RECOMMENDED CONGESTION MONITORING OPTIONS FOR WSDOT

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This report provides detail on the options for monitoring traffic congestion within the state of Washington. It refines initial estimates of straffing and equipment resource needs for the data collection systems analyzed. This document also answers questions raised by the recommendations made in the Phase 1 report for this project. Finally, this report provides specific recommendations for near-term actions the Washington State Department of Transportation (WSDOT) can take towards providing a cost-effective congestion monitoring system for the state's urban areas.

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DISCLAIMER

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RECOMMENDED CONGESTION MONITORING OPTIONS FOR WSDOT

PHASE 2 SUMMARY REPORT

This report provides detail on the options for monitoring traffic congestion within the state of Washington. It refines initial estimates and provides cost estimates of the data collection systems analyzed. This document also answers questions raised by the Phase 1 recommendations. Finally, the report provides specific recommendations for near-term actions the Washington State Department of Transportation (WSDOT) can take.

The report is organized as follows. The first section summarizes the recommendations produced in Phase 1 of this contract and presents reactions to those recommendations, questions and issues WSDOT staff raised, answers to those questions, and further clarification of the recommended congestion monitoring scheme. Next, more detailed discussions of potential short- and long-term congestion monitoring programs in urban areas are provided. Finally, the recommended actions for WSDOT are summarized.

REVIEW OF PHASE 1 RECOMMENDATIONS

In Phase 1, the project team recommended that a combination of measures of effectiveness be used in the state's congestion monitoring system (CMS). In rural or uncongested urban areas, level of service (LOS) or direct volume/capacity relationships should be used as the primary measure of effectiveness (MOE) for the congestion monitoring system. In congested urban areas (and on other roads that experience significant congestion) the state should employ a direct measure of delay or excessive travel time as the basis for monitoring congestion. These basic measures of congestion must also be supplemented with measures on the total use of those facilities and the occurrence of "external" factors, such as incidents, inclement weather, mode choice, vehicle occupancy, and other variables, that have an effect on mobility.

Figure 1 illustrates how this combination of travel times and other information would be used to describe the current status of congestion on an urban road section. A series of tables like that shown in Figure 1 would be used to describe congestion within an urban area. These tables would directly quantify the impacts of congestion on specific facilities and would allow congestion to be tracked over time.

REACTION TO PHASE 1 REPORT

WSDOT Response

In general, the WSDOT staff's response to the Phase 1 recommendations was positive. However, this section discusses WSDOT responses that require additional information, further clarification, or consideration in the final congestion monitoring system design.

One consistent response to the proposed method for tracking congestion was that whatever the selected monitoring mechanism, the cost of the associated data collection effort should be as low as possible, and the data collection effort should be tied to other existing systems/programs as closely as possible. As a result of these responses, much of the effort in the second phase of this project was expended to examine how the Phase 1 recommendations could be incorporated into existing data collection or operations projects.

Questions Asked and Issues Raised

Most questions and concerns generated by the Phase 1 report can be divided into two categories: procedural concerns ("How can this step be performed?") and cost or scoping questions ("How many sites must be counted? What does this proposal cost?").

Many of the procedural questions related to the LOS calculations for rural roads included in the state's CMS. The more important questions were as follows:

- Is LOS really the best alternative for uncongested roads, or should the volume to capacity (v/c) ratio be used?

- For "uncongested" roads, how will variation in hourly traffic volumes be incorporated into the congestion computation? (In other words, because roads are designed to (at best) the 30th highest hour volume, all roads operate at levels over capacity during some portion of the year. How is this fact taken into account during the congestion estimation process?)
- Because some recreational routes are built to 100th or even 200th highest hour standards instead of 30th highest hour standards, will this fact be incorporated into the congestion monitoring process?
- Does the existing traffic data collection and reporting system allow the accurate computation of v/c ratios for roads in the state?

The cost and scoping questions were more general than the procedural concerns and are addressed in the fourth section of this report.

The one significant question that did not fit within either the procedural or cost/scoping categories was, "Could computer models be used in place of physical collection of traffic performance data?" This question is answered at the end of the clarification section below.

CLARIFICATION OF THE PHASE 1 LOS COMPUTATIONS FOR RURAL ROADS

This section expands on the initial Phase 1 recommendations to answer the questions presented above.

LOS versus V/C

For most roads covered by the LOS recommendation for which WSDOT is responsible, using LOS or v/c to determine congestion would produce little difference. The 1985 Highway Capacity Manual (HCM) uses v/c to determine LOS for both multi-lane and two-lane rural roads. Thus both v/c and LOS will be available for rural highways. Similarly, freeway LOS is also computed primarily as a function of v/c for both rural and urban areas.

The primary advantage of using LOS instead of using the v/c ratio directly is that it would provide consistency with other state monitoring needs. For example, Service Objective H-23(a) of the state's System Plan says "provide Level of Service C (LOS C) on rural highways and high occupancy vehicle (HOV) lanes." In addition, the implementation of the Growth Management Act (GMA) has also caused cities and counties to define (and monitor) LOS standards for their roads in order to determine whether proposed development is allowed and, when development is allowed, the traffic mitigation the development will need. Thus, for two reasons, the state and other public jurisdictions must already compute and report LOS for roads covered by the "uncongested" portion of the congestion monitoring system.

Consequently, the use of LOS for congestion monitoring would allow one set of required calculations to meet several needs, would provide for consistency among various required WSDOT efforts (the CMS, GMA, and State System Plan), and would reduce the staffing, cost, time, and data processing effort needed by the CMS.

For WSDOT roads not covered by the above situation (primarily arterials in small urban areas not subject to congestion), v/c might or might not be an accurate predictor of LOS. For example, for signalized arterials, v/c does not account for the effects of signal coordination, which greatly affects the LOS on an arterial. Thus, v/c is not a reliable measure of congestion for signalized arterials. However, the LOS computation for signalized arterials is based on average vehicle speed, which is a variable that is sensitive to both the level of use and control strategies such as signal coordination. Thus, LOS would be the necessary MOE for the CMS, although it would require additional data collection for some types of roadway facilities.

Luckily, uncongested, urban arterials constitute a fairly small percentage of roads for which WSDOT must provide CMS information, and thus computation of LOS for uncongested, urban arterials should not require a substantial effort by WSDOT.

<u>Hourly Variation on Uncongested Roads</u>

A concern with using the "v/c" value to predict LOS on rural roads is that v/c is not a constant. Instead, v/c varies with the time of day, day of the week, and season of the year. The level of congestion estimated with v/c is affected by the timing of the data collection effort that provides the volume estimate used in the v/c computation. By selecting specific periods for data collection, the information represented by the v/c ratio can be controlled to some extent, but this control requires an understanding of the measurement the volume collected is supposed to represent. For example, using the volume from 11:00 PM to midnight in the v/c calculation on most roads would produce a result of little or no congestion, regardless of how the roads operated during the day.

Deciding which volume measurements to use in the v/c calculation requires a review of the function the CMS is intended to perform. The CMS is not intended to identify <u>all</u> congestion in the state. It is intended to identify roads where congestion is a <u>problem</u> and then help prioritize those roads so that.the funding available for congestion relief is spent wisely. Because of limited funding, more congested roads exist than can be remedied at any given time. Thus, the CMS can be conservative about its identification of "congested" conditions without adversely affecting the function of the CMS. (That is, roads that were only marginally congested would not be highly prioritized for congestion mitigation funds, even if they were labeled as "congested;" therefore, it would not be a serious error if these roads were not identified as marginally congested.) Consequently, the author believes that roads should be "routinely" congested before the CMS designates them as below acceptable LOS standards.

Given this function, the CMS should identify "routine" congestion, as opposed to "unusual" or "periodic" congestion. It is relatively easy to measure this level of traffic by collecting data on "normal" days (that is, non-holiday weekdays). It is reasonable to assume that traffic measured on random weekdays (seasonally adjusted as necessary) would provide an unbiased estimate of "normal" traffic conditions for most roads. Peak traffic conditions during the weekdays monitored would be an unbiased estimate of "normal" peak conditions.

The majority of traffic counts WSDOT currently collects occur under these counting conditions. (Most counts WSDOT takes are weekday counts from non-holiday periods.) These count data are currently available through TRIPS (the Transportation Roadway Information Processing and Support system) in the form of "K" factors for roads where traffic counts have been recently performed. The "K" value in TRIPS is based on the highest hourly volume observed during routine traffic counting. For non-recreational routes, this often means peak afternoon traffic volumes, although the peak may occur at any time during the day.

Congestion On Recreational Routes

The data collection and computational procedures described above would not necessarily be reliable for measuring congestion on roads subject to significant recreational traffic volumes. This is because recreational traffic tends to be very heavily peaked, and volumes often are the highest (and thus most congested) during the weekends, not the weekdays.

The "peaked" nature of recreational routes causes problems in determining their "normal" traffic congestion. Weekday traffic congestion often bears little resemblance to congestion during peak recreational periods. The timing of recreational peaks also varies considerably among recreational sites, complicating the process of creating a routine traffic counting program that will provide up-to-date traffic volume information on peak recreational movements.

WSDOT's policy is to accept more congestion during recreational peak periods than during "normal" conditions because it is uneconomical to build roads with sufficient capacity to handle peak recreational traffic. (Roads built to carry peak recreational traffic volumes at high levels of service would have large amounts of unused capacity during the vast majority of the year.)

To monitor congestion on recreational routes, a two-part congestion identification system is proposed. The first part is the same as for non-recreational routes. That is, the peak volume for an "average" weekday should be used to compute LOS for "normal" conditions. This would indicate whether the road in question had a "routine" congestion problem.

The second portion of the CMS would require special data collection efforts (i.e., data collection efforts not scheduled as part of the WSDOT's ongoing effort to provide AADT estimates on state highways). These special counts would be collected only on recreational routes that WSDOT thought were "congested."

Identification of these potential recreational congestion problems would come from a variety of sources, including existing permanent or temporary traffic counts, direct observation of a facility by WSDOT personnel (maintenance, operations), comments from civic or business organizations about the need for transportation improvements, citizen complaints, or other sources. Essentially, the recommended procedure is that if recreational congestion got bad enough that a road should be included in the CMS, someone would complain. That complaint should trigger a data collection and analysis effort designed to determine the actual scope and extent of the recreational congestion for that roadway.

The affected WSDOT Region, the Headquarters Planning Office, the office of the Deputy Secretary, or other WSDOT personnel, as determined by WSDOT policy, would then request a special congestion study. Each of these "special" studies would require the collection of data during recreational movements to determine the timing, size, scope, and nature of the recreational traffic movement for that site. Information on when to collect data for each of these movements would be provided by the source that initially identified the congestion problem.

The results of each of these studies should then be incorporated into the CMS. Within the CMS, routes with congested recreational movements would be listed and prioritized separately from routes with "routine" congestion. These two types of congestion should be treated differently because

- the definition of "congested" is different
- the data being used for measuring congestion are not equivalent and
- the decision making process for when and how to mitigate these two types of congestion is different.

This two-part process would provide the WSDOT with more useful congestion information while limiting the amount of additional data collection required from WSDOT.

Accuracy of the Existing Data Reporting System

For routine congestion, LOS should be calculated with volumes from actual peak period traffic counts recorded as part of WSDOT's routine traffic monitoring effort. These values are currently found under the variable "K" (percentage of traffic occurring in the peak hour) maintained within TRIPS. For areas where TRIPS does not have a recent measurement for routine peak period traffic, this value should be estimated from available information. (FHWA has developed a series of equations that estimate K factors from AADT estimates for rural roads.[1] WSDOT should investigate these equations.)

Some WSDOT reviewers expressed a significant concern about the ability of the existing TRIPS database to provide accurate, reliable, hourly volume estimates for use in the congestion monitoring estimates for rural roads. The primary concern was that because the existing WSDOT traffic counting budget does not allow for extensive traffic counting throughout the entire state route system, some counts upon which the congestion monitoring estimate would be based would be several years old or taken several miles from the site being investigated. As a result, some estimates of "K" would likely be in error.

If Planning Office staff found obvious errors when reviewing the output of CMS software, these errors could be reported to the Transportation Data Office (TDO), whose staff could review and correct them as necessary. Then a new data file could be downloaded to the CMS. This procedure is similar to existing WSDOT policy for other WSDOT data processing functions (such as the Pavement Management System). It would help ensure that data were consistently used by all groups within the Department and ensure that the integrity of both TRIPS and CMS data files was maintained to the greatest extent possible.

Use of Computer Models For Congestion Monitoring

Planning personnel representing various urban areas (both in Washington and from other cities around the nation) have suggested that traffic performance monitoring could be accomplished with the existing travel modeling process. Such an approach would be less expensive than collecting actual traffic performance information. Unfortunately, relying on existing modeling procedures would prevent the CMS from accurately reflecting the impacts of almost all transportation systems management (TSM) and travel demand management (TDM) measures instituted by the state. It would force the CMS to rely on procedures that in most cases do not accurately reflect actual traffic conditions.

Existing urban travel models do not have the capability to accurately model actual street volumes over the large geographic area covered by the CMS. Four-step planning models (such as TMODEL2, which WSDOT uses, as well as EMME II, UTPS, TRANPLAN, and other models) base their computations on a limited street network. Street networks of reduced size and scope lower the CPU time required for modeling computations and limit the modeling "side effects" caused by the inability to accurately replicate real arterial operating conditions.

For example, most four-step models do not include local roads, many collectors, and even some smaller arterials in their highway network representations. In addition, information necessary to model actual vehicle performance is also missing from roads that are represented in four-step models. Few four-step models incorporate traffic signal timing information or the effects of coordinating signals in a network. In most cases, four-step models use highly simplistic measures to estimate turning movement delay, not accurate representations of actual traffic characteristics.

These limitations are partly off-set by the fact that most four-step models do not effectively model many trips. For example, intra-zonal vehicle trips are not normally assigned to the highway network because they begin and end at the same modeling point (the zone centroid.) In addition, many non-work trips are not well predicted by the model forecasting process.

Finally, four-step models usually rely on simplistic assumptions to divide estimated daily travel into hourly trip tables. These assumptions (usually the modeler enters one number that indicates the percentage of daily trips assumed to occur during the modeled time frame) are marginal at best and will become less accurate as various TSM and TDM programs begin to affect travel behavior. As a result, four-step models will be unable to accurately estimate changes in travel behavior that occur when systems such as Bellevue Smart Traveler are installed and commuters change their time of departure daily to avoid congestion.

More detailed arterial models (NETSIM, TRANSYT) are no more useful than four-step models for congestion monitoring. While these models do contain the detailed analytical techniques needed to accurately model traffic conditions, these models also have major limitations. For example, they are not citywide in scope, and they require more input data than readily exist for calibration or operation. (Essentially, accurate calibration of these models for the entire city would require the same information that would be required to actually provide congestion monitoring, meaning that the models would not be needed.) Most arterial models require that the user input origin/destination matrices at the arterial level by time period (usually 1- to 5-minute periods.) These matrices simply do not exist at the city or metropolitan level. They are also affected by the TSM and TDM measures mentioned above, making the arterial models incapable of modeling these congestion relief methods.

Even if the models represented reality well (they can, in small areas with sufficient calibration information), the ground counts that exist would not be sufficient to accurately calibrate or operate the models. What exists in almost every city and state in the U.S. is a series of counts (or estimates based on a count from previous years) taken at different times, at various locations. These counts do not provide balanced flows. For example, volumes increase and decrease inexplicably along a specific street because the volume on that road during count A was different than the volume on that road during count B. As a result, the model may match the volume for Count A, but by default it can not match the volume for Count B. Thus, arterial models are difficult to calibrate for large networks and, consequently, are unlikely to accurately replicate traffic conditions.

Finally, existing models are not capable of accurately modeling the impacts of SC&DI systems, let alone of advanced traffic management systems (ATMS), on traffic performance. Not one model in the U.S. can accurately replicate the operation of the Northwest Region SC&DI (FLOW) system and its impacts. Again, these control strategies are a planned part of the WSDOT approach to congestion mitigation, but a model-based CMS would be unable to account for their contributions to congestion relief .

As a result, the author highly recommends that WSDOT not rely on computer modeling as the source of congestion monitoring information.

SHORT-TERM DATA COLLECTION ALTERNATIVES IN CONGESTED AREAS

Existing Monitoring Systems

In the short term (one to four years), travel time data will have to be collected in the state metropolitan areas through a combination of manual data collection and use of existing traffic control systems such as the Northwest Region SC&DI system, the Southwest Region changeable message sign system, the Vancouver/Portland ATMS System, and the proposed Eastern Region Autoscope system. In most cases, data collected continuously through traffic control systems would provide a more accurate picture of actual traffic performance than those collected manually because continuous data collection could measure changes in performance over longer periods and could monitor the effects of non-routine events, such as accidents and other traffic disruptions. Unfortunately, these continuously operating control systems cover only a portion of the state's urban freeway miles, leaving large portions of the freeway system and almost all of the arterial systems unmonitored.

In the Seattle area, available loop detector data could be used for congestion monitoring purposes for freeway sections that had been instrumented as part of the Northwest Region SC&DI system. Existing loop detector algorithms would allow spot speed estimates to be computed from vehicle lane occupancy and lane volume measurements collected by the SC&DI system. These estimates could be used to provide the necessary congestion information on the freeway system.

As the Seattle SC&DI system expands to reach its final design configuration, the number of roads and miles of roadway the congestion monitoring system covers will continue to increase. Figure 2 shows the current and planned configuration of the Northwest Region SC&DI system. A significant portion of the system within King County will be completed before the end of 1994. The remaining King County sections, and most of the Snohomish County sections, should be completed before the turn of the century.

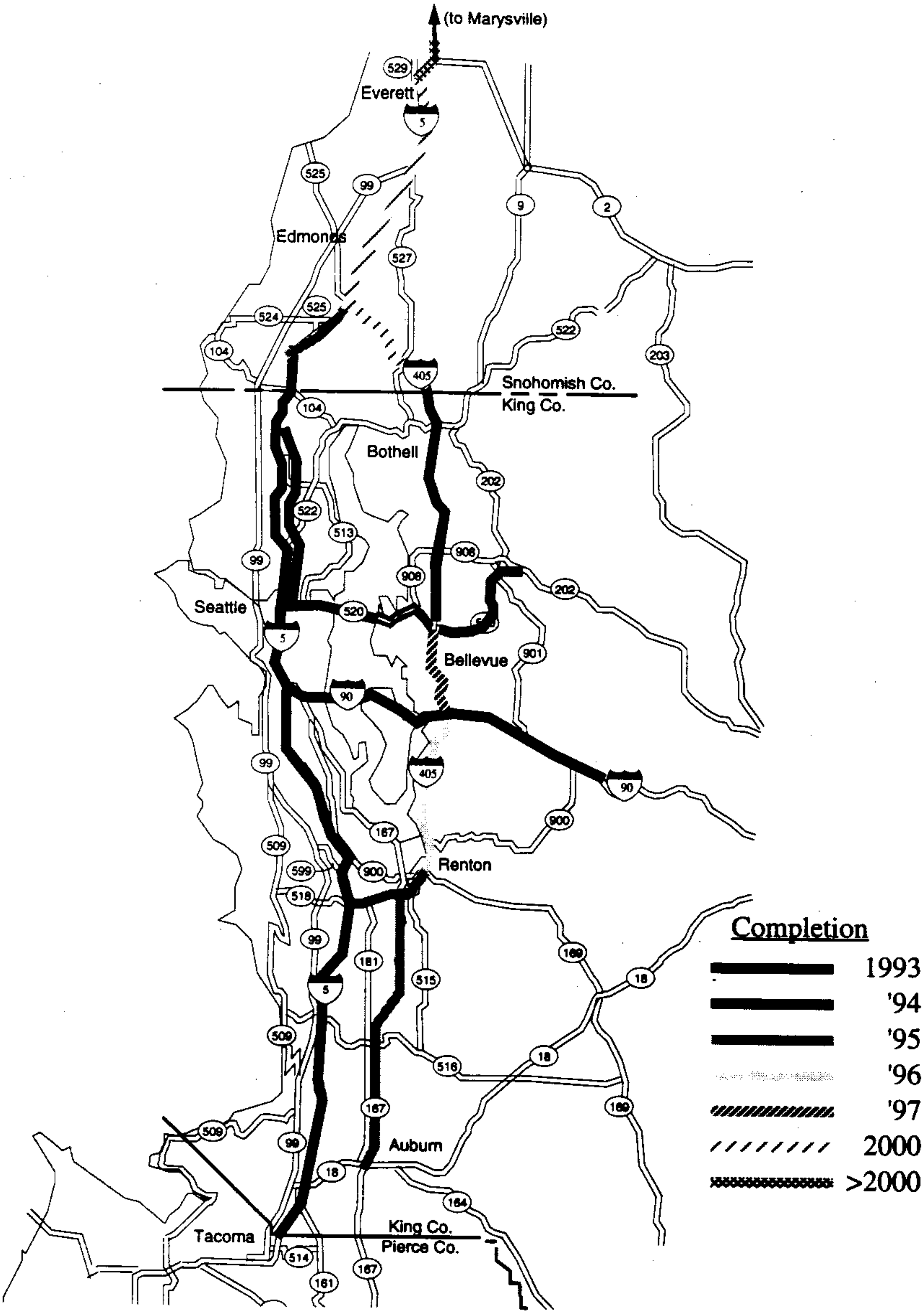

Figure 2. Northwest Region SC&DI Completion Dates

Three WSDOT Regions (Eastern, Olympic, and Southwest) are also planning SC&DI systems for freeways under their control. While current plans for these systems call for coverage of only a modest percentage of the urban freeway miles, the areas to be covered are those most likely to experience congestion and thus in the most need of congestion monitoring. Table 1 shows the time schedule the Portland ATMS study assumes for the installation and operation of surveillance equipment in Southwest Region. WSDOT must make sure that these systems also collect and report traffic performance data.

Table 1
Planned Vancouver Surveillance System Installation Dates

Roadway Section	CCTV Implementation Schedule
I-5 South of SR-500	6 years (max)
I-5 from SR-500 to 78th Street	12 years
I-205 south of SR-500	12 years
I-5 south of I-2-5 interchange	18 years
I-205 south of I-5 interchange	18 years
SR-500 from I-5 to I-205	18 years
SR-14 from I-5 to I-205	18 years

Unfortunately, as noted above, none of these systems will provide traffic performance monitoring capabilities on urban arterials. While some traffic volume information could be collected from the existing traffic signal systems for those arterials, the existing data collection capabilities would be insufficient to provide either accurate facility performance information or the inputs needed to model facility performance.

For example, the data collected by traffic signal systems lack accurate right-turn and right-turn-on-red counts at most intersections, as well as left-turn counts at intersections that do not have instrumented, exclusive left-turn lanes. Even those with exclusive left-turn lanes and left-turn queue detectors have data collection problems because the queue detectors often count vehicles poorly during congested conditions. The lack of turning movement information means that without additional manual data collection, these data can not be used to accurately model delay.

Manual Data Collection

Where automated travel time data can not be collected, data must be collected manually. Several methods exist for collecting travel time information manually. The most common methods include floating car studies and matching license plate observations collected with laptop computers. The primary alternatives to collecting travel time information manually are the use of modeling information (discussed earlier) and the use of mathematical relationships that compute vehicle performance from roadway geometry and traffic volume estimates.

In the Phase 1 report for this project, the license plate matching program was recommended. This recommendation was based on the following factors:

- Actual data collection is more accurate than computer modeling.
- For moderate sample sizes, license plate matching is less costly than the floating car method of data collection and is more capable of detecting statistically significant changes in traffic performance.
- Physically measuring travel times directly accounts for the actual traffic performance on a facility, rather than depending on a theoretical relationship between other facility use variables (i.e., traffic volume, facility operating decisions, and roadway design) that may not accurately reflect the facility's actual performance.

Given that travel time measurements will be used to estimate traffic performance, the major concern is how many travel time measurements are needed, the geographic scope of those estimates, and their cost. To determine the appropriate level of data collection for the CMS, the number of facilities that need to be monitored and the frequency of that monitoring effort must first be determined. Ideally, all facilities in the CMS should be monitored to detect changes in congestion on each facility. However, the cost for this level of monitoring is impractical; therefore, monitoring a sample of sites is the best approach.

The federal CMS rules provide a high degree of flexibility in the level of congestion information that is required. The "ultimate" system would include continuous monitoring of all facilities incorporated in the CMS, but the federal rules do not explicitly require this. The federal rules state that all roads with actual "recurring congestion" or the potential for it should be incorporated in the CMS, but the rules do not state that facility-specific congestion data must be collected and reported for each of those roads. As a result, it appears to be acceptable (within FHWA's published rules) to monitor congestion on a sample of the CMS facilities and to use that sample as a measure of congestion on the remaining facilities.

There are several options for collecting travel time samples in the state's urban areas. The sampling plan must account for two types of variation, the (geographic) variation from facility to facility, and the (temporal) variation among hours, days, and seasons throughout the year.

<u>Geographic Sampling Options</u>

In general, three options were reviewed for sampling geographically. These include sampling

- all roads in the affected areas
- a small subset (panel sample) of roads that are assumed to reflect congestion levels throughout the affected area
- a panel sample that incorporates one road from each jurisdiction in the affected area.

The strengths and weaknesses of these three options are explored below.

All Roads in the CMS

This sampling framework would require that each road in the urban CMS be included in the travel time data collection process. The primary advantage of this approach is that some facility performance data would be available for each road in the CMS. The federal legislation that requires the development and operation of congestion management systems implies that this level of congestion monitoring data should be available. In fact, the congestion monitoring approach recommended for long-term implementation would approach this level of collection through the use of data collected by control systems. Unfortunately, the size of the urban area and the cost of manual data collection make this alternative extremely expensive in the short term.

The number of road miles involved in the CMS is so large that a license plate matching approach to travel time data collection covering all road sections would be extremely expensive. Instead, a limited number of travel time runs would have to be conducted. This could be accomplished either by limiting the data collection to specific segments of each road or by using the floating car method and taking only one to three travel time measurements on each road. For example, three floating car runs would be needed on each facility to obtain at least some congestion information by time of day (AM peak, PM peak, and midday). Such a limited approach to data collection would still be quite expensive, and the scarcity of data available for any one facility would severely curtail the CMS' ability to detect changes in congestion on individual facilities.

While individual floating car runs would not provide reliable facility performance information, the geographic distribution of an all-encompassing data collection effort might provide a reasonable measure of congestion for the urban area as a whole. Because such an effort would have to be performed over several months to be cost-efficient, random, day-to-day variation in congestion levels due to changes in weather and accident occurrences would be well represented in the data collection process. While the results for any one road would be biased by the events of the day that the data were collected, these biases would be canceled out in the aggregate data, and the estimate for the region as a whole would be reasonably accurate.

Because the accuracy of congestion estimates for any given facility would be highly suspect, these data would be insufficient for calibrating MPO models or for comparing the effectiveness of one congestion reduction strategy against another. It is also not clear that the type of estimate that could be produced from this data collection effort for the region as a whole (e.g., average speed on all principal arterials in the metropolitan area) would be truly useful for the intended CMS-based decision making.

Small Panel Sample

To reduce the cost of the data collection effort and to improve the utility of the data collected, some roads would have to be eliminated from the monitoring process, and the number of data collected for each of the remaining roads would have to be increased. One of two potential plans is a small size sample.

Consideration of the small panel sample is based on the assumption that not every jurisdiction included in the CMS would have to be monitored. Instead, a small sample of facilities representing the geographic area covered by the CMS could be used to monitor changes in congestion throughout the region.

The key to this concept is to determine how to select a small group of roads that represent the region. This could be done either through a random selection process or through the definition of specific facility attributes (i.e., a stratified sample.)

The random approach would limit the amount of bias in the dataset, but it might not provide measurements at locations that were of interest to the participating jurisdictions. The stratified sampling approach would allow a more focused data collection effort. Under this approach, data collection could be focused on the facilities of "most importance" to the participating jurisdictions, thus increasing the utility of the collected data. Because these "secondary" uses of the data are important, the stratified sample is preferable to the random sample.

The primary difficulty with a "stratified" sample is determining how to stratify the sample. A secondary problem is then deciding how many data collection points need to be included within any one chosen sample. After several discussions with WSDOT and MPO staff about the CMS process, the author concluded that the panel sample should include three strata of roadways. These groups include

- roads currently experiencing routine congestion
- roads currently experiencing occasional congestion
- roads currently not experiencing congestion.

The roads in the first group are the most politically sensitive facilities in the CMS. These roads tend to be larger, serving major commute or through-traffic movements. Their levels of traffic congestion are often very visible to the public, and they are therefore good candidates for producing useful CMS information (e.g., the decision makers would want to know whether congestion was growing on Interstate 5 through downtown). This group of roads is also the most likely to be impacted by regional congestion mitigation/reduction efforts such as HOV lanes and IVHS TDM efforts. As a result, these roads would serve a very useful purpose within the panel sample.

The roads in the second group are facilities that are just becoming congested (usually in growing suburban centers). These roads differ from the first group in that they are often too small or experience too little routine congestion to be "regionally vital," and they are not sufficiently congested to warrant the significant expenditure of funds required for major HOV construction or other capital intensive TDM strategies. At the same time, these roads often experience the fastest growth in VMT and congestion in the urban area, and an analysis of their performance could provide very useful information on the relationship between specific land uses, growth management controls, and the levels of congestion experienced.

The last group of roads would allow the growth of congestion to be tracked in areas where congestion currently does not exist. The group includes roads in rural areas that are slated to become more urbanized and roads in growing suburban areas. Monitoring of these roads would provide the CMS with estimates of congestion levels in areas not directly subjected to strong TDM and other congestion mitigation efforts.

The primary advantage of this type of sampling plan is that it would significantly reduce the scope (and thus cost) of the data collection effort. The reduced number of facilities for which data would have to be collected would also allow more depth to be obtained in the data collected for each road, without increasing the cost of data collection to unmanageable levels. Thus, for the facilities actively monitored, the CMS would be able to detect reasonably small changes in congestion. If the panel was correctly selected, the results would be both a high level of understanding of regional changes in congestion and an understanding of the performance of specific, high profile facilities.

The primary drawback to the small panel sample selection approach is that, by definition, it would not cover a large number of facilities within the CMS. This drawback would increase the chance for bias in the estimation of changing congestion levels (because many roads would not be monitored at all) and would prevent the CMS from measuring congestion on a large portion of facilities.

An estimated panel sample of 35 to 50 road segments would be sufficient for monitoring the Puget Sound metropolitan region (King, Pierce, and Snohomish counties). A suggested distribution of these panel sites is shown in Table 2. A sample of around 15 facilities should be sufficient for Vancouver and Spokane.

Large Panel Sample—Including Roads From Each Jurisdiction

An outgrowth of the small panel sample approach is that in many jurisdictions within the urban area, not a single facility would be monitored for congestion. Thus, the CMS could not estimate existing or changing levels of congestion specific to those jurisdictions.

Table 2
Distribution[1] of Sample Monitoring Sections In Puget Sound

County	Arterial Sections	Freeway Sections
King	13	19
Pierce	5	5
Snohomish	3	5
Total	21	29

If this level of congestion reporting were desired, the panel sample could be expanded. After the initial panel selection process had been completed (as described above), new facilities (road segments) could be added until at least one road segment within each jurisdiction was monitored as part of the CMS. The original panel sample would still be used to provide estimates of regional congestion, but additional information would be available for jurisdiction-specific congestion estimates.

The primary benefit to this sampling plan is the assurance of data for each jurisdiction participating in the CMS. The drawbacks to this plan are the increase in cost over the smaller sampling plan (the addition of between 36 and 50 sites,[2] depending on which facilities were selected in the original panel sample), the unevenness of the data collection (the same number of facilities would be monitored in very small jurisdictions as in bigger jurisdictions), and the unnecessary collection of data in jurisdictions that had no appreciable congestion (e.g., Yarrow Point).

Temporal Sampling Alternatives

This section describes alternative sampling plans that account for variation in traffic performance over time. Temporal sampling must account for changes in

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[1] The distribution of sites is based on 1991 estimated urban VMT.

[2] 71 cities and counties were identified in King, Pierce and Snohomish counties using the Thomas Brothers map book. The number of sites needed to put a monitoring session in each of these jurisdictions is dependent on the location of the 35 to 50 locations selected for the small sample.

congestion levels both from hour to hour (e.g., congestion from 7:00 AM to 8:00 AM is different than that from 9:00 AM to 10:00 AM) and from one day to another (e.g., this Tuesday's traffic congestion is different than last Tuesday's traffic congestion). The more hours that data are collected, the more likely it is that the monitoring effort will be able to identify the actual extent of congestion within a region, as well as measure changes in the level of congestion over time.

Temporal variation is addressed both by the number of days during which counts are taken and by the duration of the monitoring sessions on each of those days. The following sampling distributions were examined to account for day to day variation in traffic performance:

- single monitoring sessions at each of the selected sites
- ten monitoring sessions at each of the selected sites
- 20 monitoring sessions at each of the selected sites.

Regardless of the number of days for which data were collected, valid congestion estimates would only be obtained for hours during which data were collected. Not all time periods are equally susceptible to congested traffic conditions, so focusing the data collection on specific hours would significantly improve the cost effectiveness of the data collection effort. As a result, for each of the sampling plans mentioned above, four alternative sample durations were considered:

- random single hours
- AM and PM peak hours only
- peak periods only
- three separate counts, including AM peak, midday, and PM peak.

The strengths and weaknesses of each of these seven strata of data collection are discussed below. Table 3 summarizes these strengths and weaknesses.

Table 3
Strengths and Weaknesses of Temporal Sampling Alternatives

Sampling Alternative	Strengths	Weaknesses
Time Periods Sampled		
Random hours	Covers all of the day Good approach for computing "average" congestion during the day	Either very expensive or insufficient data for any specific period Resources spent on data collection for periods that are not of high interest to planners and operations engineers
AM and PM peak hour only	Concentrates data collection on periods with traditionally the highest congestion Keeps costs to a minimum	Does not allow monitoring of congestion during the shoulders of the peaks May miss many of the changes that occur as a result of TDM and TSM actions
AM and PM peak periods	Allows monitoring of the shoulder periods when many of the changes in congestion are taking place	Ignores midday congestion Increases the cost of data collection substantially over the previous option
AM and PM peak periods, plus midday period	Provides the best level of information Allows analysis of both commute and non-commute congestion patterns	The most expensive option, but not much more expensive than the previous option
Number of Days of Data Collected		
Single day of data	Least costly approach	Low confidence in the results at specific sites or for small panel samples
10 days of data	Acceptable level of precision in the estimates of congestion ($\pm$ 19% at 95% confidence level)	Considerably more expensive than single day option Still not precise enough to monitor expected changes in congestion from year to year
20 days of data	Most reliable congestion measure of the options tested ($\pm$ 13% at 95% confidence level)	Most expensive option examined Still not precise enough to monitor expected changes in congestion from year to year

Single Monitoring Sessions

Monitoring travel times once per site is the least costly of the data collection plans, while it would still provide some measure of traffic performance at each data collection site. If license plate matching was used at a site, a statistically representative (and accurate) measure of vehicle performance would likely be collected at the site for that time period and day. (If a floating car technique was used, unless a large number of travel time runs were performed (e.g., more than ten), the measure of performance would probably not be accurate.)

The major drawback to a single day of data collection is that traffic performance varies considerably from day to day. For a study of SR522, TRAC staff measured a coefficient of variation (COV) for arterial travel time of over 0.3 for day to day variation. A single day of data collection would not accurately represent traffic conditions on such a facility.

However, as noted earlier in this report, if single samples for a large number of sites were collected on different days spread throughout the year, the congestion measurements for the region as a whole might be reasonably accurate. This conclusion is based on the assumption that the random errors in congestion monitoring due to lack of data at each site would balance out for the region as a whole. (That is, some sites would produce over-estimates of congestion, while others would produce under-estimates of congestion.) The result might be a reasonable estimate of "average" traffic congestion conditions in the region, but it would not be a reliable estimate of conditions or of changes in those conditions at the individual sample sites.

Single days of data collection would only make sense if very large numbers of roads were to be monitored or if the data were only being collected to "meet the letter of the law" and the only important criteria in determining sample sizes was the lowest possible cost.

Ten Monitoring Sessions

If a reliable measure of changing travel conditions for each sample site was needed, additional data collection would have to be performed at each site. The data from the SR522 study mentioned above showed that a sample size of 10 monitoring sessions will result in a measure of mean travel time that will be within ± 19 percent of the true value 95 percent of the time. (It will be within 16 percent 80 percent of the time.) Stated otherwise, an accurate measure for congestion is needed for at least ten days to estimate the mean condition for a road segment (and time period) within 19 percent with a high degree of confidence.

This measure of precision is good for any duration of data collection for which an adequate sample of travel times is collected. That is, if data are collected ten times in the morning peak period and ten times in the afternoon peak period, congestion estimates for both periods (as well as the average for both periods) can be determined within these error bounds.

Twenty Monitoring Sessions

Doubling the number of monitoring sessions to 20 per sample site will improve the precision of the mean travel time estimate to an expected error range of ± 13 percent, 95 percent of the time, or ± 11 percent 80 percent of the time.

The SR522 data indicated that roughly 100 days must be measured to achieve a mean travel time estimate within ± 5 percent, 95 percent of the time. Figure 3 illustrates the relationship between sample size and the precision of the estimate obtained on the basis of the TRAC SR522 study.

Random Single Hours

Within each of the sampling plans discussed above, congestion estimates would only be available for hours during which data had been collected. Random sampling of individual hours is one method for collecting data within each of the days selected for sampling. Under this approach, data would be collected for a random hour (or group of

Sample Precision Versus Number of Measurement Days

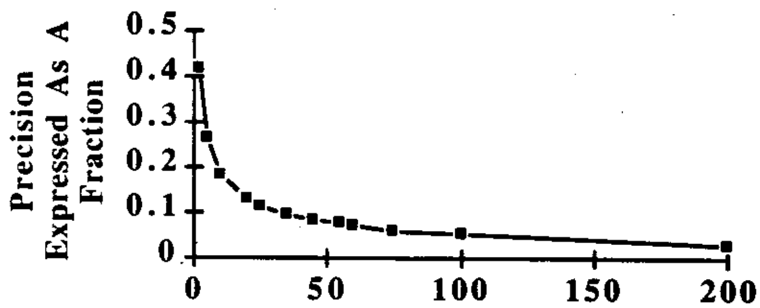

Figure 3

random hours) on each of the days selected for data collection. The result would be a statistically valid estimate of traffic performance during the day.

If all 24 hours in the day were used in the population from which the sample was drawn, the resulting mean statistic would represent the "average condition" for all 24 hours. Since congestion on most roads late at night is non-existent (and thus not worth monitoring), the sampling population could be restricted to some subset of hours (e.g., 6:00 AM to 7:00 PM). Under this approach the mean value calculated from the data collected would represent the average traffic performance within these hours of operation.

The advantage of collecting random hours of data is that such a plan would greatly simplify the sample selection and data aggregation process. It might also lead to low-cost data collection, as relatively few data collection points would be needed to produce a reasonable estimate of "average" conditions.

Unfortunately, the "average" condition might not be terribly useful to the CMS process, and randomly collected hours of data are normally not particularly useful for other secondary analyses. The CMS process is more concerned with the time congestion begins, how long it lasts, and how badly it disrupts mobility. A measure of the "average" traffic condition would only hint at these measures.

Another difficulty with the random selection of hours is that by dispersing data collection throughout the day, this plan would collect a substantial number of congestion measurements during "off-peak" hours that are often of little value for other traffic engineering studies. Thus, while the total cost of the data collection effort might be low, the cost of collecting data during times of real interest would be higher than for other sampling plans. In addition, the low number of measurements taken during traditionally congested time periods might be insufficient to accurately describe the traffic performance during those periods. For example, the data collected might not be able to accurately determine when congested conditions began.

In conclusion, this data collection plan would not serve the real needs of the CMS.

AM and PM Peak Hours Only

This sampling technique is the opposite of the random selection approach described above. It would concentrate the available data collection resources on hours that traditionally contain the highest levels of congestion, the AM and PM peak hours. Most TDM and TSM measures are designed to reduce traffic congestion during these hours, and thus their effect would be reflected to some degree by this sampling approach. This plan would provide the highest level of precision at the lowest cost for monitoring these hours. It would provide the best return on investment if the intent of the CMS is to monitor congestion during the most congested times of the day.

The disadvantage to this approach is that congestion changes are occurring primarily outside of the AM and PM peak hours. Changes in congestion are most likely to occur during the shoulders of the peak periods or during the mid-day hours, rather than during the peak hours. In addition, some suburban locations have more congestion between 12:00 PM and 1:00 PM than during morning or afternoon peak periods. By concentrating only on the peak hours of congestion, the data would probably not describe changes in congestion during the peak period shoulders. As a result of these limitations, the CMS would be unable to determine how long congestion was lasting during the day, whether a time period had changed, or the time periods that were experiencing congestion.

A smaller drawback to this focused approach to data collection is that the "average" condition of the roadway could not be calculated. This statistic might not be as important as the peak hour conditions, but it would be useful.

Peak Periods Only

To reduce the limitations inherent in sampling AM and PM peak hours only, this sampling plan would extend the traffic monitoring sessions to cover the expected peak periods, rather than just the peak hours. For example, instead of counting from 7:00 to 8:00 AM, data would be collected from 6:15 to 9:15 AM. This spread would allow changes in congestion levels to be monitored throughout the peak period. Not only would this monitoring allow the CMS to determine the impacts of traffic control measures on traffic during the shoulders of the peak period, it would also provide very useful information to urban area modelers trying to account for traffic conditions outside of the highest travel periods.

The primary drawback to this approach is the increase in cost associated with the increased length of the data collection effort. An increase from 1 to 3 hours of monitoring would likely double of the cost of the data collection effort (assuming the same number of counts). Costs would not triple because of improved efficiency in the data collection and analysis resulting from the longer counting periods. (Data collection crews would be paid for the same amount of travel time.)

A second drawback to this approach is that it would still be heavily concentrated in the peak periods. Thus, no information would be available for mid-day or other non-peak period travel.

AM Peak, PM Peak and Midday Counts

The last proposed count duration program would expand on the peak period program described above by also collecting data during a midday period at each of the sample sites. The advantage to this approach is the ability to monitor congestion during the midday period. The disadvantage is the increase in cost associated with the need for more data collection.

Conclusions and Recommendations For Short-Term Collection

In general, the more data collection that was performed, the better would be the accuracy and precision of the results of that sampling effort and the more useful would be the data for describing traffic performance throughout the day. However, the cost of the effort would also be higher . Because the resources for data collection at all levels are limited, the author concludes that the highest sampling rates presented above are not feasible from a cost perspective. In addition, limiting the hours of the data collection effort to the minimum levels presented in the first two alternatives above would jeopardize the reliability and utility of the data collected for the CMS.

Therefore, the recommended short-term program is to collect travel time data at between 15 and 50 road segments in each of the urban areas within the state covered by CMS regulations. The larger urban areas in the state would be expected to collect data at a larger number of locations, while the smaller jurisdictions would collect data in fewer sites. For the first year, at each location, data should be collected on ten weekdays. On each of those days, data should be collected using the license plate matching technique for a total of 7 hours. Data collection should take place from 6:30 AM until 9:00 AM, from 11:30 AM to 1:00 PM, and from 3:30 PM to 6:30 PM.

These data should then be analyzed in 15-minute increments to determine the average travel time by road segment during each of those increments. The distribution of the mean travel time estimates between the ten days for each of the 15-minute time periods should be computed to determine the precision of the overall mean travel time estimate. If necessary, this initial level of data collection could be refined in future years to better meet the needs of the state, depending on the variability of the data collected, the availability of funding for data collection, and support for the CMS.

LONG-TERM DATA COLLECTION ALTERNATIVES IN CONGESTED AREAS

The manual data collection described above, combined with data from the existing and planned SC&DI systems, would provide a reasonable "first cut" at the data needed for the CMS. However, the manual data collection process would be too expensive for use in the long term and would not provide the level of congestion monitoring necessary for the CMS if it will be used as Congress intends. To meet the long-term data collection needs of the CMS, a more automated and geographically complete data collection system will be required. Unfortunately, all of the "best" methodologies for collecting congestion monitoring information require a substantial investment in new infrastructure.

For the long term, WSDOT can choose from a number of congestion monitoring techniques for the CMS. The emergence of IVHS technologies has produced a large number of devices that can be used to monitor vehicle position and vehicle performance. Among the practical alternatives proposed by various vendors and consulting firms are the following:

- an automatic vehicle identification (AVI) based vehicle probe system, developed specifically to monitor vehicle performance
- video imaging techniques based either on license plate scanning technology or image matching technology that can provide vehicle performance monitoring
- GPS technology that provides a mechanism by which instrumented vehicles can be tracked for performance monitoring
- cellular telephone tracking (note that calls do not need to be placed on those phones to track their location), which provides information on the movement of vehicles in which phones are placed

- use of existing conventional inductance loops in conjunction with new electronic devices to collect the needed performance information at least on the freeway system

Data collected using any one of these technologies could meet the needs of the CMS. The difficulty is in finding the resources to purchase, install, and operate the necessary infrastructure to allow the data to be collected. WSDOT has traditionally been reluctant to collect data simply to fulfill reporting requirements, particularly when those requirements are extensive. Given the Department's significant needs and limited resources, this reluctance is not surprising.

Thus, the infrastructure needed to collect congestion data will likely not be installed specifically for congestion monitoring purposes. Infrastructure will only be installed as part of a more comprehensive system that meets significant operational or maintenance needs. (For example, the Northwest Region SC&DI system provides a considerable number of CMS data, but the primary purpose of the SC&DI system is to improve the operation of the Northwest Region freeway system, not to collect data.)

Fortunately, four types of systems have been identified that need traffic performance information similar to that needed by the congestion monitoring system. While WSDOT would not own and operate all of these systems, the data collected as part of their operation should be accessible to WSDOT for congestion monitoring purposes. These systems include

- advanced traffic management systems (traffic control systems)
- advanced urban traveler information systems
- bus location and performance systems
- bus prioritization systems for arterials.

As these types of systems are constructed, WSDOT must ensure that data collected for these systems will be available to the CMS. In the Northwest, Olympic, Southwest, and Eastern Regions projects are either programmed or currently under way to design, build, install, operate, or test one or more of these systems. CMS data requirements must be incorporated into the design, construction, and operation of these systems. As the systems are installed and expanded (which is recommended for operational needs as well as for CMS purposes), realistic traffic performance monitoring will be possible throughout the state's urban freeway systems.

Among the projects that need to be coordinated with the CMS are the following:

- Vancouver SC&DI system (part of the Portland ATMS effort)
- Tacoma SC&DI system
- Spokane SC&DI system
- North Seattle Advanced Traffic Management System (NSATMS)
- Seattle Metro/Snohomish Transit /Pierce Transit joint AVI specification and testing for prioritization of arterial signals for transit buses
- Snohomish Transit purchase of hardware/software for prioritization of buses at arterial signals
- the Office of Urban Mobility's project for translating operations data into planning data, making them available to planners throughout the state (the TDAD project)
- Metro Transit's Datalink project.

In addition, several WSDOT research efforts are under way to disseminate traffic and transit information to travelers to increase the use of high occupancy vehicles. These research efforts (which WSDOT hopes will soon become fully operational) could also provide access to information the CMS needs and/or would provide additional support within WSDOT for the collection of traffic performance data. These research projects include

- Bellevue Smart Traveler
- Traffic Reporter

- the IVHS backbone project
- the Seattle Wide Area Communication System.

Each of these projects will either use or require data that would benefit the CMS, or they will define a mechanism for obtaining this type of data. The CMS effort must take advantage of the mechanisms for collecting these data and obtain access to the data that are made available as part of these projects.

The Proposed Long-Term Monitoring System

The proposed long-term congestion monitoring system would obtain access to a variety of data that are currently, or will be, collected by freeway, arterial, and transit operational control systems. The recommended long-term program would incorporate data from the existing SC&DI systems, as well as data that will become available when the NSATMS and AVI-based bus signal priority project become operational. Where possible, additional equipment that complements these systems should also be purchased and installed to expand the geographic coverage to these systems. However, expansion of the CMS data collection effort would come primarily from the individual operating agencies' efforts to improve and expand their operational control systems.

The recommended long-term monitoring system is as follows.

- Use existing and planned freeway SC&DI systems to provide freeway performance information.
- Use data available through the NSATMS project (as well as similar projects if this concept is expanded) to provide urban arterial use information.
- Use transit signal priority systems and additional vehicle tags to provide urban arterial performance information.
- Obtain incident occurrence and duration, vehicle occupancy, and weather information from existing databases and data collection programs.

PSRC or WSDOT staff time would be needed to integrate the incident, weather, and vehicle occupancy information with the freeway and arterial performance and use information. However, the facility use information should be produced as part of a computerized process.

The use of WSDOT SC&DI system information has been discussed previously in this report and in the Phase 1 report for this project. The SC&DI systems would provide the necessary information on vehicle volumes and performance (speed) on the state's freeway system.

The NSATMS project will provide traffic volume information from arterials in the Seattle metropolitan area. The data available through NSATMS will be collected as part of the operation of existing traffic signal systems. The NSATMS will also provide a mechanism for collecting other traffic performance information at a central location. Current WSDOT thinking is that the NSATMS project is the precursor to similar integration efforts for other urban areas in the state.

The other important arterial performance information would come from the transit signal priority equipment. This system will use AVI readers and vehicle tags to identify buses as they approach signalized intersections. By measuring the distance between specific AVI readers (intersections) and comparing the time each bus (or other tagged vehicle) passes each reader, it will be possible to determine the travel time between readers. By monitoring these travel times over the course of the day and the course of the year, the CMS would obtain much of the missing traffic performance information it would need for urban arterials.

This traffic performance monitoring capability would not only provide CMS data to WSDOT, it will also provide the necessary information for evaluating the effectiveness of the signal priority process. Thus, the signal prioritization project will also benefit from allowing the collection of data for the CMS.

To reach the long-term goal of using these operational systems to provide congestion monitoring information will require coordination and, in some cases, minor changes to these ongoing projects.

Existing Projects

Five projects currently under way or scheduled to begin in the next few months would be impacted by a plan to use data from the bus signal priority system. These five projects are

- the North Seattle Advanced Traffic Management System (NSATMS)
- the Metro Transit/Snohomish Transit/Pierce Transit joint purchased of AVI-based traffic signal priority equipment (the signal priority project)
- the purchase of $1.5 million worth of AVI signal priority software and hardware by Snohomish Transit (Snohomish Transit ASAP)
- the Office of Urban Mobility's TDAD project
- the IVHS backbone project.

These projects are briefly described below. In the section that follows these descriptions, the issues that would have to be coordinated within each of these projects and the modifications that would be required to their planned scopes of work are presented.

NSATMS Project

The NSATMS project will provide a single computer that will communicate with the traffic signal and freeway ramp metering control computers in northern King County and southern Snohomish County. (This includes the Northwest SC&DI computer.) The NSATMS computer is being designed so that neighboring jurisdictions can share the traffic data (i.e., traffic volumes, lane occupancy rates, and vehicle speeds) collected by these systems. The $4 million NSATMS project includes purchasing a central computer, writing inter-computer communication software, and providing additional data collection hardware that will improve the quality and usefulness of the information stored in the NSATMS computer.

Transit Signal Priority Project

The signal prioritization project is a cooperative effort among the metropolitan area's three major transit authorities. These authorities have agreed to jointly set specifications for the purchase of AVI-based traffic signal prioritization hardware and software. Two arterials are scheduled for initial system installation and testing, SR99 in the NSATMS project area, and Rainier Avenue South in southern Seattle.

The joint specification means that, as the prioritization system is expanded, the majority of transit buses in the three counties will be equipped with compatible AVI tags. In addition, AVI readers will be located at key intersections on arterials throughout the three-county region. These AVI tags and readers could be used (and enhanced) to collect travel times on urban arterials in the CMS.

Snohomish Transit ASAP

Snohomish Transit will expand the transit signal prioritization system in Snohomish County using a $1.5 million grant from the U.S. Department of Transportation. This expenditure will potentially provide AVI readers at all intersections in the county that would have to be monitored for the CMS.

The TDAD Project

The TDAD project is a $250,000, FHWA-sponsored project that will demonstrate how operational data (i.e., data collected as part of the input to an operations-oriented process such as real-time traffic control systems, SC&DI, or traffic signal networks) can be saved and provided to transportation planners to cost effectively meet the need for traffic information for HPMS and other planning purposes.

The TDAD project will make the traffic information collected as part of the NSATMS available (in an appropriate format) to the Puget Sound Regional Council (PSRC), the WSDOT Office of Urban Mobility, and other planners as determined by WSDOT and the project's Principal Investigators.

The IVHS Backbone Project

The IVHS backbone project is attempting to develop the appropriate framework for the computer to computer communication needed by IVHS applications. This project will provide the basic communications design for the TDAD project, as well as for portions of the NSATMS project. It will set the protocols that should be used for storing, accessing, and retrieving data collected by various computers in the metropolitan region. Connections already exist or are planned among computers located at the WSDOT Northwest Region (the SC&DI computer), Seattle Metro (the Metro AVL computer), NSATMS, University of Washington research computers, and various other sites.

Modification to and Coordination Among Existing Projects

To accommodate the CMS data requirements, minor changes and additions to the projects described above would be needed. These changes are discussed below. Table 4 summarizes the decisions that must be coordinated among these projects. Table 5 summarizes the changes that would be needed in the existing scopes of work for these efforts.

The NSATMS project and the Seattle Metro/Snohomish/Pierce transit bus priority projects are the most important of these projects for enhancing the state's ability to automatically collect traffic performance data for the CMS. The transit priority projects would provide a significant part of the hardware needed for collecting traffic performance information. The NSATMS project would provide the computer and database that would store the needed data.

Table 4
Coordination Issues For Current IVHS Projects

IVHS Project	Issues To Be Addressed
North Seattle Advanced Traffic Management (NSATMS)	How, how often, and in what manner the NSATMS will communicate with the bus priority project. Needs AVI tags that don't trigger bus priority signal changes in order to perform an evaluation of the NSATMS system after it is installed Inclusion of the bus AVI data in the NSATMS database and communication structure
Joint Transit Authority - Signal Priority System Specification and Initial Purchase	Agree to allow WSDOT to have access to bus priority information. Coordinate AVI purchase with NSATMS project Ensure that AVI tags can detect the difference between SOVs and buses, and that the signal priority system can respond to the bus signal, but not the SOV signal Needs NSATMS data to perform the evaluation of the signal priority system Determine who gets access to bus AVI data
Snohomish County Signal Priority Expansion (ASAP)	Needs NSATMS data to perform the evaluation of the signal priority system
Use of Operational Data For Planning Purposes (TDAD)	Incorporate bus and SOV arterial travel time data into the TDAD data processing functions and database
IVHS Backbone Project	Coordinate with NSATMS, TDAD, and bus priority system to ensure all data are available via the backbone

The NSATMS Project

The NSATMS project has several loosely defined software programming and communications development tasks. The software needed to allow WSDOT to obtain CMS data from the transit priority hardware and store them in and extract them from the NSATMS computer should be incorporated into the NSATMS programming efforts. The CMS software requirements are well within the scope of the NSATMS project as currently planned and should not adversely affect the NSATMS project budget.

Table 5
Changes Needed To Current IVHS Projects

IVHS Project	Changes Required
North Seattle Advanced Traffic Management (NSATMS)	Purchase AVI tags for monitoring SOVs Include communications to and storage of data from bus signal priority system in NSATMS scope Write software that takes bus and SOV IDs and converts them to travel times Incorporate bus and car travel times in the NSATMS database structure
Transit Authority Joint AVI Based Signal Priority Specification and Initial Purchase	Incorporate communications into the initial purchase
Snohomish County Signal Priority Expansion (ASAP)	Include communication function as part of the hardware purchase
Use of Operational Data For Planning Purposes (TDAD)	Incorporate bus and SOV arterial travel time data into the TDAD data processing functions and database
IVHS Backbone Project	No changes required

Several CMS related capabilities or functions must be explicitly incorporated into the NSATMS project to ensure that the necessary arterial performance monitoring functions are available. These capabilities/functions include the following:

- Provide communications capabilities to signals with signal prioritization hardware in the NSATMS geographic area (this includes both communications devices such as modems and facilities such as telephone lines or cellular telephone access)
- Purchase extra AVI tags for non-transit vehicles
- Build data storage, retrieval, and access capabilities into the NSATMS database
- Write software to compute travel times from the collected data.

The communications capabilities are needed to send the bus location and information on time and date of passage to the NSATMS computer for storage. Additional AVI tags are needed to allow the NSATMS system to track non-transit vehicles (i.e., SOVs), as well as transit coaches. (The non-transit vehicles would not be given signal priority.) The data storage and retrieval functions must be specified because the CMS data are not needed by the current signal control systems and thus may not be specified within the original database design documents. Similarly, the software needed to compute the vehicle travel times was not defined in the current NSATMS documentation.

To complete these tasks, the NSATMS project consultants will have to work with the vendors selected to supply transit signal priority hardware and software (see below). A number of design decisions must be made (jointly by the two consultants/contractors/project teams) so that these two systems will interact as needed.

The communications task is necessary to send the signal priority information to a central location. As can be seen in Table 6, this communications task could be performed in several ways. The primary differences in the communications alternatives are in the timing of the data retrieval (real time, nearly real time, or batch transfers) and the location to which the data would be initially transferred (directly to the NSATMS or to a transit authority computer first and then to the NSATMS).

The decisions on the timing of data transfer from each signal to a central location and that central location will drive the remaining design considerations of how many data to store on site, the mode of communication to use, and who should pay for these capabilities. For example, if real-time communication were needed, little on-site data storage would be needed (because the data would be transferred to the central location immediately); hard wired communications would be needed (traditional telephone lines, coaxial cable) to cost effectively provide frequent transmission of data; and the transit authority would be expected to pay for the communications, as WSDOT would not need the data this quickly. If data could be transmitted in batch mode (i.e., an entire day of

Table 6
Summary of Alternative Communication Plans
For The Transit Signal Prioritization / NSATMS Connection

Frequency of Communication	**Attributes**	**Potential Technologies**
Real time	Provides real-time bus location information Usable for traveler information systems Allows remote usage of vehicle performance by potential ATMS. Requires continuous communications link Costly communications requirements, either because of high cost, fixed service, or high cellular phone airtime charges	Conventional dedicated telephone lines Fiber optic cable New technology cellular based data link?
Near real time (within 5 to 15 minutes of observation)	Probably sufficient for use by traveler information systems Adequate for detecting presence of major congestion Reduced communications needs May allow cellular phone airtime to decrease to the point where cellular phone time is less expensive than placing conventional phone lines	Cellular phone Conventional dial up or dedicated telephone lines New radio/cellular data transfer technologies (spread spectrum? cellular data transfers? etc.)
Batch data collection (daily)	Low cost communication requirements Does not allow data to be used for either bus location information or traveler information systems	Cellular phone Low volume / frequency cellular data transfer

vehicle performance information at a time), the on-site storage would have to be greater; a less capital-intensive communications technology (e.g., cellular phone) could be used; and the payment for these upgrades would likely come from WSDOT or PSRC, who would have the most to gain from obtaining this information. (The transit authority might not need the vehicle location data at all.)

In return for the added costs of connecting the signal priority hardware to the NSATMS, the NSATMS project would obtain the data required for evaluating the effectiveness of the integrated control hardware's signal coordination capabilities. The continuous data collection capability afforded by the signal priority hardware would provide a mechanism for monitoring the NSATMS system's performance during unusual conditions (for example, during major accidents), when the integrated computer network should provide significant operating improvements over the current isolated systems. It would not be possible to monitor these changes with a manual data collection effort.

To assist with the evaluation of the NSATMS and to determine "car" performance on the instrumented arterials, additional vehicle tags would have to be purchased. These tags should be placed on cars that routinely operate on the arterials being studied. The tags would be coded so that the priority system correctly read the tags but did not change the existing signal timing. Tracking these "tagged, non-priority vehicles" through the arterials would provide performance information on "average" vehicles. A before/after analysis with these data would describe the impact of the bus priority system on automobile performance. With these data, automobile performance could also be contrasted against bus performance. If express buses could carry AVI tags that were coded differently than those of local buses, local bus performance could also be compared to express bus performance on the instrumented arterials.

The extent to which the NSATMS project will be responsible for constructing software programs that manipulate data to be stored on the NSATMS computer is not clear. The NSATMS requires some database functions (data entry, storage and retrieval), but these functions have not been fully defined to date. Therefore, it is reasonable to expect that, at a minimum, the storage of the AVI data will be provided within NSATMS. The minimum AVI data storage requirement is one record per tag observation at each intersection. Each record will contain the tag ID observed, the station ID that recorded the observation, and the time and date the tagged vehicle was observed at that location.

At some point, the tag observations will have to be correlated with each other. After correlation, data records should be stored with the following information

- tag ID
- upstream location passed
- time and date of passage
- downstream location passed
- time of passage
- total travel time between locations
- total travel distance.

While it would be reasonable for the NSATMS system to perform this function, the NSATMS system might have to simply download the raw tag observations to a second computer that would perform the manipulations necessary to create the correlated records. The tag correlation records would then be summarized by a third processing program (by location, time period, tag type) as desired by researchers, planners, or the CMS. This summarization task could take place on the NSATMS computer, on a secondary computer that performed the tag correlation task (if that task was performed on another computer), or on a different computer that had access to the correlated observation records.

Transit Signal Priority Project Changes

The transit signal priority project is the key to future implementation and expansion of the proposed, automated, arterial data collection effort for the CMS. The signal priority project is important to the regional transit agencies because it will provide significant operational advantages to them. These operational advantages provide the transit authorities with incentives to

- purchase, install, and operate the AVI readers needed to identify tagged vehicles throughout the metropolitan area
- expand the system to most major arterials in the metropolitan region
- maintain the system.

In other words, the signal priority system exists for reasons other than the CMS. Congestion monitoring benefits are simply coincidental. However, because the transit signal priority system was not designed as a CMS data collection system, the WSDOT must make sure that the final design of the signal priority system will not preclude its use for that purpose. In addition, the WSDOT and/or PSRC may be responsible for funding some (or all) of the costs needed to obtain signal priority information and convert it for use by the CMS.

The most important change to the transit signal priority project concerns the need for communication between the signals equipped with vehicle tag readers and a central location. The vehicle tag information will not have to be transmitted from instrumented intersections to a central site in order for the signal priority system to work. However, access to vehicle tag, location, and time of passage information will provide the transit authorities with bus location and performance information that could be used for a number of important analyses, and thus this communication function would have value for the transit agencies. (Within Metro Transit, bus location is already determined by a beacon system that works with their current radio system. The AVI system information could supplement or improve on this information. Snohomish Transit does not have a bus location system.)

If the collection of tag ID, location, and time of observation information is not funded as part of the signal priority project, WSDOT or PSRC will be responsible for funding the data collection and retrieval function to collect arterial performance information. However, in addition to funding the purchase of the hardware and software needed for storage and retrieval of the bus ID and location information obtained from the AVI readers, these agencies will have to request that the transit authorities include the following criteria within the signal priority system's purchase specification.

- The AVI hardware must be capable of storing and transmitting the bus ID, location, and time of passage information to the NSATMS via a communications mechanism jointly selected by the transit authorities and WSDOT.

- The signal priority hardware should include sufficient memory to store tag observation information on-site until it can be downloaded to the central computer.
- The signal priority hardware should include the capability to connect to the communication system hardware (modems of various types) selected above.
- The software needed to operate the modems must be provided for each tag reader, and descriptions of the communication protocols used by that software must be provided by the vendor.
- The AVI tag system must be capable of differentiating between tags that are on transit vehicles (and require signal priority changes) and those that are not on transit vehicles (and should not change signal timing plans), while still recording the passage time of all tags.
- The scheduling of the AVI system testing and implementation process should take into consideration the needs of the NSATMS evaluation, as the evaluation will benefit highly from the AVI system.

The majority of the issues listed above are self explanatory. One that needs additional explanation is the need to coordinate the Transit Signal Priority project's schedule with the NSATMS schedule. This coordination is needed so that the AVI system could be used to evaluate the NSATMS project. (The AVI system would provide a mechanism for evaluating the NSATMS project that might otherwise be unavailable. At the same time, the evaluation of the NSATMS project could also serve as the evaluation of the signal priority project.)

The NSATMS implementation process will require data collection before completion of the NSATMS integrated control to provide the "before" data for a "before and after" study. This means that the signal priority hardware should be installed and preliminary operations begun before the completion of the two-year NSATMS project. (A preliminary AVI system should be available by roughly the end of 1995). Full communication and signal priority capabilities would not be needed at that time, but the ability to read and store vehicle tag information on site would be required. AVI tag information would be retrieved manually once per week until normal communications capabilities were established. The collection of bus performance information before the start of signal priority algorithms would also be needed to provide a baseline for evaluating the signal priority system.

The last scheduling consideration for the signal priority project is that the initial test of the system should be carried out within the NSATMS boundaries on SR99, rather than on Rainier Avenue, the second proposed test location. While both SR99 and Rainier Avenue will be equipped with the AVI devices, initial installation of the SR99 intersections would allow multiple use of the AVI readers, while the Rainier intersections would not provide this capability.

Snohomish Transit ASAP Changes

The Snohomish County expansion of the signal priority project should be the first large-scale implementation of the travel time data collection process. The only significant changes necessary to the ASAP project are the addition of communications capabilities to the individual reader locations.

Snohomish Transit does not currently have an automatic vehicle location system. Thus, the addition of communications to the AVI signal priority system might provide two significant improvements to Snohomish Transit operations, improved arterial performance for the buses and vehicle location information. Connecting the Snohomish County transit priority system to the NSATMS project would also allow collection of the data needed to evaluate the impacts of the signal priority system on Snohomish County arterials. Finally, it would provide automated CMS data collection on the vast majority of arterials in Snohomish county, thus reducing the need for other data collection efforts.

TDAD Changes

The TDAD project is designed to provide access to traffic information collected by traffic control systems to planners in the state. No reference exists to travel time data in the TDAD proposal because when the proposal was written, travel time information did not exist within the NSATMS. However, the TDAD project includes a task for the researchers to define the data needed by the planners and the manner in which planners would need access to those data. Travel time information for use within the CMS is clearly data required by planners. As a result, it is reasonable to expect that some coordination between the TDAD project and the bus priority database should be part of the TDAD project.

IVHS Backbone

No changes are needed in the IVHS Backbone project. However, the results of the backbone project might influence the hardware and software design of the NSATMS, Transit Signal Priority, TDAD, and CMS projects. This influence would arise from the project's descriptions of the methods by which traffic data should be stored and shared between applications, and these projects all have need for shared information.

SUMMARY OF RECOMMENDATIONS

The recommended congestion monitoring system would use Level of Service (as computed using volume/capacity ratios) to measure highway performance on rural roads, and travel time measurements on urban arterials and freeways. WSDOT's existing data collection effort would provide the majority of information needed for the rural road portions of the CMS. In urban areas, additional data collection would be required. The cost of collecting the additional urban congestion monitoring information would exceed the funding available for that data collection. As a result, the author recommends a staged approach to implementing the congestion monitoring system. The initial efforts are meant to provide a reasonable measure of current urban conditions while containing the cost of the data collection program. Later efforts would expand the state's ability to measure the extent of congestion in the urban areas as new technologies allowed more cost-effective collection of traffic performance information.

In the near-term, the author recommends that travel time information be collected at a panel of roadway sections selected within each of the state's urban areas. At each of these panel sites, travel time data should be collected on ten weekdays. During each weekday data collection effort, travel time data should be collected from 6:30 AM until 9:00 AM, from 11:30 AM to 1:00 PM, and from 3:30 PM to 6:30 PM. This data collection schedule would allow CMS to identify the length of time during which traffic operated under congested conditions, as well as the average vehicle performance during those time periods. Where available, measurements of average vehicle speeds obtained from existing SC&DI systems could be used in place of the travel time information collected manually.

An estimated 15 sites in Spokane, 15 sites in Vancouver, and 35 to 50 sites in the Puget Sound metropolitan region would be needed to supply a reasonable estimate of traffic performance in each of these urban areas. These sites should be divided between roadways currently experiencing heavy congestion, those experiencing moderate congestion, and those not currently congested but where congestion is expected to occur in the next few years as a result of urban growth. In addition, these sample sites should be distributed between freeway and arterial segments on the basis of the percentage of vehicle-kilometers-traveled in each of the urban areas. Wherever possible, these sample sites should also be coordinated with ongoing vehicle occupancy data collection sites.

In the long term, resources are not available for collecting data specifically for the congestion monitoring system: therefore, the state and MPOs should lean towards collecting these data from other sources, preferably, continuously operating traffic control systems. Several projects currently under way in the Puget Sound metropolitan region could help provide the needed information while at the same time increase the geographic area (i.e., number of road segments) covered by the CMS and decrease the cost of the data collection effort. These systems are the Northwest Region SC&DI system and the AVI system[3] local transit authorities are installing to provide bus priority at signalized intersections. Both of these systems would allow automated collection of roadway performance information.

The Northwest Region already collects and stores SC&DI information. The CMS would have to obtain routine access to this information. For the transit signal priority project, the PSRC and WSDOT would have to work with the transit authorities, the cities operating intersections that will be affected by the signal priority system, and the Northwest Region to collect the vehicle location data generated by the AVI devices and convert those data into roadway performance information. To allow the AVI system to provide both car and bus performance information, the WSDOT and PSRC would have to ensure that a sample of automobiles operating along the urban arterials were also equipped with AVI tags.

To send the AVI data to a central location and make it usable for congestion monitoring, the transit AVI system would have to be connected to the North Seattle Advanced Traffic Management System.[4] These projects are not currently proceeding in a coordinated fashion. It is imperative that WSDOT and PSRC make sure that the agencies and consultants working on these projects are aware of the needs of the CMS, that these needs are reflected in the scope of work for the respective projects, and that routine coordination of the design and implementation of these systems occurs. Both WSDOT and PSRC should take an active role in this coordination function.

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[3] See page 37 for a description of the transit AVI project.

[4] See page 36 for a description of the NSATMS project.