Maximum throughput in LA freeways occurs at 60 mph*

Zhanfeng Jia, Pravin Varaiya, Chao Chen, Karl Petty and Alex Skabardonis
PeMS Development Group
University of California, Berkeley

16 January 2001, v.4

Abstract

Maximum throughput occurs between 50 and 70 mph in 85 percent of all 3,363 loop detectors in Los Angeles and Ventura Counties (Caltrans District 7). Of these, at 112 'slow' detectors maximum throughput is reached at speeds below 40 mph. All but one slow detector is located in the outer lanes. Except for 25 locations, the speed at these 112 slow detectors exceeds 50 mph when the flow aggregated across all lanes at those locations is maximized. Thus traffic below free flow speed (nominally 60 mph) must result in inefficient operation of LA freeways and unnecessary traveler delay. The study is based on 5-minute averages of data from all loops on September 1, 2000, from midnight to noon, covering the morning peak period.

1 Introduction

This is a study of the fundamental flow-occupancy relationship based on a cross-sectional study of all 3,363 functioning loop detectors at 1,324 locations in Caltrans District 7 (Los Angeles and Ventural Counties) for a 12-hour period beginning midnight of September 1, 2000, bracketing the morning commute hours. The specific question addressed is to determine the speed (and occupancy) at which each freeway section achieves maximum throughput.

The question is answered by examining five-minute averages of lane-by-lane flow or throughput in vehicles per hour (VPH), speed (mph), and occupancy (percent) in every detector in the district over the study period. In the vast majority (85 percent) of detectors, maximum throughput occurs between 50 and 70 mph.

In 112 (out of 3,363) detectors maximum flow occurs at speeds under 40 mph. All but one of these 'slow' detectors is located in the outer lanes. All but 25 of these slow detectors record speeds above

*The work reported here is an effort of the PeMS Development Group and is supported by Catrans, the National Science Foundation Grant CMS-0085739, and EPRI/DoD Complex Interactive Network Initiative under Contract WO8333-04. Professors Markos Papageorgiou and Michael Zhang; Chris Williges and Elizabeth Stoltzfus of Booz, Allen and Hamilton; and John Wolf of Caltrans helped us with their encouragment and criticism. The authors alone are responsible for the opinions expressed here.

50 mph when the flow at these locations, aggregated across all lanes, is maximized. So there are at most 25 (out of 1,324) locations where speed is below 40 mph in one lane at the time when aggregate flow at that location is maximized.

The study implies that traffic below free flow speed (nominally 60 mph) results in inefficient operation of LA freeways and unnecessary traveler delay due to congestion. These implications are discussed in [3].

The data are obtained from the PeMS (Performance Measurement System) database [1]. PeMS collects 30-second, loop detector data from California freeways. These data are analyzed in real time to compute five-minute averages of speed, congestion, travel times, and other performance measures, and stored in the PeMS database. Many applications of interest to Caltrans managers, engineers, planners, researchers, and the public are accessible over the World Wide Web at transacct.eecs.berkeley.edu. Other applications, such as the study reported here require access to the PeMS database.

2 Method

A total of 1,324 vehicle detector stations (VDS) are located in District 7. Each VDS reports 30-second averages of count and occupancy from loop detectors in every lane at that location. There are between three to five lanes at each location, for a total of 4,199 detectors, excluding those in HoV lanes.

A properly functioning loop detector should report 144 data points over the study period (12 five-minute intervals per hour for 12 hours). We exclude from the study those detectors that don't report the full data set. (In virtually every case, they report no data at all.) In addition, we exclude detectors that reveal a maximum throughput of more than 3,000 VPH or speed more than 90 mph, on the grounds that the data are inaccurate. The study is based on data from the remaining 3,363 "good" detectors.

For each of these 3,363 detectors, we record its VDS number, lane location, and 144 five-minute averages of flow or throughput (VPH), speed (mph) and occupancy (percent). We then find the maximum flow reached in that detector, and the flow and occupancy at the same time that the maximum flow is recorded.

Note that if there are (say) four lanes at a VDS location, we get four different values of maximum throughput, one for each lane, and the corresponding values of occupancy and speed at which the maximum throughput occurs. There is, in addition, a separate value for the maximum throughput aggregated across all lanes at this location, and the corresponding speed and occupancy, averaged across lanes, when this aggregate maximum is reached. These aggregate throughput values are discussed in the next section.

Figure 1 summarizes the results for the 3,363 lane-by-lane detectors. In each of the four plots the y-axis is the number of detectors. The top left plot gives the number of detectors vs the maximum recorded flow in VPH. The most interesting feature here is the wide variation in the maximum recorded flow. Roughly half of the detectors record a maximum flow between 1,500 and 2,200 VPH; a quarter record a maximum below 1,500 VPH; and a quarter record a maximum larger than

2,200 VPH.[1]

The top right plot gives the number of detectors vs the speed at the time when the detectors record their maximum flow. For the vast majority of detectors (about 85 percent) this speed is between 50 and 70 mph. At these detectors, the speed of most efficient freeway operation is at free flow, nominally 60 mph. The slow detectors are discussed in more detail in the next section.

The bottom right plot gives the number of detectors vs the occupancy at the time when the detectors record their maximum flow. In 85 percent of detectors this occurs when the occupancy is between 8 and 15 percent. The relatively wide variation in occupancy (8 vs 15 percent) at which the maximum flow occurs is likely due to the variation in the tuning of the individual loop detectors. There is an important implication here for setting ramp metering parameters. A good local ramp metering strategy such as ALINEA [2] attempts to maintain downstream occupancy just below its critical value, usually defined to be the value at which maximum throughput or capacity is achieved. The large variation in the critical occupancy values as seen in Figure 1 implies that it is essential to measure it at each individual ramp. Setting this value to any *a priori* nominal value will lead to poor ramp metering performance.

The bottom left plot gives the the number of detectors vs the lanes in which they are located. Lane 1 is the innermost (fastest) lane. The reason there are fewer lane 1 detectors than (say) lane 2 detectors is because more of them were not functioning during the study period.

3 Slow detectors

As noted, the vast majority of detectors (independent of the lane in which they are located) achieved maximum flow at speeds near 60 mph. However, a few detectors (top right in Figure 1) reached maximum flow at lower speeds. We examine these 'slow' detectors in detail, focusing on those that reached maximum throughput at speeds below 40 mph. There are 112 such detectors, 3.3 percent of the total sample.

Figure 2 summarizes the behavior at these 112 slow detectors. The format of the plots is identical with those in Figure 1. Only one of these 'slow' detectors is in lane 1, 11 are in lane 2, and the remaining 100 are in the outermost lanes 3, 4, and 5. At all except 14 of them, these slow detectors have occupancy values at least 18 percent when the maximum flow is reached, indicating congestion. So we suspect that if we examine the time when the aggregate flow at these locations is a maximum, these slow lanes would be uncongested and show higher speeds. We pursue this suspicion.

The 112 slow detectors are located at 100 different locations, since 12 detectors reached their maximum flow at two different times during the study period. For each of these 100 locations, we determine the time at which the throughput, aggregated across all lanes, reaches a maximum. We also record the speed at the slow detector at that time. Figure 3 summarizes the results. In 75 of these 100 locations, the speed of the slow detector at which the *aggregate* throughput reaches its

[1] This deviation between maximum observed flow and the nominal capacity of 2,000 to 2,200 VPH is discussed more extensively in [3].

maximum is larger than 50 mph. This confirms our suspicion. So for these 75 (out of 100) locations, the conclusion that the most efficient operating speed is 60 mph is unchanged.

Next, we further narrow the focus to locations with a lane where the loop detector speed at which the maximum flow occurs is below 30 mph. There are 40 such ‘very slow’ detectors. (These are of course included in the 112 considered above). Figure 4 summarizes these data. The plots here are almost the same as in Figure 2, limited to those values for which the speed is less than 30 mph. As expected, virtually all locations are congested.

At each very slow detector location we determine the time at which the flow aggregated across all lanes reaches a maximum value, and we record the speed in the slow detector when this maximum is reached. The result is summarized in Figure 5, which corresponds to Figure 3. The bottom right plot gives the slow detector speed when the *aggregate* flow reaches its maximum value. In only six instances is the speed below 50 mph. An examination of the raw data reveals that there are only four locations, since at two of these the maximum aggregate value is reached at two times. We study one of these locations in more detail.

Figure 6 displays the aggregate flow and Figure 7 displays the averagee speed across all three lanes at post mile 4.20 on 105-E during the study period. Until congestion starts at 7.00 am, flow is well below capacity and speed is at 60 mph. Recovery from congestion starts at 7.30 am. The flow reaches a maximum value at 7.45 am benefitting from the accumulated queue. The speed then is 30 mph, reaching 60 mph within 15 minutes. At the other three locations, the situation is similar: flow is well below capacity until congestion starts and reaches its maximum during the recovery phase; the speed then is below 30 mph but quickly reaches 60 mph.

4 Conclusion

This study of 3,363 loop detectors in Caltrans District 7 (Los Angeles and Ventural Counties) over the 12-hour period beginning midnight of September 1, 2000 reveals that:

- More than 85 percent detectors recorded a maximum throughput at speeds between 50 and 70 mph (Figure 1);
- At 100 (out of 1,324) locations, there is a lane in which maximum throughput is reached at speeds below 40 mph. Only one of these is lane 1; (Figure 2);
- In only 25 (out of these 100) locations, there is a lane with a speed below 50 mph at the time that the aggregate flow at that location is a maximum (Figure 3);
- Only 40 detectors reached maximum throughput at speeds below 30 mph (Figure 4). In only four locations, there is a lane with speed below 30 mph at the time that the aggregate flow at that location is a maximum (Figure 5). At all four locations, the flow throughout the study period is well below capacity, except for the period of congestion, followed by a recovery during which the aggregate flow reaches a maximum at speed below 30 mph, soon succeeded by a speed of 60 mph.

These findings imply that the objective of ramp-metering and other traffic control equipment should be to maintain the flow at 60 mph. Traffic flow anywhere below 60 mph must result in inefficient operation of the expensive infrastructure of LA freeways and unnecessary traveler delay.

References

[1] C. Chen, K. Petty, A. Skabardonis, P. Varaiya, and Z. Jia. Freeway performance measurement system: mining loop detector data. To be presented at TRB Annual Meeting, January 2001. Available at paleale.eecs.berkeley.edu/~varaiya/papers_ps.dir/pems_paperf.pdf.

[2] M. Papageorgiou, H. Hadj-Salem, and J. Blosseville. Alinea: a local feedback control law for on-ramp metering. *Transportation Research Record*, 1320, 1991.

[3] J. Zia, P. Varaiya, C. Chen, K. Petty, and A. Skabardonis. Congestion, excess demand, and revealed capacity in california freeways. Submitted for publication. Available at paleale.eecs.berkeley.edu/~varaiya/papers_ps.dir/delay7-eff.pdf.

Appendix

Further analysis of the data indicates the robustness of the principal conclusion that the speed when a detector registers maximum throughput is near 60 mph. That conclusion was based on per detector five-minute averages of throughput, occupancy, and speed.

Figure 8 gives the distribution of detector speeds averaged over 25 minutes surrounding the five-minute interval with maximum throughput. That is, suppose a detector recorded its maximum throughput in the five-minute interval t. We calculate the average speed over the five five-minute intervals $t-2, t-1, t, t+1, t+2$. The figure gives the distribution of this average speed.

The figure strengthens the principal conclusion: not only is the speed at the time maximum flow is reached near 60 mph, but this speed is *sustained* for a 25-minute period.

Figure 9 disaggregates by lane the data in Figure 8. As expected, the typical speed at maximum throughput decreases from 65 mph in lane 1 (leftmost) to 55 mph in lane 4 (rightmost).

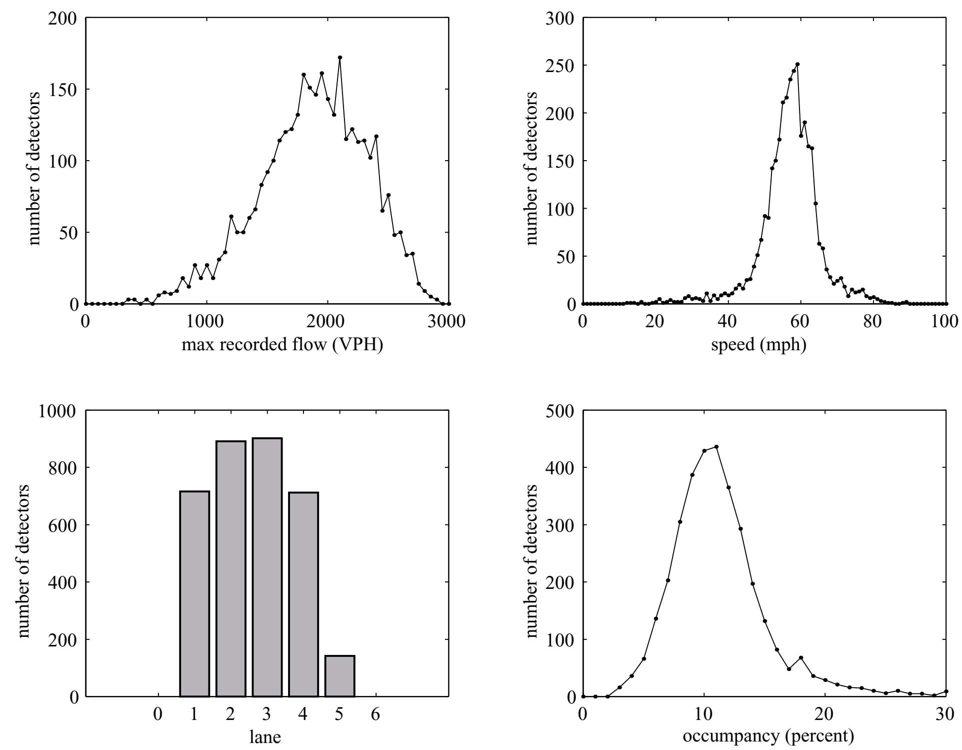

Figure 1: Summary of data from 3,363 detectors. Top left is the number of detectors vs maximum recorded flow (VPH). Top right is number of detectors vs speed (mph) when the maximum flow occurs. Bottom right is the number of detectors vs occupancy (percent) when the maximum flow occurs. Bottom left is number of detectors vs the lane in which they are located (lane 1 is the innermost lane).

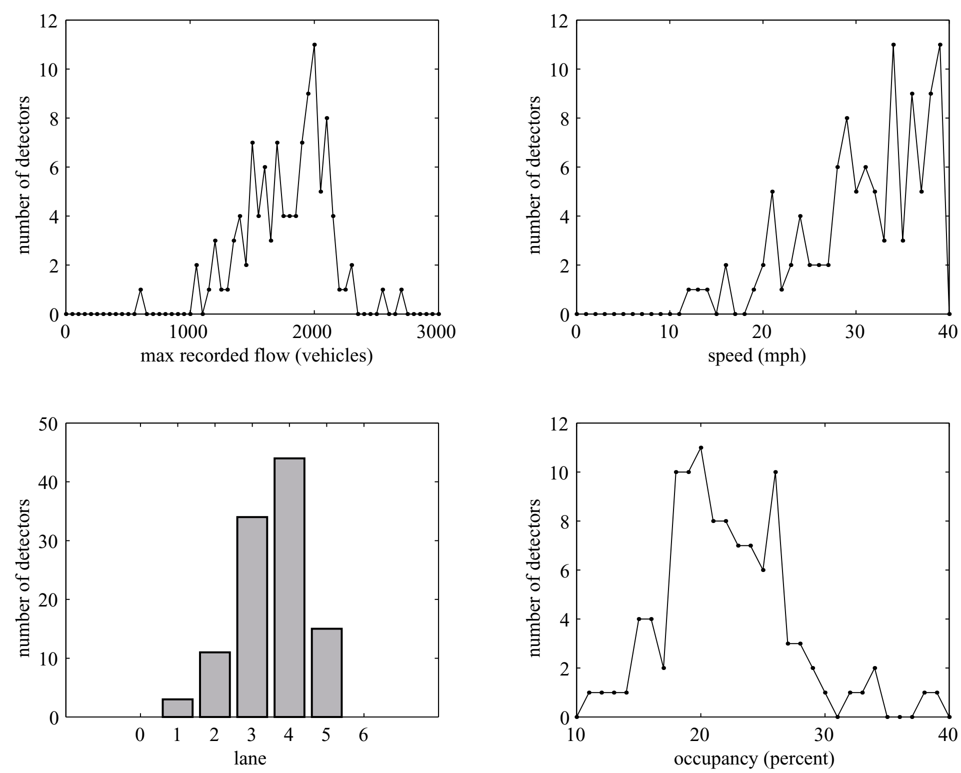

Figure 2: Summary of data from 112 detectors where the speed was below 40 mph when maximum flow is reached. Most of these detectors are in the outermost lanes, and the occupancy when maximum flow is reached is much higher than in the overall sample, indicating congestion.

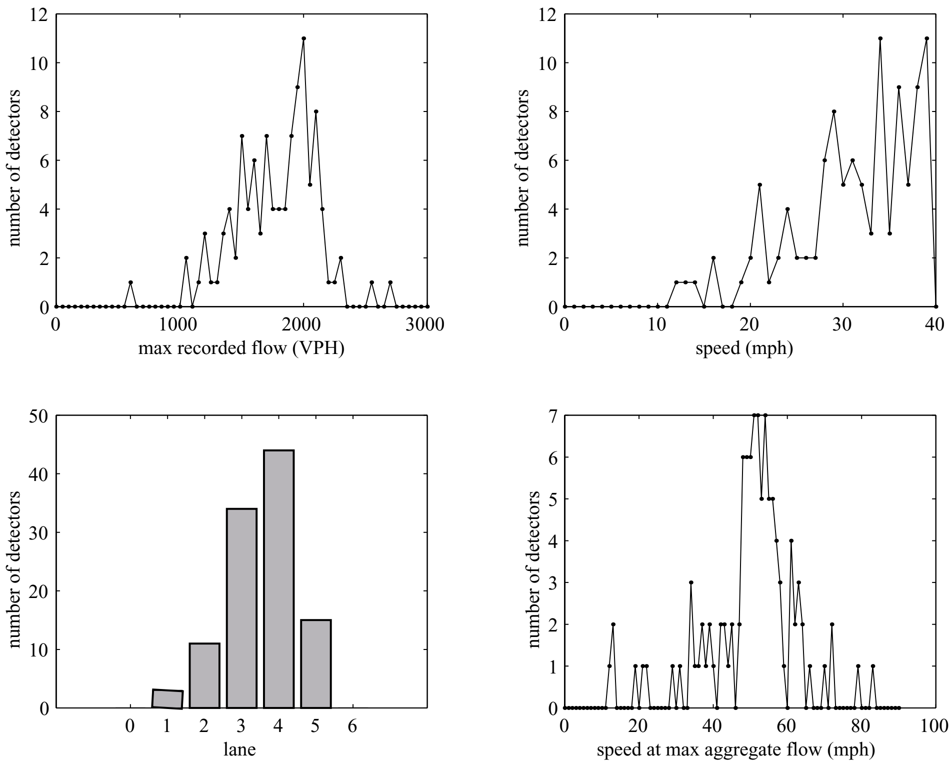

Figure 3: At 100 locations there is a lane at which maximum flow is reached at speeds below 40 mph. The bottom right plot gives the speed in those slow lanes when the *aggregate* flow across all lanes at that location reaches its maximum. In 75 of these locations, the speed in those slow lanes is above 50 mph when the aggregate flow is maximized. The other three plots are identical to those in Figure 2.

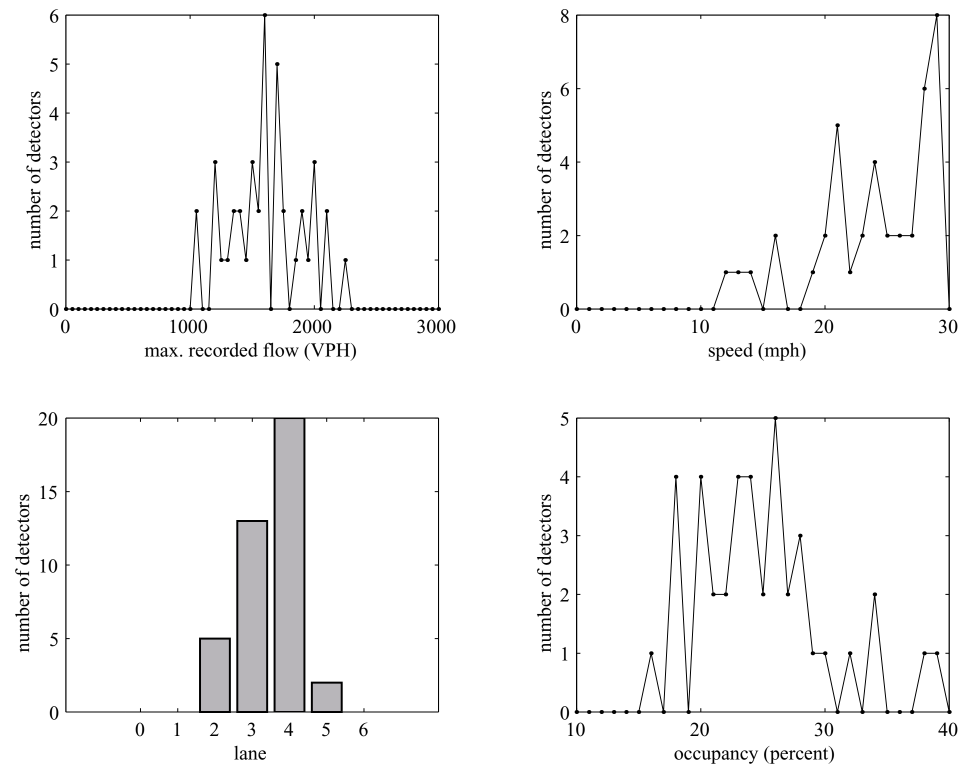

Figure 4: Summary of data from 40 detectors where the speed was below 30 mph when maximum flow is reached. Most of these detectors are in the outermost lanes, and the occupancy when maximum flow is reached indicates congestion.

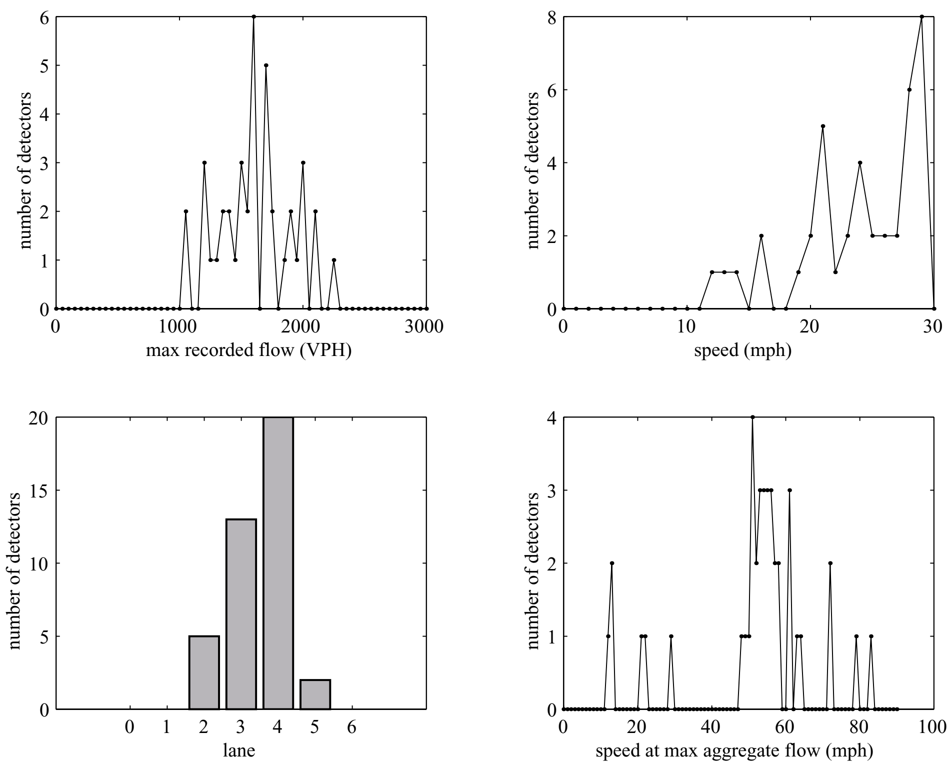

Figure 5: The locations are those where in one lane maximum flow is reached at speed below 30 mph. The bottom right plot gives the speed in those slow lanes when the *aggregate* flow across all lanes at a location there reaches its maximum. The other three plots are identical to those in Figure 4.

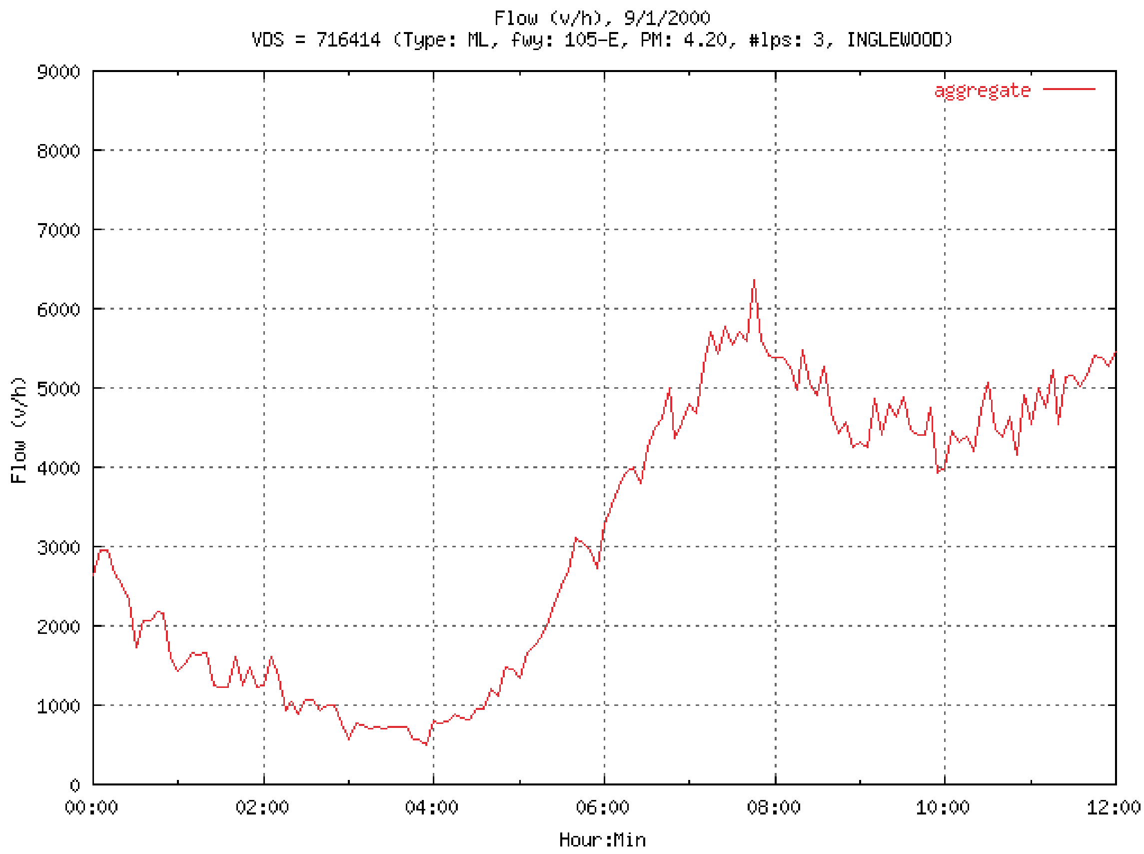

Figure 6: Aggregate flow across three lanes at VDS 716414, located at PM 4.20 on freeway 105-E, from midnight to noon on September 1, 2000. Flow is well below capacity except during congestion, 7.00-8.00 am.

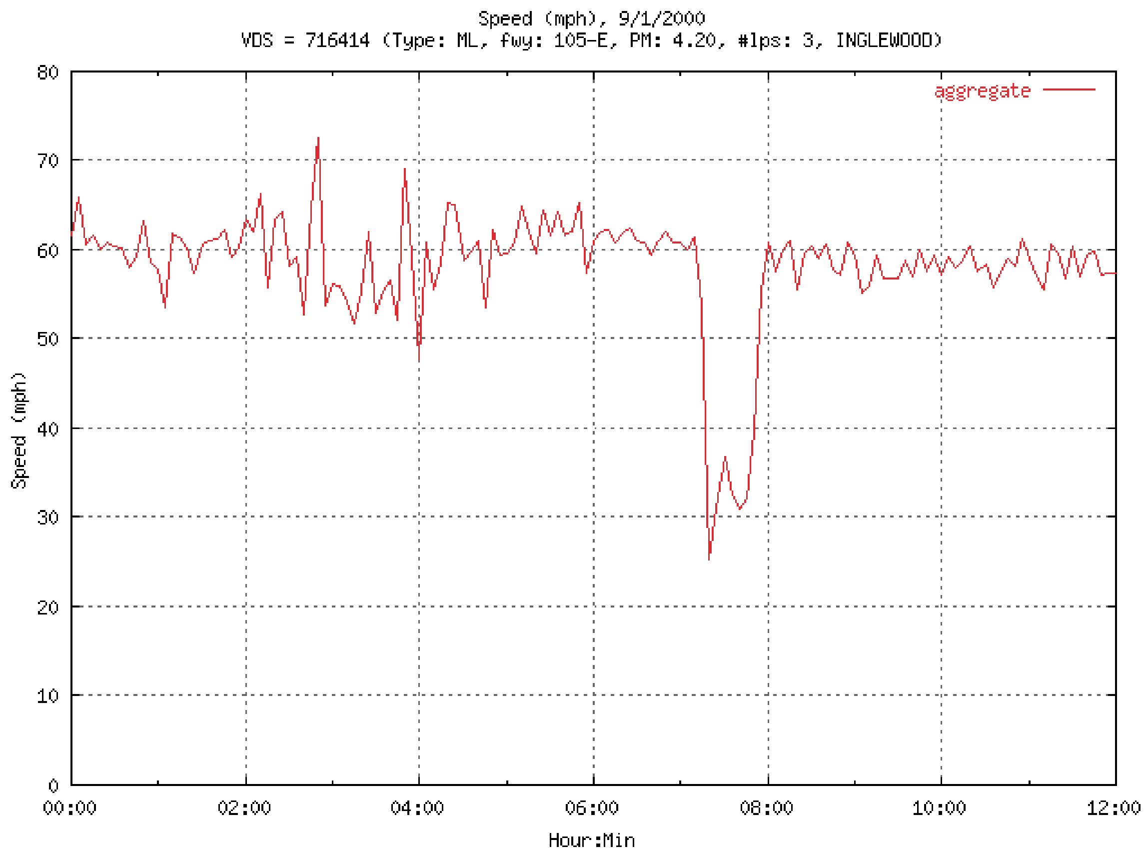

Figure 7: Average speed across three lanes at VDS 716414, located at PM 4.20 on freeway 105-E, from midnight to noon on September 1, 2000.

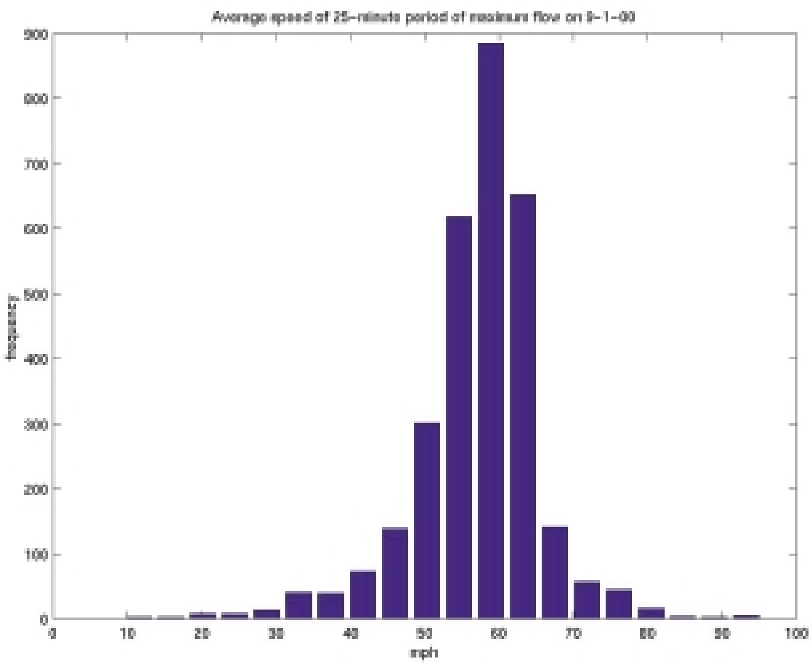

Figure 8: Distribution of average detector speed over a 25-minute interval around the time when the detector records the maximum throughput.

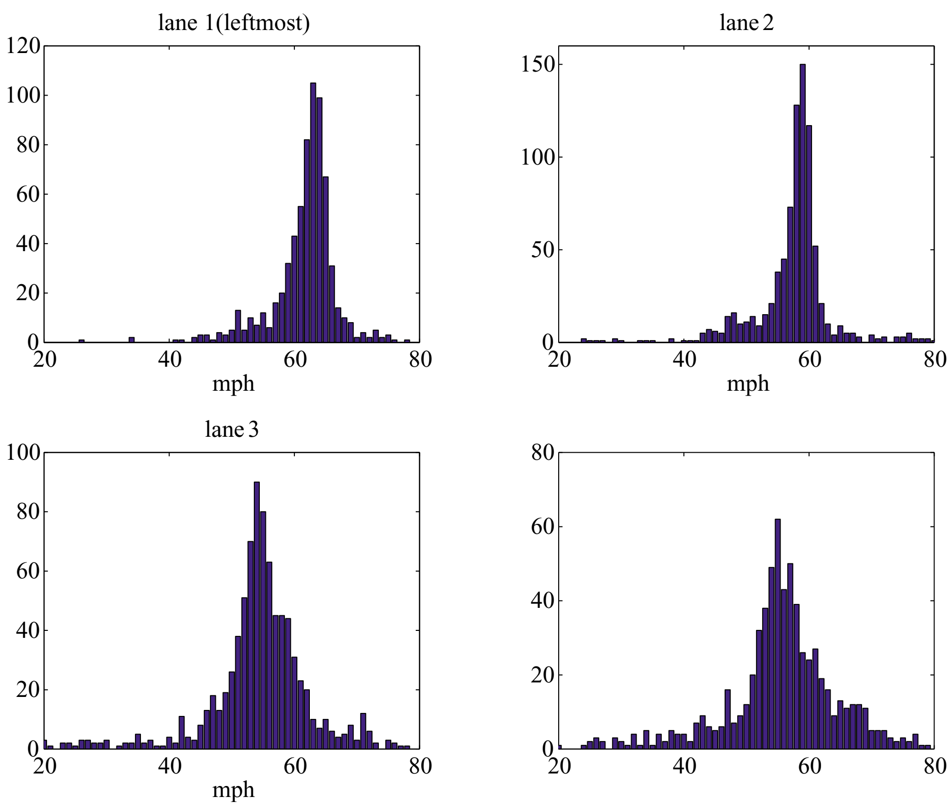

Figure 9: Distribution by lane of average detector speed over a 25-minute interval around the time when the detector records the maximum throughput.