Transportation Achievement Award Category: Transportation Systems Management and Operations
ITE ~~Southern California Section~~ Nominee: City of Arcadia (Lead Agency)
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Transit Signal Priority in Software

This project combined multiple innovative ideas to reduce the time Arcadia Transit buses on fixed routes spend waiting at red lights by a factor of two. At a high level, this is achieved by (italicized items are new for this project): (1) having Arcadia traffic lights provide information on current status, (2) *having the buses provide live position information using a newly developed iPad app, (3) using machine learning to predict when the buses will arrive at signalized intersections, (4) using machine learning to project the light phase when a bus will arrive, and (5) having the light extend or advance a specific green phase when doing so would allow a bus to pass unimpeded*. The city of Arcadia and Connected Signals, Inc executed the project itself jointly

In order to reduce delay time at red lights for buses, decrease route times, maintain bus schedule adherence, and improve the overall "ride" experience on a bus, transit signal priority implements strategies at signalized intersections to minimize the time a bus's run is disrupted by light interactions. These improvements make riding transit more comfortable, efficient, and efficacious by reducing jerk, delays, and deviations from set schedules, respectively. Adjusting traffic signals is viewed as a more cost-effective means to improving transit performance. The work described here was performed in Arcadia, California, where average commutes are almost 30 minutes and only 2.51% of commuters use public transportation (less than half the national average). Most approaches to TSP work by extending a green signal if a bus can be predicted to arrive shortly after the green ends, or by accelerating a green signal if a bus can be predicted to arrive shortly before the green would otherwise begin.

Traditional approaches to TSP rely on the installation of dedicated, special-purpose hardware at every affected intersection. This hardware may consist of infrared (IR) optical receivers, or short-range radio. The transit vehicle in turn is equipped with an emitter (IR) or radio that is used to signal the vehicle's approach to the signal (or entry into a predefined region). When a bus approaches a prioritized intersection, it sends a signal that is relayed to equipment in the cabinet which determines if and how to service the priority request. This approach has several drawbacks, typically involving cost and time of deployment (typically tens of thousands of dollars per intersection with full deployment taking months or years), and limited range or line-of-sight requirements of the receivers used. The hardware used typically has an approximately ten-year lifespan, increasing costs further. Finally, hardware-based TSP systems generally support bus operations only, with no attendant benefits to emergency vehicles, cyclists or pedestrians.

Connected Signals' Approach

The City of Arcadia worked with Connected Signals to deploy TSP that requires no new infrastructure. The work was supported by a Net Toll Grant from Los Angeles Metro to implement strategies to improve the efficiency and efficacy of transit operations and provide priority at signals. Connected Signals developed a TSP system for Arcadia that does not require the installation of special-purpose infrastructure and offers significant flexibility to "future proof" the system. Dubbed SPS (Signal Priority System), the system consists of an App that runs on the iPad already installed on each bus and a cloud-based software system that tracks vehicles, manages the service, and communicates with the City's traffic network to relay requests to individual intersection controllers, which are connected to a central traffic management center (TMC) (Figure 1). The onboard device relays the vehicle's location and expected arrival time at the upcoming signal to the cloud-based system using the commercial cellular network.

Transit signal priority can be provided by the traffic signal controller software. The software is responsible for the priority strategies used by the controllers to implement TSP at each signal. Software in the traffic signals receives a message from the TMC about arrival time and changes the treatment at the signal by green extension or early green, where applicable.

Connected Signals' strictly software-based approach has innate advantages over hardware for implementation and flexibility as described below.

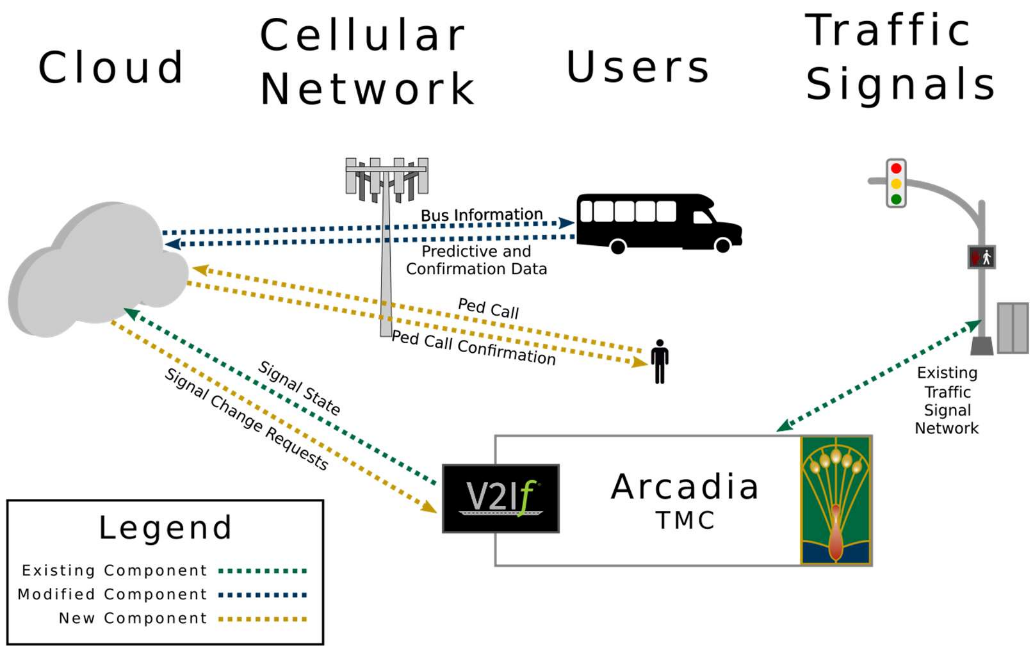

Figure 1: Connected Signals' Signal Priority System Architecture for Arcadia

Installation: The installation uses existing architecture and in most instances could be enabled using commands from the traffic management center (TMC). In Arcadia, the installation at the controller requires a technician to enable the signal priority at each signal which is dramatically less expensive than acquiring and installing new hardware. (Federal mandates require intersection controllers to have a TSP interface.) A small, low-cost hardware device was installed in the City's TMC to support communications between the cloud-based system and the intersection controllers.

Maintenance: No additional maintenance is necessary to service the system other than for the original signals' operation and replacement schedule. Upgrades to the system can be done through software releases in the App Store for changes to the in-vehicle application and through normal software updates for the cloud-based components. Patches for security and additional functionality can occur remotely and require minimal agency involvement.

Operation: Because it is based on cellular and internet connectivity, Connected Signals' transit signal priority system is not reliant on line-of-sight. The system can transmit around corners, multiple cycles ahead, and even multiple signals ahead to minimize the disruption to coordinated cycles if necessary.

Security: All communications are encrypted, and access is controlled by tightly controlled and revocable security certificates, which prevents spoofing of messages.

Flexibility: As a software system, SPS is more flexible and cheaper to maintain than a similar hardware approach. Any necessary security and functionality enhancements can be deployed without equipment acquisition or changes. As an example, the original implementation on Arcadia's Green Line was extended to the Red and Blue lines in a matter of days, requiring little more than enabling TSP in the D4 controllers in the intersections involved.

Similarly, extension to EVP, cycle priority, etc. can be achieved through software changes, again without additional hardware requirements.

Analysis

In order to evaluate the effectiveness of the system as deployed, we evaluated both the impact on the efficiency of Arcadia buses and compared this impact to those provided by other TSP systems. There are many metrics by which transit efficiency can be measured, but we focused primarily on three such metrics that are almost universally accepted: reductions in variations of bus speeds, decreases in the number of stops, and reductions in red-light delays. Data was collected from the iPads already present in the buses in question. In this abbreviated submittal, we present results for the Arcadia Green Line only; results on other bus lines were similar.

Speed consistency: Analysis of speed consistency and stopping focuses on the speed driving profile on approach to lights. This profile shows the proportion of the time a bus travels at a given speed as it traverses an intersection or throughout the route, broken into two-miles-per-hour (mph) buckets.

Figure 2 shows the speed profile as a bus approached a signal. (Speeds travelled as a bus approaches a signal gives a more specific measure of how TSP affects speed than the speed profile as a whole.) The chart graphs overlaid speed profiles of both the baseline and active phases. Where one color shows on the top of the bar, it means that that phase had a greater proportion during that phase.

There are two areas of interest. The first, is for speeds below 5 mph where the chart clearly shows a significant distinction between the speeds travelled in the baseline phase when compared to the active phase. More time was spent completely stopped at lights during the baseline. On the Green Line, time spent at or below 2 mph at lights was 39.4% less than during the baseline phase.

The rest of the profile also shows that buses operating during the active phase were typically traveling for longer durations at faster speeds than in the baseline phase. Buses operating during the active phase were able to stop for shorter durations and maintain speed longer.

Both treatments benefit speed here as an early green lets buses approach lights without slowing down or stopping, and green extensions enable the same behavior.

Stops: We saw a 35.6% reduction in the number of times a Green Line bus stopped, which the average number of stops dropping from 5.26 (without TSP) to 3.39 (after SPS was deployed).

Average delay: Over the course of driving a route, buses will make many stops for stop signs, passenger boarding and unloading, and signalized intersections. The delay at a single intersection due to poor timing or just bad luck can have significant adverse effects on the arrival times of bus routes. A single minor delay over the course of a route might have a negligible impact on the overall experience of riding the bus, but cumulatively, these small delays can add up to significant time loss.

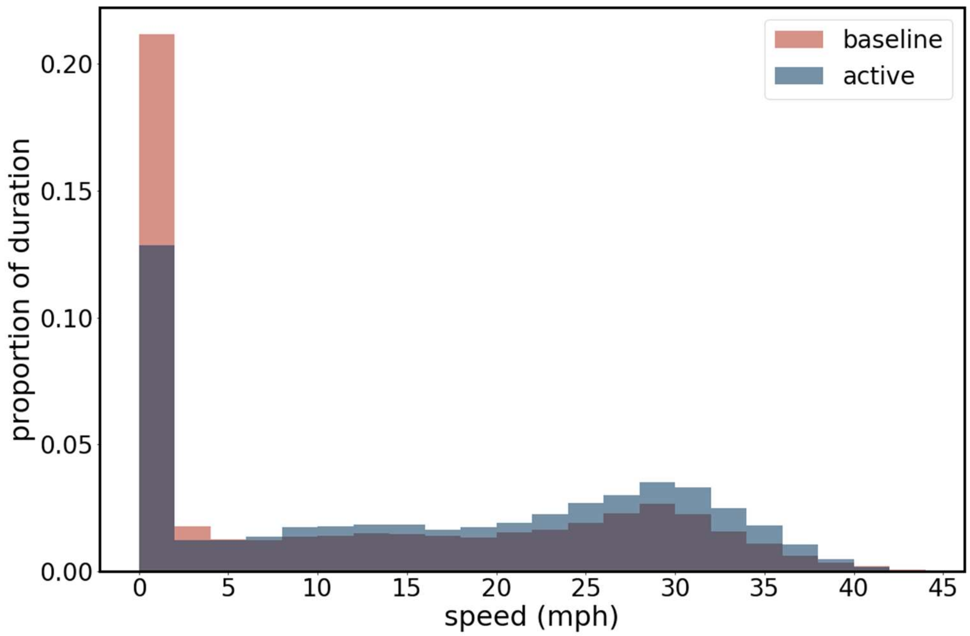

Figure 2: Green Line Approach Speed Profile

Experimental data appears in Figure 3 (next page). The bars of the chart indicate how long in seconds at each approach, on average, a bus was stopped at each signal. Some approaches were marginally impacted by the active phase, but most bus approaches significantly decreased their average delay with the introduction of the active SPS. The Green Line averaged about 223 seconds of signal-related delay per run in the baseline. During the active phase, this dropped by 54%.

Impact

Finally, let us summarize the results of this project when set against the five criteria specified in the description of the Transportation Achievement Award.

Innovation: To the best of our knowledge, development of a purely software-based TSP system is novel. There was a similar effort under way in Fremont to deliver priority to cyclists via software, but that project appears to have been at best partially successful.

Challenge and perseverance: This criterion does not really apply to the work that we have described. Once the overall system architecture was developed as in Figure 1, implementation was relatively straightforward; perhaps the most challenging element was the need for a single device (labeled V2I*f* in Figure 1) that could handle the necessary communication between the Connected Signals cloud and Arcadia's TMC. Fortunately, such a device already existed (www.v2if.com), having been developed to routinely handle communications in the opposite direction (infrastructure to vehicle or I2V). It was repurposed as needed for this project.

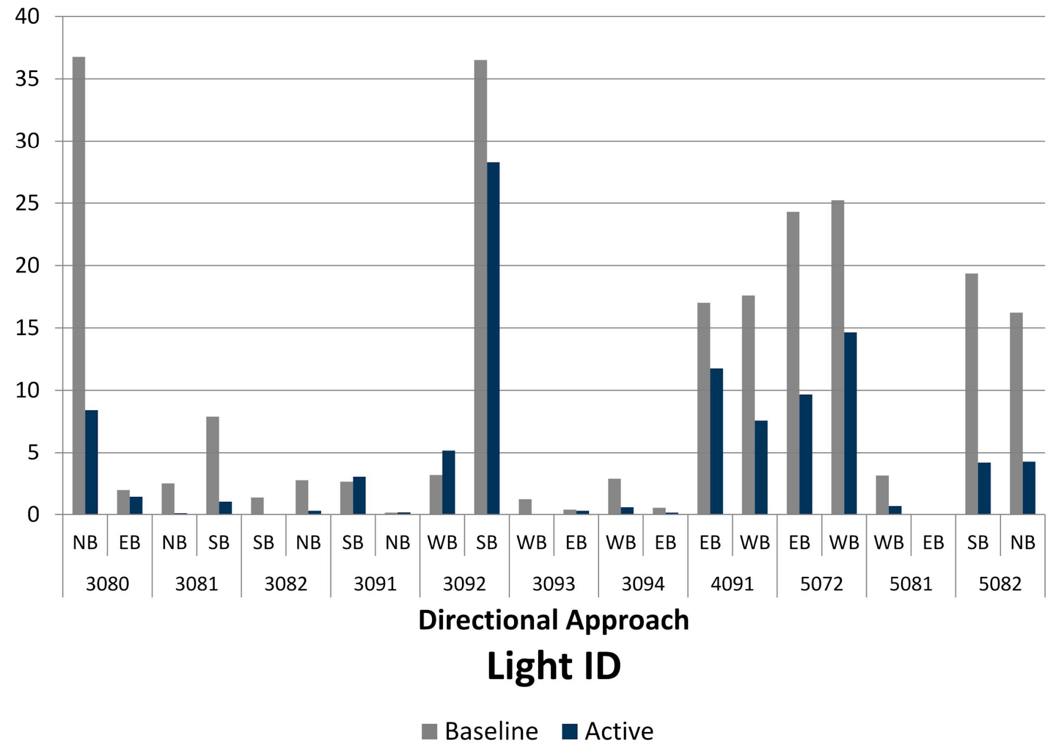

Figure 3: Green Line Approach Delay

Significant impact: It is clear that the techniques that were developed for this project can provide the benefits of TSP to cities that could not otherwise afford such a system, and can provide those benefits more cost effectively to larger cities. In addition, the flexibility of the system means that priority can also be provided to emergency vehicles, cyclists, pedestrians, etc. We are already in the process of deploying pedestrian technology in Arcadia that pushes the walk button from a significant distance, thereby avoiding the situation where a pedestrian arrives at an intersection with the light green but the walk indicator off (and typically jaywalks as a result). A specialized version of this system is being prepared for a city in Ohio where it will help students walk to and from school, improving the safety of their journeys.

Multifaceted: The project we have described clearly reaches across a relatively wide range of individual elements of the transportation system. It includes the development of specialized software for individual use cases (buses, pedestrians, etc.), appropriate software modifications to the signals and the TSP to mediate the communication among the various components.

Major advance in efficiency and/or economy: Needless to say, this is the element in which we are the most pleased. Arcadia's current problem (that their buses run behind schedule!) may allow them to introduce a bus route or increase the frequency of buses on their existing lines. Safer school children will have a profound impact on future generations. A software approach will generally be less expensive, more flexible, more robust, and easier to deploy than a hardware solution.