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MEASUREMENT OF RECURRING VERSUS NON-RECURRING CONGESTION: TECHNICAL REPORT

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16. ABSTRACT

This report documents the technical results of a WSDOT-sponsored research effort to determine the nature and cause of congestion on Seattle-area freeways based on an analysis of available databases of traffic incidents and freeway performance. The focus of this effort was to develop a methodology for estimating freeway congestion as a function of its estimated cause (principally, its recurring or non-recurring nature) by using readily available data, as well as to develop, implement, and use a prototype tool set that would apply that methodology.

The resulting methodology and tool set produce estimates of congestion (delay) associated with recurring and non-recurring conditions as a function of various user-specified parameters and assumptions. The method is able to analyze Seattle area corridors using data from existing databases. The process makes extensive use of the TRAC-FLOW analysis process, as well as supplementary prototype tools.

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CONTENTS

FIGURES

Figure *Page*

TABLES

Table *Page*

INTRODUCTION

This report documents the technical results of a WSDOT-sponsored research effort to determine the nature and cause of congestion on Seattle-area freeways based on an analysis of available databases of traffic incidents and freeway performance. The focus of this effort was to develop a methodology for estimating freeway congestion as a function of its estimated cause (principally, its recurring or non-recurring nature) by using readily available data, and to develop, implement, and use a prototype tool set that would apply that methodology.

The document is organized as follows:

Background: A description of the research problem, the initial research approach and methodology, the resulting products of this project, and a list of tasks performed.

Feasibility evaluation: A description of the feasibility testing of the incident databases.

Methodology description: An overview of the recurring/non-recurring congestion analyses methodology.

Test of methodology: A description of the tests performed for the initial steps in the methodology.

Typical user process: A description of the process by which the methodology was implemented with Seattle-area data, and an overview of the tools developed to implement the methodology.

Future Research: Outstanding issues and future directions.

BACKGROUND

The choice of tools to cost effectively combat congestion on the state's transportation network is dependent in part on a good understanding of the causes of congestion; a better understanding of those factors would enable the WSDOT to employ tools that specifically address and mitigate those factors, and thus make the most effective use of limited resources. Of particular importance is a better understanding of congestion that is caused by or related to incidents and other transient events, versus congestion caused by geometric limitations or a lack of capacity. Significant occurrences of the former would suggest that incident response strategies that reduce incidents and mitigate their effects would be cost-effective options, while more occurrences of the latter might suggest that other approaches would be suitable for consideration.

WSDOT currently lacks specific information on the relative causes of congestion within the Puget Sound freeway system, as well as a method for estimating those causes. Specifically, the Department does not have data describing the extent to which delay occurs because of temporary capacity reductions caused by transient events such as incidents, versus the extent to which congestion is caused by demand outstripping inherent capacity.

The approach described in this report focuses specifically on the assignment of estimated congestion delay into two general categories: recurring delay and non-recurring delay. For the purposes of this project, recurring delay is considered to be delay that occurs routinely and is not triggered by a transient event, whereas non-recurring delay is delay that occurs in response to a transient event. Because the role of incident response strategies is the issue that initiated this research, the methodology was initially developed to investigate blocking incidents in particular, though additional analyses suggest that the methodology might also provide a better understanding of the significance of other types of transient events (e.g., weather, special events).

APPROACH

The following guidelines were used in the development of a methodology for estimating recurring and non-recurring congestion.

1. The process should be capable of analyzing congestion on all the major freeway corridors in the Seattle area. This includes I-5, I-405, SR 520, I-90 and SR167.
2. The methodology should make use of readily available databases. The potential databases include the WSDOT Northwest Region's Traffic Systems Management Center (TSMC) blocking incident log, the WSDOT Incident Tracking System (WITS) database, and the WSDOT NW Region's FLOW freeway database.
3. To facilitate efficient development of a methodology tool set, the process should make use of, and build upon, the capabilities of the existing TRAC-WSDOT FLOW analysis process. This process, developed over the last eight years, uses software developed at TRAC to analyze freeway surveillance data collected by WSDOT's NW Region FLOW system and compute performance measures for operational or policy analyses. This project represents the next step in the continuing improvement and refinement of the TRAC-WSDOT FLOW analysis process.
4. Tools should be developed to automate the process as much as possible, within the time constraints of the project.
5. The process should enable the analyst to modify thresholds, key assumptions, and other parameters used in the methodology on the basis of user judgment.
6. The method and tool set should be developed to the point that they can be used to analyze all the Seattle-area corridors, within the timetable of this project.

The resulting methodology meets these guidelines. The tool set and process that apply the methodology produce estimates of congestion (delay) associated with recurring and non-recurring conditions as a function of various user-specified parameters and

assumptions. The method can be used to analyze all Seattle area corridors and requires only the use of the databases listed above. The process makes extensive use of the TRAC-FLOW analysis process, as well as supplementary prototype tools.

PRODUCTS

There are three primary products from this project. These products are as follows:

- An analysis process that can be enhanced and used in the future to measure changes in the distribution of recurring and non-recurring congestion on the Puget Sound freeway system.
- Software programs built into the current FLOW/CD Analyst software, as well as supplementary tools, that enable the WSDOT to perform the above analytical process.
- A report that describes the size, scope, and nature of congestion on the Puget Sound freeway system, with specific emphasis on the relative causes of that congestion.

This report documents the first two products. Analytical results for the Seattle area freeway network are summarized in a separate project report.

TASK LIST

The following tasks were completed as part of the methodology development for this project:

1 **Analyze databases**. Determine the feasibility of using incident data and freeway performance measurements based on WSDOT data collection to develop a recurring/non-recurring congestion analysis process.

2 **Develop the analytical methodology**. Develop a process to combine incident data with freeway performance data to produce estimates of congestion delay by level of recurrence.

3 **Develop an associated tool set.** Modify the existing analytical software tool set to implement the methodology. Use a combination of existing and new tools as required.

4 **Use the method and tool set, and document results.** Deploy the methodology using available freeway data for the Seattle area. Prepare a technical report of the methodology and tools, with a separate analytical report summarizing the use of the methodology to analyze Seattle area freeways.

INITIAL FEASIBILITY REVIEW

The initial project activities focused on the feasibility of using existing data to perform this research task. Because good information about the time, location, and nature of incidents is a key requirement of this project, the initial activities focused on the quality of the incident database information, its usefulness for this project, and the ability to extract required incident descriptions from the database in a user-friendly, analyzable form.

The candidate incident databases were the following:

1. WSDOT NW Region TSMC log of blocking incidents, compiled by WSDOT NW Region from direct video observations by traffic management center staff,
2. WSDOT Incident Tracking System (WITS) database of incidents for which WSDOT incident response teams were utilized, compiled by WSDOT from incident response data.
3. Computer-aided Dispatch (CAD) log of incidents, compiled by the Washington State Patrol from incident reports prepared by its personnel.

Each of the candidate databases was evaluated to determine the nature of its contents, its completeness and accuracy, its ease of use, and its overall potential utility for this project. Table 1 summarizes the review of these databases.

Table 1. Comparison of Incident Database Attributes

	TSMC log	WITS	CAD
Contents of interest	Location Type of incident Time start Time clear	Location Type of incident Time start Time clear Other report info	Location Type of incident Time start Time clear Other report info
Time Period	5:30 AM – 7:30 PM Weekdays, 9-6 Weekends	All day	24/7
Format	Text file	Filemaker Pro or text	Manual query
Types of Entries	Blocking incidents only, with time stamp based on CAD info or TSMC CCTV observation	All WSDOT IRT	All reports to WSP
Benefits	Database focuses on blocking incidents that are actually observed and verified Electronic format	Detailed descriptions Electronic format; can be analyzed via Excel (text export)	Comprehensive
Limitations	Start time relies on operator observation when CCTV-based; could be after the actual start time Requires new software or macro for automated analysis Time stamps are approximate	Does not necessarily include all calls of I-5 Service Patrol Blocking info can be ambiguous (thus, difficult to search/automate) Time stamps are approximate Not all are complete entries (e.g., no MP or other location info)	Inefficient to query and process; analysis cannot be readily automated No searchable lane clear time; that info is only in comment field No radio available during some WSDOT training for new IRTs; therefore, no data for some incidents (after 7/2002)

OBSERVATIONS

This review of database characteristics, and previous incident database experience, suggested that the CAD system would provide a comprehensive database of information that could be used in this project. However, this significant benefit was outweighed by practical considerations. In particular, the manual query system of the existing CAD system is cumbersome and not readily amenable to subsequent automated post-processing of the data. Given the large quantity of data to be processed, the CAD database was not considered to be the most cost-effective choice for the large-scale corridor-wide and regional analyses that were envisioned as future applications of the methodology, particularly given the schedule constraints of this effort. Therefore, focus shifted toward the two newer databases, the TSMC log and WITS.

WITS is the more detailed and comprehensive database in terms of incident descriptions. The incident comments, in particular, provide valuable information about the circumstances of an incident that can help determine the extent to which lane blocking could be occurring. However, WITS contains some ambiguities (approximate time stamps, occasional incomplete entries) that could make it difficult at times to identify which entries were truly blocking incidents. Because the focus of this research was on blocking incidents, this was a significant issue. Also, WITS does not necessarily include every I-5 service patrol call. In contrast, the TSMC's log focuses specifically on only blocking incidents, the incident types of interest in this project. TSMC operators record time stamps (start time, clear time) that are usually the result of direct (video) observation, as opposed to the WITS time stamps, which can be approximate or estimated. However, detection by observation also means that TSMC start times could be noticeably different from the actual incident start time (i.e., the time at which blocking incidents are first <u>noticed</u> on closed-circuit television (CCTV) is the start time that is entered in the TSMC log). Both databases have a formatting limitation (text data fields for comments) that would inhibit fully automated processing and

require manual inspection. They are, however, available as electronic files, unlike the CAD system whose data can only be retrieved in paper form.

In an effort to compare the contents of the two databases and evaluate their ease of use, TSMC and WITS entries were compared for selected days in 2002 on I-5 and I-405 in the Seattle area. This helped determine the extent to which these databases provided good incident coverage and agreed with one another during the time period when the databases overlapped (approximately 6:00 AM to 7:00 PM). Comparisons of all database entries on those days showed that most of the TSMC entries were also listed in the WITS database, with the exception of a) short duration (< 5 minute) TSMC entries, b) I-5 service patrol entries, and c) some ambiguous entries. In contrast, most of the WITS entries were not in the TSMC log because WITS a) includes non-blocking incidents, and b) does not necessarily include I-5 service patrol calls.

In summary, WITS is detailed and provides valuable information on the specifics of the incident, while TSMC's log was found to be very useful in supplementing WITS information, providing more specific time stamps, and clarifying borderline WITS blocking cases. The CAD database could be used to analyze unusual and ambiguous cases if they were significant and could not be resolved otherwise, but it is too tedious to use on a routine basis; it is also difficult to work with data from the CAD on an automated basis. Both the WITS and TSMC databases provided benefits to this project and were used extensively.

METHODOLOGY DESCRIPTION

After the incident databases were evaluated and selected, the methodology was developed. This was followed by a test of the methodology process to confirm that its components could be completed with the available data. After testing suggested that the approach was feasible, an associated tool set was developed to automate key steps in the process and facilitate the regional analyses required in this project.

PROCESS OVERVIEW

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:

- **Prepare incident data**. Clean and process the incident database(s) to determine all blocking (non-recurring) incidents during the period of interest.
- **Prepare traffic data**. Compute the traffic profiles for each day of interest. Each traffic profile is a matrix of traffic loop measurements (volume, lane occupancy, or speed) as a function of time of day and milepost for the corridor of interest.
- **Prepare a reference traffic profile.** Compute a single background traffic profile of lane occupancy, using the median traffic profile for all days, that can be used as a reference for comparison with non-recurrent traffic profiles.
- **Compute changes in congestion patterns during blocking incidents**. Compare the traffic profile of lane occupancy for each "non-recurring" day (i.e., a day with a blocking incident) with the background traffic profile by computing the difference between the two profiles. This difference matrix

indicates the locations where and times when incident-related delay occurred, by highlighting atypical differences in occupancy that are thought to be associated with non-recurring events such as blocking incidents.

- **Define regions of non-recurring congestion and compute associated delay.** Tabulate the locations and times associated with apparent congestion from a blocking incident. For those combinations of location and time, estimate the delay by comparing the estimated speed to a reference speed (e.g., the speed limit or a fixed optimal speed) and computing 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 all blocking incidents.
- **Summarize results.** Compare the total non-recurring delay with an estimate of overall delay (i.e., the combination of both recurring and non-recurring) to determine the significance of non-recurring delay versus overall delay.

METHODOLOGY TEST

Testing was performed to evaluate the feasibility of this methodology, with particular focus on the ability to determine the backup delay associated with each blocking incident by inspecting the difference matrix (non-recurrent profile minus background profile), either visually or by other means. To perform this test, one month of I-405 northbound weekday data (Tuesday-Thursday AM peak period only) was processed manually using the method described above. Selected days with blocking incidents were compared with a background profile, to determine whether congestion associated with incidents could be discerned from the resulting difference matrix. Selected incidents of varying magnitudes and lengths were

checked to determine whether a) the difference pattern was consistent with an incident at the time and location noted in the database, and b) the difference pattern suggested an associated congestion backup. Below are examples of those comparisons.

1) Long duration incident (1 hour) (injury collision): Results showed congestion building at the location and time suggested by the databases. A region of congestion backup could be determined by using a near-zero or sign change threshold as a criterion for the edge of the congested region. (October 15th, entry in both TSMC and WITS.) It is interesting to note that the congestion region in the difference profile was much larger, and started earlier, than the timing suggested in the WITS database. However, a check of the TSMC log found what appeared to be the same incident with an earlier start time based on CCTV observation; the TSMC times better matched the congestion region's location. This is an example of the usefulness of TSMC data to supplement WITS incident information.

2) Long duration incident (1.5 hours) (injury collision): Results showed congestion building at the location and time suggested by the databases. (October 30th TSMC and WITS.) Note: This incident was originally found in TSMC's log; WITS was then searched for a match, and one was found among entries that were originally considered non-blocking events. This is another example of the usefulness of TSMC data when WITS data were insufficient to categorize an incident entry.

3) Short duration incident (30 minutes) (injury collision): Results for this incident also showed congestion building at the location and time suggested by the databases. A region of congestion backup could be determined by using a near-zero or sign change threshold as a criterion for determining the edge of the congested region. (October 8th entry in both TSMC and WITS.) This is an example of a non-recurrent entry that was confirmed in both TSMC and WITS.

4) Very short duration incident (10 minutes) (blocking incident): This is an example of a short blocking incident that was in the TSMC log but not in WITS. Results were similar to those of the other examples. (October 22nd TSMC only.)

In each of the above examples, a congestion region could be estimated by using a sign change (or a change from a near-zero value to a large positive value) in the corresponding difference matrix as a criterion for defining the edge of the region. Figure 1 shows an example of a difference matrix and a congestion backup pattern from an incident. Milepost values are along the top, with time of day along the side; the direction of travel is left to right. Each value in the matrix is the difference between lane occupancy for a given non-recurrent day and the corresponding lane occupancy of the background matrix. The vertical line shows the WITS/TSMC-based location and duration of the incident. Gray cells are the estimated upstream backup from the blocking incident based on non-zero/sign change edge detection criteria. This can be interpreted as a region with a larger than typical level of congestion, whose leading edge (the incident location) produces a downstream improvement in traffic (a sign change).

Three methods of computing background profiles were also tested to evaluate their effect on the difference matrix. In addition to the average-based difference matrix used above, a median-based background matrix was tested to see whether a reduction in the influence of outlier recurrent days might enhance the edge detection process. (It was thought that by using median values only, the extreme recurrent values would have less of an effect.) This was compared to the average-based background matrix. Results based on the tests above suggested that the median-based matrix worked as well as the average matrix,. In one case (#2 above), the edge was more distinct with the median matrix. A variation, using all days rather than only recurring days, produced similar results, suggesting that the median approach was not as sensitive to the effect of non-recurring days (outliers) when the background matrix was computed.

After the feasibility reviews and methodology testing had been performed, the methodology was then used to analyze the regional freeway network in the Seattle area, as described in the next section.

	Milepost											
	2	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**	**7.5**
6:40	1.15	-0.8	-0.9	0.03	-1.6	-13	-13	-7.2	-4.6	5	3.07	-3.1
6:45	1.3	0.51	1.52	0.84	-14	-17	-3.4	9.46	-1.1	0.95	-1	-4.9
6:50	-0.6	-1.3	-1.8	-1.4	-9.1	-2.6	-0.2	-2.3	-8.1	-7.9	6.76	5.73
6:55	0.85	0.64	0.85	-0.2	-19	-14	-9.1	-2.2	-5.9	5.34	0.75	-5.3
7:00	0	0	-1	-9	-32	-3	1	4	-3	-1	-4	-8.6
7:05	0	-1	-2	-3	-9	-2	-3	-15	-3	-6	4	-1.9
7:10	1	0	1	0	-27	-21	-18	-14	10	9	-10	-12
7:15	0	-1	-1	-2	-22	-16	6	18	-6	-21	-6	1.28
7:20	0	-1	-2	-12	-10	7	4	-22	-15	-7	10	-1.2
7:25	-1	-1	-6	-15	-12	-17	-12	-2	9	16	-15	-23
7:30	-1	-2	-5	-21	-24	-13	8	22	7	10	-18	-4.9
7:35	1	0	-16	-19	-19	4	10	11	11	11	-24	-26
7:40	0	-1	-2	-21	2	8	8	12	13	5	-27	-28
7:45	-1	-1	-3	-7	13	16	21	26	8	3	-21	-29
7:50	0	-1	1	31	27	26	16	12	14	8	-22	-31
7:55	1	0	30	23	23	17	19	24	16	-16	-23	-28
8:00	0	12	58	48	42	29	14	-6	-16	-26	-14	-23
8:05	2	31	54	31	46	8	-18	-25	-14	-18	-14	-11
8:10	3	64	34	18	11	-7	-15	-13	-15	-29	-16	-11
8:15	13	30	6	-20	8	-2	-10	-22	-16	-17	0	-4.2
8:20	0	-2	-23	-29	16	-2	-14	-12	-5	-10	-9	-2.1
8:25	1	-2	-23	-19	1	2	-6	-8	-15	1	6	11.6
8:30	0	-3	-17	-23	13	-7	-20	-10	13	11	-1	-8
8:35	0	-1	-22	-18	-1	5	10	13	4	-15	-6	0.68
8:40	1	-1	-26	-25	28	20	-1	-13	-8	4	6	-2.5
8:45	1	-2	-25	-16	30	2	-16	-4	3	3	-4	-17
8:50	0.93	-0.1	-7.1	-31	6.44	14.5	6.09	6.47	-10	-16	-7.5	-6.4
8:55	1.97	-0.1	-26	-21	5.81	0.37	-9.5	-8.8	-8.8	-9.5	-6.3	-13

Figure 1. Difference Profile

ANALYTICAL PROCESS

The previous section described the analytical approach in general. The following is a more specific discussion of the process and the tool set that was developed to implement the methodology, using the Seattle area network as an example. For each major Seattle–area facility (I-5, I-405, SR 520, I-90, SR167), two months of midweek loop data and incident data were processed (Tuesday through Thursday, September-October 2002) by using a combination of software tools and manual inspection. Estimates of recurring and non-recurring delay were then computed and summarized for each facility, in each direction of travel, for three time periods (AM peak from 6:00 AM to 9:00 AM, Midday from 9:00 AM to 3:00 PM, PM peak from 3:00 PM to 7:00 PM).

IMPLEMENTATION EXAMPLE: REGIONAL NETWORK ANALYSIS

1. Process the incident databases.

The first step is a review of the incident databases. For each combination of corridor, direction of travel, range of days, and peak period, the incident databases are processed for information about blocking incidents that occurred. The steps in this process are as follows:

1.1. Clean the WITS database. The process to develop a list of relevant incidents begins with the WITS database. The first step is a data cleaning operation, which involves a) manual inspection to correct typographical errors or ambiguous notations, particularly those that might affect subsequent processing (e.g., corridor number, milepost, and travel direction); b) manual deletion of duplicate entries; and c) removal of incomplete entries that cannot be resolved (e.g., no milepost or direction information).

1.2. Extract the WITS database entries that match the corridor, travel direction, and days of interest. This step involves sorting the cleaned data, then extracting the subset (milepost segments, direction of travel, specific days) of interest.

1.3. Develop a list of blocking incidents. Because the focus of this method is the analysis of delay produced by blocking events, the database entries are processed to determine the likelihood that the incident blocks one or more lanes. Stepping through each incident in the subset of entries from step 1.2, the following criteria are considered:

a) WITS incidents that clearly specify blocking activity are designated as blocking incidents.

b) If WITS information is not conclusive about the blocking status, interpret available data. Some WITS reports are not fully completed in the field, and lane blocking status is not obvious from those reports. In such borderline cases, all available data, however incomplete, must be analyzed for indications of blocking. The following WITS data field entries often provide useful information about the nature of potentially blocking incidents:

A) Closure Reason: Blocking incidents can be designated as "blocking disabled" or "debris blocking traffic"

B) Closure Status (SLanes and Mlanes): These checkboxes indicate whether a single or multiple lanes were closed during the incident. These checkboxes are not used consistently, so these fields cannot be used as a sole factor in determining blocking status.

C) Lanes Open (time): This time stamp (time when lanes reopen) is sometimes present, even when other closure information is not present, suggesting that a blockage might have occurred.

D) Any comment fields such as "landmark," "description," "comment," "comment 2," and "supplement" can have descriptions that suggest blocking.

c) Use the TSMC log to clarify borderline WITS cases, and to verify the time and location of incidents identified in WITS as blocking.

d) If incidents are in the TSMC's log but not in the WITS database, they are added to the list of blocking incidents taken from the WITS database. The TSMC log by definition only includes blocking incidents that are verified by TSMC personnel.

As the criteria above suggest, designation of incidents as blocking can require processing of one or more incident databases, as well as some interpretation of the information. In general,

a) If a blocking incident entry is in both WITS and TSMC databases, the event is considered verified as blocking.

b) If a blocking incident entry is only in the TSMC log of blocking incidents, the event is considered verified as blocking.

c) If a blocking incident entry is only in the WITS database, the event could be considered blocking, even if no matching entry is in the TSMC log. For example, this could occur for a blocking incident in an area without CCTV coverage (TSMC log entries are usually based on CCTV confirmation). WITS-only entries that suggest a high likelihood of blocking because of the nature of the incident are generally classified as blocking.

d) All other events that are borderline or inconclusive are temporarily categorized as blocking for the time being (see step 5).

Note that CAD data can also be used to resolve ambiguous situations, but because of the time required to use that system, it should only be used for significant borderline situations.

2. Compute traffic profiles for all days.

Process the loop data for the corridor using the TRAC-FLOW CD Analyst software, to produce congestion (lane occupancy) matrices for each day of interest (compute

volume and speed matrices as well, since they will be used later in the process). Each matrix shows a traffic value (occupancy, volume, speed) as a function of time of day and milepost.

3. Process a single background profile.

Combine the congestion profiles via averaging or median values to get a single background matrix. The profile can be based on all days, or only recurring days. In the Seattle area analyses, a median value was used.

4. Compute difference profiles for each non-recurrent day.

Produce a difference matrix for each non-recurrent day by subtracting the background profile (from step 3) from each non-recurrent day's congestion (lane occupancy) profile.

5. Determine regions of congestion associated with each blocking incident.

The next step is to determine the amount of congestion associated with each blocking incident. Three methods are used to determine this level of non-recurrent congestion; these three alternative definitions provide a range of values that can be used to better understand the variability of non-recurrence, depending on the definitions used. A conservative definition ("min") takes into consideration only the region of congestion that appears to be directly related to the blocking event. A more liberal ("max") definition includes the effect of one blocking event's congestion on adjacent recurring congestion. For comparison purposes, a third definition, even broader than the other two definitions, was also used. This third definition takes into account all non-typical congestion. It can be interpreted as a broad definition of non-recurrence that takes into account all atypical events such as incidents, weather, and other special events.

All three methods depend on the same process: Locate the time and milepost of each blocking incident on the corresponding difference matrix, then estimate the region of congestion associated with the incident by noting the pattern of difference values. The

region of congestion is located by noting the upstream backup that one would expect from the incident; this backup should emerge in the difference matrix in the form of a prominent region of increased lane occupancy, which appears as positive difference (> 0) values. To define the edges of this region, we use edge detection rules based on the magnitude of the difference. In this case, the criterion used for edge detection is a minimum difference of +5 percent, or a sign change in the difference. The 5 percent difference roughly corresponds to the approximate change in occupancy that results in a change of one or more levels of service when the initial condition is LOS E or better, based on certain assumptions about vehicle length and loop detection length. For example, for an effective loop detection length of 22 feet and other freeway assumptions, we have

LOS A,B,C	0-10 percent occupancy
LOS D	10-13 percent
LOS E	13-19 percent
LOS F	>19 percent

A freeflow traffic condition in the range of LOS C or better, with between 5 and 10 percent occupancy, shifts to LOS D or E, depending on the initial condition, if occupancy changes by 5 percent. LOS D shifts to LOS E with a 5 percent change in occupancy. (Note that while a +5 percent change does not produce significant changes in LOS at the low occupancy values, the delay is not significant in that occupancy regime, and therefore its inclusion does not significantly affect overall delay computations.)

A sign change criterion is also commonly used at the leading edge of the incident, where the blockage can cause a temporary downstream improvement in traffic congestion (thus producing an occupancy difference < 0 relative to the background profile). Finally, the region does not extend back in time; its edge cannot go farther back than the approximate starting time of the incident (within the 5 minute granularity of the data).

Note that the approach described above for detecting the edge of congestion regions generally works well only in ideal situations where the edge of the region is clearly visible.

Frequently, however, events occur near other patterns of congestion; therefore, the edges are difficult to determine. To cope with this more common situation, the edge detection rules are modified; if difference values steadily drop as one moves away from the center of the region of congestion, then begin to rise as one approaches an adjacent area of congestion, the local minimum is used as the edge. This is the "min" definition. In the case of the more liberal "max" definition, the "local minimum" specification is relaxed to instead include all directly adjacent regions that meet the minimum difference threshold. The third definition takes into account all adjacent and non-adjacent regions that meet the minimum difference threshold.

Note: This process should also be performed for the borderline or unknown cases from step 1.3. If there is no clear region of congestion associated with those cases, they are not considered blocking and are not factored into the computations.

6. Estimate the delay associated with the region of congestion associated with each blocking incident.

For each cell[1] of the difference matrix within a region of congestion, estimate the corresponding vehicle-hours of delay by using values from the corresponding volume and speed matrix:

a) Estimate the travel time for each cell by using spot speeds on each end of the 0.5-mile segment (from the speed matrix) and computing the estimated travel time for the segment. Compare this travel time to the time corresponding to freeflow speed (e.g., the speed limit, or some other user-specified optimal speed; both 50 mph and 60 mph were used for the Seattle analyses). The resulting time difference is the associated delay per vehicle for that segment at that time.

b) Multiply this per-vehicle delay by the number of vehicles in the segment at that time, using the volume matrix values.

[1] Cell = a combination of location and time (a given 0.5-mile segment and a given 5-minute segment).

c) Sum up these segment delays within the region of congestion.

7. Summarize the delay associated with all regions of congestion to estimate the amount of non-recurrent delay. Do the same for total delay.

For a given combination of corridor, direction of travel, day, and peak period, sum up the (non-recurrent) delay for all regions of congestion. To compute total delay from both non-recurrent and recurrent events, use the same process as the previous step, but do so for every matrix cell, not only those in a region of non-recurrent congestion. Summarize the non-recurrent, total, and recurrent delay values (recurrent = total – non-recurrent). Figures 2 and 3 show sample output; Figure 2 is a summary of the percentage of all delay attributed to non-recurrent delay, based on the three definitions of non-recurrent congestion, while Figure 3 shows the same information by day.

TOOL SET DEVELOPMENT

Ideally, this methodology would be implemented using primarily automated software tools. However, given the project schedule constraints, a combination of enhanced versions of existing tools (TRAC-FLOW CD Analyst), new tools and macros, and manual processing were used. The existing tools (Analyst) were used to process loop data, while new tools and macros were developed primarily to accelerate the manipulation and formatting of data and to perform other computations that were relatively simple to describe with algorithms. Manual processing was reserved for tasks that required (or were faster with) human interpretation and judgment; it was felt that such tasks, while possible to automate, could be performed more quickly in the short term by human processing. (See Table 2.)

Non Recurrent Delay (% of all delay) (quick summary)

September 2002	*SeaTac to Seattle* [153.00,166.00]			*Seattle to SR 526* [166.50,188.50]		
50 MPH optimal	min	max	red	min	max	red
AM	5%	5%	19%	17%	17%	73%
Midday	18%	26%	58%	45%	54%	81%
PM	6%	13%	40%	6%	16%	45%

	SeaTac to Seattle [153.00,166.00]			*Seattle to SR 526* [166.50,188.50]		
60 MPH optimal	min	max	red	min	max	red
AM	4%	5%	17%	11%	11%	48%
Midday	14%	20%	46%	15%	18%	28%
PM	5%	11%	34%	5%	13%	37%

Types of Non-recurrent Estimates

min=conservative estimate
max=liberal estimate
red=all "non-typical" congestion

Table values (vehicle-hours of delay)

Total=all delay based on 50/60 mph
NR = delay based on min/max/red regions
R = Total - NR (not computed separately)

Figure 2. Output: Percentage of Non-recurrent Delay, by Congestion Definition

50 MPH optimal speed: Vehicle-Hours of Delay							
I-5 NB		***SeaTac to Seattle***			***Seattle to SR 526***		
September 2002		**[153.00,166.00]**			**[166.50,188.50]**		
min		Total	R	NR	Total	R	NR
[06:00,08	9/4	730	730	0	52	52	0
AM	9/5	1305	1189	116	15	15	0
	9/6	978	978	0	5	5	0
	9/11	1270	1270	0	116	116	0
	9/12	1650	1650	0	164	164	0
	9/13	1631	1631	0	21	21	0
	9/18	1650	1379	271	383	109	274
	9/19	1854	1854	0	436	436	0

Figure 3. Output: Percentage of Non-recurrent Delay, by Congestion Definition and by Day

Table 2. Tool Development Summary

Task	Automated (TRAC-FLOW s/w)	Semi-Automated (Filemaker or Excel)	Manual (Human Judgment)	Output
1. Incident database analysis (allocate events into recurrent/ non-recurrent category)	None	Some steps performed using functions in Filemaker Pro and Excel Export database from Filemaker to Excel	Manual inspection of database entries and comments to determine recurrent/non-recurrent category of blocking entries Comparison of WITS and TSMC log and comments to determine blocking entries	Excel files of incident data
2. Compute traffic profiles	(**New**) CD Analyst computes each day's congestion (occupancy), volume and speed matrix	None	Review the results	.occ, .vol, .spm traffic profiles
3. Variation from median background profile	(**New**) CDRAPreProc preprocessor computes median background profile and difference profiles	(**New**) Day-M Excel macro reformats difference matrix	Review the results	Excel file of difference profiles
4. Edge detection	None	(**New**) Excel macro (ColorDiff) used to highlight potential boundaries of incident-related congestion in the difference matrix (**New**) Excel macros (Dff to Edg and Dff to Edgred) used	Manual inspection of color-coded difference matrix to determine edges Manual evaluation of borderline cases, using pre-defined rules	Edge files (.edg) that define regions of congestion

		to create mask filters (edge files) of boundaries of incident-related congestion in the difference matrix for differentiating R and NR delay computations		
5. Veh-hrs delay computation	(**New**) CDRAPostProc computes veh-hr delay	(**New**) Excel worksheets and macros	Review the results	.sum and .vhd files that summarize delay
6. Summarize results	None	(**New**) Excel worksheets and macros	Review the results	

Items marked with (**New**) are new tools that have been developed for this project.

FUTURE RESEARCH

This methodology was developed using existing data; when data limitations required that assumptions be made, reasonable estimates were used to enable the methodology to be completed. Because of time limitations, the methodology's algorithms were developed with the assumption that additional enhancements would likely be necessary before it could be applied in an ongoing analytical environment. The associated tool set was developed primarily as a proof of concept, to verify that the method could be implemented in an automated fashion; here as well, it was expected that significant enhancements to the tools would be performed in a subsequent phase of development.

The following are some of the major aspects of the methodology that are candidates for future research and development.

INCIDENT DATABASES

The incident database review process is a key element of the methodology. Because of the issues noted previously in this report (e.g., incomplete or ambiguous entries, formats that limit automated processing), the incident database phase of the process is the most labor-intensive phase, requiring extensive manual processing and human judgment. While it is possible that a rule-based software procedure or similar tool might be developed to reduce some time-consuming human judgment elements of this task, for the moment it appears that the most cost-effective method of analyzing these databases is through the use of a skilled, experienced analyst. However, automated tools for cleaning up the database or resolving some of its ambiguities might be useful for that analyst and could be a useful area of research exploration.

A revised version of the CAD database, now under development, should be evaluated for potential use in this process.

TRAC-FLOW SOFTWARE MODIFICATIONS

The existing TRAC-FLOW software was used extensively to process loop data that were required for volume, occupancy, and speed estimates. The primary modification required for this project was the ability to produce traffic profiles (volume/occupancy/speed vs. milepost vs. time of day) for individual days, rather than average profiles across several days. This feature was implemented and used effectively in an automated fashion for this project. It is important to note, however, that the traffic profiles produced by this software have the same limitations as other single-location performance measures that it produces. Principally, these issues include individual loop data quality limitations and associated data replacement methods, per-lane averaging procedures when one or more lanes at a location have data quality issues, and speed estimation limitations when speed is derived solely from individual loops. The methods that CD Analyst software uses to detect and cope with data quality limitations, and the assumptions used in its speed estimation algorithm, are both promising candidates for future research.

EDGE DETECTION FOR REGIONS OF NON-RECURRENT CONGESTION

The method developed to identify locations and times of non-recurrent congestion relies upon the assumption that the pattern of congestion for a blocking event is noticeably different from the "typical" congestion pattern. This method is implemented by taking the difference between a given day's occupancy profile (a surrogate value for congestion), and a "typical" profile computed using median congestion values. There are a number of promising areas of future research for this element of the methodology.

First, the median value for the background profile was chosen instead of the average value in an effort to minimize the potentially distorting effect of outlier values on the background profile values. Testing suggested that the median was at least as effective as the average value in searching for regions of non-recurrent congestion in the difference profile. Further research and development of this method could be useful to enhance the ability to detect regions of congestion in an automated fashion.

Second, the detection of the congestion regions uses a minimum threshold occupancy difference (+5 percent). Research to determine the sensitivity of results to that threshold would be useful. In addition, three methods were used in this project to define the edges of the congestion regions. Their principal purpose was to bound the estimates of non-recurrent delay by using different assumptions; it would be useful to explore other methods of computing the edges of the congestion regions.

DELAY ESTIMATION FOR REGIONS OF NON-RECURRENT CONGESTION

The method developed to estimate non-recurrent congestion delay relies upon the assumption that the volumes detected by loops in the congestion region can be used to compute vehicle-hours of delay. In heavy congestion, however, it is possible that the loop volumes would underestimate the number of vehicles affected by delay, since they do not directly measure vehicles stopped in a backup but not detected recently by a loop. This limitation could be addressed by using volume estimates based on vehicle density rather than loops for heavy congestion situations. Density can be estimated from occupancy if assumptions are made about vehicle length and sensor detection range. Testing of this approach would be useful.

TOOL DEVELOPMENT

Because of the large data sets involved, the ideal tools for this methodology would be fully automated ones. However, because of time limitations, the tool set developed for this project was a combination of tools that could be quickly developed or adapted for use on this project, including existing tools, new standalone utilities, Excel macros, and when necessary, manual processing. There is significant opportunity for additional streamlining and automation of the tools for this methodology. A potential area of research is the development of rule-based systems that allow human judgment to be codified in a way that allows automated systems to be used in place of manual processing when possible. This

would have a significant effect on the ability to process large incident databases and data patterns (e.g., the difference profile) that would otherwise require manual processing.

CONCLUSION

This research produced a method for analyzing the recurring and non-recurring components of urban congestion; the method is based on a conceptually straightforward approach and utilizes readily available data. A preliminary tool set enables the WSDOT to perform the above analytical process on a semi-automated basis. Though the method is still in a preliminary form, this analytical approach nevertheless offers promise as a conceptually direct mechanism by which to measure and monitor the distribution of recurring and non-recurring congestion on the Seattle-area freeway system, enhance understanding of the components of urban congestion, and convey that understanding to engineers, planners, and decision makers.