TSP (Transit Signal Priority) From Yesterday to Tomorrow

This paper reviews existing TSP algorithms in signal systems and examines future innovative methods to address the demands and needs for new applications. Traffic signal controllers are expanding from manipulated machines to short range planning tools that can adapt and plan green phases for transit vehicles. Their current capacity has room for new applications in traffic control. This paper explores how software development for light rail systems HCT (high capacity transit) may also have applications for other types of HCT such as BRT (Bus Rapid Transit) systems, including those systems operating within existing roadway space.

Traffic signal equipment has changed

Over twenty years ago traffic signal controllers became processor based. This expanded their ability to store conventional timing features and additional timing plans for coordination or backup. They were capable of doing more than ever before. However, their capacity became pretty much used up with new features and their inputs and outputs were limited to standardized connectors with off/on pins that were mostly specified by standards. There was very little room for innovation with the limited inputs and limited processing power.

Today’s traffic control equipment is much more powerful. According to Moore’s Law, processing power has increased 10,000 times in the past 20 years. Inputs and outputs are now virtually unlimited with serial ports. Fiber optic communications carry hundreds of times the data of older technologies. The development of software is the primary obstacle to more abilities and features in traffic control equipment. The development of software is a one-way street that increasingly adds abilities and clarity to previous programs. The current processing power is hardly challenged by conventional traffic signal operation and we are again at a point where innovation can rule. The stage is set for adaptive timing and unique timing for certain events such as transit priority.

Transit Priority Architecture

Most transit priority systems have an architecture that operates the priority locally with interaction between a single bus and a single traffic signal. Some systems make the priority decisions on the bus and others make these decisions at the roadside or in the traffic signal controller cabinet. The decision to request signal priority from an intersection controller may be based on adherence to schedule, rider ship, priority of route, or other factors that may warrant reduced delay at traffic signals.

The local control architecture may change. Improved communication between buses and central locations make decisions at a central location more practical. The central location is where knowledge of other inputs such as other transit vehicles, emergency vehicles, or other signal input can play into the priority decisions. Transit vehicles are being equipped with GPS that transmit location data to central systems. This location data could provide advanced detection, speed, and checkout detection. A central transit system can use this data to determine signal arrival time and place priority calls though a central signal system.

Transit Vehicle Detection Requirements for TSP

For a traffic signal to provide effective TSP (Transit Signal Priority) it needs information about approaching transit vehicles. First, the traffic signal must know the arrival time of the transit vehicle. Secondly, it needs to know this information in advance so the traffic signal has time to manipulate operation without violating minimums or clearances.

Typically, transit priority detects approaching transit vehicles with special detectors. These detectors are commonly wireless devices in advance of signalized intersections or a coded infrared light device. The wireless devices transmit information from the bus to a roadside antenna. The antennas are installed at a known distance in advance of the intersection. This allows the system to estimate the transit vehicle arrival time by estimating the average speed of the transit vehicle from that fixed location. The infrared devices use a photocell to detect transmission from an approaching bus. They have distance limiting adjustment that requires a level of intensity to place a priority request. These systems can predict the arrival time by estimating the distance of the transit vehicle from the light intensity. Then like other systems, they estimate the arrival time by calculating the travel time from the known location.

The distance from a signal for advanced detection area is normally dependent on the last bus zone on an intersection approach. Calculations for arrival times may be inaccurate if a bus must travel through a bus zone with a variable stopping time. Therefore, the detection area normally follows a prior bus zone location. Detection areas close to traffic signals provide accurate arrival times but the time in advance is short. This limits the amount of time for signals to respond. Detection areas further in advance give more time for signals to respond. However, the greater distance to the signal can cause less accuracy in the arrival time if variable traffic conditions cause speeds to vary during different times of the day.

Checkout detectors detect priority vehicles that proceed through the intersection. They improve operation if a system has a variable length extension time that can terminate a priority green at an checkout call and resume normal operation. Checkout detectors have the greatest value when detection areas are far in advance of a traffic signal. The estimated arrival time has more variability with more distance. The check out detectors could allow long extension times for slow transit vehicles that could be terminated early for faster transit vehicles. This reduces the priority impact by shortening the green extensions after a priority vehicle has passed.

More and more, smarter transit vehicles are being employed with geographical location systems that can improve the predictability of arrival time. The predictability can be improved by calculating the speed of the buses from one point to another point and projecting the travel rate to a traffic signal where priority is desired. Information about the predicted arrival time could be sent to the transit central system, transferred to the signal central system and relayed to the local controller as either input or instructions. These systems can also use identify when a transit vehicle has passed like checkout detectors. This will reduce the impact of signal priority.

In all systems transit arrival times are dependent on the travel time between the location detected and the traffic signal where priority is desired. This travel time is dependent on consistent speeds and predictable or nonexistent stops. Consistent speeds can be dependent on traffic conditions on a signal approach unless a transit vehicle has exclusive lanes. Bus zones or traffic signals between a detection area and a traffic signal destroy predicted arrival times unless the stopped time in known in advance. For this reason TSP detection zones are normally located not further in advance as the nearest traffic signal or bus zone. Within this limitation they should be located as far in advance as possible to give the signal time to maneuver towards a priority green.

Traditional TSP in Washington State

The first transit priority in Washington State was installed in the mid 1990's in a few cities with main bus routes for local buses. These Opticom based systems preempted traffic signals to provide green lights for transit vehicles but they often broke the signals from coordination and skipped phases to provide their function. Their priority base gave first priority to emergency vehicles that could also override a transit priority if in conflict. This operation was not acceptable to large cities such as Seattle. Larger cities had many more transit vehicles and had to stay in coordination signal to avoid gridlock.

In the late 1990's the City of Seattle established strict guidelines for transit priority. These requirements added complexity that challenged the abilities of existing controllers. Here are those requirements:

1. Priority could not cause a traffic signal to break from coordination.
2. Priority could not cause the traffic signal to skip phases.
3. Priority could not cause the signal to violate minimums or clearances.
4. An adjustable time between priorities could limit the number of priorities that could be implemented in a given time range.

Transit agencies contracted with signal controller manufacturers to develop firmware that could accomplish the Seattle requirements. Several manufacturers failed to deliver because of capacity limitations with their existing equipment.

To meet the Seattle requirements traffic signals had to maintain their background cycle when in coordination. Without skipping phases the only option for priority was to change the signal splits allocating more green to a transit priority phase. Within the same background cycle providing more green for a priority phase requires reducing the green intervals of other phases. This method provides the following two options of priority depending on the arrival time of a transit priority vehicle.

First, if the transit arrival time is immediately following a green phase the signal could use the longer split to extend the green time for a priority phase and allow the transit vehicle to proceed through the extended green. This is known as green extension. Secondly, if the green extension is not long enough for the arrival time or the arrival time is during a red interval, then the signal could use the same priority split to shorten the red intervals. Shortening the red intervals provides an earlier green interval for the priority vehicle. This is known as red truncation.

Transit vehicles do not always want or need signal priority. Here are several reasons they may not want priority. If a transit vehicle arrival time is during a green interval a priority call will not benefit their travel time. If they are running ahead of schedule the priority could work against them and force them to delay their operation more to get back on schedule. If more than one route arrives at a traffic signal about the same time the priority may be reserved for one route were priority is more beneficial. For these reasons transit vehicles normally screen their priority calls to signal controllers.

TSP Ideas for Tomorrow

Signal equipment today has capabilities to greatly expand TSP options. With much greater processing power, unlimited inputs and outputs, and faster communications, software development is the only limitation. Tomorrow will have many optional features to reduce transit delay while maintaining traffic flow. Even existing systems could be improved with check out detectors that minimize the transit green time with variable length extensions. Here are some possibilities we may see in the future:

Adaptive signal operation – Adaptive traffic signals are already being tested. These adaptive systems develop cycles, splits, and offsets on the fly using inputs to include traffic data or status of nearby signals. These systems can be developed to include transit priority as one of the inputs and include them in the algorithms.

Phase sequencing – Changing phase sequencing on the fly is already possible with some signal equipment. Changing the signal sequence for an approaching transit vehicle can have a large impact on transit delay reduction while having a minimum impact on intersection capacity. Changing a leading left turn phase to a lagging left turn phase can allow a priority phase to occur sooner. Reversing the order of split phases can also help if one of the split phases is a priority phase.

Double greens – Existing systems reduce splits in some phases to add green time for transit in a priority phase. This additional green time could be a floating green time that could occur at other times in the cycle. Especially with transit only lanes the floating green time could act much like a queue jump and provide a short green for transit vehicles while crossing the barrier, between split phases, or at other times in the cycle.

Background cycle expansion – Background cycle expansion on the fly is already possible with some control equipment. Expanding the cycle along an arterial could leave dedicated transit time in each traffic signal to be inserted into the cycle at appropriate time for a transit vehicle. This could provide more transit green time than is normally available by reducing splits in a system with pedestrian timing in short background cycles.

Activated bus zones – Some transit agencies are experimenting with pushbuttons at bus zones that give transit drivers advanced notice that a bus zone is occupied. This notice may help them get into a particular lane or prepare to stop. A bus zone that does not have activation could move the detection area further in advance to provide more time for the signal to react.

BRT (Bus Rapid Transit)

Light rail transit often has many features not present in bus transit systems that will reduce travel time for the rail users. Some of these features include stations where patrons pay as they enter the station instead of paying when the board the vehicle. This allows all transit vehicle doors for loading and unloading and reduces loading times. The stations are normally further apart than bus stops to reduce the number of stops. Exclusive right of way is a feature that keeps vehicles from getting caught in congestion of general purpose vehicles. Some regions are considering bus systems that employ many of these features.

The features of a light rail system improve their operation through traffic signals by improving the advanced notice and the reliability of their arrival times. Software development is underway that monitors rail trains as many as three traffic signals in advance. The arrival time is verified or adjusted several times on the approach. Their exclusive right-of-way keeps their speeds consistent and the distance of their stations provides longer runs without stopping. As BRT systems are developed with many of the light rail features, the software for light rail vehicles may be effective for transit priority also.

BRT systems with stations instead of bus stops every few blocks will increase the non-stop distances on the approach to some signals. This will provide estimated arrival times further in advance. Exclusive right of way or lightly used right turn lanes will bypass congestion in though lanes make travel speeds more consistent. The consistent speeds will improve the reliability of estimated arrival times. Reliable arrival times further in advance will provide more time for traffic signals to prepare for approaching transit vehicles after timing minimums and clearances.

Bus/Traffic Signal Coordination

Many transit corridors serving several routes have short headways between transit vehicles. The density of transit vehicles may rival the importance of general purpose traffic. Modifying signal operation with TSP would keep signals continuously out of normal operation. If regulating transit headways is practical, coordinating transit vehicles with traffic signals is possible.

Coordination of transit vehicles with traffic signals has several requirements. The operation requires regulating headways ways and departure times of transit vehicles from a fixed location. It also requires accurate clocks set to the same base as the traffic signals. Time stopped at stations must be fixed or speeds must be adjusted to coincide with time at stops. From the signal side the cycle lengths must be compatible to the time between transit vehicle headways. Also, the system must allow cross street arterial offsets to be adjusted within the green band of transit vehicles including their stops. If these conditions can be met the transit vehicle can have very consistent times through the corridor and the signals will be in the same status every time though. This helps operators learn the system and develop driving patterns that help the travel time reliability.

The City of Tacoma is developing a system of coordinating light rail vehicles with their downtown corridor traffic signals. The rail vehicles will run on 10 minute headways (600 seconds) and the signals will be changed to 100 second cycles. Trains will pass through the signals each direction each six cycles and preempt the signals during their preempt window that will not deteriorate vehicle progression. Station stops normally vary in length but this system will require fixed length stops or speed adjustments at the operator discretion. If trains get out of their green band the signals will not give them immediate preempt. They will be held to the next green band in the next cycle. Drivers will have a catch up area near the end of each round trip where they can get back into a previous green band if they get behind schedule. If the Tacoma test has success with trains it could also show value for buses when the conditions are right.

Summary

Signal equipment increases in processing power, ports with unlimited input and output, and faster communications open many possibilities for TSP tomorrow. The architecture may take advantage of these improvements and operate with GPS systems and communications through central transit systems and central signal systems. Processing power can use transit inputs in adaptive timing algorithms, make sequence changes on the fly, or provide transit green time between or during several phases in the signal cycle. Communications could implement TSP from central control centers with more data for TSP decisions or extend entire background cycles to provide transit green time for many signals at once.

GPS systems may provide flexibility for transit vehicle detection. These systems may not only simulate advanced and checkout detectors but may also have the flexibility to move the detection zone under certain conditions. They can also calculate real time speed and make adjustments to predicted arrival times.

Bus Rapid Transit initiatives may provide exclusive lanes for transit vehicles and increase he distance between bus zones. As transit vehicle operation becomes more like light rail operation, rail software may also be applicable for transit vehicles. Exclusive lanes provide more consistent travel speeds and therefore arrival time reliability. Fewer bus zones may Increase advanced notice of approaching transit vehicles and provide more time for traffic signals to cycle to a priority green.

The future transit priority options will reduce travel time for transit vehicles while having less impact on general purpose traffic.

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