

Measuring Arterial Performance for Corridor Management in Carson, CA

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Corridor management is an emerging practice aimed at optimizing system-wide transportation operations. In California, the state department of transportation (Caltrans) is developing Corridor System Management Plans (CSMPs) on major urban corridors to identify mobility challenges and prioritize improvement investments. While existing efforts have largely focused on freeway microsimulation, it is clear that an arterial performance framework is needed to fully understand system-wide interactions. This presents a challenge. Arterial data collection is relatively undeveloped, and agency fragmentation along corridors can block needed information sharing and coordination efforts. However, without this data, it is impossible to fully understand the multi-modal interactions along the corridor.

Berkeley Transportation Systems, Inc. (BTS) has developed an analytic approach that overcomes these challenges and provides a toolset for assessing arterial corridor performance. The methodology has been prototyped on Carson Street in Los Angeles's South Bay, a corridor which connects two CSMP freeways and thus offers the opportunity to link arterial and freeway interactions. By collecting second-by-second detector data, BTS's Arterial Performance Measurement System (A-PeMS) continuously monitors corridor conditions and calculates performance measures in real-time. These measures are then reported through a web-based interface to provide access to multiple stakeholders across institutional boundaries.

This paper describes the application of this performance measurement framework on Carson Street, and the results of using A-PeMS to evaluate a major traffic signal coordination project on the corridor.

Introduction

Corridor management is driven by an in-depth understanding of system-level performance. On all facilities, the selection of operational improvements and the quantification of their benefits need to rely on extensive data. On arterials, automating the data acquisition process will let agencies spend less time on data collection and more time on performing the analyses that will highlight problem areas and improve performance.

This paper describes the application of automated performance measurement to an arterial corridor in Carson, CA, performed as part of a Model Corridor Management Plan project for the Southern California Association of Governments and the South Bay Cities Council of Governments. Specifically, this paper describes the detection infrastructure needed to support arterial monitoring, the web-based system that was designed to distribute data and performance measures to corridor stakeholders, and the signal phasing estimation algorithm that drives signal timing performance measures. Finally, it presents the results of the system's evaluation of a major signal coordination project undertaken during the study period.

Arterial Performance Measurement System (A-PeMS)

To automate performance monitoring and facilitate the distribution of information across agency boundaries, BTS developed a web-based system that reports real-time and archived volumes, speeds, travel times, and other performance measures. Reported corridor performance measures, such as control delay and queue lengths, are standard benchmarks of arterial performance and are calculated from methods recommended in the Highway Capacity Manual (HCM). One benefit of automation is that, while HCM equations are generally tailored to inputs of hourly data, A-PeMS adapts them to calculate performance measures for every 5-minute period of the day. This means that the system can report both temporally fine-grained measures (useful for investigating the operational impacts of an incident, for example) and can also aggregate data up to hourly, daily, and weekly summaries (useful for understanding baseline performance trends). Another benefit of this systematic, data-driven approach is that, rather than simply reporting average volumes and performance, it allows users to explore maximum, minimum, and percentile measures. These types of analysis, such as viewing the 95th percentile queue length in a short storage lane or the highest volume served by an intersection over a month, allows users to quantify corridor variability and worst-case performance.

Carson Street Corridor

Description

A-PeMS was prototyped on a 1.8 mile segment of Carson Street in Los Angeles's South Bay. The corridor, shown in Figure 1 and Figure 2, has eight signalized intersections and intersects with two major regional freeways, Interstate-110 and Interstate-405. In addition to its proximity to managed freeway corridors, Carson Street was an ideal candidate for corridor management because: (1) it was to undergo a signal coordination

project during the study period; (2) both the City of Carson and Los Angeles County have responsibilities for its signal timing; and (3) it is located just to the west of the Carson Street designated truck route.



Figure 1: Regional Overview of Carson Street Corridor



Figure 2: Corridor Intersections

Detection

Automated performance monitoring is driven by the underlying detection infrastructure. To support the calculation of fine-grained performance measures, the project installed 125 Sensys wireless vehicle detectors along the corridor. Each detector transmits a timestamp record every time a vehicle crosses over it, with a precision of 1 second. To compare, the majority of freeway loop detectors that drive BTS's Freeway Performance Measurement System (PeMS) report 30-second summaries of volumes and occupancies. The advantage of this data granularity is that it paints a second-by-second picture of intersection operations. This assisted in the estimation of real-time signal phasing, to be discussed in the following subsection, and thus allowed performance measures to be closely linked with the operating signal timing plan.

Detector placement was also critical. Conventionally, arterial detection is installed to control actuated traffic signals. As such, detectors are placed upstream of intersection stopbars so that they register queued vehicles. Because the Carson Street detectors were installed specifically for performance measurement, they were placed just downstream of the stopbar in every intersection approach lane. This prevented detectors from registering stopped vehicles, and informed on when each movement had a green light. Additionally, midblock detectors were placed at four locations (two in each direction) to report corridor speeds in between intersections and enable the assessment of progression quality.

Signalization

At the beginning of the study period (June 2009), corridor intersections were actuated-uncoordinated. Beginning in September 2009, intersections were retimed, one-by-one, as part of a coordination project overseen by Los Angeles County. The corridor was fully actuated-coordinated as of October 19, 2009. Time-based coordination plans are now in effect Monday through Friday, with the time-of-day breakdowns summarized in Table 1. Figure 3 plots the timing plan bins over the average and 95th percentile volumes at one intersection, measured over every weekday in October 2009. The volumes at this intersection are typical of those observed over the entire corridor- the peak hour is at 5:00 PM, with smaller peaks at 7:00 AM and 12:00 PM. All of these hours are in different timing plan bins. The difference between the 95th percentile volumes and the average volumes is consistently less than 200 vehicles per hour, indicating that flows are predictable and not susceptible to fluctuations due to special events or other factors.

Table 1: Time of Day Plans

Time of Day	Plan
6:00 AM – 9:00 AM	1
9:00 AM-3:00 PM	2
3:00 PM-6:00 PM	3
6:00 PM-9:00 PM	1

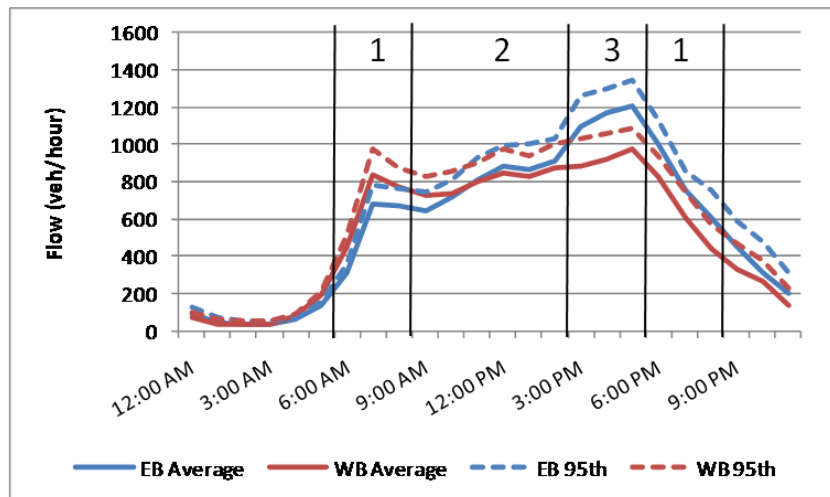


Figure 3: Time of Day Volumes at Carson/Orrick

Arterial performance is driven by signalization, but real-time data from corridor signal controllers was not obtainable within the project timeline. Since HCM arterial performance measures require signal-based information, such as the cycle length and the effective green time, phasing information had to be estimated from other sources.

When the project began, the corridor was uncoordinated, and phase green times were estimated solely based on vehicle arrivals at intersection detectors, using a hidden Markov Model.¹ Once the corridor was coordinated, it became clear that parameters from the active time-based coordination plan, such as cycle lengths, splits, and yellow and red clearance intervals, could be used to improve the A-PeMS phasing estimator.

The enhanced phasing estimator still relies on the raw vehicle arrival data at intersection detectors, but imposes cycle length and other parameter constraints to improve green time estimates. Figure 4 plots three cycles of intersection arrival data, color-coded by simultaneous movements, from Carson/Figueroa during the PM peak hour. While clear phasing trends are evident from the vehicle arrivals plot, this figure also highlights two of the challenges that had to be systematically handled by the phasing estimator. Firstly, what does it mean when no vehicles are detected at the intersection, as shown in the beginning of cycle 3? The algorithm needs to resolve which phases are red, and which phases are green but have no demand. Secondly, how can the method reconcile arrivals from conflicting movements being detected at the same time? This scenario, which can occur when vehicles cross over the stopbar and stop in the crosswalk, can be seen in Cycle 2, when an eastbound-through arrival is detected during what appears to be a conflicting protected left-turn phase.

These gaps and discrepancies were masked using splits and ring extensions defined in the time-based coordination plans. A visualization of the output of the phasing estimator (for the same cycles depicted in Figure 4) is shown in Figure 5. A summary of the method that drives it is as follows:

- 1) Figure 4 shows that the end of the coordinated green is most clearly demarcated by the beginning of vehicle detections at its following phase (at the example intersection, the protected uncoordinated left-turn, shown in black). The algorithm determines the most likely start of green for the uncoordinated left-turn phase based on its arrival data and the split imposed by the timing plan. The end of the coordinated green is then calculated as the start of green for the following phase minus the coordinated yellow and red clearance interval.
- 2) Once the end of coordinated green is fixed, minimum and maximum green parameters are imposed on the cycle to determine a range of possible coordinated green start times. Within this range, the coordinated arrival data is used to find the green start time that overlaps with the most vehicle arrivals. This time is preliminarily assigned as the start of coordinated green.
- 3) The arrivals at the beginning of the assigned coordinated green phase are assessed to see if any conflicting movements were detected. If a conflicting movement was detected, the start of coordinated green is shifted over from the conflicting movement by the yellow and red clearance interval.
- 4) The signal is assumed to be green in the coordinated direction for all seconds between the start of green and the end of green. Green times for all other phases can then be estimated using the timing plan splits and the remaining cycle length.

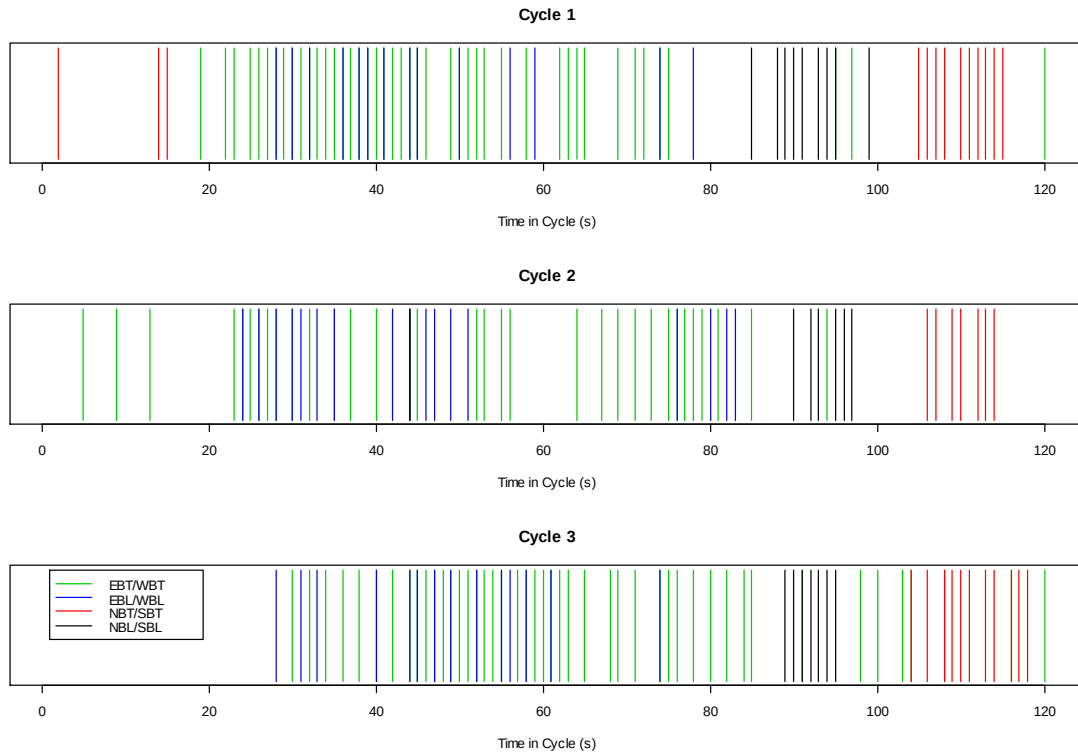


Figure 4: Raw Vehicle Arrivals by Movement, Carson St. and Figueroa Ave.

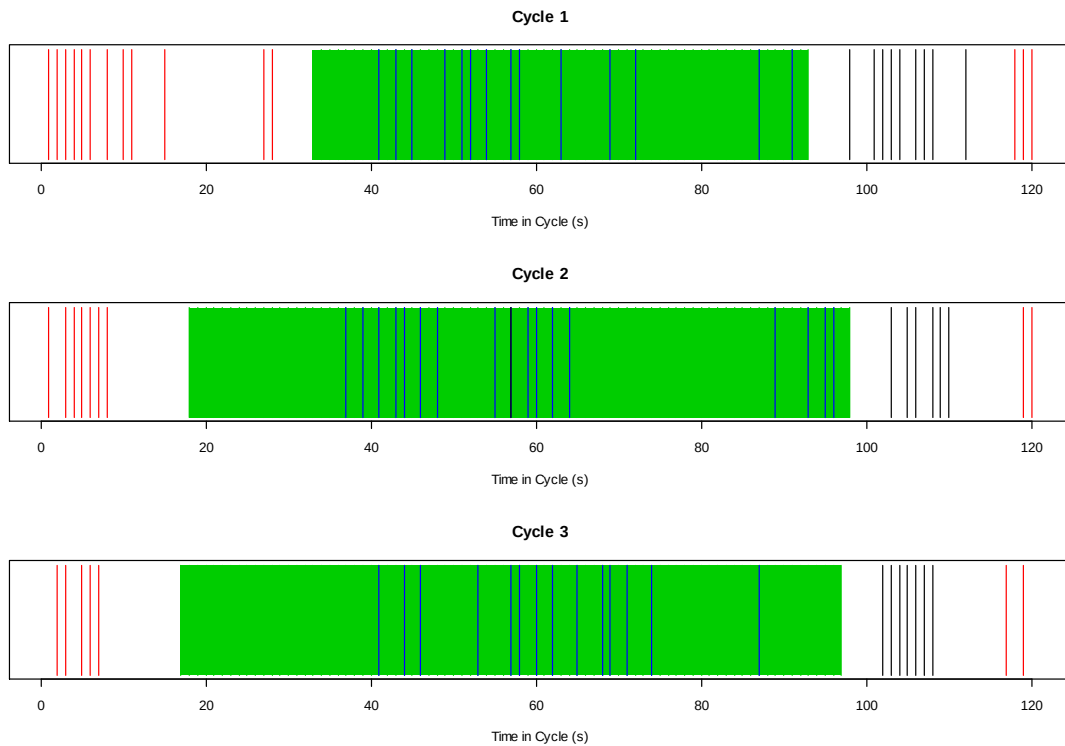


Figure 5: Green Time Estimation for the Coordinated Phase, Carson/Figueroa

Results

One of the real values of automated performance measurement is its ability to inform on the impacts of traffic management changes, both the same day they are implemented and continuously over time. This section highlights the results of using A-PeMS to analyze the effectiveness of the fall 2009 coordination project on Carson Street. Three aspects of corridor operations were considered. Firstly, control delay by approach was evaluated at each isolated intersection, to see the local impacts of the intersection retiming. Secondly, corridor-level travel times were assessed to see if coordination resulted in significant improvements. Finally, the percentage of vehicles that arrive on green was calculated to evaluate the progression quality impacts of the coordination project.

Intersection Control Delay

Control delay is the delay that an average vehicle experiences at an intersection due to the traffic signal. Figure 6 compares the control delay at each through-approach of Carson/Avalon before and after its retiming on October 19, 2009. Control delays in the “before” period represent the average over every weekday in the three months preceding the retiming, and control delays in the “after” period represent the average weekday values calculated over the three months following the retiming. The time-based coordination plans implemented at this intersection all significantly reduced control delay at the Carson Street approaches, by 62% in the AM, 63% in the midday, and 50% in the PM. Control delay on the Avalon Boulevard approaches did not change significantly following the retiming, so overall intersection control delay was reduced under each new timing plan by up to 45%. Out of all the corridor intersections, Avalon Boulevard experienced the most significant reduction in control delay. One plausible explanation for this trend is that Avalon Boulevard was the final intersection to be retimed. As such, its quantified improvements also reflect the progression improvements following the retiming of other signals.

Travel Times

Travel times are perhaps the most important measure to travelers, and thus are a critical component of arterial performance measurement. Travel times were calculated from speeds at midblock detectors and control delay measured at each intersection approach. The “before” travel times incorporate data collected for every weekday between the project start in June 2009 and the first signal retiming in August 2009. The “after” travel times are based on data averaged over every weekday between the final intersection retiming, in October 2009, and February 2010. The impacts of the midday coordination plan on eastbound Carson Street travel times are shown in the timespace diagram in Figure 7. The points on the plot represent the average departure times at each corridor intersection, and the slope of the lines between them show the average speed (including control delay at the downstream intersection) along the link. Overall, midday eastbound travel times decreased by 11 seconds (4.5%), with improvements mostly concentrated at the far west end of the corridor (the intersections of Carson/Figueroa and Carson/Moneta). Travel times also decreased during the AM

timing plan period, though by a lesser magnitude (5 seconds, 2.1%). Travel times during the PM peak did not change significantly.

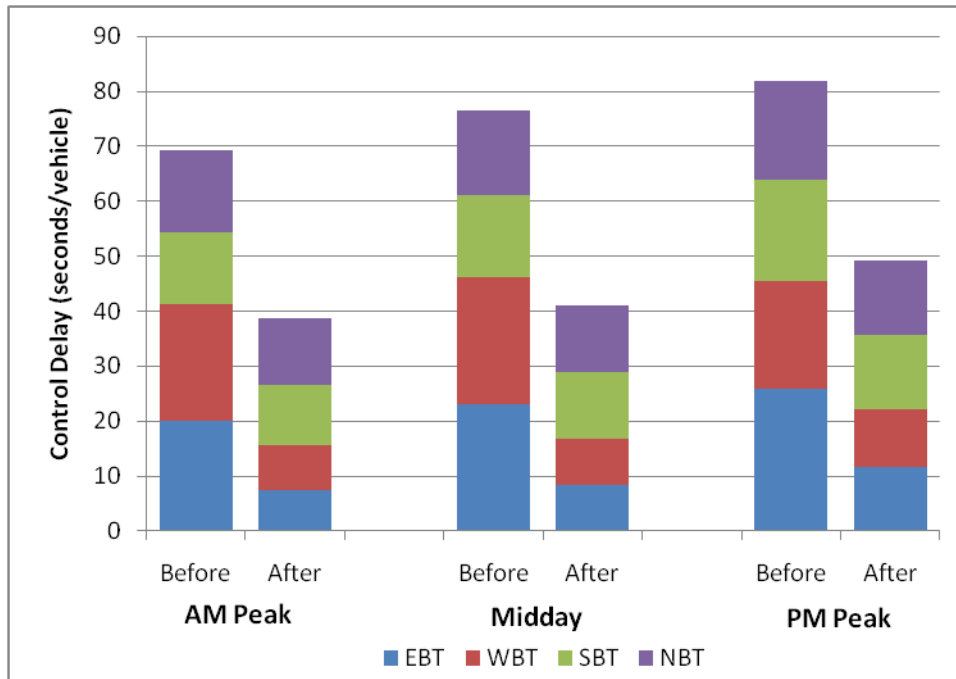


Figure 6: Control Delay at Carson/Avalon

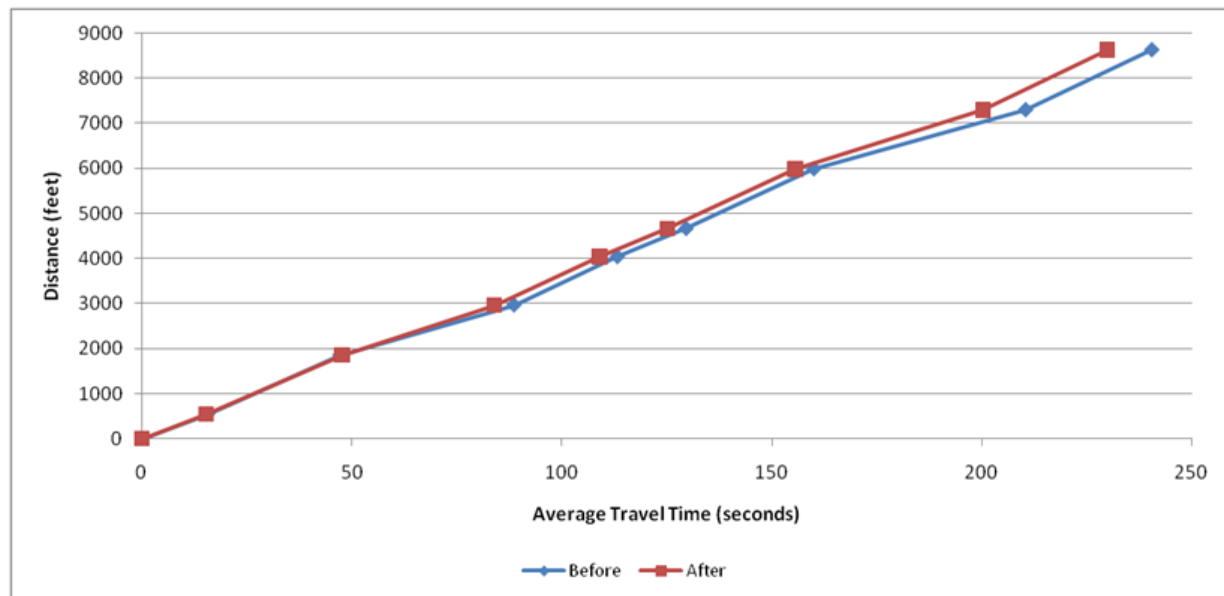


Figure 7: Midday Corridor Travel Times

Progression Quality

One of the best measures of a coordination project is its impact on progression quality. The performance metric selected to quantify this was the percentage of vehicles arriving

on green at each coordinated intersection approach. These calculations relied on (1) the enhanced green time estimator described earlier in this paper; and (2) the midblock vehicle arrivals. The vehicle's measured speed at the midblock detector was used to estimate an expected arrival time at the intersection, enabling an assessment of whether the signal was green or red when it arrived. This section presents the progression quality analysis for two days of data- July 31st, 2009 and February 26th, 2010, chosen for comparison because of their similar demand levels.

Figure 8 depicts the vehicle arrivals and green time distributions measured over the signal cycles during the PM coordinated timing plan period. This figure is based on the Purdue Coordination Diagram, designed to visualize progression quality.ⁱⁱ The distribution of vehicle arrivals shows two clear platoons, the first peaking at 45 seconds into the cycle and the second peaking at 84 seconds into the cycle. The signal is green for both of these platoons. Overall, the percentage of arrival on green during this time period was 68%. Percent arrivals on green for the other timing plan periods are summarized in Table 2. The variation in the start of the coordinated green time evident in the figure is caused by two factors: (1) these are green time estimates, based on flow data and constrained by broad timing plan parameters; and (2) early returns to green in the coordinated direction due to low demand on the other approaches.

Figure 9 plots the same data for the same hours of the day before the corridor was coordinated. This type of visualization is less suited for showing arrivals during uncoordinated time periods, when there is no fixed cycle length. Nevertheless, it serves to highlight the difference in intersection operations between actuated-coordinated and actuated-uncoordinated corridors. In contrast to Figure 8, there is no discernable trend in the occurrence of green times across cycles, and vehicle arrivals occur much more randomly. Overall, the percentage of arrivals on green for the PM period prior to coordination was around 45%.

It should be noted that, due to our ability to more accurately estimate green times for the coordinated time periods, these values likely underestimate the percentage arrival on green without coordination, and thus overestimate the improvement impact of the coordination project. Future research will focus on refining our methods for calculating green times from vehicle arrival data, without the constraining factor of a fixed cycle length.

Table 2: Progression Quality at Carson/Figueroa

Timing Plan Period	Arrivals on Green pre-coordination	Arrivals on Green post-coordination	Improvement
6:00AM-9:00AM	47%	64%	17%
9:00AM-3:00PM	52%	65%	13%
3:00PM-6:00PM	47%	68%	21%
6:00PM-9:00PM	45%	65%	20%

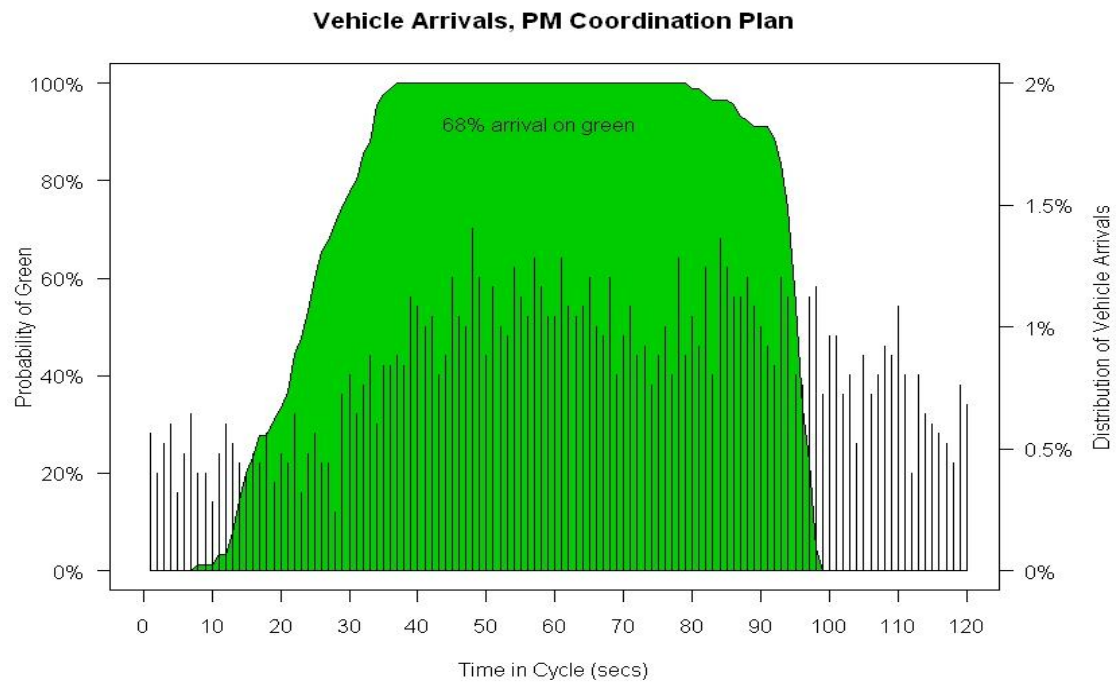


Figure 8: Vehicle Arrival Distributions, post-coordination

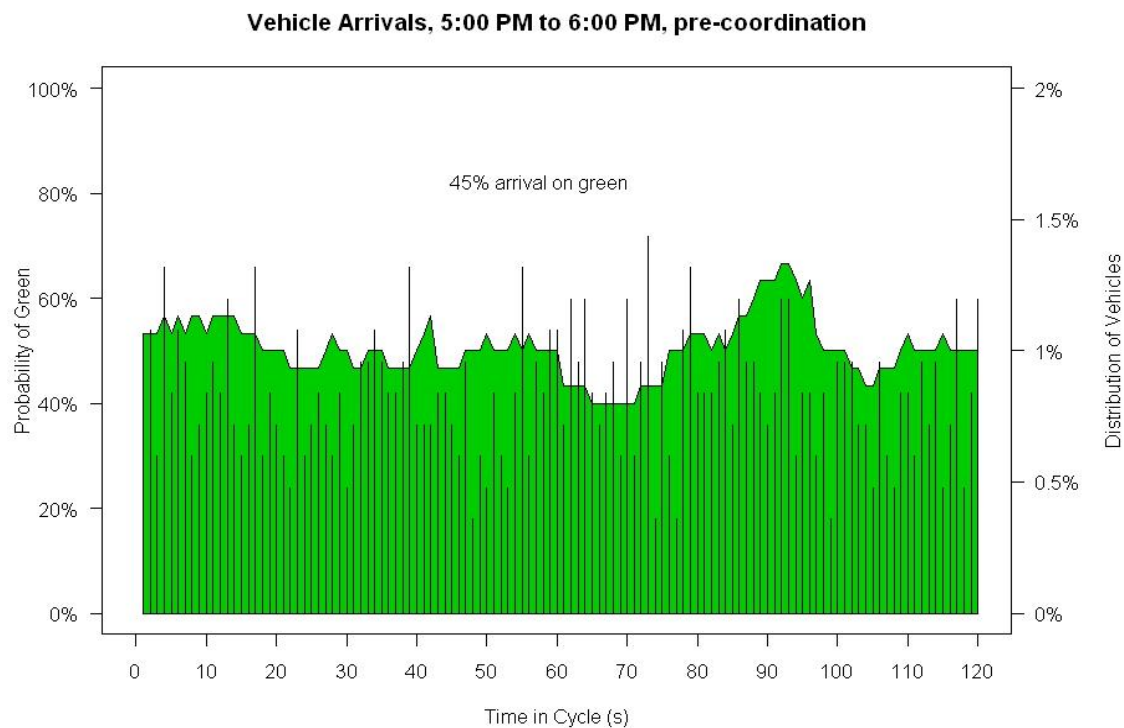


Figure 9: Vehicle Arrival Distributions, pre-coordination

Conclusions

Corridor management can best support sound operational decision-making if it is founded on continuous performance monitoring and measurement. This is achievable on arterials, and rests on a solid detection infrastructure and an automated process for collecting and analyzing data. The prototype Carson Corridor effort showed that:

- 1) Arterial performance measurement is achievable using only in-road vehicle detection, which avoids the complicated and expensive process of interfacing with traffic signal controllers. This approach requires estimating signal phasing based on second-by-second vehicle arrival data and constraints imposed by signal timing plans.
- 2) Automated performance monitoring enables a before-and-after comparison that measures the effectiveness of traffic management changes. On Carson Street, A-PeMS was used to comprehensively evaluate intersection and approach control delay, corridor-level travel times, and the percentage of arrivals on green time at coordinated approaches.

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ⁱ Kwon, J., and K. Petty (2009). Real-Time Signal Phase Estimation from Second-by-Second Traffic Count Data Using Hidden Markov Models. For Presentation and Publication: 89th Annual Meeting of the Transportation Research Board.

ⁱⁱ Bullock, D., C. Day., R. Haseman, H. Premachandra, T. Brennan, J. Wasson, and J. Sturdevant (2009). Visualization and Assessment of Arterial Progression Quality Using High Resolution Signal Event Data and Measured Travel Time. Transportation Research Board Paper 10-0039.