# Arterial Queue Spillback Control based on Connected Vehicle Technology

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## 1 Objective

Traffic congestion is one of the biggest problems that urban areas are facing. Infrastructure extensions that could mitigate congestion problems are restricted due to financial and other physical constraints related to limited space in cities. There is a clear need to use advanced technologies to design real-time signal control strategies that can improve traffic conditions in congested urban networks.

A major problem in signalized arterial networks is queue spillbacks, which can lead to gridlock and excessive delays. When intersections operate under oversaturated traffic conditions, queues grow and spill back to upstream intersections. Consequently, upstream vehicles trying to enter the affected intersection are not able to do so during the green time. Thus, the green time allocated to this movement is wasted, a phenomenon also known as "de facto red" [1]. This could be avoided with real-time signal control strategies that detect the possibility of spillbacks and adjust the signal timings accordingly.

The Connected Vehicle (CV) technology is a mobile platform that will enable a new dimension of data exchange between vehicles and infrastructure and could lead to better monitoring of the system in real-time and development of more advanced signal control strategies. The objective of this study is to use information from Connected Vehicles to detect spillabacks on arterial links and develop a real-time signal control system that adjusts the signal settings at the upstream intersections in order to avoid spillbacks.

## 2 Methodology

The developed algorithm for spillback detection is based on estimation of queue length with the use of information from Connected Vehicles. The algorithm uses the Maximum Likelihood Estimator (MLE) method to determine queue lengths for different penetration rates of the CV technology. The MLE simply estimates the queue length in a given link during a signal cycle as the position of the last Connected Vehicle that is detected to have stopped in that link during the signal cycle. Despite its simplicitly, this queue length estimation method has been shown to provide more accurate estimates than other approaches for a range of market penetrations of the CV technology and traffic conditions [2].

The queue length estimate is then compared with a queue length threshold, commonly defined as the product of a percentage of the link length, e.g. 90%, and a coefficient of adjustment that depends on the CV market penetration rate. This coefficient of adjustment is found under the assumption that the number of non-equipped vehicles between two connected vehicles can be probabilistically characterized as a geometric distribution. This allows us to detect a potential spillback by simply comparing the MLE queue length and the adjusted queue length threshold. Then, when the estimated queue length surpasses the aforementioned threshold, the alternative signal control strategy is triggered.

The control strategy is based on the idea of reducing the green time that is available for the through movement (the one that causes the spillback) and provide more green to the cross-street. The reduction in the green time for the through movement is such that it allows only as many vehicles as they are served by the downstream intersection. The goal is to limit the queue growth at the link of interest and avoid spillbacks over the next cycles. However, such a strategy could lead to transfering the problem of spillbacks at further upstream links. Therefore, the proposed signal control system is extended to test all usptream links for the potential of spillbacks and implement the real-time signal control strategy at upstream intersections as needed. In addition, to reducing the available green time for the through movement, the algorithm adjusts the signal settings such that there is a homogeneous distribution of queues along the arterial. This means that the signal settings are adjusted to result on the same queue over link length ratio for all affected links.

## 3 Findings

The proposed spillback detection algorithm has been tested through simulation on a segment of San Pablo Avenue in Berkeley, CA (Figure 1). In particular, the intersection of University and San Pablo Avenues has been chosen, since this is the most critical one on the studied arterial segment and the one where the incidence of spillbacks for high auto traffic demand is more likely. Since the link between University and its upstream intersection, Addison, is short we decided to implement the algorithm at the further upstream one, Allston, that also had the advantage of being able to store longer queues due to its longer length.

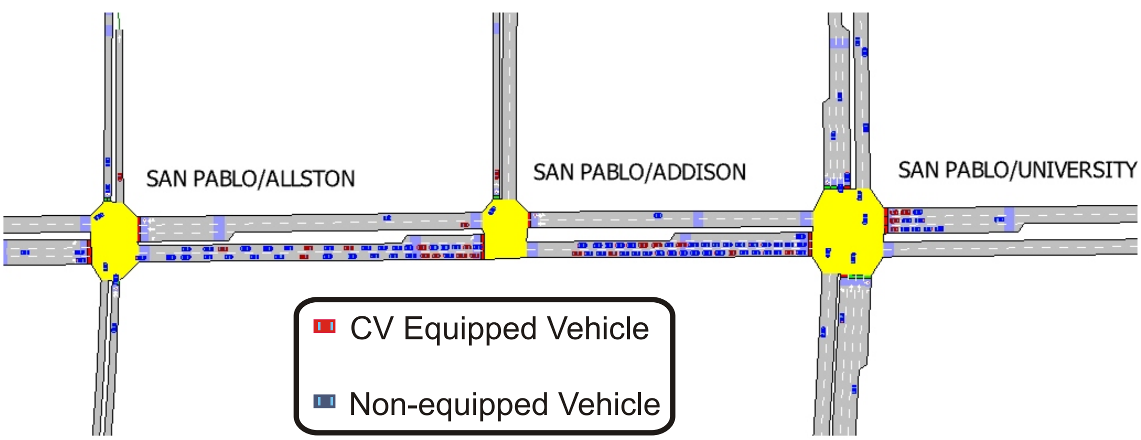


Figure 1: Simulation snapshot with a CV market penetration rate of $p = 20\%$.

The tests were performed using the AIMSUN microscopic simulation model through Emulation-In-the-Loop-Simulation. This technique consists of connecting the algorithm for the proposed strategy, coded in C++, with the simulator through its Advanced Programming Interface. Simulation tests were ran for 1 hour with a time dependent demand profile that led to oversaturated traffic conditions and spillback formation. The spillback detection algorithm as well as the signal control strategy were evaluated for a variety of market penetrations. Preliminary results indicate that the queue spillabck detection algorithm performs very well even for market penetrations as low as 25% as shown in Table 1. The signal control system has also been evaluated with several performance measures such as average number of stops, delays, emissions, and maximum queue lengths for each link separately and for the system as a whole.

Table 1: Detection accuracy of potential queue spillbacks based on CV data for different market penetration rates.

| Market Penetration | 0.1 | 0.25 | 0.5 | 0.75 | 1 |
|---|---|---|---|---|---|
| Total Signal Cycles | 12 | 12 | 12 | 12 | 12 |
| Correct Detection | 8 | 10 | 10 | 11 | 12 |
| False Alarm | 3 | 1 | 2 | 1 | 0 |
| Spillback not detected | 1 | 1 | 0 | 0 | 0 |

The findings of this study suggest that CV technology can improve monitoring of transportation systems, which can be further used to develop more advanced and efficient signal control strategies to mitigate congestion and its externalities in urban multimodal transportation systems.

## References


[1] Abu-Lebdeh, G., and R. Benekohal, "Development of traffic control and queue management procedures for oversaturated arterials" *Transportation Research Record: Journal of the Transportation Research Board*, 1603, 119-127, 1997.

[2] Argote, J., Christofa, E., Xuan, Y., and A. Skabardonis, "Estimation of Arterial Measures of Effectiveness with Connected Vehicle Data", 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 22-26 January, 2012.