Signal Patterns for Improving Light Rail Operation

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Abstract

This paper describes the follow up to a pilot project to coordinate traffic signals with light rail trains in the City of Tacoma. The pilot project eliminated system conflicts resulting in periodic long delays to transit vehicles, light rail trains, and general purpose traffic. The pilot program improved traffic operation, but provided little flexibility for light rail trains to adapt to changing dwell times at stations. External logic manipulated the twenty five year old controllers to provide a single schedule for light rail trains. The single schedule served all times of the day throughout the year regardless of demand variations.

A new train station lengthened train headways thus requiring new signal timing throughout the downtown area. These changes created the best opportunity to change signal equipment and provide more flexibility in signal timing. The installation of modern signal equipment with new timing patterns will give better service to light rail riders, transit vehicles, and general purpose traffic. The project will improve light rail operation by upgrading signal equipment and providing signal patterns designed around the needs for variable station dwell times.

Tacoma CBD Transportation

The City of Tacoma has a population of about 200,000. The downtown core has a grid of mostly two way streets with about 40 traffic signals. The north/south streets provide mostly local circulation traffic because the I-705 freeway skirts the east edge of the downtown core. The most heavily travelled east/west streets have heavy directional splits all day because they connect directly to on or off ramps on the I-705 freeway. Traffic volumes in Tacoma remain consistent throughout the day with peak hours increasing directional splits on east/west streets to and from the I-705 freeway.

A north/south light rail system shares traffic lanes with general purpose traffic for about a half mile through the downtown area then operates down the center of an arterial street for another three-fourth mile. The light rail route then turns east for another half mile to a large parking area for a multipurpose dome stadium. The 1.75 mile line has stations on each end and now four stations along the route with the opening of a new station. Trains that used to leave each end of the route on ten minute headways now have twelve minute headways with the addition of a new station in each direction. The County Transit System, Pierce Transit, has a major transit garage near the northernmost light rail station. Approximately 15 transit routes produce 40 to 50 buses each hour along the light rail route during all daytime hours. The buses operate on a shared street through the downtown grid and mostly run on the same streets as the light rail trains.

Initial Pilot Project

The initial pilot project was initiated by a committee consisting of representatives from the City of Tacoma (signal operations), Sound Transit (light rail trains and buses), and

Pierce Transit (county wide bus system). This Committee hired DKS Associates to investigate concerns and develop recommendations for solutions. The Committee noted periodic gridlock at several locations at unique time periods with no consistency or apparent cause. DKS found the cause to be conflicts between the train operation on ten minute headways and signal coordination which ran 70 second cycle lengths. The 70 second cycle lengths and ten minute or 600 second train headways meant that every time the trains went through the system, the signals would be at a different point in the cycle. Occasionally, the trains would preempt the traffic signals at a time in the cycle that caused a sequence of events causing traffic queues that block traffic and keep all directions of traffic from proceeding. In some cases, the trains would hold signals in preempt while being unable to proceed through the intersection due to the traffic stalled by the train's own preempt.

Recommended Solution
DKS concluded the solution to the problem was to coordinate the train and the signal operation. Although this solution had little national precedence, technology advancements had improved the ability to run two independent systems synchronized together. To coordinate train and signal operations, the solution had to accomplish the following three changes in operation:

1. The trains and the signals had to operate on compatible cycles that would support repetitive operation working continuously.
2. The trains and the signals had to operate on the same time base to make each action predictable across systems within a few seconds.
3. The trains had to have predictable travel times between signals and between stations.

With these three changes, the signals could be timed around expected train arrivals with the intention of having the arrivals occur at a time in the cycle that would minimize impact to the flow of traffic. Other traffic signals in the downtown area would then be timed from signals in the train corridor to produce a timing plan that works for the entire downtown core. New signal timing for the downtown area would result in signals operating designed for traffic flow that would also accept train preempts at a time in their cycle that minimized disruption to the overall traffic flow. The compatible cycle lengths would make each train arrival occur at the same point in each signal cycle for every arrival. These repetitive actions would occur throughout the entire day.

Project Method
Prior to the pilot project, signals in the CBD grid operated on 70 second cycles during all three weekday time periods. Most signals were two phase fixed time operation with the exception of Pacific Avenue that operated six phase signals with protected/permissive left turn operation on Pacific Avenue. Pacific Avenue extended beyond the grid system with fully actuated multi-phase signals operating free. These signals needed to be changed to a cycle length compatible with the 10 minute or 600 second train headways.

A compatible cycle length needed to divide into 600 seconds evenly; DKS chose a 100 second cycle length for the system. A longer cycle length was necessary in order to accommodate a construction project adding more pedestrian phases to one signal in the CBD grid. The 100 second cycle was also just long enough to accommodate an eight phase fully actuated signal in the system. DKS provided new timings for all of the signals in the CBD grid and the Pacific Avenue extension for all three time periods. The 100 second cycle length would allow six signal cycles between each train arrival in a single direction. However, now, each train arrival would find each signal in the same part of its cycle.

Special clocks were installed to key the signal timing to the official US time from the atomic clock in Colorado Springs. If similar clocks were installed in the trains, then the systems could more easily stay in sequence. However, field runs found that train operators soon learned the repetitive signals and operated off the signal timing. They began their runs based on wrist watches set daily to the official US time from Colorado.

Train timing for arrival times and dwell time at stations came from Sound Transit records of many actual runs. DKS used worst case timings for travel times and dwell times to set a train schedule. Then, engineers developed a time space diagram to note the time the trains passed through each traffic signal on the route. A timing pattern set signals on the train route first to accommodate trains in both directions as long as they stuck to their preset schedule. Then, the signal timing were developed spreading outward from the train route for cross street coordination. The result was a signal pattern that could accommodate trains in both directions in a preempt window without major disruption to cross street vehicle progression. Although some of the preempt windows cut into the end of the cross street splits, the changes were minor and quickly corrected into normal splits in the next cycle.

Longer Range Challenges
Although the pilot project mostly solved the previous traffic congestion, it was far from perfect. The old signal equipment had to be manipulated with external logic to recognize preempt windows in the cycle and preempt patterns when a train arrived. Only one pattern was possible allowing for a single train schedule for the entire day. This caused the following main shortcomings in traffic operations:

1. The dwell time at stations was set for the busiest time period and was too long for many other time periods.
2. Although the train system had check out detectors, the signal system could not use the inputs. Train clearances were set to a conservative fixed time for the trains to pass though intersections.
3. Different cycle lengths for the traffic signals were not an option for special occasions or seasonal variations.

Newer signal equipment could overcome many of the issues around the pilot project.

Current Project Construction
In 2009, Sound Transit, Pierce Transit, and the City of Tacoma came together again to develop a technology plan for the Downtown Tacoma area. This plan was the basis of the scope provided for a Congestion Management and Air Quality (CMAQ) grant

application. DKS Associates was hired to conduct an evaluation study to identify the exact equipment that would be deployed by the City as a part of the technology plan.

DKS worked with the three agencies for the planning, design and implementation of a new signal system in downtown Tacoma. The purpose of the signal system upgrade was to improve traffic operations; allow for transit signal priority at more intersections; and upgrade the priority operations for the light rail intersections. One impetus of this work was the new light rail station planned on Commerce St. With the new station in place, new signal timings would have to be developed. New controller developments would allow for much improved signal timings.

This aspect of the project began with an evaluation of various signal systems for the City; Siemens SEPAC with TACTICS was ultimately selected for its LRT and transit signal priority (TSP) capabilities. The new controllers were deployed at 80+ traffic signals. DKS performed all the signal timing conversions from the old LMD9200 and Traconex controllers to be compatible with the TACTICS software.

Because of the controller upgrades and TSP equipment to be installed, many existing Type M cabinets had to be replaced due to lack of space; type P cabinets would be installed in their place. Design plans were created to upgrade 22 of the traffic signal controller cabinets and to deploy Opticom detectors for TSP. TSP was ultimately deployed at 40+ intersections. DKS developed the TSP timings and installed them in the field. DKS also worked with Pierce Transit to fine-tune the ranges on all the Opticom detectors for improved TSP performance. Implementation of the system also required coordination with the City of Tacoma IT department to develop the IP addressing scheme for the new Ethernet communications network and to determine how to route data from the field to the signal shop. All agencies and departments had to work together in order to accomplish the goals of this project.

Though Siemens SEPAC controllers were selected as the controller of choice, the agencies had some specific requests for the software in relation to light rail operations. The requirements for a light rail priority system that would use both high priority and low priority differ from the priority systems used for heavy rail. Tacoma’s light rail priority system had very specific needs in terms of reordering phases, allowing for dummy phases and all red phases to clear vehicles that may be using the same lane as the train. Due to these specific requirements, the agencies, DKS, and Siemens began working together to develop software that will provide the best operations for transit signal and light rail priority. While Siemens is developing the software, DKS is providing monitoring, testing, and implementation support and will assist the City of Tacoma with the field work to implement the new software once it is complete. This work at time of publication is still on-going.

Developing New Signal Patterns

The Tacoma project to add new light rail stations in each direction was independent of the signal system upgrade project. Contractors completed stations construction before all the new controllers were in place with new software. DKS had to develop a new timing pattern to operate the system until all the new traffic controls were ready. This pattern set the new parameters and procedures for developing more traffic patterns when the signal equipment was ready.

New Light Rail Parameters

The new signal timing changed the following three light rail parameters from the original pilot program.

1. Train Headways – The ten minute headways in the pilot program were very challenging. Train operators had about 90 seconds at the end of each run to gather their things, walk to the other end of the train while it was unloading and loading, and get the train ready to go in the opposite direction. If the train became behind schedule, catching back up was difficult. With the addition of new stations, the headways were increased to twelve minutes to maintain the two train system with more leeway.
2. Train Travel Times (speed) – Train travel times were consistent but not uniform. The pilot program used station arrival times to determine average speeds. However, these times were adjusted in the field to compensate for trains slowing for switches and curves and speeding up on straightaways. Data collectors timed the trains between traffic signals to improve the accuracy of train travel times. These times were verified by train operator supervisors to assure the times were valid.
3. Station Dwell Times – The pilot program used worst case timing from Sound Transit records to determine dwell time at stations. Although these times were good for the pilot program, conditions changed and some of the dwell times became too short. Train operator supervisors collected new information to update the dwell times to existing conditions.

With the above information, engineers were able to determine the time of a train's arrival at each traffic signal for each direction from the beginning of the train cycles. A strict schedule planned the twelve minute headways to begin at the top of each hour and each twelve minute interval following from the beginning of the route.

New Traffic Signal Parameters

New traffic signal parameters are dependent on the train parameters. New cycle lengths have to divide into the train twelve minute or 720 second headway evenly. This leaves options of 80, 90, or 120 second cycles. The City of Tacoma prefers cycles as short as possible for pedestrians, but 80 second cycles are too short for some of the multiphase traffic signals on Pacific Avenue extending from the CBD grid.

The 2009 MUTCD as adopted by Washington State required new pedestrian timing at all traffic signals. Pedestrian clearances had to accommodate pedestrians walking at a speed of 3.5 feet per second instead of the previous standard of 4.0 feet per second. DKS used Google maps and field measurements to measure all crossing distances and set new pedestrian timing at all signals. Signals in the CBD grid could easily accommodate the pedestrian timing, but the multiphase traffic signals on the Pacific Avenue extension barely had enough time due to long pedestrian crossings and turn phases to accommodate. A capacity analysis of each signal determined that the pedestrian timing had enough time for through vehicle splits in all cases. The focus became accommodating pedestrian timing and turn phases within a 90 second cycle at the multiphase intersections.

One intersection on Pacific Avenue, at the terminus of the SR 509 freeway, could not accommodate the pedestrian timing and still have enough time for turn phases within a 90 second cycle. The long pedestrian crossings across the five vehicle lanes plus light rail tracks on Pacific Avenue and the seven lanes across the SR 509 freeway did not leave enough time for the turning vehicles. However, the capacity analysis indicated the signal had enough time if the pedestrian phases were not activated. Since the pedestrian volumes were light at this location, DKS chose a 90 second cycle for the system and let the pedestrian timing exceed the phase splits. This procedure would allow the signal to provide time for pedestrian movements if called and take time away from the following turn phases if all other phases served their maximum split. To help reduce the time needed for cross street splits, signals were coordinated on the cross street to assure saturated flow at the Pacific Avenue intersection. Field observations have noted satisfactory levels of service during peak hours. However, an increase in pedestrian activity could cause a breakdown in the level of service.

Signal offsets on the train route in the CBD grid (on Commerce St) are set to accommodate train arrivals in both directions without disrupting the cross street splits. In some cases, short increases in train dwell times were added to adjust train arrival times, and in some cases, the end of the cross street splits was shortened to accommodate train preempts. This enabled cross street coordination with very little disruption from trains. DKS staff used Synchro to establish offsets in the entire CBD grid after setting the train route signal offsets. Vehicle progression was timed outward from the train route. Staff optimized the system by minimizing stops and delays from Synchro reports.

The Pacific Avenue extension from the CBD has five signals and only one station. The trains travel in the median parallel to traffic. The offsets that are best for the trains work fairly well with the general purpose traffic. However, with the pedestrian timing being dominant, very few split changes could be made for train preempts.

Signal Preempts

Shared lanes in the CBD grid accommodate trains, buses and general purpose traffic on Commerce Street. These signals operate normally with two phases, but train preempts activate a turn phase in the direction of the trains to clear out any traffic that may be in front of an approaching train. At two of the CBD intersections, special phase sequences are necessary in order to avoid a left turn trap where the left turn driver expects the opposing through vehicles to be receiving a yellow or red light, creating a false sense of safety for their desired movement. To avoid this scenario, a special phase sequence will be called with the train preempt. At one location, the phase sequence will call up left turn phases in both directions for a short interval allowing the left turn phase to turn red before the train arrives for its preempt. At another location where protected left turn phases are not present, a train preempt will cause the signal to call a non-existent "dummy" phase that produces a short all red interval prior to the train's arrival. In another unique situation, a near side station requires timing the signal so that the train will approach at the end of a green interval to assure traffic stopped at the signal will not keep the train from reaching its station.

Each of the signals on the Pacific Avenue extension has a unique preempt. The signal at the critical intersection, SR 509 terminus, has preempts that do not change the normal cycle. Trains in both directions preempt at the same part of the cycle during different cycles. The preempt only changes timing if the signal is out of coordination. This helps intersection efficiency by keeping the intersection splits and cross street coordination normal.

The train route turns from Pacific Avenue at South 25th Street. The trains in both directions preempt the signal into an all red interval to allow the turn. The all red interval can extend longer than the cycle if all pedestrian phases are called, causing the signal to break coordination and transition back into coordination during the next two phases.

The unique preempts on the Pacific Avenue extension are close to the normal signal cycling. The minor timing changes occurring during preempts only occur once in each direction every eight cycles. These changes are not significant enough to change the levels of service.

Additional Timing Patterns

The existing timing pattern supports light rail trains progressing through their route without stopping at any traffic signal as long as they remain on their strict schedule. If they get off of their schedule, they may progress 90 seconds late on the following signal cycle. The end of the route provides opportunity to get back on schedule. The layovers average about three minutes on the end of each train run.

Additional timing patterns will use many of the same parameters used by the existing timing pattern. The signal splits, train travel times, train headways, and cycle lengths will likely remain the same. However, it is possible that part of the system could operate on 120 second cycles with a repetitive cycle for the trains every 360 seconds. The most likely pattern changes will have different train dwell times at stations to decrease train travel times during off peak hours. Additionally, new patterns could support special events for large conventions that triple pedestrian activity and fill trains to capacity. Sound Transit operator supervisors monitor train operation closely and can identify the need for new traffic patterns. These supervisors can also determine station dwell times in each direction for specific signal patterns during any part of the day or week.

Existing splits with the 90 second cycles in the CBD grid are adequate for variations in traffic volumes. However, the new signal equipment will provide flexibility for major changes caused by new office buildings or extensions to the light rail system. Once the new software is in place for the City of Tacoma, the ability to run different time of day plans as well as event plans will create an extremely robust system for the City of Tacoma and its transit services.

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