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Capacity Drop: A Relation Between The Speed In Congestion and The Queue Discharge Rate

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Abstract

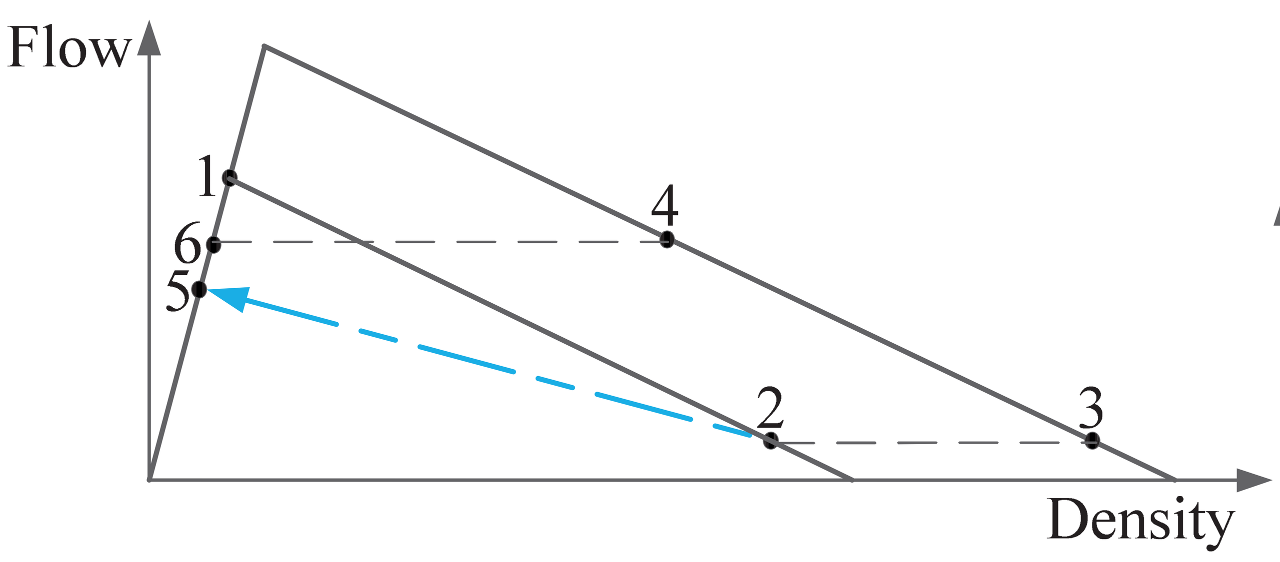
It has been empirically observed for years that the queue discharge rate is lower than the pre-queue capacity. This is called the capacity drop. The magnitude of capacity drop varies over a wide range depending on the local traffic conditions. However, up to now it is unknown what determines the capacity drop value. In fact, there is still no thorough empirical analysis revealing a reliable relation between the congestion level and the capacity drop. This paper tries to fill in the gap by revealing the relation between the vehicle speed in congestion and the queue discharge rate through empirical analysis. The queue discharge rate is shown to increase considerably with increasing speed in the congestion. This finding indicates a promising speed-control scheme for increasing queue discharge rates.

Methodology

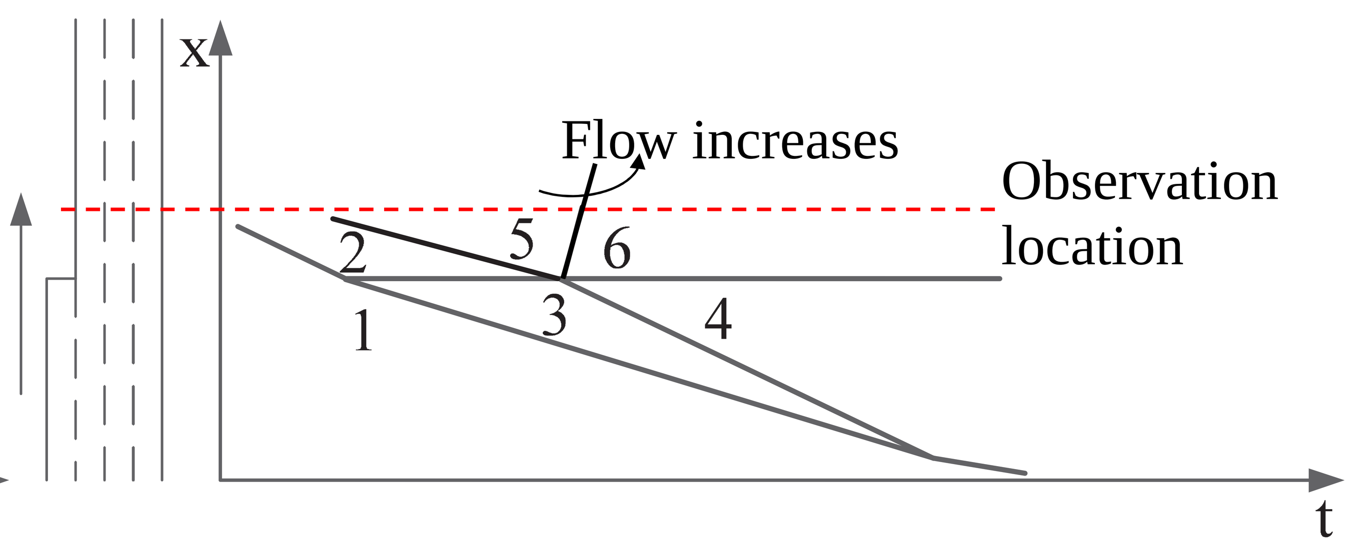
- Analyze a traffic scenario: a bottleneck gets active immediately after a stop-and-go wave passes
- Apply shock wave analysis to identify traffic situations
- Apply slanted cumulative counts to calculate queue discharge rates
- Speed in stop-and-go wave is the average of all the lowest speed in downstream locations when wave passes
- Speed in standing queue is the average of speed at location close to congestion front
- Analyses data in different weather and freeways to see whether it is necessary to do situation-specific validation

Shock Wave Analysis

- Lane-drop bottleneck

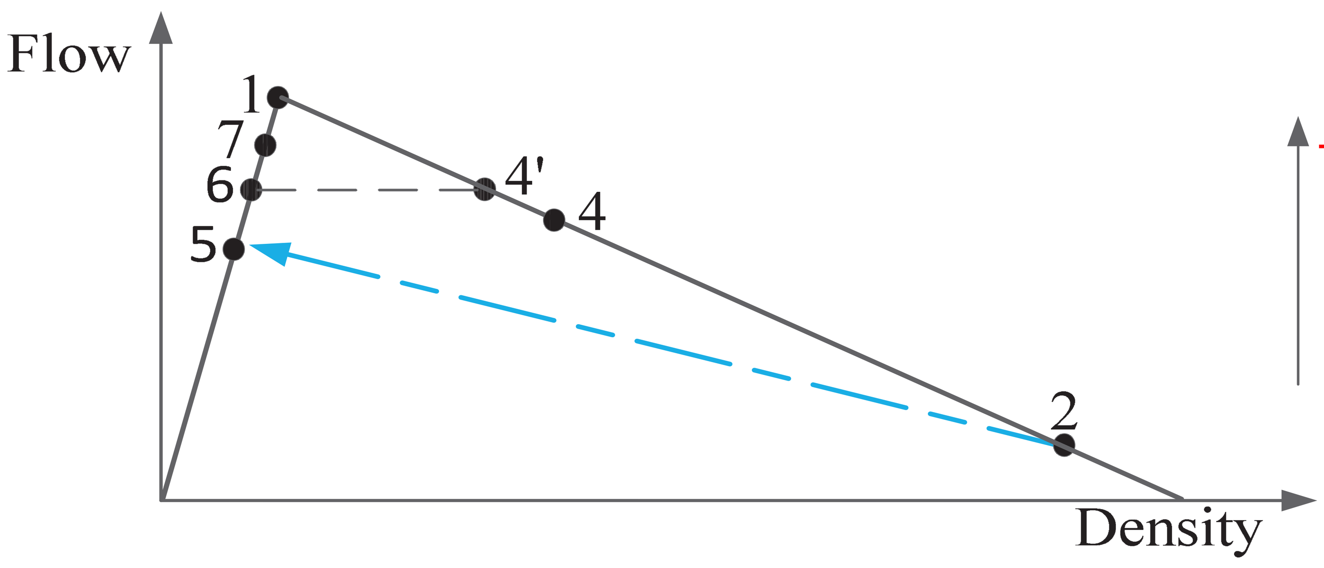


a) Fundamental diagram

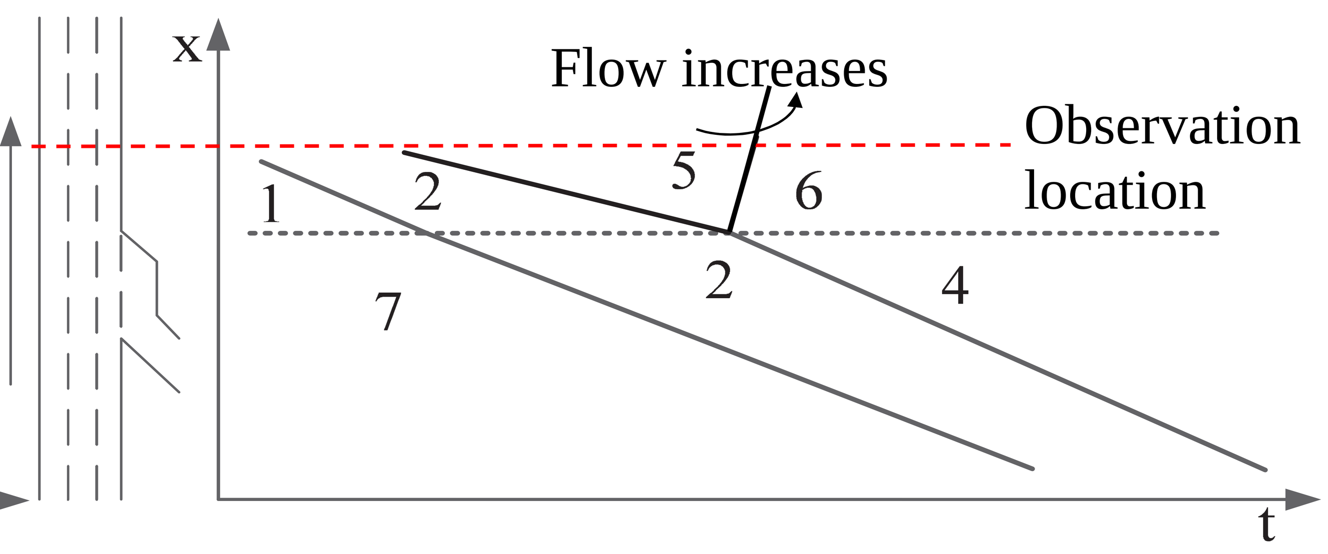


b) x—t plot

- On-ramp bottleneck



c) Fundamental diagram

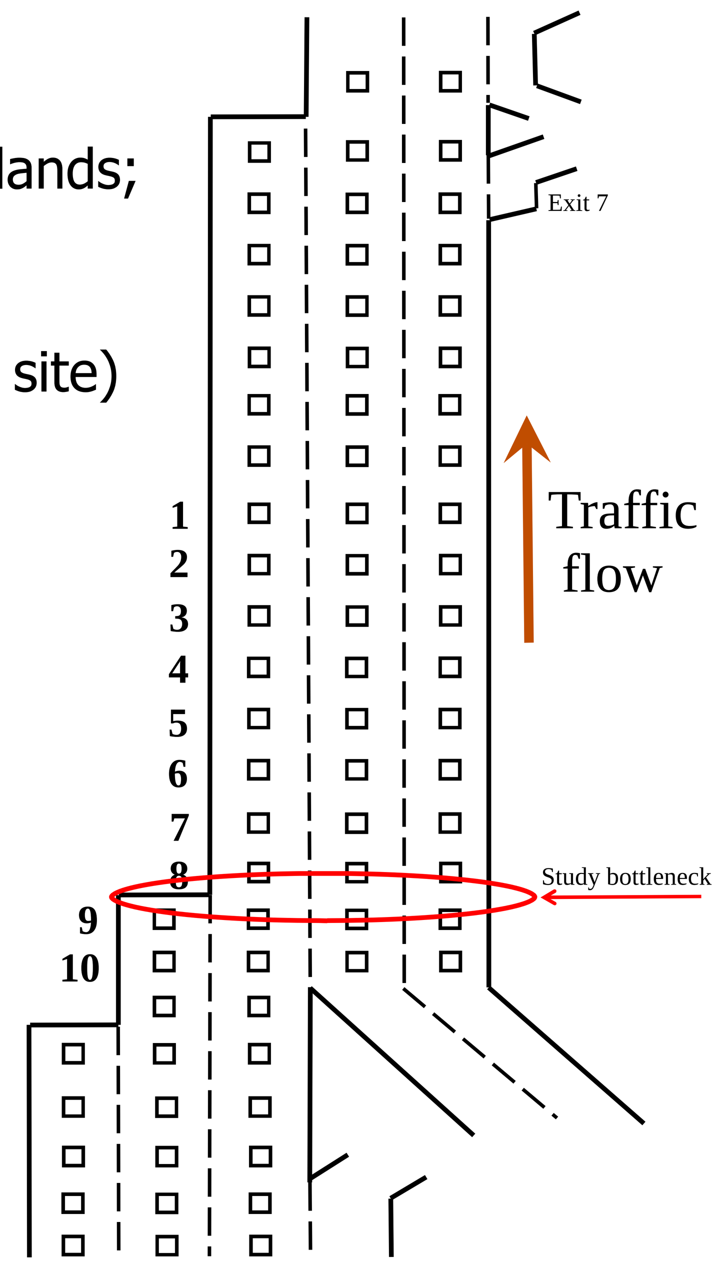


d) x—t plot

Study Sites

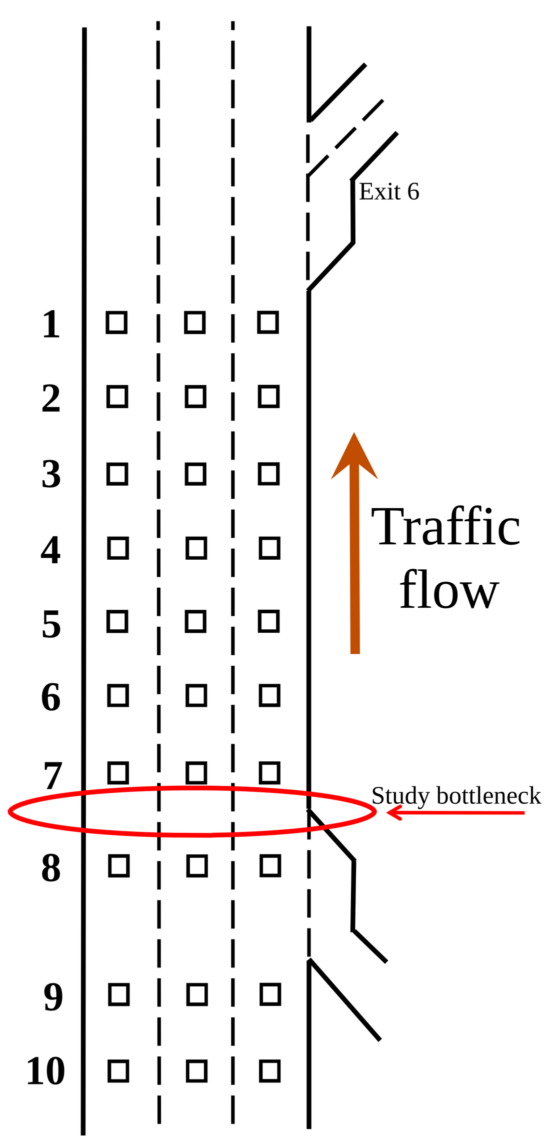
- Two freeways (A4 & A12) in the Netherlands;
- Lane-drop & On-ramp bottlenecks
- 1 min aggregated loop data
- 6 days of observations (3 days for each site)

Freeway A4



- Around 500m between every two detect locations
- At least 3.5km homogeneous freeway section in the downstream of the bottleneck
- Two sunny days and one rainy day (March 18, 2011) of observations on freeway A12
- Three sunny days of observations on Freeway A4

Freeway A12



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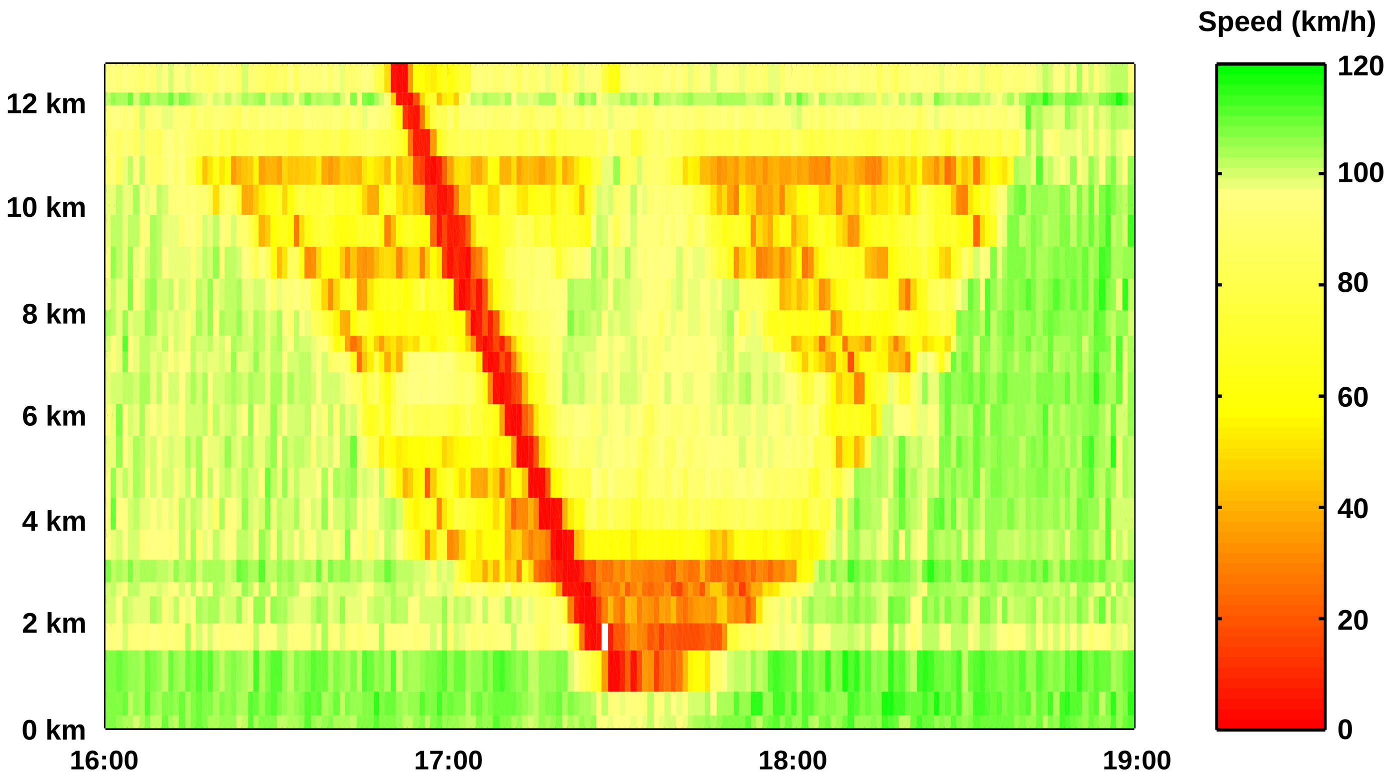
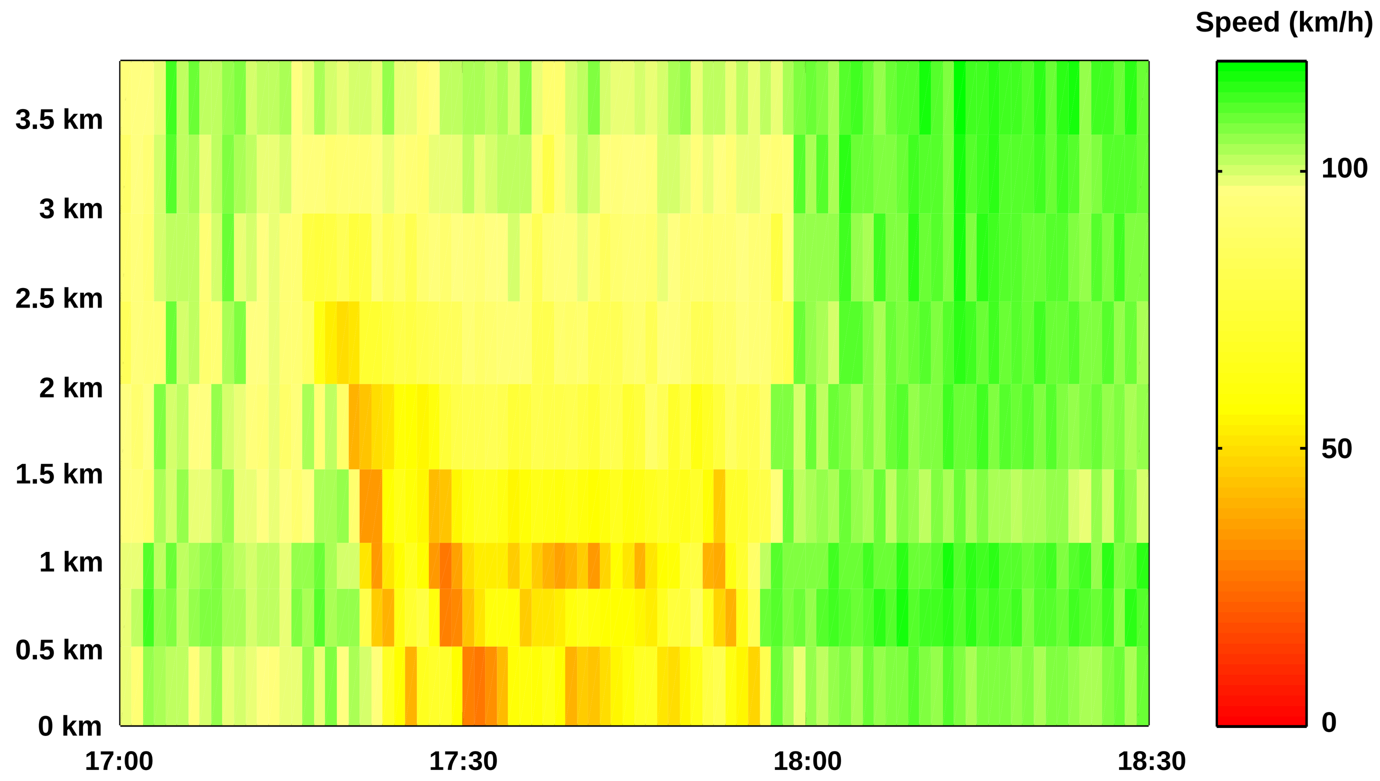
Data

- The bottleneck got activated immediately after a stop-and-go wave passes by
- The downstream traffic states of congestion are free flow



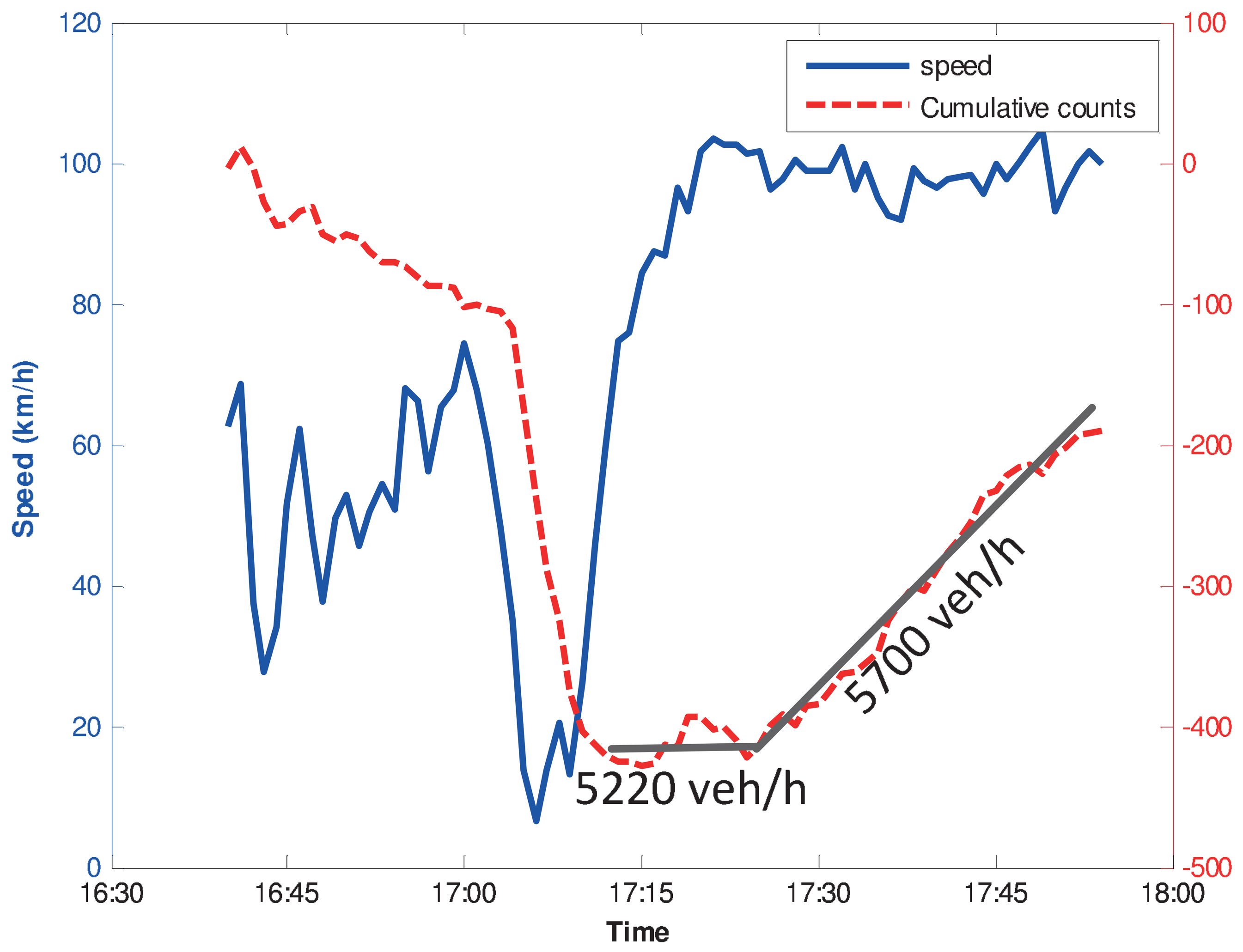
A4, May 28, 2009



A12, March 24, 2011

Observations

- Observe the traffic flow at the location furthest downstream
- Traffic remains in free flow state after the passing of a stop-and-go wave
- Flow increases if the outflow of the standing queue reaches the downstream point
- Shock wave theory predicts this



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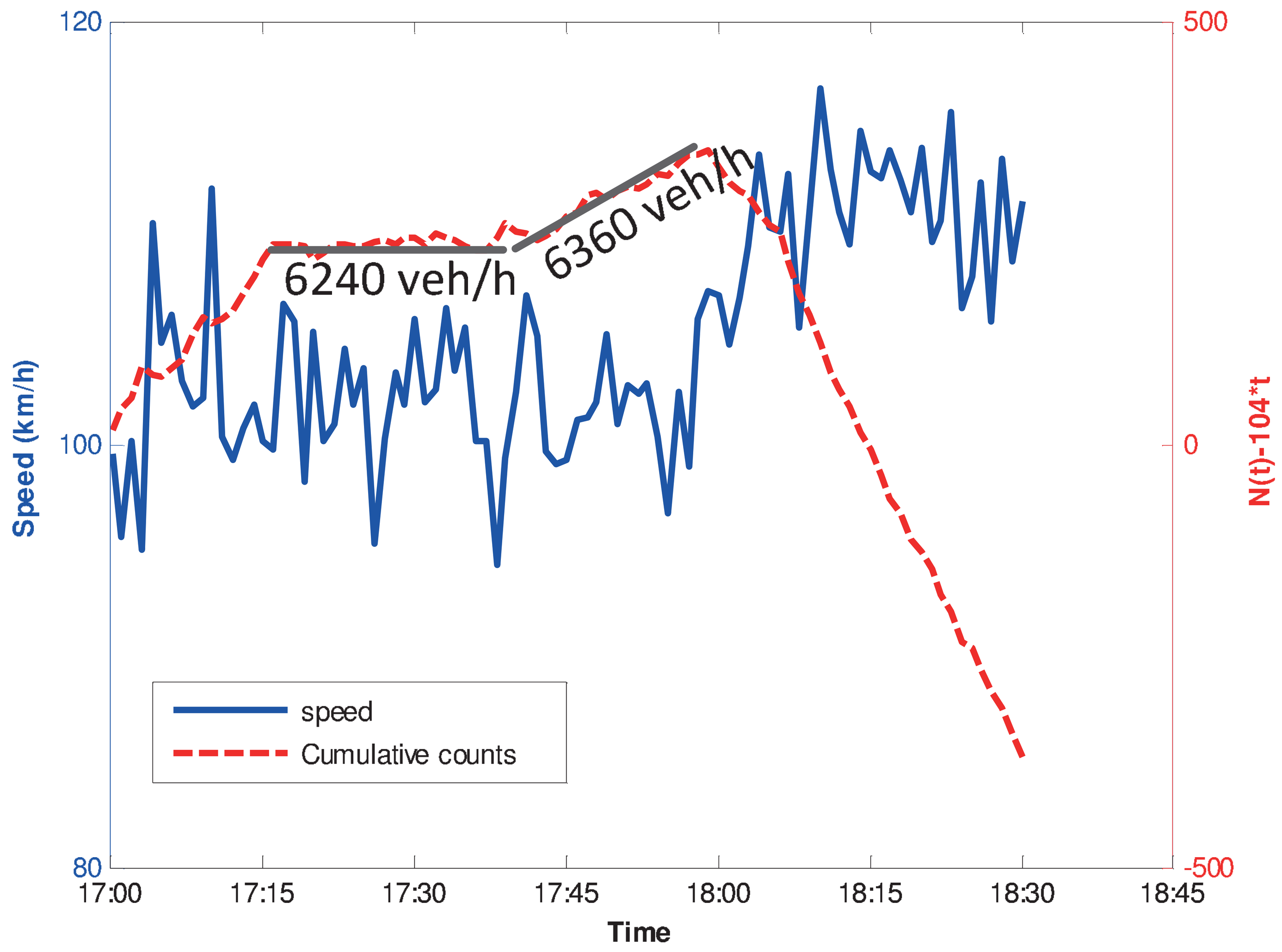
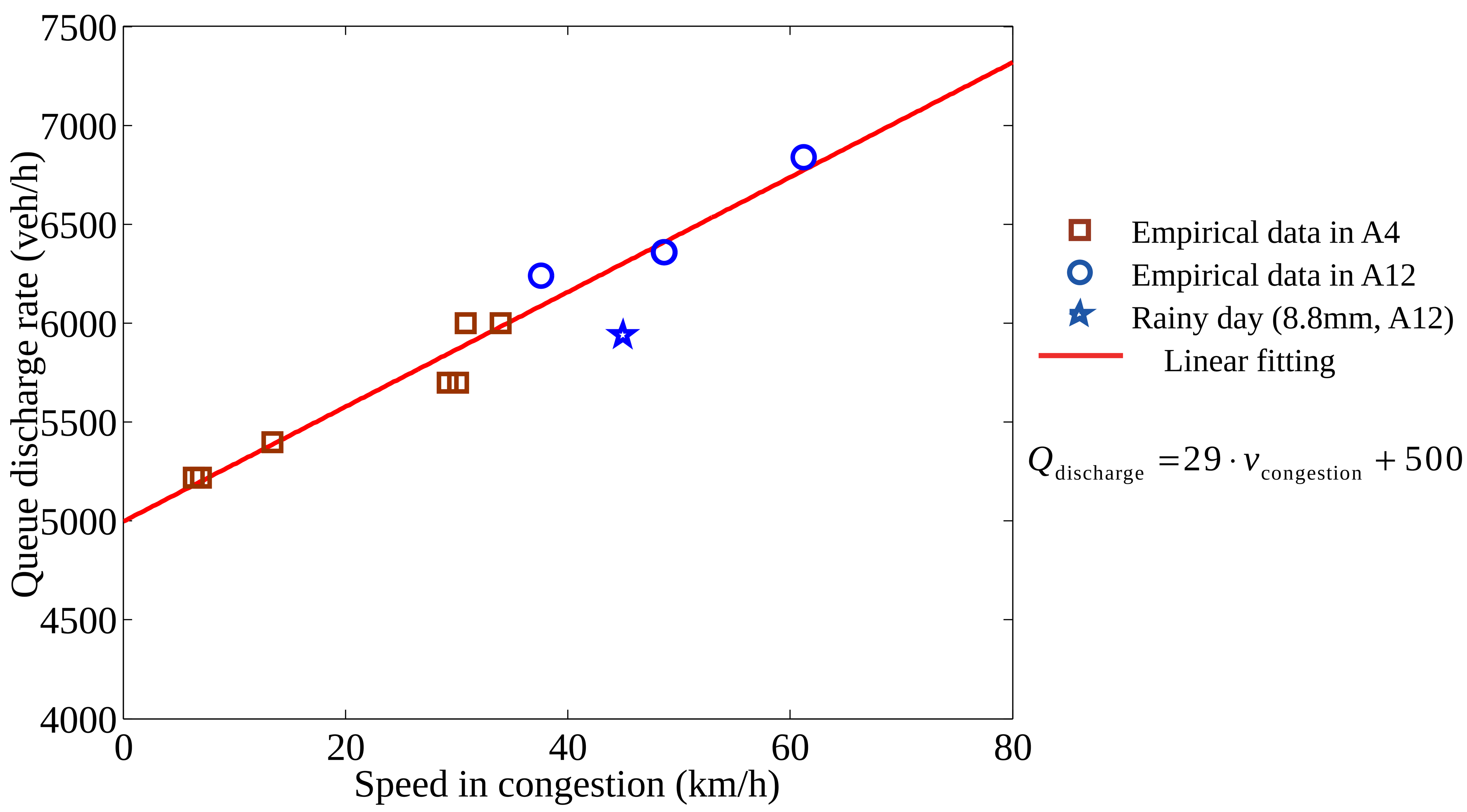


A12, March 24, 2011

Relation between speed in congestion and queue discharge rates

- A linear equation can fit the relation between the speed in congestion and the queue discharge rate very well
- When the speed in congestion is high enough, the observed queue discharge rates in this study can be much higher than three-lane pre-queue capacity (6300 veh/h) on freeways with a higher percentage of trucks (15%)
- In this study, the rainy day shows a lower queue discharge rate than the other observations in sunny days



$$Q_{discharge} = 29 \cdot v_{congestion} + 5000$$

Conclusions

As the speed in congestion decreases, the outflow decreases substantially. In this study, the range of speed in congestion is broad enough, from 6 km/h to 60 km/h. The flow at three-lane section ranges from 5220 veh/h to 6840 veh/h. The quantitative relation requires calibration because discharge rates are greatly influenced by local traffic situations, such as weather and proposition of trucks. The finding can provide fundamental theory for promising control strategies.