SIMULATION-FREE RAILROAD GRADE CROSSING DELAY CALCULATIONS

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ABSTRACT

To prioritize potential improvements at 33 grade crossings in Los Angeles County's San Gabriel Valley, the Alameda Corridor East Construction Authority required calculations of delay to motorists blocked by the passage of freight, commuter rail, and Amtrak trains. Blockages were observed to occur as much as 80 times per day at some locations. The roadway configurations ranged from simple isolated crossings to complex crossings with preempted traffic signals on one or both sides. A quick estimation of delay was needed for this level of study. Webster's model of uniform delay was ideal for the simpler crossings. However, for a complex crossing featuring preemption of adjacent traffic signals, the Webster formula was believed to underestimate the delay endured by motorists waiting not only at crossing gates but at preempted traffic signals as well. Microsimulation could estimate delay at such preempted crossings, but this project's time and budget constraints prevented its use.

Instead, a quick estimation method was developed after collecting 24-hour video recordings at 33 crossings, observing how traffic signals and the motoring public reacted to each blockage event, and applying modifications to the Webster formula's saturation flow rate. These modifications used parameters obtainable by video like upstream traffic signal phasing and downstream signal green-to-cycle ratios. The resulting spreadsheet instantly calculated delay for the dozens of blockage events occurring each day. The videos served as high-quality event recorders, providing accurate gate-down times so every individual event throughout the day had its own delay calculation. The spreadsheet and videos combined to provide an economical and reasonably accurate delay methodology for a prioritization study.

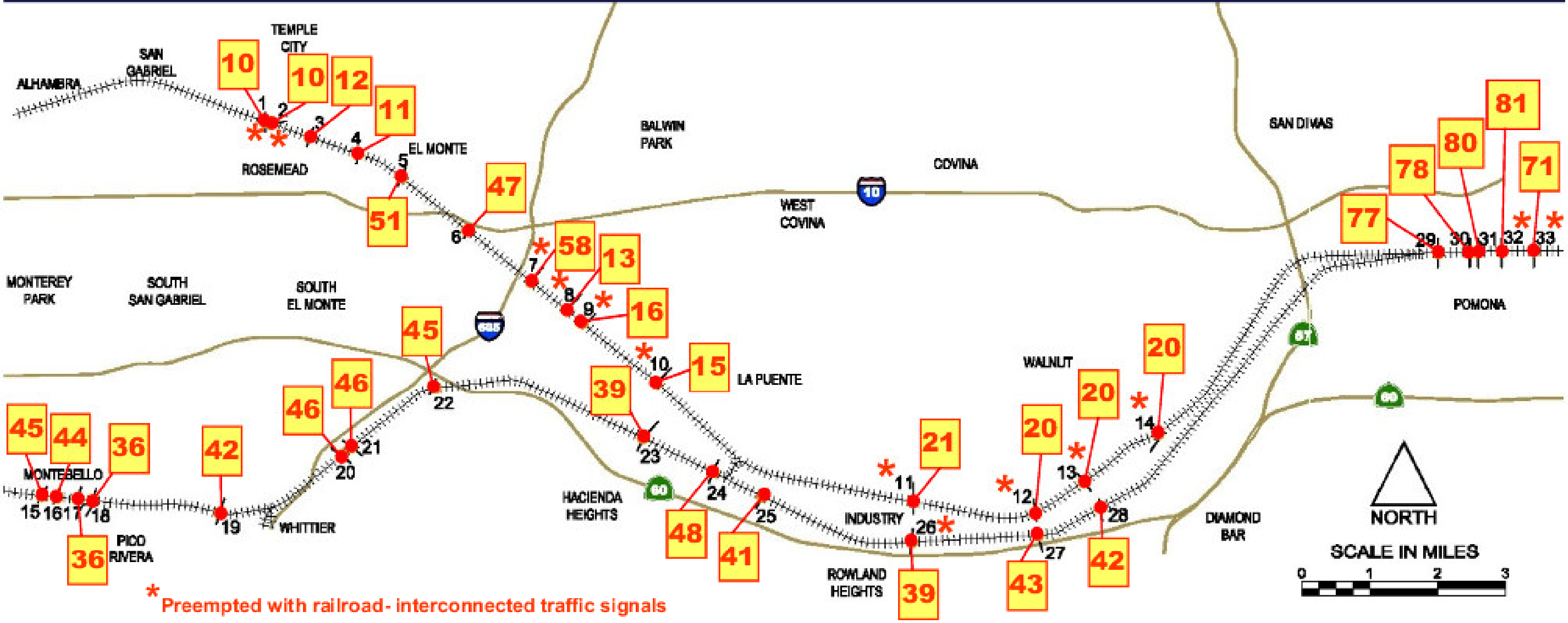
INTRODUCTION

The Alameda Corridor East Construction Authority is in the process of prioritizing potential grade separations at 33 railroad-highway crossings along two rail lines owned by the Union Pacific Railroad in the San Gabriel Valley region of Los Angeles County. Freight, Amtrak intercity, and Metrolink commuter trains use these crossings, causing delay to motor vehicle traffic on the cross streets. The Authority desired estimates of vehicle delay at the grade crossings, both under existing conditions and with future projections of motor vehicle traffic, as measures for prioritizing improvements.

The crossing locations are shown on the map in Figure 1, along with the counts of crossing activities causing railroad gates to block traffic that were recorded on a typical weekday in September 2009.

FIGURE I
EXISTING 2009 RAIL TRAFFIC VOLUMES

● — X Total Daily Railroad Events



* Preempted with railroad- interconnected traffic signals

UPRR Alhambra Subdivision Grade Crossings

1) Encinita Ave., Temple City/Rosemead
2) Lower Azusa Rd., Temple City/Rosemead
3) Temple City Blvd., El Monte/Rosemead
4) Arden Dr., El Monte
5) Tyler Ave., El Monte
6) Cogswell Rd., El Monte
7) Temple Ave., Industry/LA County
8) Vineland Ave., Industry/LA County
9) Puente Ave., Industry/LA County
10) California Ave., Industry/LA County
11) Fullerton Rd., Industry/LA County
12) Fairway Dr., Industry/Walnut
13) Lemon Ave., Industry/Walnut
14) Brea Canyon Rd., Industry/Walnut

UPRR LA Subdivision Grade Crossings

15) Vail Ave., Montebello
16) Maple Ave., Montebello
17) Greenwood Ave., Montebello
18) Montebello Blvd., Montebello
19) Durfee Ave., Pico Rivera
20) Rose Hills Rd., Industry/LA County
21) Mission Mill Rd., Industry/LA County
22) Workman Mill Rd., Industry/LA County
23) Turnbull Canyon Rd., Industry/LA County
24) Stimson Ave., Industry
25) Bixby Dr., Industry
26) Fullerton Rd., Industry
27) Fairway Dr., Industry/LA County
28) Lemon Ave., Industry/Diamond Bar

Both Subdivision Grade Crossings (Downtown Pomona)

29) Hamilton Blvd., Pomona
30) Park Ave., Pomona
31) Main St., Pomona
32) Palomares St., Pomona
33) San Antonio Ave., Pomona

This study represents Phase II of grade crossing analyses for the Alameda Corridor East. The 1997 Phase I study[1] analyzed many of the same crossings using deterministic queueing theory. This methodology has long been in use for analyzing delay at grade crossings, including in a 1982 study by J.L. Powell.[2] The general methodology used for the delay analysis was based on Webster's model of uniform delay, derived from classical deterministic queueing theory. It should be noted that while this queueing model is applicable for isolated grade crossing locations, it tends to underestimate delay at crossings that are preempted with railroad interconnected traffic signals. For crossings that are interconnected with preempted traffic signals, a more enhanced methodology was used for this study. The alternative methodology takes into account traffic signal operations during preemption, including the number and duration of phase sequences after the passage of trains through the crossings.

DATA COLLECTION

Video recordings were taken at each of the 33 crossings on a typical weekday. The observed grade crossing activity ranged from a low of 10 to as high as 81 per day. Approximately 1,300 crossing activities were captured in a 24-hour period. The videos captured a mix of freight, Amtrak, and Metrolink trains, as well as road-rail maintenance trucks operating upon the rails. The video recordings also captured several occurrences of gates dropping where no rail vehicles were observed, possibly due to nearby switching activities. The duration of crossing blockages ranged from a few seconds to 53 minutes. In the longest incident, a train was parked after midnight stretching across 3 crossings for almost an hour.

MODELING ISOLATED CROSSINGS

Most of the grade crossings were somewhat isolated from traffic signalized intersections, thus making them well-suited for use of a mathematical model such as the Webster uniform delay model, which is based on classical deterministic queueing theory. Total vehicle delay caused by each blockage event is calculated using the formula below:

$$\mathbf{D = [AR * Q * (B + LT)]/2}$$

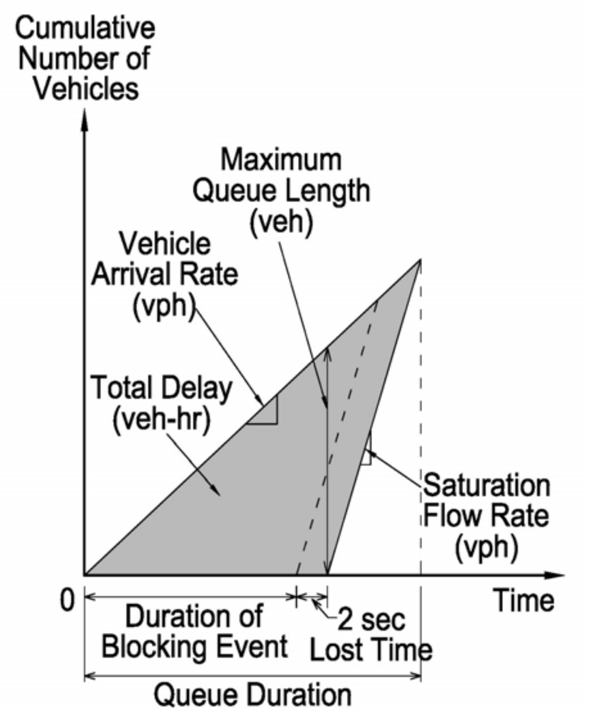
Where:

D = Total delay in vehicle-hours
B = Duration of blockage event in hours
AR = Vehicle arrival rate in vehicles per hour
LT = Lost time in hours
Q = Queue Duration in hours

Queue duration is the period starting when the gates begin their descent and ending when the vehicles queued at a crossing dissipate after a gate blockage event. Queue duration is estimated based on the following formula:

$$Q = \frac{\text{(Blockage Event Duration + Lost Time)}}{\text{[1 - (Arrival Rate / Saturation Flow Rate)]}}$$

The delay can be represented graphically as the area of the triangle in the following figure:



The vehicle delay is calculated for each blockage event and for each direction recorded during a day. The total daily vehicle delay is the summation of these vehicle delay calculations throughout the day.

Because the mathematical model relies on only a few parameters, such as motor vehicle traffic, duration of the blockage, and the saturation flow for departing vehicles once the blockage is removed, delay is easily calculated for a given direction of traffic. The formula fits in a cell of a computer spreadsheet.

The frequency and duration of the crossing gate blockage events were obtained from video recordings conducted in September 2009. Through review of the video recordings, it was observed that vehicles continued to traverse through the crossing when the warning lights flashed, but vehicles generally did not traverse through the crossing after the gate arm began to drop. It was also observed that the first vehicles in the queue began to traverse through the crossing as soon as the gate arm began to rise. Thus, for the delay analysis, the gate blockage event duration is considered to be the time when the gate arm begins to drop until the gate arm begins to rise. In most cases, a single train was observed to traverse through the crossings during the blockage events. In some instances, two or more trains traversed through the crossing on different tracks during a single blockage event.

Vehicular arrival rate is the number of vehicles arriving at the grade crossing within an identified time period. The arrival rate is based on the traffic count data collected with video recordings in September 2009 at each crossing over a 24-hour period. For the purpose of calculating delay (vehicle-hour) at the rail crossings during a gate blockage event, the vehicular arrival rate was assumed to be the number of vehicle arrivals during the hour when the gate was down.

Vehicular saturation flow rate is the maximum rate of vehicles for a lane group to traverse the crossing immediately after a gate blockage event. This rate excludes any start-up lost time vehicles experience prior to queue dissipation after the end of a gate blockage event. Based on traffic flow observations, a saturation flow rate of 1,700 vehicles per hour per lane (vphpl) was observed at isolated crossing locations.

Lost time is the difference between the time the gates rise and saturation flows stabilize, which from review of the video recordings was found to be 2 seconds. The lost time was added to the total blockage event duration.

Maximum total queue is the maximum number of vehicles waiting at the crossing, which occurs at the end of the blockage event duration plus the lost time period.

ADJUSTMENTS FOR PREEMPTION

For crossing locations with traffic signal preemption, the saturation flow was adjusted in to account for the disruptive effects of preemption. The traffic signal operations during preemption were observed from the video recordings for the 13 preempted crossing locations in the study area. Preemption sequences can become extremely complicated, seemingly defying simplification into a mathematical model. The preemption sequence includes track clearance phases, limited service phases or flashing red operation, and recovery after the end of preemption. The recovery period, in particular, is complicated because it is highly dependent on the detection of vehicles and pedestrians after the event. As a result, a microsimulation of the traffic signal controllers appears desirable for delay analysis at crossings involving preemption. However, microsimulation was deemed infeasible due to expense and time constraints.

Instead, the effects of preemption were modeled through a modification of the saturation flow rates. The number and duration of signal phases were observed and used to adjust the saturation flow rate.

Based on observations of traffic flow, a saturation flow rate of 1,500 vphpl, 1,425 vphpl and 1,375 vphpl was used for a preempted crossing location that has an upstream traffic signal with 2, 3 and 4 critical signal phases, respectively. These saturation flow rates were based on the Critical Movement Analysis planning method from Transportation Research Circular 212[3]. The intent of these more restrictive saturation flows was to provide a measure of additional delay incurred by motorists who were held at the upstream signal, because the delay appears to be related to the complexity of signal phasing.

For a crossing location with signal preemption downstream, the saturation flow rate was based on the g/C ratio (the effective green time divided by the cycle length of the traffic signal) after a gate blockage event. This ratio is the proportion of time that allows vehicles to pass through the crossing and the downstream intersection. This factor takes into account the bottleneck that could occur at a downstream signal. To account for the randomness that could occur after preemption, it was assumed that the base saturation flow rate for a crossing with signal preemption downstream is the average of the base saturation flow rate for an isolated crossing (i.e. 1,700 vphpl) and the same base saturation flow rate times the g/C factor.

For a crossing with both upstream and downstream signal preemption, the lesser of the upstream and downstream base saturation flow rates was used.

The number of buses and heavy vehicles also affects the saturation flow rate because these vehicles are typically slower than passenger and other non-heavy vehicles. The saturation flow rate at the crossing locations was adjusted for buses and heavy vehicles using a passenger-car-equivalent (PCE) factor of 2.0 based on traffic flow observations.

AN EXAMPLE: GRADE CROSSING WITH UPSTREAM AND DOWNSTREAM PREEMPTION

The Fullerton Road crossing of the Los Angeles Subdivision in the City of Industry is presented here as an example of the adjustments made to account for preemption. Two Union Pacific Railroad tracks cross Fullerton Road, which has two lanes in each direction. This crossing represents the most complicated scenario, with a preempted signal at intersections on each side of the crossing. As a result, adjustments for both an upstream and downstream preempted signal were applied to delay calculations for each direction of motor vehicle travel. The calculation sheet for the northbound direction is provided as Table 1.

For example, the 20th blockage event was caused by a single freight train at about 12:04 PM on Tuesday, September 1, 2009. The observed blockage duration was 232 seconds. The arrival rate during the hour when the blockage event occurred was 738 vehicles, and it is assumed that arrival rate stayed uniform throughout the event. The upstream signal was controlled by an 8-phase signal, i.e. 4 critical phases. The downstream signal had an observed g/C ratio of approximately 0.5.

Because of the presence of preempted signals both upstream and downstream, two saturation flow rates were calculated. The base saturation flow rate resulting from the upstream preemption was 1,350 veh/hr/lane, due to the upstream signal having 4 critical signal phases. If the upstream signal phasing were simpler, the base saturation flow would have been higher at 1,425 to 1,500 veh/hr/lane.

The base saturation flow rate resulting from downstream preemption was the arithmetic average of the isolated saturation flow rate of 1,700 vphpl and the adjusted saturation flow rate multiplied by the g/c ratio of 0.5, i.e. 1700*(1+0.5)/2, resulting in a value of 1,275 veh/hr/lane. Note that the downstream preemption results in the saturation flow being only 75% of that for an isolated crossing. Using the lesser of the two base saturation flow rates, i.e. 1,350 versus 1,275 vphpl, yields an adjusted base saturation flow rate of 1,275 vphpl.

TABLE 1: Sample Delay Calculation

KOA CORPORATION

RAILROAD CROSSING DELAY ANALYSIS

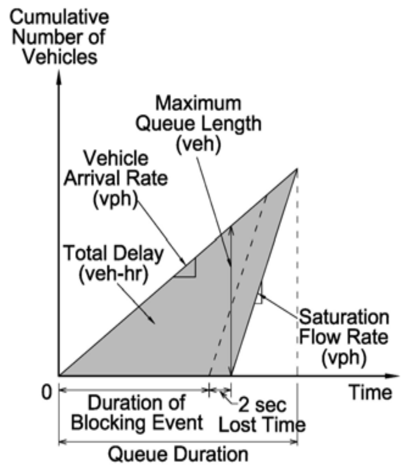
Street: Fullerton Rd @ Los Angeles Subdivision Crossing

Crossing Number: 810880T
Nearest Cross Street: Railroad St/Gale Ave
Location: Industry
Type of Crossing: Pre-empted
Traffic Condition: Existing (2009)

Direction: Northbound
Daily % Heavy Vehicles: 5.8%
No. of Lanes: 2
Date: 9/1/2009
Day: Tuesday

Traffic Signal Upstream: Yes
No. of Critical Phases (Upstream): 4
Traffic Signal Downstream: Yes
g/C (Downstream): 0.5

Gate Blockage Event	Start of Gate Blockage Event	Duration of Blockage Event (sec)	Blockage Type (sec) [1]	Lost Time (sec)	Arrival Rate (vph) [2]					Saturation Flow Rate (vph) [4]	Maximum Total Queue (veh)	Queue Duration (sec)	Total Delay (veh-hr)
					Other Vehicles [3]	School Buses	Public Buses	Trucks (4+ Axles)	Haz-Mat Trucks				
1	0:10:13	218	a	2	95	0	0	13	0	2410	7	230	0.211
2	0:33:45	97	a	2	95	0	0	13	0	2410	3	104	0.043
3	0:39:10	90	a	2	95	0	0	13	0	2410	3	96	0.037
4	1:04:30	93	a	2	58	0	0	14	0	2410	2	98	0.026
5	1:49:40	56	a	2	58	0	0	14	0	2410	1	60	0.010
6	2:01:50	90	a	2	40	0	0	7	3	2410	1	94	0.017
7	2:26:40	136	a	2	40	0	0	7	3	2410	2	141	0.038
8	4:12:20	70	a	2	149	0	0	10	3	2410	3	77	0.035
9	4:15:58	189	a	2	149	0	0	10	3	2410	9	205	0.245
10	4:35:12	54	a	2	149	0	0	10	3	2410	3	60	0.021
11	5:03:18	98	a	2	149	0	0	10	3	2410	5	107	0.067
12	5:29:49	34	e	2	149	0	0	10	3	2410	2	39	0.009
13	6:29:28	33	e	2	385	2	0	18	0	2410	4	42	0.023
14	7:02:00	31	e	2	630	3	1	41	1	2410	6	46	0.040
15	7:44:45	34	e	2	630	3	1	41	1	2410	7	50	0.047
16	8:30:23	172	a	2	820	0	0	35	5	2410	42	271	1.565
17	8:50:24	148	a	2	820	0	0	35	5	2410	36	233	1.160
18	9:04:00	32	e	2	634	0	1	35	3	2410	6	47	0.041
19	11:39:29	152	a	2	570	0	0	60	2	2410	27	209	0.785
20	12:04:34	232	a	2	680	0	0	55	3	2410	48	337	2.245
21	12:51:42	156	a	2	680	0	0	55	3	2410	32	228	1.026
22	13:08:47	538	a	2	766	1	0	32	1	2410	120	808	13.467
23	13:42:44	44	e	2	766	1	0	32	1	2410	10	69	0.098
24	14:51:41	78	a	2	762	1	0	46	1	2410	18	121	0.303
25	16:00:05	100	e	2	732	0	1	42	3	2410	22	151	0.462
26	16:45:35	40	e	2	732	0	1	42	3	2410	9	62	0.078
27	17:24:58	41	e	2	772	0	0	24	3	2410	10	64	0.085
28	17:56:53	40	e	2	772	0	0	24	3	2410	9	63	0.082
29	18:37:08	92	e	2	709	0	0	29	1	2410	19	136	0.364
30	19:05:52	53	e	2	557	0	0	19	3	2410	9	72	0.088
31	19:34:51	105	a	2	557	0	0	19	3	2410	17	141	0.337
32	20:10:06	51	a	2	486	0	0	18	1	2410	7	67	0.069
33	20:39:23	94	a	2	486	0	0	18	1	2410	13	121	0.226
34	20:43:58	70	a	2	486	0	0	18	1	2410	10	91	0.128
35	21:27:00	189	a	2	298	0	0	23	1	2410	17	220	0.522
36	21:41:35	192	a	2	298	0	0	23	1	2410	17	224	0.540
37	22:07:43	100	a	2	257	0	0	18	1	2410	8	115	0.125
38	22:39:52	76	a	2	257	0	0	18	1	2410	6	88	0.073
39	23:12:45	87	a	2	201	0	0	12	1	2410	5	98	0.072
Total													**24.810**



[1] a = Freight Train; b = Amtrak; c = Maintanence Truck; d = Switching Activity; e = Metrolink

[2] The arrival rate shown is the expected arrival rate of vehicles during the hour when the gate is down.

[3] Includes all vehicles excluding school and public buses, 4-plus-axle trucks and hazardous material trucks.

[4] The saturation flow rate was adjusted for traffic signal pre-emption at the crossing location, and to take into account buses and other heavy vehicles using a passenger-car-equivalent (PCE) factor of 2.0.

Heavy vehicles make up approximately 5.8 percent of the northbound traffic at the crossing. Application of a passenger-car-equivalent factor of 2.0 to adjust the saturation flow rate in order to account for heavy vehicles, and multiplying by the two lanes available results in a saturation flow rate of 2,410 vph, as calculated below:

Saturation Flow Rate due to preemption =

(1275 x 2 lanes) / [(1 - 0.058) + (0.058 x 2.0)] = 2,410 vph

The next step was to determine the queue duration in hours, which is based on the blockage event duration, lost time, arrival rate and saturation flow rate, as shown in the formula below:

$$\text{Queue Duration} = \frac{(\text{Blockage Event Duration + Lost Time})}{[1 - (\text{Arrival Rate / Saturation Flow Rate})]}$$

= (232 sec + 2 sec) / [1 – (738 vph / 2410 vph)] = 337 sec

The queue clears 337 seconds after the start of the blockage event, or 105 seconds after the gates rise.

The vehicle delay is based on the arrival rate, queue duration, blockage event duration and lost time, as shown in the formula below:

Vehicle Delay =

[Arrival Rate x Queue Duration x (Blockage Event Duration + Lost Time)] / 2 =

[738 vph x (337 sec x 1 hr / 3600 sec) x ((232 sec + 2 sec) x 1 hr / 3600 sec)] / 2

= 2.245 vehicle-hours

If no adjustment for preemption had been applied, the vehicle delay would have been calculated as 1.991 vehicle-hours.

Similar calculations were applied to the 38 other northbound blockage events that occurred that day, and for the events in the opposite (southbound) direction.

RATIONALE FOR ADJUSTMENT

The main consideration for any adjustment method was that it be sufficiently simple to be run from a spreadsheet with only a few variables. For this reason, delay that occurs at preempted signals upstream and downstream, i.e. at locations other than the crossing, has been added to the queued delay at the crossing by reducing saturation flows rates. During the course of this study, an alternative method to perform queueing analysis for the upstream and downstream signals was considered, but discarded due to its higher complexity with questionable improvements in accuracy.

FOR FURTHER STUDY

The adjustments made to saturation flows for preemption gave resulting vehicle delays that were reasonably consistent across the 13 preempted crossings, and with the queueing that could be seen from the collected video recordings. However, calibration was not possible for this project due to the lack of complete data. In particular, the activity at the adjacent signalized intersections could not be observed with just two cameras. Calibration would require more cameras to capture all approaches at preempted traffic signals, which would have allowed for further verification of such factors as the base saturation flow rates and the factors adjusting for g/C ratios. For the purposes of this project, however, the delay results appear to be satisfactory in relation to the results that would have been obtained if the crossings were assumed to be isolated.

For grade crossing analysis, microsimulation cannot be ruled out. With sufficient time and budget, a microsimulation model that accurately simulates the functions of a traffic signal under railroad preemption is probably the best available method for determining vehicle delay. However, taking shortcuts such as performing a single microsimulation for an average blockage time and scaling the delay in proportion to the actual blockage time should be discouraged. Delay at a crossing does not grow linearly with blockage time; delay grows geometrically. Until the day arrives when such a simulation can be performed in seconds rather than hours, a mathematical model such as the one presented in this paper remains the most practical method for analyzing thousands of grade crossing activities for a screenline-level analysis.

REFERENCES

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