FREEWAY CORRIDOR OPERATIONAL ANALYSIS SR-91E

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Objective:

The purpose of this project is to perform a freeway operational analysis using the freeway performance measurement system (PeMS) database. This project consists of two parts: bottleneck identification, and analysis of corridor traffic performance.

PART A. Bottleneck Identification

Study section:

Freeway: Eastbound SR-91 in Orange County

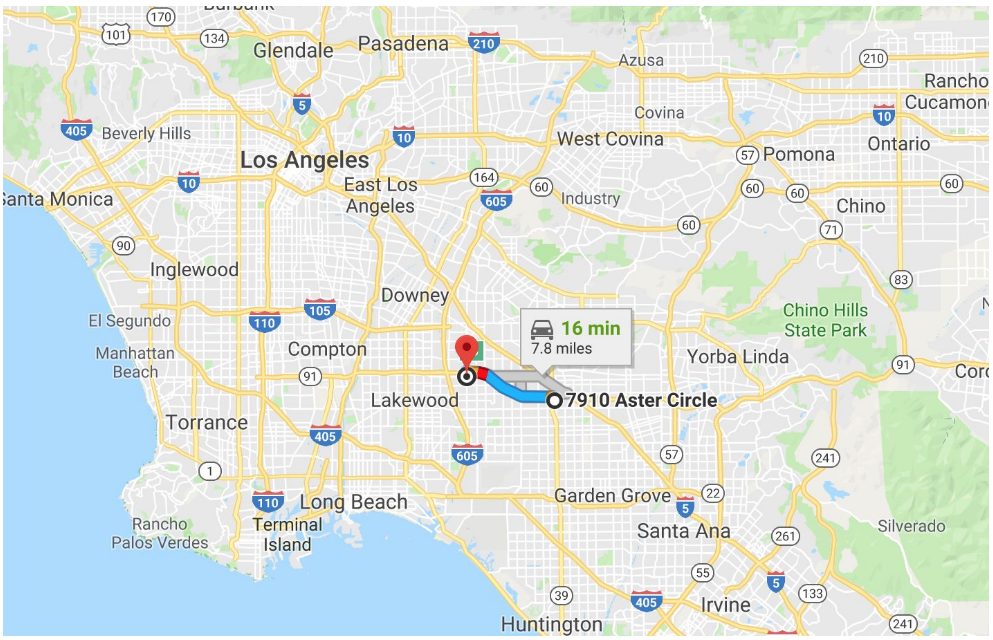
Length of corridor: 6 mi

Start: Pioneer Blvd. Interchange

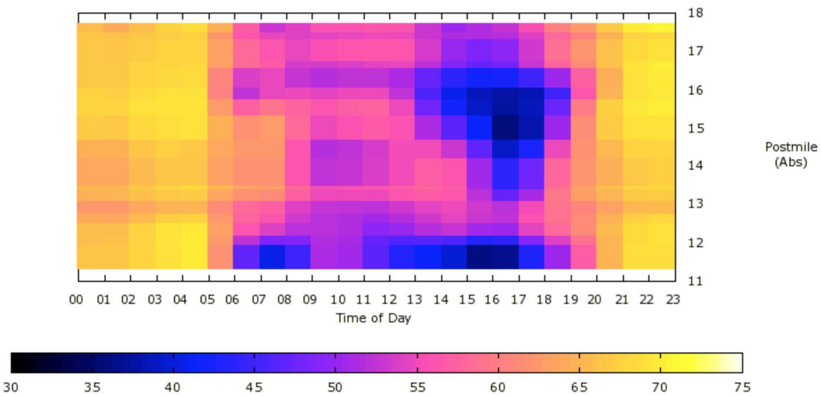
End: SR-39 Interchange

Time of Day: Weekday PM Peak

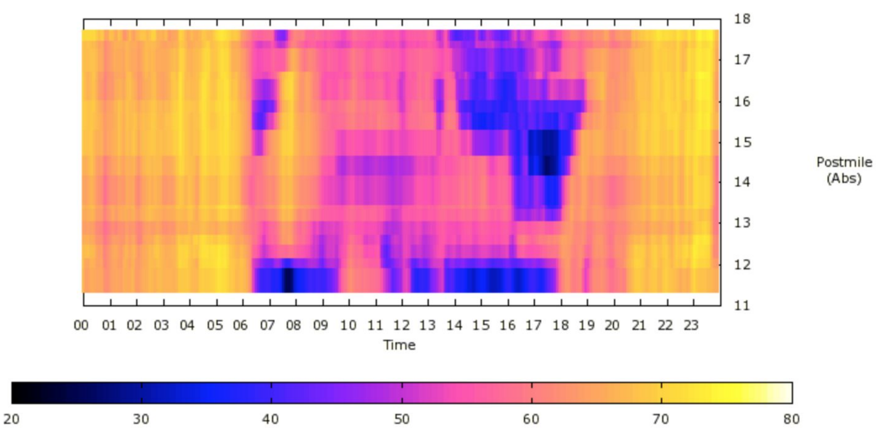
Abs PM: 11 -- 18



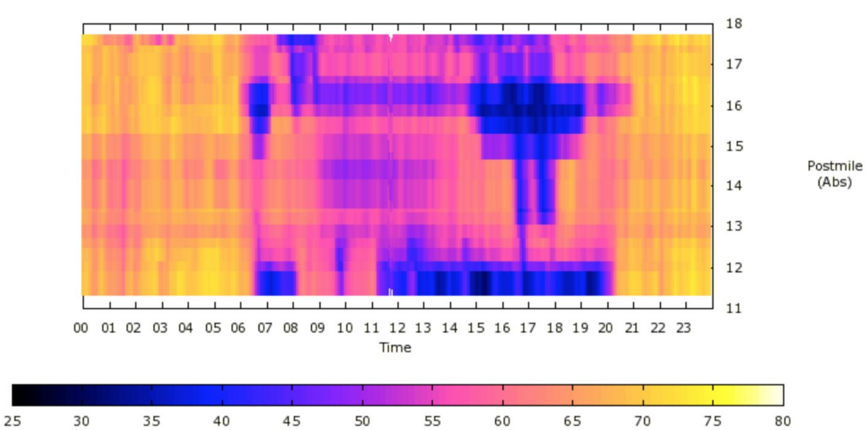
Average Speed (mph) (81% Observed)
Segment Type: Freeway Segment Name: SR91-E
Mon 03/25/2019 00:00:00 to Fri 03/29/2019 23:59:59
Traffic Flows from Bottom to Top

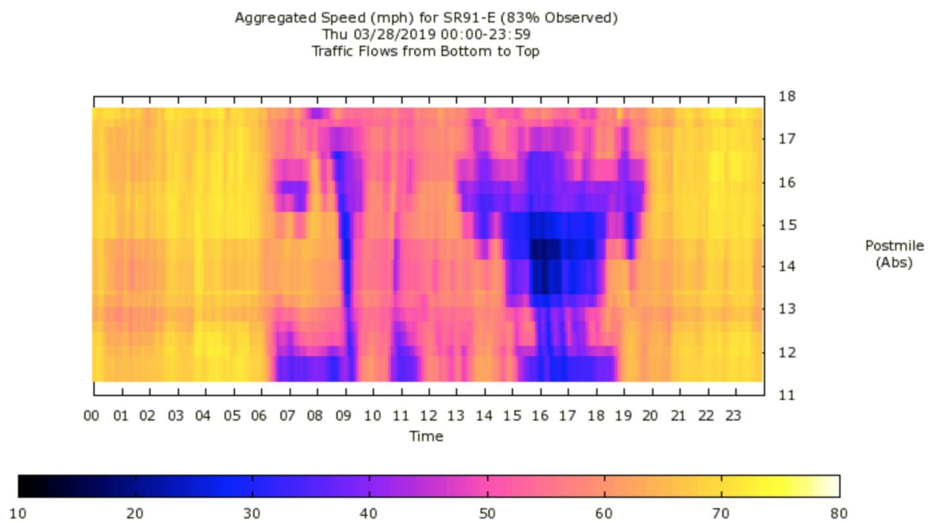


Aggregated Speed (mph) for SR91-E (80% Observed)
Tue 03/26/2019 00:00-23:59
Traffic Flows from Bottom to Top



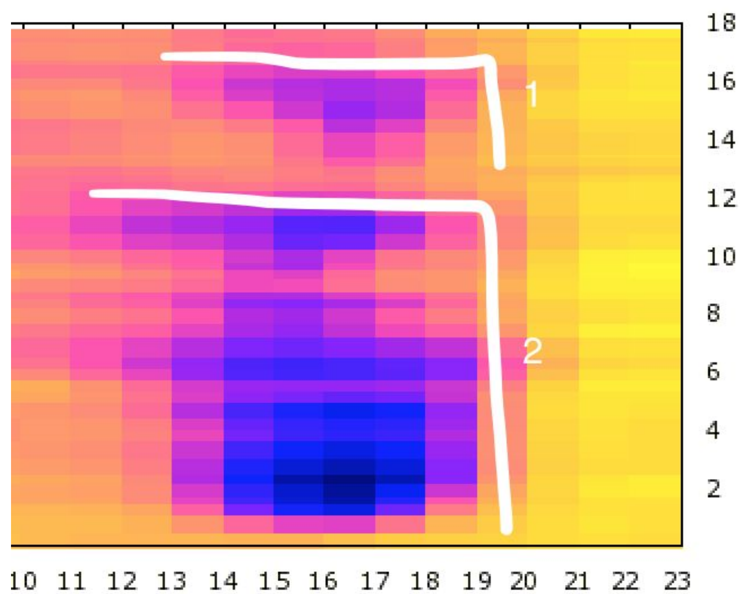
Aggregated Speed (mph) for SR91-E (79% Observed)
Wed 03/27/2019 00:00-23:59
Traffic Flows from Bottom to Top





I. Bottleneck Location and Duration

In the weekday PM peak hour, we identified two bottlenecks.



Bottleneck 1 is between PM 16 and 17. The bottleneck lasts for 6 hours (13:00 to 19:00) and the queue lasts for 3.5 miles (~13 PM to ~16.5 PM).

Bottleneck 2 is between PM 11 and 12.5. It is almost congested all the time and the queue propagates very long. At some time the queue ends between PM 8 and 9, which makes the queue length about 4 miles. At the busiest hours the queue extends to the beginning of the highway, as seen in the graph below.

The previous page has the time series contours of weekday PM peak hours for an entire week between 3/25 and 3/29. From those graphs, we can see that the two bottlenecks we identified appear on most days at approximately the same location and duration, meaning that these are recurrent congestions.

II. Bottleneck Causes

The cause of those two bottlenecks, besides the obvious high traffic flows during the rush hour, is the geometry of the highway around those two locations. From the highway layouts shown below, we can see that, between PM 11.5 and 12.5 and between PM 15 and 17, there are a larger-than-usual number of entries and exits spreaded on a short segment of highway. The average distance between an exit and/or entry ramp is 0.2 mile and the distance between some of the closest ramps is only 0.1 mile. The vehicles which exit or enter the highway will not be able to go at full speed, and the lane changing maneuvers also slows traffic down. Also, some high-demand exit ramps can be congested during rush hours and propagates the queue onto the right lanes of the main highway, which further reduced the highway capacity. All those factors contribute to the recurrent congestions at those two bottleneck locations. Some of the ramps go to or come from other major roadways. Those cause a high traffic flow in those highway segments which slow the traffic down.

Particularly, Bottleneck 1 has an off-ramp to SR 39, which bring a high volume of merging and/or diverging traffic. Bottleneck 2 happens at the intersection of SR 91 with I-605, a major interstate highway in that area. That results in a major bottleneck.

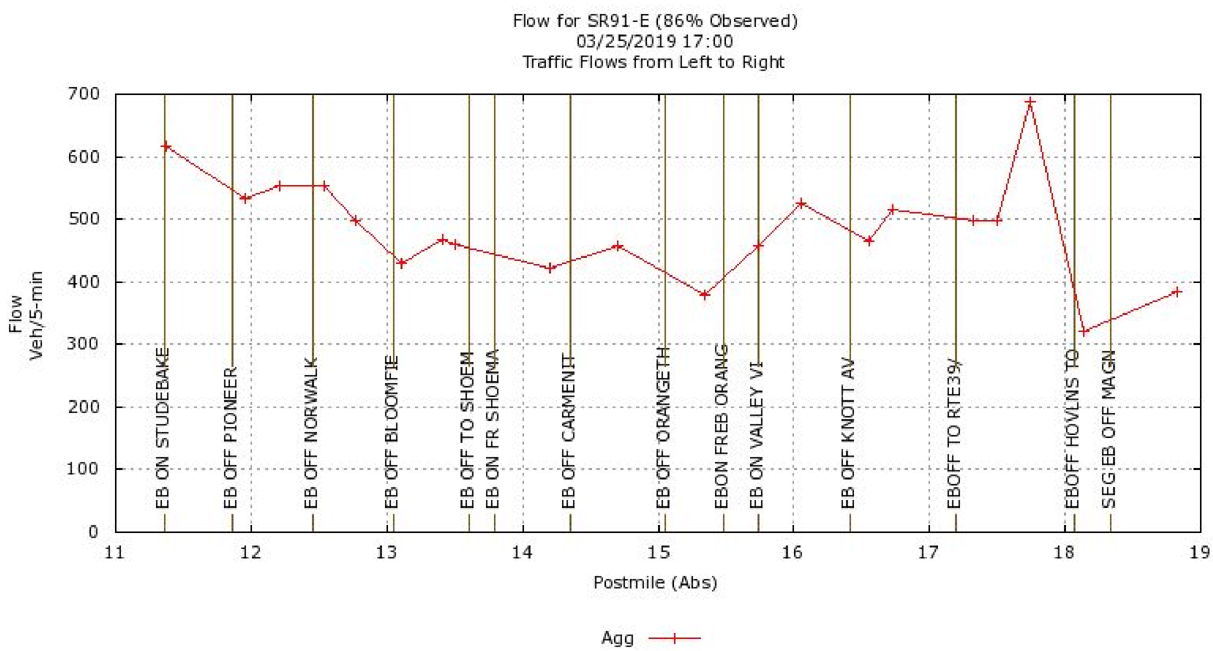
Another cause of bottleneck that is worth noticing is the weave traffic caused by bad highway design. In the geometry graph, we can see that some entry and exit ramps are paired in the way that the entry ramp comes before the exit ramp. This means that the merging traffic flow will conflict with the diverging traffic flow in a very short highway segment, known as a weave. The weave disturbs traffic more severely than normal lane changing actions. The negative impact of weave on highway traffic flow has been well studied by scholars. The addition of weave to the typical congestion factors mentioned in the previous paragraph undoubtedly contribute to the unusually bad bottleneck conditions in those two locations.

III. Bottleneck Discharge Rate

From the speed graphs above, we assume that the traffic condition 17:00 represents a typical congested state in the bottleneck. We used PeMS to get the flow rates on the highway segment at 17:00 on 3/25/19.

From the graph below, we can see that there is no obvious discharge flow from Bottleneck 2 on the upstream. We see a small but almost negligible increase of flow rate at PM 13, with a flow rate of 4980 veh/hr. This is not much different from the flow rate in the bottleneck. We guess the reason is that a significant amount of discharging flow actually go off the highway. As seen in the graph, there are a series of off-ramps in the area where Bottleneck 2 discharges. As a result, the discharging flow remaining on the mainline does not appear to be much higher than the flow rate in the bottleneck.

For the Bottleneck 1, we see an obvious increase in the flow rate at PM 18 after the bottleneck. The discharge rate is 8400 veh/hr across four lanes.



IV. Bottleneck Impacts

Location									Bottleneck Characteristics			
VDS	Name	Type	Shift	Fwy	Abs PM	CA PM	Latitude	Longitude	# Days Active	Avg Extent (Miles)	Avg Delay (veh-hrs)	Avg Duration (mins)
1203561	KNOTT 2	ML	PM	SR91-E	16.729	R1.99	33.855926	-118.008847	1	2.2	80.8	45.0
1203536	KNOTT 1	ML	PM	SR91-E	16.549	R1.81	33.855903	-118.011986	2	1.8	46.1	30.0
1213891	HOLDER	ML	PM	SR91-E	16.059	R1.32	33.855843	-118.020532	12	1.4	181.9	145.4
1213889	HOLDER	HV	PM	SR91-E	16.059	R1.32	33.855843	-118.020532	15	1.4	72.1	106.7
1212124	KNOTT 2	HV	PM	SR91-E	16.729	R1.99	33.855926	-118.008847	4	1.3	40.9	56.3

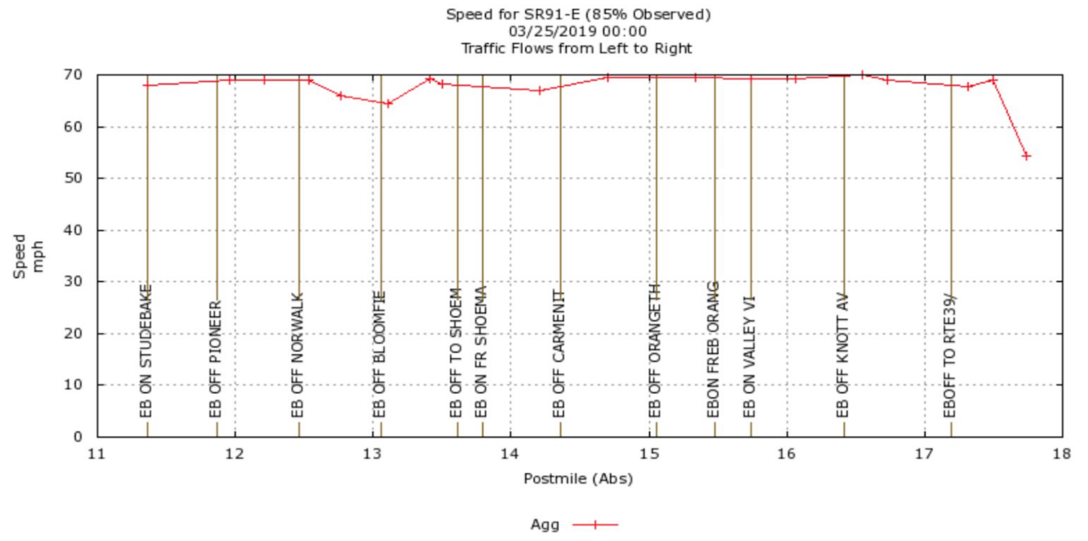
Location									Bottleneck Characteristics			
VDS	Name	Type	Shift	Fwy	Abs PM	CA PM	Latitude	Longitude	# Days Active	Avg Extent (Miles)	Avg Delay (veh-hrs)	Avg Duration (mins)
759975	PIONEER 2	HV	PM	SR91-E	12.208	R18.21	33.876324	-118.080425	4	1.4	64.9	83.8
759974	PIONEER 1	HV	PM	SR91-E	11.958	R17.96	33.876317	-118.084773	8	1.0	33.5	83.8
766210	STUDEBAKER	HV	PM	SR91-E	11.368	R17.37	33.876279	-118.095037	13	0.6	10.8	64.6
717431	PIONEER 1	ML	PM	SR91-E	11.958	R17.96	33.876317	-118.084773	17	4.2	758.1	92.4
766209	STUDEBAKER	ML	PM	SR91-E	11.368	R17.37	33.876279	-118.095037	18	2.3	408.8	86.1

The PeMS system actually identifies multiple bottlenecks at a finer grain in those two locations. When adding the numbers together, we find that the bottleneck between PM 16 and 17 has an average delay of 421.8 veh-hrs per day and the bottleneck between PM 11 and 12.5 has an average delay of 1276.1 veh-hrs per day. These certainly mean a very large negative impact of the bottlenecks on the traffic. Also, as mentioned in the previous sections, both bottlenecks have queue that last for several miles and cause a long, consecutive slow-moving highway segment.

PART B. Freeway Operational Analysis

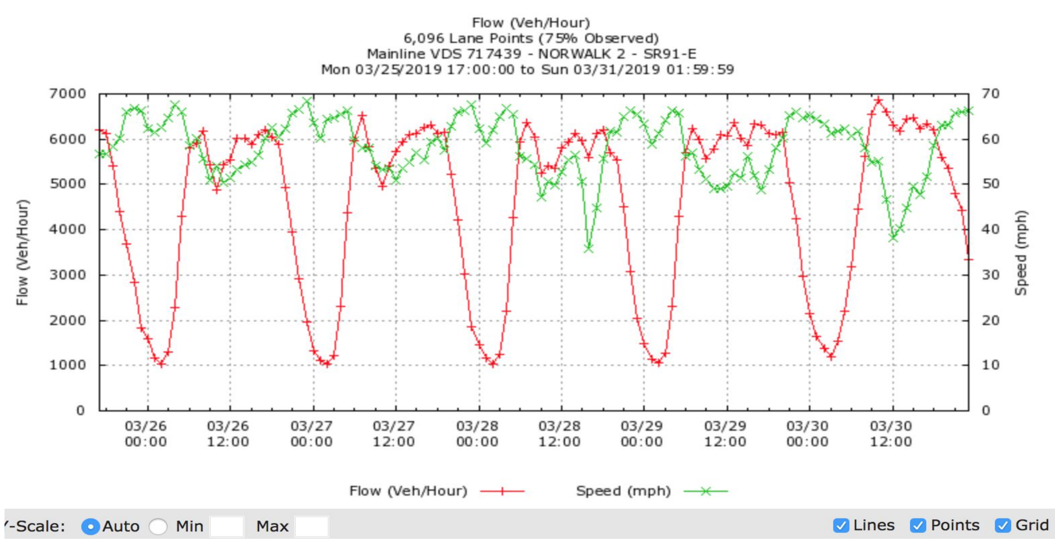
I. Estimating parameters of traffic flow:

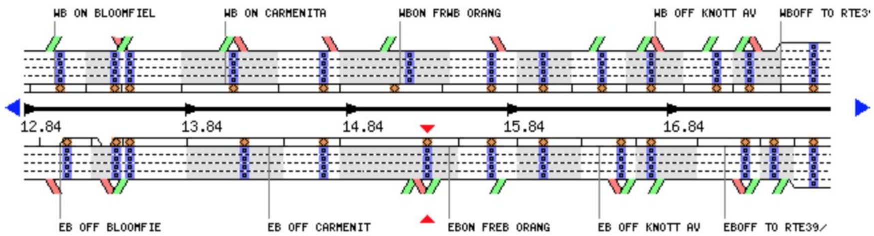
Free flow speed, wave speed and jam density are key macroscopic parameters of traffic flow. In this section, we determine these parameters from the data.



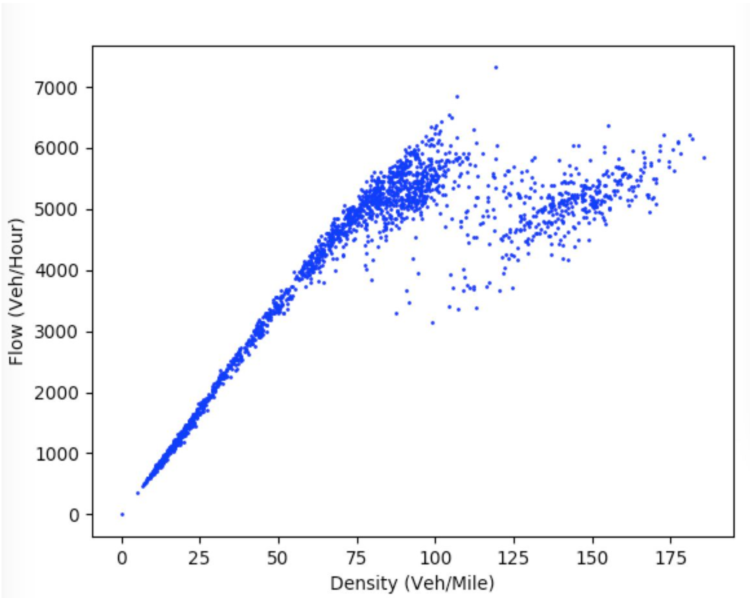
As shown in the figure above, **free flow speed** of the study section is **70 mph**.

To estimate the wave speed and jam density of the section, we downloaded speed and flow data for the week of 03/25/2019 -- 03/31/2019 at the desired section from the PEMS dataset, as shown in figure below.





After calculating density from flow and speed data, we can plot all the flow and density data point at the bottleneck, to get the fundamental (Q-k) diagram:

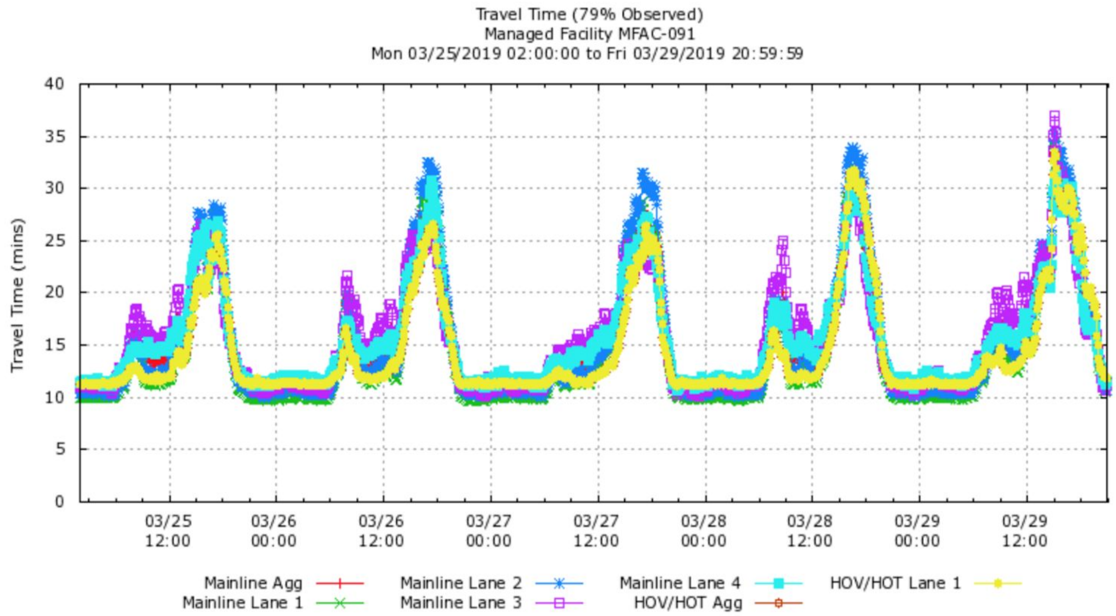


Estimating from the diagram above, we can find the maximum flow to be approximately 6000 veh/hour. Extrapolating from the scatter plot, we estimate the **wave speed** to be (6000 - 5500)/(150 - 95) = **9.1 mile/hour**, thus the **jam density** is 6000/9.1 + 95 = **754 veh/(mile * 4 lane)**.

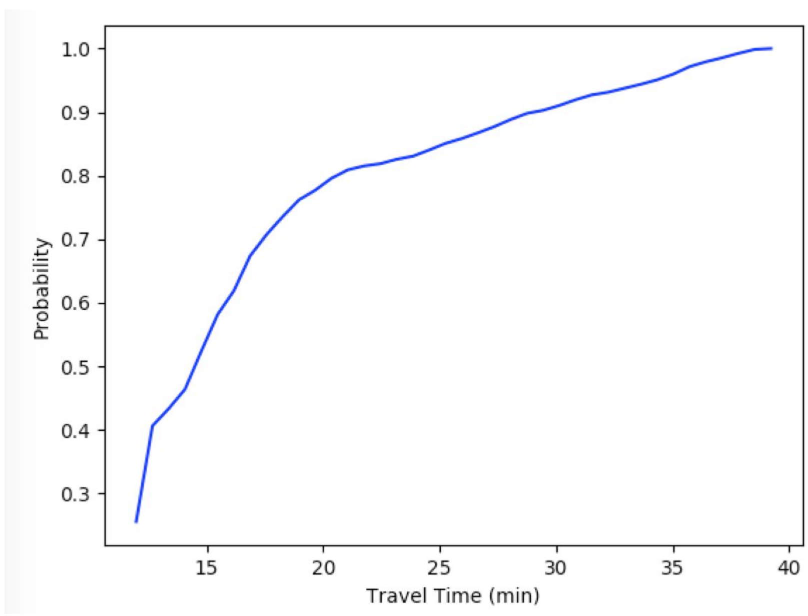
II. Travel times:

In this section, we estimate the average travel time and travel time reliability measures in the study corridor.

As shown in the Figure below is weekday travel time of the week 03/25/2019 -- 03/29/2019 (Mon. -- Fri.) for each lane separately.

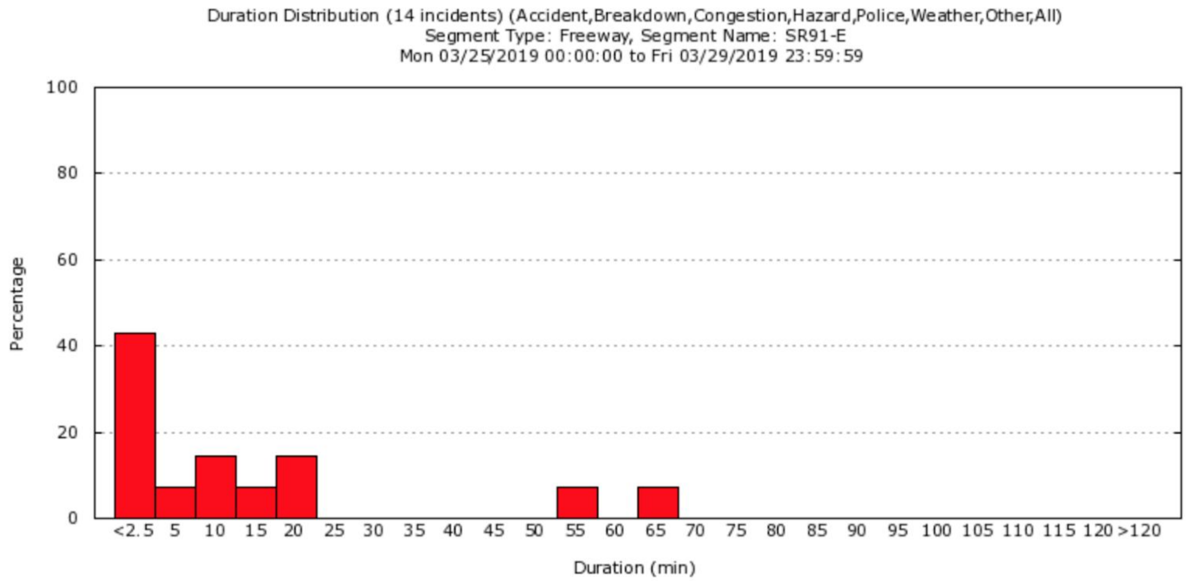


Averaging all travel times, we estimate that the average travel time of the corridor is: **17.77 minutes**.



As shown in the figure above is cumulative probabilities of all the travel times. At the average travel time, 17.77 minutes, the probability is approximately at 70.7 percent. And at the 90 percentile, the travel time is 29.44 minutes.

Travel time increases as bottleneck occurs. As the severity of the bottleneck increases, travel time increases. As shown in the figures above, without bottleneck, the free flow travel time is around 11 minutes. However, at weekday PM peak hours, travel time typically go up to about 30 minutes, and could go up to 38 minutes.



The presence of accidents also affect travel times. During the week of 3/25-3/29 that we studied, there are 14 accidents reported. Most of the accidents last for less than 20 minutes, but there are two accidents that last for ~60 minutes, which could severely impact the traffic.

Appendix:

Code to plot the fundamental diagram:
Attached as process-data-1.py

Code to plot cumulative probabilities of travel times:
Attached as process-data-2.py