.48% | 1.03% |
| I-405 NB | 0.15% | 0.27% | 1.86% |
| I-405 SB | 0.45% | 0.45% | 0.70% |
| I-90 WB | 0% | 0% | 2.58% |
| I-90 EB | 0.32% | 0% | 0.03% |

## THE EFFECTS OF SPILLBACK

### Methodology

One of the limitations noticed in the Phase 1 analysis of lane blocking incidents was that when an incident occurred on one freeway, congestion on that road often spilled back up on-ramps from other freeways. Ramp congestion spilled back onto the second freeway often caused congestion on that second freeway. Because the lane blocking incident occurred on a separate freeway from the congestion on the second freeway, the Phase 1 analysis was not able to associate the congestion with its real cause, the lane blocking incident.

To correctly assign this spillback congestion to lane blocking events, the research team created "virtual spillback incidents" that "occurred" at the ramps leading to connecting freeways. The start time of the "virtual incident" was whenever non-recurring congestion occurred at the ramp location after a lane blocking incident took place on the second freeway. The “virtual spillback incident” was determined to be “cleared” when the original incident that produced the non-recurring congestion ended.

Note that while spillback congestion was defined on the basis of its time-space proximity to the original incident, there as not necessarily a direct cause-effect relationship. In addition, spillback congestion was only determined in this analysis for lane blocking incidents. Spillback congestion caused by other factors was not computed. For example, on I-405 southbound, the congestion caused by capacity limitations at the merge to SR 167 was not determined and is thus not defined as “spillback congestion” in this report.

**Results**

Table 12 shows the percentage of all delay related to spillback congestion based on our analysis. Table 12 shows that for most routes and time periods, spillback from lane blocking incidents on other freeways was a negligible contributor to congestion. However, in seven of the 18 cases (westbound SR 520 midday and evening periods, and I-405 in both directions throughout the day, except for southbound in the evening), lane blocking incidents on other freeways contributed measurably to total delay.

For westbound SR 520 in the evening, spillback congestion was roughly half the size of delay caused by lane blocking incidents on SR 520 itself. (This is because the performance of westbound SR 520 is frequently affected by congestion on both I-405 and I-5.) Northbound I-405 in the evening was also significantly affected by spillback congestion, as it can be affected by westbound congestion from both SR 520 and I-90, as well as congestion on southbound SR 167.

**Table 12: Percentage of All Congestion Related to Spillbacks**

| Corridor | AM | Midday | PM |
|---|---|---|---|
| SR 520 WB | 0.04% | 1.01% | 1.64% |
| SR 520 EB | 0% | 0% | 0% |
| I-405 NB | 0.44% | 1.24% | 1.73% |
| I-405 SB | 0.51% | 1.21% | 0.14% |
| I-90 WB | 0.02% | 0% | 0% |
| I-90 EB | 0.05% | 0% | 0.02% |

While the percentages in Table 12 appear small, it must be remembered that the analysis process used as the most conservative of the three measures developed in Phase 1 for assigning specific congestion to individual events.

## DAY-OF-WEEK CONGESTION

### Methodology

The automated analysis processes developed for this research produces a variety of delay statistics that can be aggregated to provide additional insight into congestion in the Seattle metropolitan region. One interesting set of statistics involved the differences in vehicle delay by day of week. The analysis results discussed below account for the fact that January and February included a number of "unusual" weekdays from a congestion standpoint (January 1st and 2nd, as well as holidays on January 20th, and February 17th). [10]

Additional research is needed to determine the statistical significance of these estimates. This additional analysis may be performed as part of Phase 3. Given the fairly small data set

[10] These low congestion days were removed from the analysis of average day-of-week conditions.

involved (there were only seven to nine data points for any one weekday), there is no doubt that one or two bad days of congestion could adversely affect the relative percentage of delay associated with any given day of the week and time period.

**Results**

The one "common truth"[11] confirmed by the day-of-week analysis is that Friday morning consistently has the least congestion of all of the weekday morning commute periods. Conventional wisdom is that the majority of workers who work four 10-hour days take Friday off, and thus Friday commute volumes are lighter than other weekdays. The other four days of the week experience delays that are reasonably similar. Table 13 shows the percentage of morning traffic congestion by day-of-week.

**Table 13: Percentage of Morning Commute Period Traffic Congestion by Day of Week**

| | Mon | Tues | Wed | Thurs | Fri |
|---|---|---|---|---|---|
| SR 520 WB | 22% | 24% | 21% | 21% | 12% |
| SR 520 EB | 24% | 20% | 22% | 20% | 14% |
| I-405 NB | 23% | 21% | 20% | 23% | 13% |
| I-405 SB | 22% | 19% | 28% | 21% | 11% |
| I-90 WB | 24% | 22% | 22% | 22% | 10% |
| I-90 EB | 23% | 25% | 22% | 19% | 12% |

On some routes, Friday afternoon partly made up for the morning being relatively free from congestion by being particularly congested (see Table 14). However, unlike Friday morning, which

[11] One Seattle radio station traffic reporter routinely describes Friday morning congestion as "Friday Lite."

was lightly congested on all routes and directions, Friday afternoon was only particularly congested on specific corridors and directions. For example, westbound into Seattle, evening congestion was particularly bad on Friday nights, but eastbound out of downtown Seattle, Friday afternoon traffic was reasonably light. Conventional wisdom is that the workers who do not go to work on Friday morning are all out making trips on Friday afternoon. These results indicate that if this is the case, those workers are making a specific set of discretionary trips: those associated with evening recreational travel.

**Table 14: Percentage of Evening Commute Period Traffic Congestion by Day of Week**

| | Mon | Tues | Wed | Thurs | Fri |
|---|---|---|---|---|---|
| SR 520 WB | 16% | 18% | 21% | 23% | 21% |
| SR 520 EB | 17% | 22% | 23% | 23% | 15% |
| I-405 NB | 23% | 22% | 21% | 19% | 15% |
| I-405 SB | 20% | 16% | 20% | 24% | 20% |
| I-90 WB | 6% | 22% | 17% | 30% | 25% |
| I-90 EB | 14% | 21% | 29% | 21% | 15% |

Interestingly, Table 14 shows that Thursday afternoon experienced more congestion than Friday afternoon. Additional analysis needs to be performed to determine whether this initial result is statistically significant or a function of the specific days of data used (i.e., the incident occurrences) in the analysis data set.

When all weekday delay is accounted for (see Table 15), a more mixed picture of congestion appears. The lack of Friday morning congestion decreased total Friday delays, but higher Friday evening delays on some directions of travel somewhat balanced the low Friday morning delay. As a result, Thursday was the "most congested" day of the week, in part because it had no "low congestion" time periods and experienced slightly greater than average afternoon delays. More data are needed for this analysis before statistical significance can be applied to these conclusions.

**Table 15: Percentage of Total Weekday Delay by Day of Week**

| | Mon | Tues | Wed | Thurs | Fri |
|---|---|---|---|---|---|
| SR 520 WB | 17% | 20% | 20% | 24% | 19% |
| SR 520 EB | 20% | 21% | 22% | 23% | 15% |
| I-405 NB | 22% | 21% | 20% | 22% | 14% |
| I-405 SB | 20% | 16% | 21% | 22% | 22% |
| I-90 WB | 19% | 22% | 20% | 24% | 14% |
| I-90 EB | 17% | 22% | 26% | 20% | 15% |

## FURTHER STUDY IS REQUIRED AND/OR LIMITATIONS

The primary disappointment with both the Phase 1 and Phase 2 research is that the methodology selected continued to be unable to assign a large portion of non-recurring congestion to a specific cause. The detailed analysis performed in Phase 2 indicates that a significant portion of the "unassigned delay" is in fact caused by the 'incidents and events' included in the Phase 1 and Phase 2 analyses, but the congestion takes place at times and/or locations removed from the site of the incident itself.

The empirical review of corridor performance indicates that the traffic disruption caused by an incident creates a change in traffic patterns. The change in traffic pattern in turn creates new congestion elsewhere along the corridor. The following example illustrates some of the limitations with the Phase 1 and Phase 2 analytical techniques:

> A major, multi-vehicle accident happens westbound on I-90, east of Issaquah, and earlier than the start of the morning commute period. The accident creates a significant traffic queue, but that queue is located east of the monitored freeway system (i.e., east of the freeway segments used in this analysis). Shortly after the accident site is cleared, a very large "pulse" of traffic arrives at the eastern edge of the monitored freeway corridor. The "pulse of released traffic" is much larger than the ramp metering algorithm is designed to accommodate, and the resulting volume levels cause the freeway to break down. (This "unusual congestion" is illustrated in Figure 1.) The breakdown, while directly the result of the release of the queue that formed because of the accident, occurs at a location several miles <u>downstream</u> of the accident site and <u>after</u> the accident has been cleared from the roadway. A "wave" of non-recurring congestion continues to move westbound throughout the morning commute on I-90 as the unexpectedly large flow of vehicles continues westbound. All of the congestion measured in

this case is registered by our current analysis system as being “non-recurring” but having an “unidentified cause” as it does not occur where the accident took place nor within 30 minutes of when the event (accident) occurred.

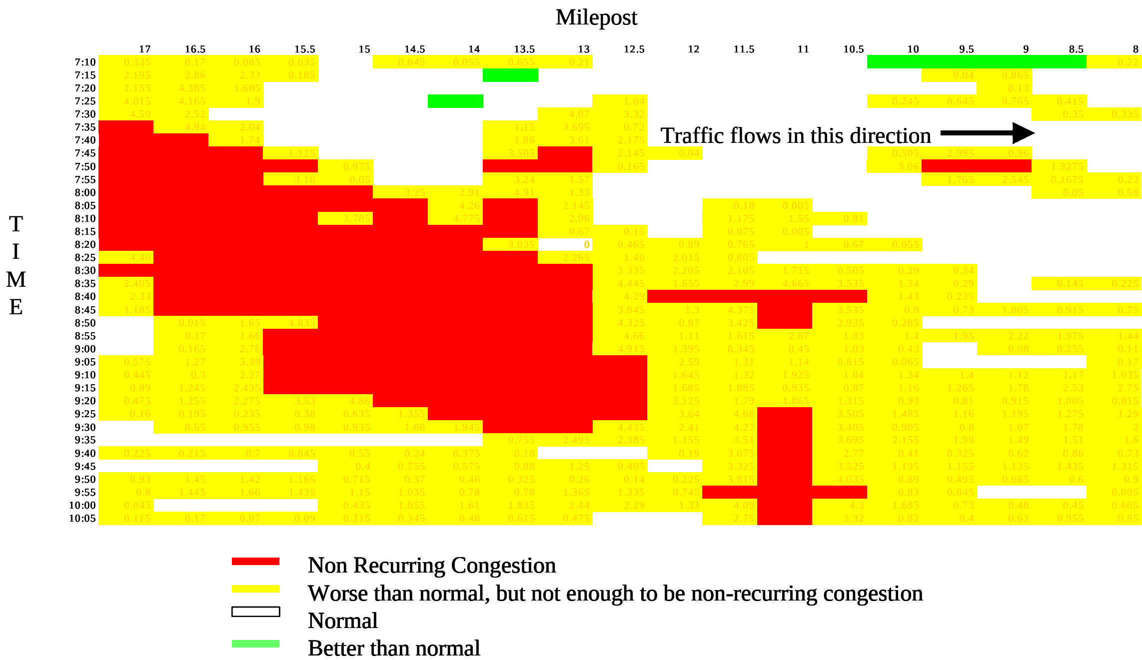


**Figure 1: Extra Congestion Caused by Release of Traffic Delayed Behind a Major Accident Scene on Westbound I-90**

This example illustrates how traffic incidents not only cause congestion approaching the scene of an existing incident, by also disrupt normal traffic patterns elsewhere on the freeway system.

The simple T-tests used to examine lane blocking and special event congestion were an initial attempt to examine the use of other statistical techniques for more effectively capturing these types of delays. In future phases of this analytical work, more sophisticated statistical approaches should be tested to determine whether they offer new insight into the relationship between delay and the nature of the congestion event. For example, can a relatively simple statistical model be developed that predicts the delay effects of an incident on the basis of the duration of that incident? Can more sophisticated analyses predict increases in delay on the basis of the size of special events?

If these approaches prove to be reliable, does the delay they predict account for a larger amount of "non-recurring" delay than the process used in the Phase 1 and Phase 2 analyses?

Another limitation noted in the current analysis is that it treats roadway performance at a location as a single value, the average speed of traffic across all lanes. This approach creates some interesting boundary conditions, especially at freeway to freeway ramps where back-up congestion occurs. Because the "through lanes" continue to move fairly quickly, the current process may under-estimate congestion approaching these ramps. Only when ramp congestion is so severe that the entire freeway's mainline performance suffers is the congestion readily apparent. This may under-estimate the level of recurring delay occurring at ramps.

Despite the imitations in the current analytical technique, the project team does not recommend that the Phase 1 and Phase 2 analytical technique be abandoned in Phase 3 of this research. The limited time and budget for Phase 2 prevented testing of the threshold values that are key to the performance of the model. Sensitivity tests of key parameters used in the algorithms, especially threshold values like the +5 change in occupancy percentage used to define "non-recurring congestion," the use of only "lack of lane-blocking events" to define recurring days in the calendar, and the use of average of all lanes, to determine traffic congestion, would add considerably to our understanding of congestion in the Seattle metropolitan region.

Among the issues that should be explored in future phases of this work is the whole definition of recurring non-recurring congestion, which relies heavily on a) how we define a recurring day (based only on the lack of lane-blocking right now), and b) how we define threshold of non-recurring (based on a fixed +5 percent value from the median recurring condition.) Item (a) could be explored by expanding the definition to include other types of events, e.g., special events, to define recurring days. Item (b) could be tested for the sensitivity of the +5 value, and for possible variable thresholds based on corridor, time of day, or background conditions. For example, maybe the threshold value for congestion shouldn't be a fixed value, but a function of what the background condition was at the time the event occurs. Perhaps a more sophisticated threshold definition could cause two separate congestion regions in the difference matrix to become one region, thereby allowing more of the congestion to be associated with an event. The detailed analysis of specific daily corridor performance supports this interest in further exploring the basic definition of "recurring congestion." For example, it revealed a number of "semi-recurring" congestion conditions. An example of such a condition is on I-90 westbound at the exit from the Mercer Island tunnel during the morning peak period as vehicles approach the floating bridge. Delays occur at this location roughly once per week for no apparent reason. The infrequency of congestion makes this a "non-recurring" condition as defined by the Phase 1 methodology, in part because on the other four days of the week the freeway flows reasonably well at this location. A question that needs to be discussed within the context of the recurring/non-recurring analysis is whether such delay is more appropriately considered "recurring" (it does happen about once a week, but the day it will occur is not predictable) or whether this is more correctly labeled "non-recurring."

Finally, additional analysis needs to be performed with the weather information obtained. More significant weather events need to be incorporated into the analysis period. In addition, more sophisticated analysis needs to be undertaken. For example, if rain does not fall for a month, when it does rain, will a greater amount of delay (and incidents) occur than if it has rained for the past three days?  If this is the case, WSDOT might want to schedule additional incident response staff for days on which rain is predicted after prolonged dry spells.

Perhaps the point that best summarizes the findings of this phase of the ongoing roadway performance research is that the research results to date reinforce the idea that traffic performance is very complex, and considerable work remains before we truly understand the interactions of all of the factors which cause traffic congestion.

# APPENDIX A

## DESCRIPTION OF METHODOLOGY[1]

The general analytical approach developed was as follows: For a given combination of **corridor** (e.g., I-5 from milepost 153 to 166), **direction of travel** (e.g., northbound), **range of days** (e.g., September 2002, Tuesday through Thursday), and **time period** (e.g., AM peak period), do the following:

1. Compute the traffic profile for each day of interest. The traffic profile is a matrix of traffic loop measurements (volume, lane occupancy, or speed) as a function of time of day and milepost.
2. Clean and process the incident database(s) to determine all blocking (non-recurrent) incidents during the time period of interest.
3. Compute a single background (recurrent condition) traffic profile of lane occupancy, using the median traffic profile for all days minus days with lane blocking incidents, that can be used as a reference for comparison with non-recurrent traffic profiles.
4. Compare the traffic profile of lane occupancy for each day with the background traffic profile (based on the median traffic pattern) by computing the difference between the two profiles. This difference matrix indicates the locations where and times when incident-related delay occurs by highlighting atypical differences in occupancy that are thought to be associated with non-recurring events such as blocking incidents.

[1] This initial section of this appendix is taken from the Phase 1 report, *Measurement of Recurring versus Non-recurring Congestion, Technical Report*, Hallenbeck, M. E., J. M. Ishimaru, and J. Nee. 2003, WA.RD, 566.2 It is included as a reference for the reader. Additional details on the methodology are included in the original report.

5. Tabulate the locations and times associated with regions showing apparent congestion from a blocking incident; for those combinations of location and time, estimate the delay by computing the difference between the actual estimated speed and a reference speed (e.g., the speed limit or a fixed optimal speed) and convert that value to an associated per-vehicle delay. Convert the per-vehicle value into vehicle-hours of delay by using the estimated number of vehicles at that time and location. Perform that process for each blocking incident, and sum up the results to estimate the portion of congestion (i.e., the amount of delay) associated with blocking incidents.

## METHODOLOGICAL ADDITIONS AND ASSUMPTIONS FOR PHASE 2

### Overall Process

The methodology used in this project computes estimated vehicle-hours of delay associated with recurring and non-recurring (NR) events on a freeway corridor. NR event categories include lane blocking incidents, non-blocking shoulder incidents, blocking incidents producing congestion that backs up from one facility to another, planned events (e.g., sporting events), and miscellaneous non-recurring congestion. The general approach to identify and estimate non-recurring congestion delay for a given corridor and time period involves the following:

- Identify the location and time of non-recurring events on the freeway corridor, and estimate the region of congestion (in both time and space) associated with each event.
- Estimate the vehicle hours of delay associated with each resulting region of congestion.

- Sum the vehicle hours of delay by time period and/or event category.

To estimate the region of congestion of a NR incident (**step 1 above**), a comparison is made between actual freeway conditions on the day of the incident, and the typical background condition when no non-recurring events are occurring. Non-recurring events are assumed to produce associated congestion that would not normally be present; therefore, a comparison of conditions during a non-recurring event versus the background condition is hypothesized to yield a difference in time-space conditions that can be used to identify the geographic scope and duration of the NR event-related congestion. (These conditions are described in the time-space domain, which can be thought of as a matrix of freeway condition as a function of both time of day and location along a corridor. Lane occupancy percentage is used as an estimate of freeway conditions.) Once this region of congestion is determined, the associated vehicle volume and speed estimates can be used to estimate vehicle-hours of delay (**step 2**) based on a specified reference speed (e.g., a speed threshold, such as 60 mph, below which delay is defined to occur). The individual event delays are then summed for each non-recurring event category, for each day (**step 3**), to determine the relative contribution of each event type toward overall congestion delay.

The sum of the delays associated with all non-recurring events (including any non-recurring congestion not associated with a known event) is the estimated total non-recurring congestion delay. In addition to NR delay, total delay and recurring delay are also estimated. Total overall delay is defined as the sum of non-recurring delay and recurring delay. Total overall delay is estimated by computing delay using vehicle volumes and speed estimates for the entire time-space domain, not just NR regions of congestion. To compute recurring congestion delay, the total non-recurring congestion delay is subtracted from the total overall delay.

In addition, the correlation between congestion and precipitation is estimated, using precipitation levels per hour on each corridor segment as an overlay to further subdivide the congestion delay according to the weather conditions at the time.

## Step-by-Step Procedure

The following steps are followed to implement the process, for a given corridor segment, direction of travel, time period (e.g., AM peak period, midday, PM peak period), and set of days processed (e.g., weekdays in January 2003):

1) **Prepare Incident and Events Data.** Clean incident databases (e.g., remove typographical errors and ambiguous data), and prepare listings of the relevant incidents (blocking, shoulder) in the proper format for processing. Prepare a list of special events and their time and location.

2) **Prepare hourly precipitation data.** Collect precipitation data from regional weather stations. Re-code the hourly precipitation levels to the following categories: no precipitation, low, moderate, or heavy. Assign each station's data to a corridor segment. Format the data as time-space matrix overlays with the same dimensions as the freeway condition matrix. Each time-space matrix (milepost vs. time period) will show hourly precipitation levels on a given corridor for a given day. (The weather information is used as a mask to allocate subsets of the delay to different precipitation conditions.)

3) **Prepare Freeway Condition Data**. Compute each day's time-space matrix (i.e., time of day vs. location) of estimated vehicle volume, lane occupancy percentage, and speed, using loop data.

4) **Compute Background Matrix:**

a) Identify which days have incidents in the database, for a given time period. Do this for each month.

b) Compute the median occupancy matrix for each month, based on the occupancy matrix for those days that have no blocking incidents. The median is computed individually for each matrix element (i.e., a given milepost/time combination). This median time-space matrix is used as the background condition for that month. (The use of the median value reduces the potential biasing effect of outlier days.)

5) **Compute the Difference Matrix**. Subtract the monthly background condition (median matrix) from the freeway condition matrix of each day. (Use the background condition appropriate for the month being analyzed.) The result is a difference matrix that is used to highlight unusual time-space regions.

6) **Detect Regions of Congestion associated with each incident**:

a) Evaluate each element of the difference matrix for each day, based on the value of the difference. Any element in the "+5 and higher" difference category is considered a time/location combination of non-recurring congestion.

b) Identify the time-space location (day, milepost, start time, clear time) of each **lane blocking** or **shoulder** incident of that corridor.

c) Identify the time-space location (day, milepost, start time, clear time) of each virtual **spillover event** produced by incidents on a related (adjacent) corridor, using the off-ramp to the adjacent freeway as the location of the spillover "incident", with the start time determined by the first appearance of non-recurring spillover congestion in the difference matrix, and clear time determined by the duration of the original incident that produced the spillover. Note that spillover congestion is defined based on its time-space proximity to the original incident; there is not necessarily a direct cause-effect relationship.

d) Identify the time-space location (day, milepost, start time, clear time) of each **special event** incident on that corridor. The location of a special event is a "virtual" one, defined as the start of the off-ramp that is most likely to serve traffic on that corridor that is going to the event. The virtual clear time is defined to be the event start time, while the virtual start time is defined to be (event start time minus 1 hour).

e) Locate the congestion region of each incident (both real and virtual) by looking for a cluster of contiguous difference matrix elements near the incident location that have high difference values (i.e., +5 or greater, which is defined as non-recurring congestion as noted in step 6 a). The edges of this region are determined by looking for local minima (a "valley") of the difference values, or a difference that drops below the +5 threshold (+5 defines NR congestion).

7) **Compute Vehicle-Hours of Delay.** Compute the delay for each congestion region from step 6e), using the volume and speed matrix of the corresponding day. Assign each region's delay estimate to the corresponding NR category, as well as any category combinations. Also, allocate the congestion delay of each NR category by weather category, using the precipitation overlay.

**<u>Notes on the Incident Region Procedure</u>**

The following are specifics on the procedure used to detect the region of congestion that is related to a particular NR event. The general approach is to use information about the start time, clear time, and location of an NR event as a starting point to locate the region of congestion that appears to be associated with that event, using the corresponding time-space difference matrix as a guide. A series of rules are used to determine whether an element of the difference matrix is part of the region of congestion. The purpose of the difference matrix is to help clarify the location of congestion related to non-recurring events by indicating areas with unusual congestion relative to the median (recurring) condition.

The following procedure is used for the lane blocking, shoulder, spillover, and special events types of NR events (although the special event region is handled somewhat differently, as described below):

1) Identify the position of each NR event on the time-space difference matrix, using the milepost location, start time, and duration (or clear time) of the event.
2) Use the start location, start time, and duration from step 1 to define the associated congestion region for that event in the difference matrix. The congestion region is determined as follows:
    a) **Establish a starting point.** Beginning at the incident location (intersection of start time and location), search for a nearby NR congestion element (i.e., difference > +5). If one is located at the incident location, or 0.5 miles upstream at the start time, or at the incident milepost 5 minutes later, or 5 minutes later and 0.5 miles upstream (search in that order), use that as the starting point for the next steps. Otherwise, a region of congestion cannot be located for this event.
    b) **Locate congestion that occurs from the event.** If a starting point was determined in 2 a), start at that matrix element and process a series of consecutive matrix elements by keeping the milepost fixed and moving forward 5 minutes at a time until the clear time is reached. For each 5-minute value of this series of elements

(beginning at the start time), move left along the row (i.e., upstream), as long as the values are steadily decreasing, until one of the following stopping conditions occurs: 1) a value < 5 is reached, 2) a local minimum is reached, i.e., the values begin to go up. Each element processed before the stopping condition is considered part of the congestion region. If the values are going up initially (and are NR values), continue until the values start dropping, then look for one of the stopping conditions.

Note that changes (up or down) of less than or equal to 2 are considered transient fluctuations of the data and are not considered to be a change of direction, so a minimum change of +3 is required to meet the stopping condition. For example, if the value drops to +8, then fluctuates between +8 and +10, the stopping condition is not reached until the value reaches +11, at which point the most recent element at +8 will be defined as the congestion region edge.

c) **Locate congestion that continues after the event.** Beginning at the incident milepost, start from the most recent region cell identified in step b) in that column, and move forward in time as long as the values are steadily decreasing, until one of the following stopping conditions occurs: 1) a value < 5 is reached, 2) the values begin to go up (i.e., using the same stopping conditions as shown above). Do this for each 0.5 mile increment upstream, until no region values are located.

d) The resulting cells are the congestion region. Assign a code to these elements based on the event type.

**<u>Notes on the Spillover Method (i.e., spillover from adjacent corridor to primary corridor)</u>**

**Primary** corridor = corridor you are processing

**Adjacent** corridor = intersecting corridor that might have incident congestion that spills over to the primary corridor

1) Check any adjacent corridors that have the potential to spill over onto the primary corridor that you are evaluating. Look for a "blocking" incident (only blocking incidents qualify) on the adjacent corridor up to 10 miles downstream from the interchange (in the direction that makes sense). For example, if you are processing delay on I-90 WB, check for incidents on I-405 NB from Factoria north past Bellevue (up to 10 miles) to see if there are any blocking incidents that might have the potential to be backing up onto I-90. Do the same on I-405 SB toward Renton (up to 10 miles).

2) For each incident found, look for NR congestion at the interchange milepost of the primary corridor you are analyzing; check the 30 minute period after the incident start time (i.e., check from start time to (start time + 30)). For the I-90 example, if you find a blocking incident on I-405 NB in Bellevue at 7 AM, check on I-90 from 7-7:30 AM at the intersecting milepost (MP 9.5, defined by user) and look for NR congestion.

3) If you locate +5 or higher differences, that becomes a new "virtual" incident, with start time and location set to the first encountered NR congestion, and duration set to be equal to the duration of the original incident. You then process the virtual incident the same as any other incident.

**Assumptions**

- Only blocking incidents can cause spillover.
- 10 mile search limit (from the interchange) for incidents on the adjacent corridor
- 30 minute search limit (from incident start time) for NR congestion on the primary corridor

- Mileposts of the interchanges are user-specified (they should be locations that are sufficiently upstream from the interchange to be affected by spillovers), e.g.,

**<u>Route: I-90 Westbound</u>**

| Adjacent, | Incident Database, | Direction, | Primary MP, | Adjacent MP |
|---|---|---|---|---|
| I-405, | I-405.csv, | North, | 9.5, | 12 |
| I-405, | I-405.csv, | South, | 9.5, | 10 |
| I-5, | I-5.csv, | North, | 3.5, | 165 |
| I-5, | I-5.csv, | South, | 3.5, | 164 |

- Congestion is assumed to be continuous from adjacent blocking incident to the primary corridor. (This is not verified by the code.)
- The congestion on the primary corridor is assumed to not be caused by a NR event on the primary corridor itself. (This is not verified by the code.)

**<u>Notes on the Special Events Method (i.e., congestion from an event that has a specific location and start time)</u>**

1) Develop a list of events that have a specific start time. Identify the freeway “location” of the event; this usually corresponds to the off-ramp primarily used for traffic to the event.
2) Beginning one hour before the event, check the off-ramp location at successive 5-minute intervals until NR congestion (red) is located. That time, and the off-ramp location, defines a “virtual” blocking incident that is put into the list of blocking incidents, where it is processed like any other blocking incident.

**Assumptions**

- EV.CSV shows the start time of the event, and the "location" of the event on the freeway (usually the off-ramp). Each event has one primary off-ramp that can be located. (If not, each off-ramp could be designated as a separate special event and processed.)

- The search limit (from the off-ramp) for NR congestion is one hour before the start time of the event.
- Associated congestion is assumed to begin at the off-ramp.

**Notes on the Weather Method**

1) Weather is categorized at each weather station in terms of precipitation level (inches per hour), on an hour by hour basis for each day, using data from UW Atmospheric Sciences department:

| | |
|---|---|
| 0" | dry |
| 0 to 0.1 | light |
| to 0.3 | moderate |
| >0.3 | heavy |
| no data | use max(0, most recent change in accumulation on that day) |

2) The precipitation from each weather station is assigned to a specific corridor and milepost range.

3) All other NR processing (blocking, shoulder, spillover, special events) is performed before the weather information is used.

4) The resulting NR distribution is then combined with the weather, using weather information as an “overlay”. Therefore, each NR category (blocking, shoulder, spillover, special events) is further subdivided by the weather categories (dry, light, moderate, heavy)