Using Simulation to Evaluate Traffic Signal Preemption at Railway-Highway Grade Crossings

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Abstract
This paper describes the development of highway traffic signal timing plans used at railroad-highway grade crossings. Both pro-active controls and preemptive controls are considered. A widely used highway traffic simulation program was extended to include railroad-highway grade crossings. The use of simulation to evaluate the alternative control schemes is demonstrated. The presentation of results in the form of animated 2-D graphics facilitates the evaluation and enhances communication. Also, 3-D graphics, including accurate representations of railroad and highway vehicles, can be used to enhance the analyst’s ability to communicate with non-technical audiences.

Background: Why Worry About Highway Traffic

Railway-highway grade crossings have been in the news lately because of several crashes between highway vehicles and trains. These highway vehicles have included cars, trucks, and school buses. Consequences to railroads include the following

- Damage to railroad property, both fixed plant and equipment (locomotives, freight cars)
- Damage to railroad customer property
- Delays to customer shipments - both on the involved train and other trains
- Risk of injury and death to railroad employees
- Additional hours required to investigate and clear the site
- Potential liability to the railroad
- Adverse public image of railroads and railroad safety
- Potential for regulation and additional burdens associated with grade crossings
- On tracks with passenger trains, risk of injury and death to railroad passengers
Delays to railroad passengers on this and other trains
There are a variety of causal factors, *e.g.*, risk takers illegally choosing to ignore active warning devices. One cause of particular note is innocent motorists stopped on railroad tracks because of spillback from nearby signalized intersections. (Often, motorists cannot perceive, before they enter the crossing, that there is insufficient room downstream for them to clear the crossing before they join a queue spilling back from a downstream traffic signal.) This paper discusses this topic in some detail.

Another situation that warrants concern is where traffic signal timing at a highway-highway intersection in the vicinity of the highway-railroad grade crossing is suboptimal. One might ask why should railroad engineers and officials be concerned about the optimality of traffic signals. One answer is the less unnecessary waiting there is after a train has passed, the less likely motorists are to attempt to violate the warning devices before the train arrives.

**Why Use Simulation**

Computer simulation is a tool that can facilitate analysis of systems that cannot readily be analyzed by other means. Simulation, by itself, typically does not contain an optimization algorithm. Rather, it “shows” how well a proposal will or will not work. This is accomplished by using Measures of Effectiveness (MoE) that are selected to evaluate a particular project or kind of project.

Simulation, which represents “what if” in terms of how a particular scheme or alternative would work, is not an optimization routine. Rather, with the human as part of the process loop, successive iterations could result in improvements to the Measures of Effectiveness.

Highway traffic simulation, because of the large number of vehicles usually included, was often accomplished with macroscopic models. However, the increasing speed, the increasing capacity, and the declining prices of computers has made microscopic simulation largely the norm. Microscopic simulation means that each vehicle is moved individually, typically updated at least once each second. Since each vehicle is modeled, the variations in performance between, for example, passenger automobiles and trucks, is explicitly modeled.

As the real world contains random variations, microscopic simulation models must - if they are to accurately reflect reality - contain stochastic features. Thus, for example, if two motorists are driving the same type of vehicle with identical
performance, a stochastic model recognizes that one motorist is likely to be more aggressive than the other.

Thus, with a microscopic, stochastic computer simulation model, the performance of highway vehicles - and railroad vehicles - and their interactions can be accurately and realistically shown.

The WATSim Model

KLD Associates had developed a microscopic, stochastic computer simulation model for the U.S. Federal Highway Administration. This model simulates traffic on street networks and was named NETSIM. (As it is part of FHWA’s TRAF package of models, it is also called TRAF-NETSIM.) Licensed copies of the model are available for purchase through McTrans at the University of Florida. The model is widely used by traffic engineers at consulting firms and transportation departments of states, cities, counties, and other jurisdictions.

KLD extended the NETSIM model into the Wide Area Traffic Simulation Model, or WATSim. The original impetus for this extension was to able to simulate traffic on freeways as well as streets with one consistent model. In addition, a number of features have been added, including highway and railroad traffic at grade crossings. Capabilities now include the following:

- Streets and arterials, including networks
- Freeways, including entrance and exit ramps
- Ramp metering on freeway entrance ramps, including queue bypass lanes for buses or buses and other high occupancy vehicles (HOV’s)
- Exclusive bus lanes or bus/HOV lanes on streets or freeways
- Light rail transit, in exclusive or shared right-of-way
- Railroad-highway grade crossings
- Traffic signal priority for transit - bus and light rail
- Traffic signal preemption for emergency vehicles or at railroad grade crossings
- Toll plazas with full service, exact change, electronic toll collection, or any combination
Airport and other (passenger) intermodal terminal frontage roads (The model could readily be extended to intermodal freight yards.)

Animation in two dimensions (termed “2-D”) is produced by TRAF-NETSIM and has been incorporated into WATSim. A major enhancement is the capability to produce 3-D visualizations of traffic with these models. Unlike other visualization software known to the authors, KLD’s visualization contains accurate vehicle movements and reflects traffic signal and grade crossing signal conditions since they are “driven” by the simulator. We have found that the 2-D animation has two benefits: (1) It facilitates the evaluation since problem locations can usually be readily spotted by eye much more readily than can problems be identified by scanning output consisting of various MoE. (2) It facilitates communication with both technical and non-technical audiences as people can literally see how a particular alternative or scheme would perform under the specified conditions. The 3-D animated visualization - which we regard as the ultimate form of communications - can vastly improve the effectiveness of any type of public outreach program which seeks to involve the community in understanding a proposed transportation project, e.g., closing a grade crossing.

CASE STUDIES

The following is a description of two case studies where we used simulation to evaluate highway traffic operations at grade crossings. Then we will discuss the concept of proactive controls and distinguish them from preemptive control and signal priority.

Case Study 1: Port of Long Beach

Figure 1 presents the unusual geometry at the grade crossing at the entrance to the Port of Long Beach, California. Henry Ford Avenue is a key vehicular thoroughfare. This intersection, in addition to Henry Ford Avenue and the access to the port and egress from the port, also contains a freeway on-ramp and off-ramp. In the middle of this intersection is the at-grade railroad crossing. The crossing is used by long, slow freight trains which can require up to ten minutes to clear the crossing.

The objective of this study was to implement the signal preemption policy and identify any instances where vehicular / train conflicts occur. In addition to extending the WATSim simulation model to add grade crossings, we customized the graphics to add flashing red signals to represent the active warning devices.
We simulated the grade crossing for a one hour period, encompassing the range of daily traffic variation and the inbound and outbound train schedules. We confirmed that the proposed traffic signal preemption policy did not allow vehicle / train conflicts.

Although the objective of this project was to assess the possibility of vehicle / train conflicts, the simulation gave us important information concerning traffic operations in this area. The analysis based on simulation showed no apparent problems if there were no trains occupying the crossing. All traffic on all of the approaches was flushed every traffic signal cycle.

When the freight train approached the intersection, the traffic signals controlling the numerous approaches to this complex grade crossing began to transition to their preemption settings. Vehicles were stopped prior to the grade crossing at the same time as vehicles in the conflict zone were flushed from the tracks. Vehicles arriving at the grade crossing began to queue in response to the preemption traffic signal settings. The long slow freight train required nearly ten minutes to clear the crossing.

By this time, there were significant queues on all approaches. Also, some queues took much longer than others to clear. Of particular note is the queue on the freeway off-ramp. This queue which spills back onto the freeway mainline - like any queue on a freeway that blocks some lanes, but not others - represents a significant safety issue with high-speed vehicles next to queued vehicles.

After the train cleared the grade crossing, all traffic signals reverted to their normal operation. The queues, which had grown during train passage, began to discharge at the maximum rate allowed by the normal signal timing plan. However, shortly after all of the queues fully discharged, the following train arrived. Until the queues fully discharged, the highway traffic at the grade crossing was operating under what is termed “oversaturated (i.e., congested) conditions.” This important finding could only be discovered by simulation rather than any other type of analysis.

As a result of this finding, we recommended to the agency that controls the highway traffic signals that, after the passage of a train, the traffic signals should transition to a phase plan which maximizes queue discharge rather than the normal timing plan. After the queues fully discharge, the signals could revert to their normal operation.
In this particular case, we were able to use simulation to improve traffic signal timing to achieve two objectives:

(1) Eliminate queues on all of the approaches sooner.
(2) Eliminate the queue on the freeway off-ramp - or at least the spillback onto the freeway mainline - first, rather than last.

Case Study 2: Vista - San Diego

The impetus for this study was the development of a major recreational complex in the town of Vista California, north of San Diego. This site is served by three transportation modes: automobiles, public transit buses, and two car commuter trains which cross streets at-grade. A transit center services buses arriving from all directions as well as the commuter trains. Figure 2 presents a frame capture showing the Vista Transit Center, two railroad grade crossings - one on Vista Village Drive and one on Main Street - and the surrounding surface street network.

The purpose of the study was to assure local officials that the grade crossing signal timing policy would preclude any highway vehicle from crossing the tracks as the train approached.

We used simulation to test traffic signal timing. Specifically, we employed a combination of three measures:

(1) Have the downstream signal turn green to flush the queue that spills back onto the crossing.
(2) Have an upstream signal go red to prevent additional vehicles from entering the crossing.
(3) Have turn signals go red for the same reason.

Preemptive and Proactive Controls

As noted above, collisions between trains and highway vehicles at actively controlled grade crossings are generally caused by (1) violations of grade crossing controls or (2) the presence of queued vehicles on the tracks - spillback. Spillback can trap one or more vehicles on the tracks during the approach of a train. This condition can be addressed either by a preemptive signal policy, or a combination of preemptive and proactive signal control policies.

A preemptive traffic control policy is initiated upon the detection of an approaching train. When the train is detected, active grade crossing warning devices (i.e., flashing lights, bells, and sometimes gates) are activated. In addition,
where there is a downstream signalized intersection that can develop a queue that spills back upstream across the tracks, this downstream traffic signal can transition to a preemptive phase which permits the queue to discharge sufficiently to clear the tracks. This typically requires an additional track circuit to detect the train before the normal active crossing devices are activated.

If the vehicle queue is long enough, then the preemptive signal control of the downstream intersection, initiated by the detection of the train, may not be sufficient to clear the tracks. Figure 3 presents such a scenario.

A proactive control would prevent vehicles from proceeding onto the tracks if there is insufficient room for them to safely queue on the roadway segment which is downstream of the tracks. Such a policy would not be initiated by the detection of a train, but rather it would be operational at all times.

The proactive control policy operates as follows: Using a vehicle detector, occupancy can be measured on the roadway segment downstream of the tracks. As queuing grows on this roadway segment, the occupancy measured at the detector will increase. At some threshold value, the vehicle traffic signal, placed upstream of the tracks, will transition to a red indication, preventing additional vehicles from crossing the tracks.

The threshold values used in the preemptive and proactive control policies are the result of site specific geometries and conditions. The use of simulation to test the traffic signal control policy - whether preemptive or proactive - in a realistic environment is strongly recommended. Among the issues which can be investigated are the location of the train detectors, the location of the vehicle occupancy detector, the numeric value of the vehicle occupancy which triggers a response, and the specific traffic signal control patterns which result from the preemptive and proactive strategies.

Spillback of highway onto railroad tracks at a grade crossing can occur whenever there is a signalized intersection near a grade crossing. However, we find that there is a relatively common phenomenon: A highway is parallel to a railroad track or set of tracks. There are cross streets that cross the track or tracks at grade and have signalized intersections with the highway that parallels the track or tracks. Spillback from these signalized intersections onto the grade crossing can occur at each of these intersections. Thus, there is often a need to use simulation to analyze the set of signalized intersections along a highway that parallels a track.
Depending on the specific values of several parameters, different remedies are appropriate. The parameters that affect the selection of appropriate action include the following:

The distance between the signalized intersection and the railroad grade crossing.
The number of motor vehicles traveling from the crossing to the signalized intersection.
The number of lanes from the grade crossing on the approach to the signalized intersection.
The traffic signal cycle time and the percent of the time each approach has a green signal.
The traffic volume on the street paralleling the track.
The time between the detection of the train and its arrival at the grade crossing.

**Preemption vs. Priority: What About Light Rail**

The discussion above distinguished between preemptive control and proactive control. It is also important to distinguish between Priority and Preemption. We find in our practice that these terms are often used interchangeably - which is incorrect - when discussing preferential treatment for transit vehicles, including light rail.

Preemption, as should be clear from the discussion above, is when an immediate action is taken upon the detection of some event. For example, the detection of a train approaching a grade crossing causes active highway traffic control devices to become activated; this is preemption. Some communities have installed preemptive systems for emergency vehicles to be given the right-of-way; this is another example of signal preemption. By contrast traffic signal priority is a less intrusive system. We have used simulation to study traffic signal priority schemes. For SEPTA, the commuter rail and transit agency in the Philadelphia, Pennsylvania area, we have looked at extending the traffic signal green phase, or truncating the cross street green phase, to expedite light rail transit. In some cases, there can be both signal preemption and signal priority. For example, the light rail system operated by the RTD in Denver has signal preemption at grade crossings outside the downtown area and is expected to have signal priority within the downtown area.

**Conclusions**
Simulation can be a very helpful tool to evaluate traffic signal preemption and the need for proactive upstream signal controls when traffic approaching a signalized intersection can spill back across railroad tracks at a grade crossing. We have extended the WATSim simulation model to enable this type of evaluation. In addition to the statistics (measures of effectiveness) produced by the simulation models for evaluation, the animation can facilitate the evaluation and provide valuable communications. Furthermore, the capability to produce 3-D visualization can further facilitate communications with public officials, the media, and the general public.

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The above does not contain the graphics. I simply could not get the Windows clipboard to copy them from WordPerfect to my e-mail software for transmittal to you. I am overnighting the paper with bios to you.

Thanks for your cooperation and assistance - and patience.

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