ARTERIAL PERFORMANCE MONITORING USING STOP BAR SENSOR DATA

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ABSTRACT

The primary objectives of this research were to analyze a hypothesis that traffic data from a basic sensor located near a signal stop bar, combined with signal state data, can be used to estimate arterial traffic conditions (congestion); develop a prototype analytical method to test that relationship, and evaluate requirements and other issues associated with future application of the method.

Specifically, lane occupancy percentage values from a sensor located just upstream from a stop bar for an arterial traffic signal, when appropriately filtered by signal state data to determine occupancy during green and amber phases only, were hypothesized to be associated with nearby arterial performance (such as congestion or traffic delay), and this relationship was proposed to be used to develop a basic arterial performance estimation method.

From the results analyzed, the use of occupancy values from a stop bar sensor during the green and amber signal states shows promise as an indicator of arterial performance, and the hardware and analytical requirements for the method do not appear restrictive. Additional testing of the robustness of this method would be beneficial, to further document the applicability of the method for different scenarios.

INTRODUCTION

The Washington State Department of Transportation (WSDOT) has a long history of developing freeway data archives and freeway performance monitoring capabilities. The WSDOT's research efforts have produced a performance monitoring methodology and tool set that have been deployed to monitor instrumented freeways with the assistance of the WSDOT's FLOW system of detectors and data archiving processes. Given the inherent interaction between the freeway and arterial networks, analogous monitoring capabilities for the arterial component of the state road network would be useful for both the transportation engineer and the general public. This research focuses on exploring a method of monitoring arterial performance that complements existing freeway monitoring techniques, from a roadway operations and planning perspective as well as a traveler information perspective.

The following were the objectives of this research:

- Explore potential methods to monitor arterial performance using basic stop bar sensor data; use signal data as a filter to estimate occupancy during green and amber signal phases only.
- Develop a prototype method for arterial monitoring and test it by using simulated data calibrated for a real-world corridor.
- Evaluate the feasibility for deployment, and the potential functional specifications, of signal systems and sensor systems required to make the method workable in practice.

BACKGROUND

This research effort to develop an arterial performance monitoring technique is an outgrowth of a longstanding WSDOT research effort to archive traffic data and apply that archive to develop useful performance monitoring capabilities for Washington state's freeways (*1*). In 1995, WSDOT initiated an applied research and development program with the Washington State Transportation Center at the University of Washington (TRAC-UW) to develop an analytical methodology and tool set that exploits the potential of the WSDOT FLOW data archive to support freeway performance monitoring and management activities. The resulting freeway performance monitoring methodology, TRACFLOW, was developed to analyze mainline freeway lanes in instrumented regions of the state, using the WSDOT FLOW archives.

The arterial monitoring approach described in this paper was designed to complement TRACFLOW's objectives and methods, which focused on taking advantage of common sensing hardware and data collection processes, using existing data streams when possible in order to expand the versatility of the resulting method, and producing metrics of performance that would be useful to engineers, planners, and travelers.

There are some notable ways in which arterial performance monitoring differs from freeway monitoring, however. First, while urban freeways such as those in the Seattle area are often equipped with a dense network of sensors, arterial sensor density can vary significantly. Arterials can also have varying types of instrumentation, ranging from sophisticated sensors and signal systems to very basic sensors or no sensors at all. While well-instrumented arterials can collect a broad array of data, making them easier to monitor, arterial performance on the significant number of lane-miles of surface streets with less extensive or less sophisticated sensors can be more difficult to evaluate. Because one of the goals of this effort was to develop a versatile method, the research described in this paper focuses on the feasibility of monitoring performance in common arterial scenarios that use sensors with basic data collection capabilities, e.g., inductive loops (and alternative sensors which provide similar data), while imposing minimal requirements for sensor density and placement.

Second, signalized intersections introduce inherent variability in arterial road performance, as vehicles slow and stop for red lights, then resume travel when the light changes. Unlike freeway flows that commonly exhibit fluid state changes, at least under recurring congestion conditions, arterial flow, by its very nature, displays frequent uneven fluctuations in performance over time, even during uncongested conditions. Even under those conditions, the methodology described in this paper proposes that one can still make use of detectors such as those commonly found on freeway (and arterial) systems, based on the reasonable assumption that as congestion varies on a roadway, corresponding sensor values (e.g., the occupancy percentage) will generally vary in a consistent way in response. This is not a new idea; the same basic concept is currently used for freeway applications by methods such as TRACFLOW, and previous research has explored the use of sensor data for a variety of arterial performance analysis applications using various levels of existing instrumentation. For example, Luyanda, et. al., and Gettman, et. al., describe a research effort to employ detector data to develop adaptive signal control algorithms that can be used for arterial signal timing analyses and timing adjustments (*2*,*3*). Of particular note is the focus of that research on the development of methods that can be applied to existing closed-loop signal control systems in a cost-effective manner, using typical detector configurations and common detector data types. That objective of developing a versatile method that is designed to adapt to existing equipment in commonplace field conditions, using commonly available data types, is one that is shared with the research described in this paper.

Other research has focused on the use of detector data for arterial performance monitoring applications. Sharma, et. al. described two methods to estimate arterial performance attributes (vehicle delay and queue formation) using a combination of detector data, signal phase information, and other parameters (*4*). Perrin, et. al. used detector occupancy data to estimate vehicle/capacity ratios and arterial level of service for arterial performance monitoring tasks (*5*). In Bellevue, Washington, loop occupancy values were used to estimate arterial segment performance for display on an updated online traffic map (*6*,*7*).

Third, the interrupted nature of arterial flow, caused by such factors as signal operations and associated queue buildup and dissipation, means that the utility of detector data will be affected by the detector's position relative to the sources of flow interruption (e.g., stop bar detector vs. advance detector). For example, the relationship between detector occupancy percentage and arterial roadway performance is affected by the location of vehicle queues that form while waiting for a red light, relative to the location of that detector. For stop bar detectors, a single vehicle stopped at the associated red light creates an occupancy value of 100 percent until the light changes to green and the vehicle departs. If the detector is placed 100 feet back from the stop bar, and again only that one vehicle is present, detector occupancy is zero for the same roadway performance scenario. Thus, depending on detector location, the same roadway performance can generate completely different occupancy values. The use of alternate or supplementary detector locations has been demonstrated to be useful in addressing this ambiguity. The two methods described by Sharma, et. al. for performance estimation both used advance detector data, and one method also used stop bar detector data as well. (*4*). Perrin, et. al., also used a combination of stop bar and advance detector data to monitor arterials in real time (*5*). Bellevue, Washington's traffic maps used occupancy values from loops located approximately 100 feet upstream from signal stop bars for their online monitoring system (*6*,*7*).

The ambiguity of stop bar data illustrated in the example above suggests that from a roadway performance/traffic monitoring perspective, stop bar detectors are not at the ideal location for monitoring volume or detecting the extent of traffic queues. However, the stop bar detector is a sensor that is relatively common because it provides the most basic detection—"a vehicle is waiting"—required to operate actuated traffic signals. While the use of stop bar detector data as a performance monitoring tool represents a "most difficult case" situation, successful development of a method that employs data from this commonly found sensor would enable that approach to be used in a broader variety of scenarios. For that reason, data from a stop bar detector was the focus of this effort.

TEST APPROACH

The focus of this research was on the development of a useful relationship between a) the data from an arterial sensor, b) signal state data, and c) the overall level of congestion on the arterial segment near the detector for that direction of travel, that could be used to provide a good indicator of local arterial performance. Specifically, lane occupancy percentage values from a sensor located just upstream from a stop bar for an arterial traffic signal, filtered using signal data, were analyzed to determine if they could be a reasonable surrogate value for nearby arterial congestion levels.

Because the research involved analyses of various hypotheses regarding the effects of changes in sensor configuration and location on arterial monitoring capabilities, it was impractical to use an actual fixed loop installation in the field. Instead, a microscopic traffic simulation model of a real arterial segment was developed to determine whether a predictable relationship between volume, occupancy, signal timing and congestion might exist.

TEST SCENARIO

The specific location modeled was a 1.6 km (1-mile) segment of a multilane state highway, State Route 522 near Bothell, Washington, featuring three successive signalized intersections: 61st Avenue NE, 68th Avenue NE, and 73rd Avenue NE (from west to east). Most of the analyses focused on the eastbound segment from 61st Avenue NE to 68th Avenue NE. The arterial scenario being modeled for this research used a common field sensor configuration, namely, detectors at each signal's stop bar.

The methods explored in this research assumed that a) there would be access to all data that <u>could be</u> detectable by sensors in that scenario, and b) there would be a mechanism available to collect and store those data. In many real-world cases, though, data from arterial detectors are not stored after use, and even if they can be stored, the proposed research would require previously undeveloped mechanisms of data storage and reporting, and new data archiving capabilities (software) within the traffic signal control software to support the monitoring process.

MODELING TASKS

To explore the potential relationship between stop bar sensor data and congestion levels, a simulation model was constructed to represent the test segment. The model was developed by using the VISSIM microscopic simulation environment (*8*) and was calibrated by using the most recent available complete data for turning movements, average vehicle volumes, and signal timing plans.

The simulation used the following parameters:

- Speed limit = 56.4 km/h (35 mph)
- Vehicle speed distribution = 50.1 km/h to 65 km/h (31.1 mph to 40.4 mph), with vehicles assigned to speeds within that distribution
- Average vehicle length = 4.7 meters (15.44 feet)
- Stop bar detector zone length (through movements) = 9.2 meters (30 feet), matching existing field installations on SR 522
- Driver/vehicle following behavior was governed by the Wiedemann 74 model for non-freeway links (with default values)

The resulting simulation model was set to generate the following output data for each test:

- volume and occupancy percentage data for eastbound traffic, from a modeled detector located just upstream from the stop bar, at one second intervals.
- signal event data (a record of changes of signal state, with time stamps) for the eastbound signal at the same intersection
- average per-vehicle segment speed and delay, for a 1-block upstream segment leading to the stop bar. (For most tests, the segment length was the intersection spacing of approximately 0.88 km (0.55 mile).) Each modeled vehicle's delay is based on a comparison of its actual segment travel time to the travel time if there were no other vehicles and no delay due to signals; those delays are then averaged.
- average and maximum queue lengths, for a 1-block upstream segment leading to the stop bar.

ANALYSIS TASKS

The model was used to perform a sequence of experiments on a single multilane modeled approach to a signalized intersection operating at a 180 second signal cycle along the peak direction of traffic, specifically the eastbound approach to 68th Avenue NE during one hour of the PM peak period, from 4:00 PM to 5:00 PM. Three hypotheses, representing different methods of filtering the sensor data, were tested in each of the experiments. The hypothesis options were designed to address the concern that without some filtering of the stop bar detector data, the average occupancy percentage would be biased upward by the normal presence of vehicles that were stationary at the stop bar during a red light, making it difficult to distinguish between high occupancy values caused by stationary vehicles without congestion, and high occupancy values caused by vehicles moving slowly past the stop bar and on through the intersection during a green light under congested conditions. Therefore, to minimize the ambiguity produced by that situation, the occupancy data were filtered as follows:

- A “fixed green time” stop bar occupancy was computed, based on the occupancy during the first 30 seconds of green signal status in each signal cycle, by comparing the stop bar occupancy data from the model’s detector output file to the time stamped signal event data from the signal output file;
- A “green time plus amber time” stop bar occupancy was computed by using occupancy data from the entire green and amber time of each signal cycle, rather than just the first 30 seconds of green time;

- For comparison, a baseline "all data" stop bar occupancy was computed, using all data regardless of signal phase.

These hypotheses were tested using a matrix of experiments. Each experiment was defined by different combinations of

- A specific rate of arriving (upstream) volume (a range of values was used to generate a range of traffic congestion conditions, where congestion was defined by the model's estimates of system delay and queues and supported by visual inspection of the associated model outputs)
- A particular scenario of arterial conditions (coordinated signals, uncoordinated signals, heavy turning movements, or a blocking incident/construction)
- A particular stop bar detector occupancy filtering method, i.e., use all data values, or use the first 30 seconds of green values, or use all values during the green and amber phases

Similar tests were also performed at two other intersections on SR 522. The modeled stop bar occupancy values were then compared to the associated modeled traffic conditions to determine the extent to which there was a predictable association between specific ranges of stop bar occupancy and particular levels of congestion, such that stop bar occupancy could be used as a surrogate indicator of nearby congestion.

OBSERVATIONS

Overall Detector Data Patterns

A review of the analyses suggested the potential utility of stop bar detector data to monitor performance. As hypothesized, there was a relationship between higher occupancy values and heavier congestion (as congestion grew, occupancy values grew), when appropriate filtering of the data was used. The pattern could be seen when using data from light, moderate, and heavy congestion scenarios.

Figure 1 illustrates this pattern, showing how the occupancy values (based on the green+amber occupancy method) tended to be larger as congestion grew. The figure shows the combined results of six simulation runs representing different levels of congestion. Each run is a different color; each circle represents the average occupancy for the green+amber time of one signal cycle during that run. When traffic was light and delay was minimal (e.g., green circles), volume and occupancy were both relatively low. As traffic grew, both volume and occupancy also grew (e.g., yellow, orange, red circles). At approximately 30 percent occupancy, congestion built significantly, and while occupancy continued to grow, volume throughput leveled off and began to decline. The values for the heavy congestion tests (blue and black circles) continued the pattern observed at the low to moderate congestion levels, with occupancy values continuing to grow (and volume leveling off and dropping).

The various test cases showed similar patterns to one another, although some were less distinct than others.

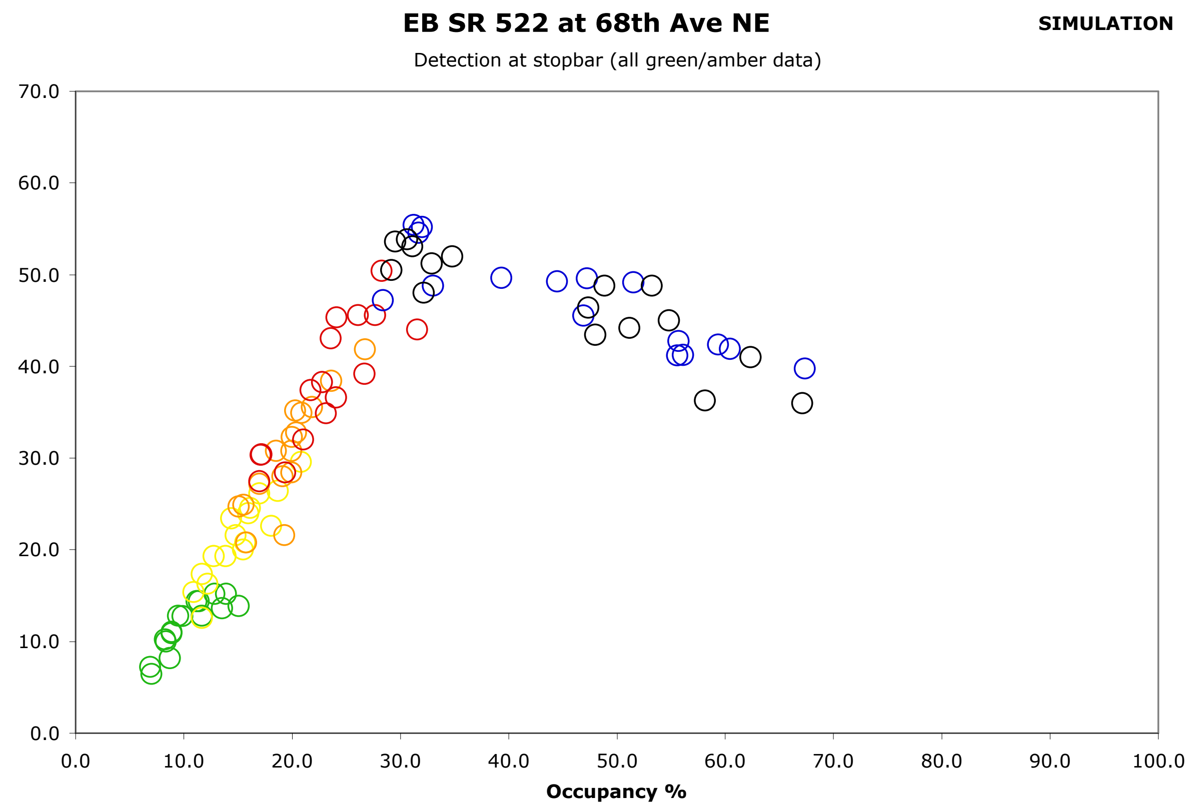

Figure 1 A comparison of occupancy percentage values (x axis) and corresponding arterial congestion (volume is on y-axis) for base case, using data from the all green and amber time per signal cycle.

Effects of Different Occupancy Filtering Methods

The alternatives tested for filtering occupancy data for each signal cycle were as follows:

- average all occupancy data during each cycle (one-second data)
- average all occupancy data during the first 30 seconds of the relevant (e.g., eastbound thru-traffic) green phase of each cycle
- average all occupancy data during the entire green and amber phases of each cycle.

A comparison of the three methods showed that the "all data" method produced data that were clustered around a combination of high occupancy values and low volume values, as one would expect given the method's inclusion of the red phase data, when vehicles are stopped at the stop bar and no vehicles are moving across the stop bar. The 30-second green method appeared to noticeably clarify the pattern of occupancy versus congestion. The green+amber method produced the clearest association between occupancy and congestion, providing more tightly clustered data for a given test case, and clearer patterns at the heavy congestion levels. Figure 2 compares the "all data" result (triangles) to the green+amber result (circles). (Unless otherwise noted, all results described throughout this report are based on the green+amber method.)

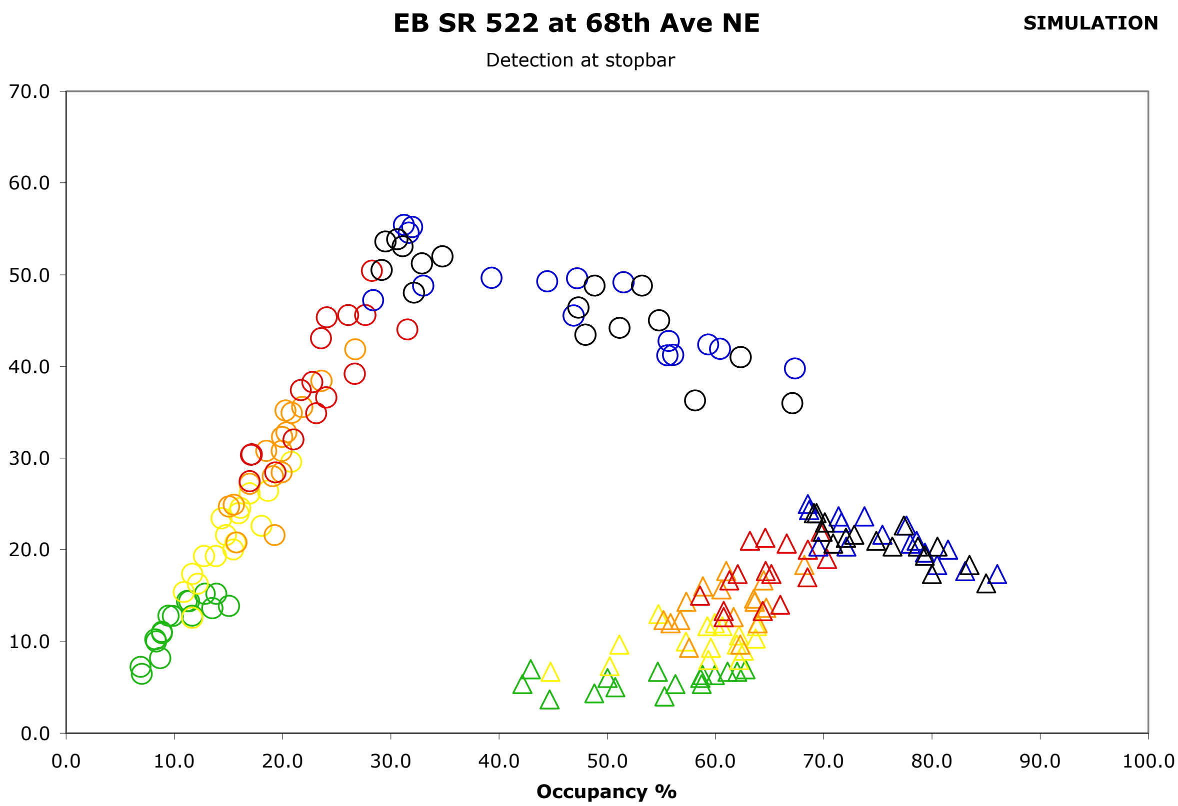

FIGURE 2 A comparison of occupancy percentage values (x axis) and corresponding arterial congestion (volume is on y-axis) using all data vs. green+amber data.

Exploring Patterns through Data Aggregation

The results described above suggested a relationship between occupancy and congestion. Those results were based on data aggregated at the individual cycle level, i.e., each data point represented the average occupancy at the stop bar detector during the green and amber time of a single cycle. For a given test (a specific congestion level), the aggregated cycle data points were generally clustered in the volume-occupancy space; however, the clusters were not always compact and well defined. This variability made the determination of a clearer relationship between the occupancy and congestion more difficult. The researchers then hypothesized that if the data were aggregated at a higher level, transient cycle-level variability of the detector data would have a less direct effect on the analysis and perhaps enable a clearer picture to emerge of the overall nature of the relationship between detector data and congestion. So, for each simulation test run, an aggregate average occupancy percentage for the entire 1-hour test period (after the initial start-up time of the run) was computed, rather than cycle-by-cycle values. As for the corresponding congestion indicator, the aggregate value used was the average per-vehicle speed (or alternatively, delay) associated with the arterial segment upstream from the stop bar.

When those two aggregated variables (occupancy and speed) were tracked for each test case, and the various test outputs were combined, the results still show some variability, particularly at the higher congestion levels (slower speeds), but the overall pattern showed an upward trend in occupancy percentage as a function of congestion (represented by average speed), as proposed in the original hypothesis. See Figure 3.

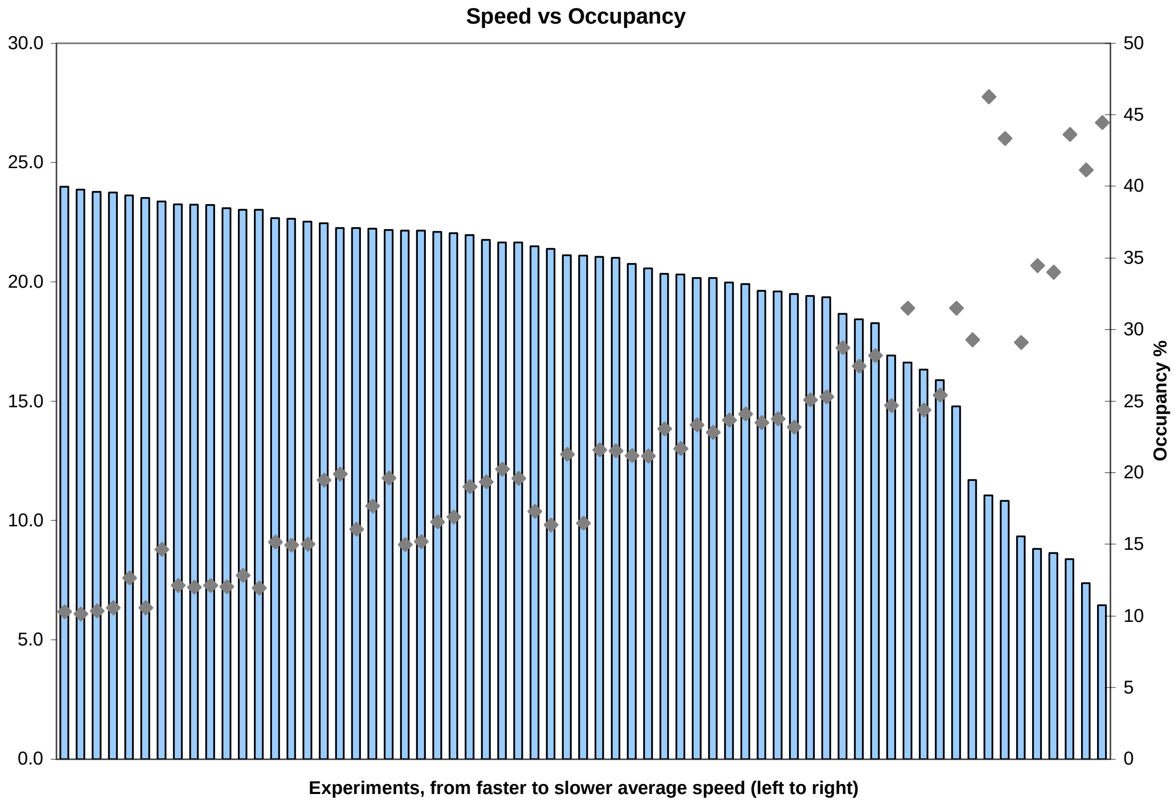

FIGURE 3 A comparison of occupancy percentage values (right axis) and corresponding arterial speed (left axis), for each test case (scatter plot = occupancy, column = speed).

Given the stop-and-go nature of signalized arterials, it is perhaps not surprising that the analyzed data at heavier congestion levels (slower speeds) might show fluctuations in occupancy values over time. Figure 4 shows examples of the time-varying patterns of occupancy for successive signal cycles during light congestion (green, yellow, orange), moderate congestion (red), and heavier congestion (black, blue). At low to moderate congestion levels, average occupancy values per signal cycle tended to be more clustered, varying more smoothly over time. At heavy congestion levels, associated occupancy values appeared to vary more noticeably over time.

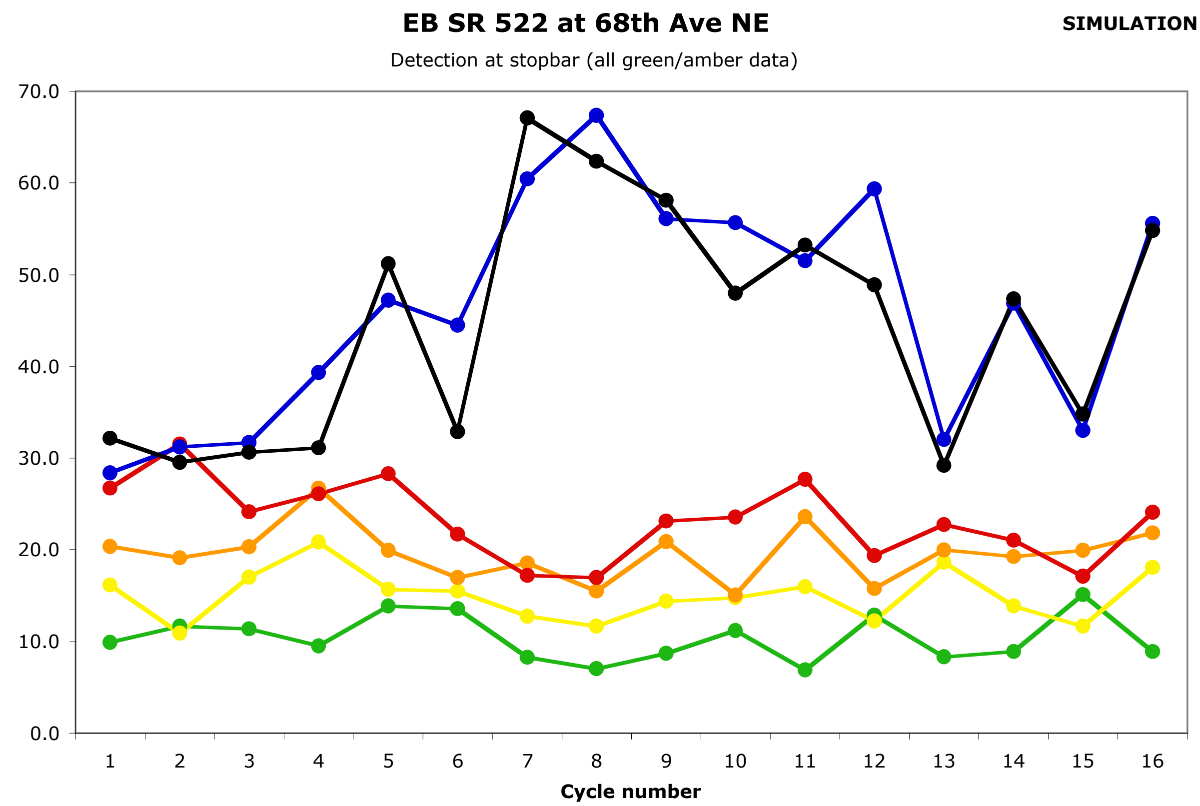

FIGURE 4 Variability of average per-cycle occupancy over time, for different congestion levels.

Using Occupancy to Estimate Congestion

The relationship between occupancy and speed indicated in Figure 3 suggested that average occupancy could be used as a general indicator of associated congestion levels. For example, one approach would be to subdivide the occupancy range, with each subrange corresponding to a different congestion level (based on speed). For example, a web-based display of arterial conditions might show congestion in three categories: light, moderate, and heavy. In that case, the occupancy range would also be split into three subsets, one for each congestion category. As traffic conditions varied over time, the occupancy would be tracked, and the congestion level corresponding to that occupancy value would be displayed.

The use of such a relationship could involve the following steps:

1) Produce occupancy vs. speed data, such as that shown in Figure 3, using a particular occupancy computation method (e.g., green+amber data). Verify that the data show an upward trend in occupancy together with a downward trend in speed.

2) If the occupancy data have some variability, consider smoothing the data to produce a central trend of the occupancy data (vs. congestion) that is less influenced by those fluctuations. (See note below following step 4.)

3) Define congestion categories on the basis of speed on the arterial segment being analyzed. For example, the light/moderate/heavy congestion display website described above might use categories based on Highway Capacity Manual guidelines for Level of Service standards on that type of arterial. Or, a more direct approach might be to simply specify speed

ranges (0 to 10 mph, 10 to 20 mph, 20 to 30 mph etc.) that are either consistent with other existing analytical practices, or coincide with existing local performance standards. Simple speed categories also have the benefit of being more easily interpretable by travelers.

4) Determine the range of occupancy values that correspond to each congestion category defined in step 3. Do this by looking at the sorted distribution of congestion delay values (speeds) across all the test cases and dividing them into groups by congestion level (i.e., each specified speed range from step 3), then looking at the corresponding occupancy range. The result is a functional relationship between occupancy ranges and speed/congestion ranges (e.g., 0 to 10 mph corresponds to occupancy values of between M and N percent). Once this function has been established, it can then be applied to a performance monitoring application.

Note that in this process, the development of a function based on subdivisions of the occupancy range requires the existence of a one-to-one relationship between occupancy and congestion, i.e., occupancy should grow monotonically as congestion grows (or as speeds slow). In reality, though, some variability of the field data might occur. That is why some type of smoothing operation may be desirable, one that removes transient spikes but still displays the overall character and trend of the data. Although this smoothing approach helps facilitate the specification of the threshold values for each congestion category, the precision of the category boundary definitions will be reduced, something that should be considered when defining the categories.

An Application of the Occupancy versus Congestion Relationship

The following is an example application of the approach described above.

1) Produce occupancy vs. speed data. Figure 5 shows an example of such data. The graph also suggests the presence of an occupancy trend that grows with congestion.

2) Because the occupancy data have some variability, the data are smoothed to reduce the fluctuations by applying a polynomial fit to the data.

3) Congestion levels are defined as speed ranges (for example):

Light congestion	>20 mph
Moderate congestion	10 to 20 mph
Heavy congestion	<10 mph

4) For each congestion category above, the corresponding occupancy value range is determined by using the data in Figure 5. The process is shown in graphical form in that figure, where each speed threshold value is matched to the closest corresponding occupancy value. In this example, the smoothed value associated with that occupancy value is used instead.

5) The resulting function is

Speed	Occupancy
>20 mph	0 to 23 percent
10 to 20 mph	23 to 35 percent
< 10 mph	>35 percent

6) Each incoming occupancy data point can then be assigned to one of the speed categories.

Note that depending on the smoothing method chosen, occupancies do not necessarily monotonically grow with congestion, which means that the threshold values may be ambiguous. Also, different smoothing options can produce different thresholds. This illustrates the limits to precision of the congestion category boundaries with this method.

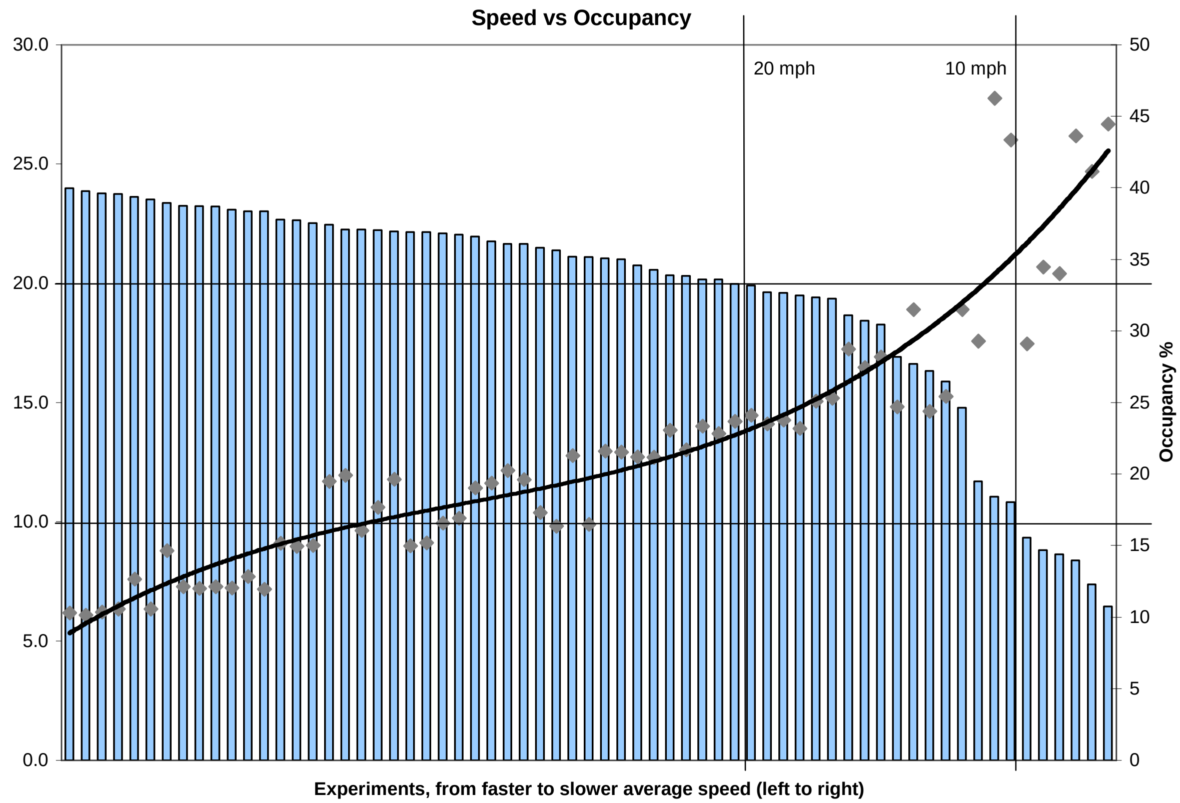

Figure 5 Determining congestion category thresholds from a comparison of occupancy percentage values (right axis) and corresponding arterial speed (left axis) from each test case, using a polynomial smoothing fit and a simple 10 mph speed range.

Results at Other Locations

Similar tests were also performed at two other intersections, 61st Avenue NE and 73rd Avenue NE, both in the eastbound direction. The results at the two locations were consistent with those from the original test location, showing data points that either followed the pattern of data from the primary test location or were a logical extension of the pattern to higher congestion levels. Figure 6 shows the data from the two locations (shown as solid markers) superimposed on the data from the primary test location (open markers). The 61st Avenue NE samples are shown as solid squares, while 73rd Avenue NE data are shown as solid triangles.

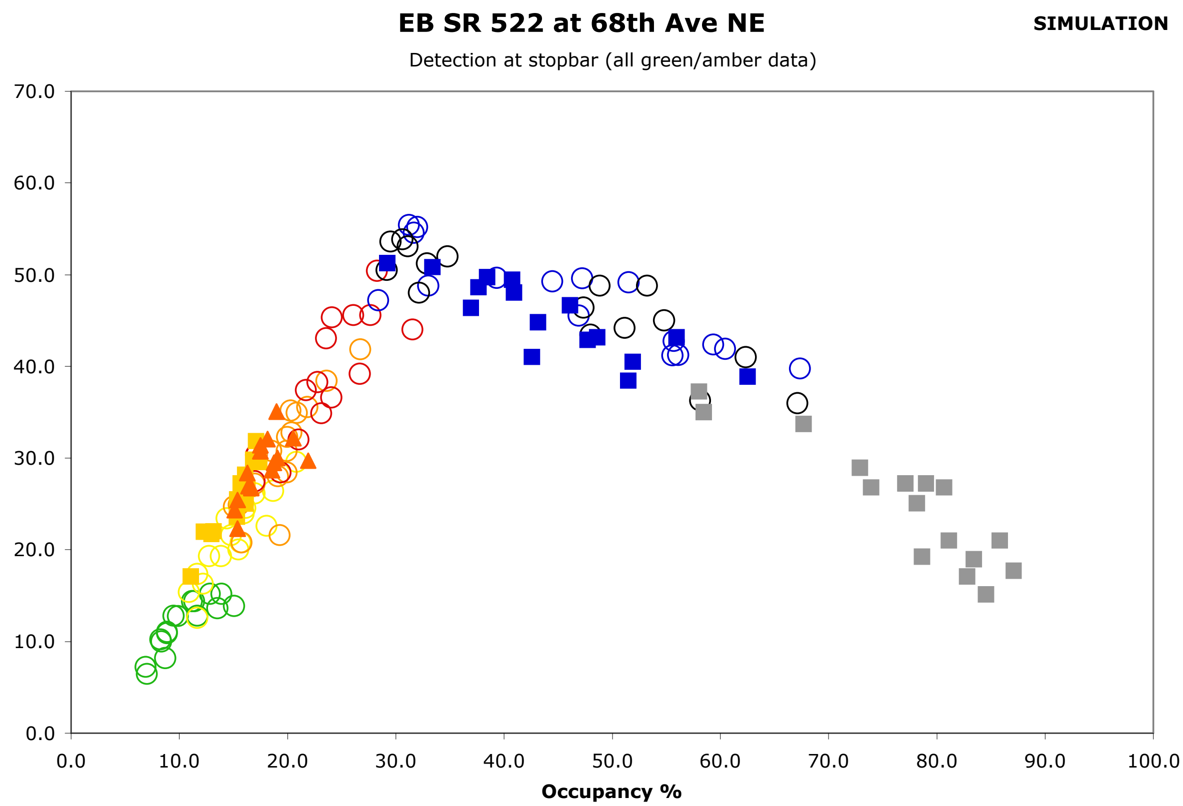

FIGURE 6 A comparison of occupancy percentage values (x axis) and corresponding arterial congestion (volume is on y-axis) for base case, plus two new locations.

IMPLEMENTATION REQUIREMENTS

The method described above would require the following:

Supporting Data:

- Stop bar sensors capable of producing occupancy percentage values at the desired level of frequency
- Signal state data and signal event time stamps or durations
- A data storage capability (or data transfer capabilities to a central facility)

Method:

- A specified congestion categorization approach (e.g., speed ranges)
- Threshold occupancy values for each congestion category

Processing:

- Software to filter and smooth data as required.

The supporting data are producible by a basic sensor at the stop bar. The implementation software and associated parameters would have to be developed or specified by the user. Given the relatively straightforward algorithms employed in this method, the processing software should be relatively inexpensive to develop.

A more significant upgrade requirement might be the data archiving capability. The proposed method requires some storage and processing, performed centrally or on-site. For arterial networks that either did not store their data locally at all, or did store the data but did not centrally archive the values, some mechanism to transfer data would also be required. Either way, the data would need to be archived to support the desired performance monitoring activities.

The signal data types required would likely involve a change of traffic signal controller software to record volume/occupancy by using variable time frames, and to store along with those time frames the length of the actual green+amber condition. (That is, the proposed approach to performance monitoring is to use stop bar statistics of volume and occupancy collected only when that phase is green and amber. To do this would require the traffic signal system to no longer use a “fixed time” reporting framework but, instead, one that varied with signal phase lengths.) This would be particularly important when some type of adaptive traffic control was used (including actuated and semi-actuated traffic signals and signal timing plans) that did not have fixed phase lengths. Smaglik outlined the potential benefits of signal event-based data for intersection analyses, and described a method by which a general purpose data collection module for an existing signal controller could provide signal event-based detector and signal state data (*9*).

The good news is that implementing this new capability to support arterial monitoring would allow traffic signal engineers to not only examine the level of congestion present but also determine how signal timing algorithms were actually being used in the field and thus might be modified to improve congestion. For example, if there is a permissive phase extension of 20 seconds, how often are all 20 seconds being used? How often is none of that possible extension being used, and why was it not used? Was it the result of a pedestrian button on a perpendicular approach that forced off the signal, or a lack of traffic volume on that approach while a conflicting approach had a waiting vehicle? The result would be a capability to evaluate not only how congested each approach had become but how arterial signal timing plans were actually being used. This would provide engineers with detailed diagnostic information that could be used to tune timing plans to decrease delay without having to pay for new short duration traffic data collection.

IMPLEMENTATION ISSUES

While the tests conducted thus far suggest that this method is potentially useful, there are other methodology development issues that should be considered.

Method Calibration and Robustness

The results described in this report were based on simulation of a typical 1-mile arterial section. While the analyses suggest that the results were consistent for different intersections and approach directions in this single model, it would be desirable to perform additional tests to further validate and calibrate the proposed monitoring methodology to help confirm the general nature of the method.

Stop Bar Limitations

It may be that data from a stop bar detector alone is sufficient to estimate “intersection approach” performance, but not overall arterial performance. The approach described in this report could be a good “overall” arterial performance metric as long as delays are primarily intersection based, and not from mid-block occurrences. In addition, because we only have measurements at the intersection, we can say that the signal has failed, but we cannot say that one is likely to sit through one, two, three or more cycles to get through that signal. One alternative that might provide additional monitoring capabilities might be to look at the volume associated with each green phase, the green phase length, and the number of signal cycles in a row that the cycle has shown "failed" performance levels.

Variability of Occupancy during Reporting Process

In the previous discussion, occupancy variability was addressed through smoothing techniques to better define the central trend of the data, for the purposes of establishing the threshold occupancy values used by that method. However, occupancy variability over time can be an issue when one applies the method as well. Namely, how should the method address data variability when arterial performance is reported? Should short-duration oscillations be considered useful indicators of performance, or are they transient values that distract from a more important goal of showing the central tendency of the traffic conditions? There are several options to address this:

- Aggregate occupancy data over time to remove the influence of short-term oscillations.
- Use broader congestion categories that cover larger subsets of the occupancy range, so that occupancy variability is less likely to cause oscillations in reported performance. However, the result would also be less specific.
- Reclassify the congestion categories to include the variability, e.g., develop new categories that represent transition categories between existing categories.
- Do not change the original data.

The application might dictate the approach used. If the required time increment for monitoring performance is larger, then aggregate values might be sufficient.

CONCLUSIONS

This research provided additional understanding of the feasibility of using traffic data from basic stop bar detectors, combined with signal state data, to estimate arterial traffic conditions (congestion) in a cost-effective manner. From the results thus far, the use of occupancy values from a stop bar detector during the green and amber signal states shows promise as an indicator of arterial performance, and the hardware and analytical requirements do not appear restrictive. Additional testing of the robustness of this method would be beneficial, to further document the applicability of the method for different scenarios.

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