Genetic Algorithm Based Stochastic Optimization for Preempted Signals at Highway Railroad Grade Crossing

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16. Abstract

Decreasing the number of accidents at highway-railway grade crossings (HRGCs) is an important goal in the transportation field. The preemption of traffic signal operations at HRGCs is widely used to prevent accidents by clearing vehicles off the tracks before a train arrives. However, by interrupting normal traffic operations, preemption operations can contribute to congestion in highway traffic networks. This report presents a genetic algorithm (GA)-based stochastic optimization approach for preempted signals that is designed to minimize highway delays while improving safety. The first step of proposed method determines the preemption phase sequences that prevent the queue from backing on to the HRGC. The second step is to implement a GA-based algorithm to find the optimized signal phase lengths for reducing highway traffic delay. The GA-based Stochastic Optimization of Preempted Signals (GASOPS) model optimizes signal timing plans for both normal and preemption operations simultaneously, while current signal optimization models can optimize for only normal operations. Results show that the proposed approach is more efficient in signal optimization than traditional methods. This optimization approach reduces the delay by a maximum of 17% compared to optimal timing plans found using state-of-the-art methods. This model also improves safety because all queue lengths in GASOPS scenarios are 0, even when demand is doubled. This approach will be useful for designing and improving the preemption operations for signalized intersections near HRGCs.

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ABSTRACT

Decreasing the number of accidents at highway-railway grade crossings (HRGCs) is an important goal in the transportation field. The preemption of traffic signal operations at HRGCs is widely used to prevent accidents by clearing vehicles off the tracks before a train arrives. However, by interrupting normal traffic operations, preemption operations can contribute to congestion in highway traffic networks. This report presents a genetic algorithm (GA)-based stochastic optimization approach for preempted signals that is designed to minimize highway delays while improving safety. The first step of proposed method determines the preemption phase sequences that prevent the queue from backing on to the HRGC. The second step is to implement a GA-based algorithm to find the optimized signal phase lengths for reducing highway traffic delay. The GA-based Stochastic Optimization of Preempted Signals (GASOPS) model optimizes signal timing plans for both normal and preemption operations simultaneously, while current signal optimization models can optimize for only normal operations. Results show that the proposed approach is more efficient in signal optimization than traditional methods. This optimization approach reduces the delay by a maximum of 17% compared to optimal timing plans found using state-of-the-art methods. This model also improves safety because all queue lengths in GASOPS scenarios are 0, even when demand is doubled. This approach will be useful for designing and improving the preemption operations for signalized intersections near HRGCs.

INTRODUCTION

Crashes occurring at highway-railway grade crossings (HRGCs) have more potential for severe and serious consequences compared to crashes occurring among vehicles on highway crossings. During the past 10 years in the U.S., 9,898 people were injured and 3,056 people died in crashes at HRGCs [1]. As shown in Figure 1, the HRGC fatality rate during the past decade was one person for every 8.27 crashes. In 2012, 1,962 crashes occurring at HRGCs resulted in 233 fatalities and 932 injuries. Crashes, along with a lesser number of trespassing incidents, accounted for 95.16% of fatalities at HRGCs in 2012. Reducing the number of crashes at HRGCs is an important goal in the transportation field. Grade separation or relocating highways and railroads would eliminate hazardous HRGCs, but these intensive construction options entail high operational costs and user inconvenience. Preempting traffic signals is an economic alternative that does not involve construction and is widely used to prevent accidents at HRGCs by clearing vehicles from the tracks before a train arrives. However, by interrupting normal traffic operations, preemption can increase congestion in traffic networks. This report presents a traffic signal optimization approach designed to minimize the highway traffic delay while simultaneously improving safety under preemption conditions, as will be described in the following sections.

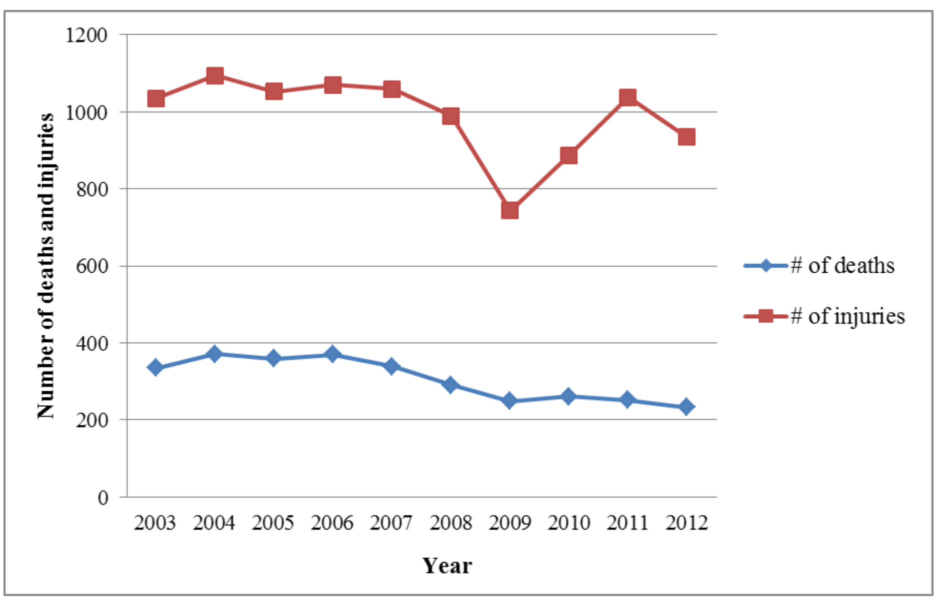


Figure 1: Numbers of deaths and injuries at HRGCs

LITERATURE REVIEW

Manuals and Guidance on Preemption Operation

The Manual on Uniform Traffic Control Devices (MUTCD) defines preemption as the transfer of normal operation of a traffic control signal to a special control mode of operation [2]. Preemption control gives the right of way to specified classes of vehicles such as trains, boats, emergency vehicles, and light rail transit [2-4]. Preemption control for trains is used to prevent crashes between trains and queued vehicles at crossings. MUTCD provides guidance for traffic control signals at or near HRGCs, stating that the traffic control signal should have a preemption option if an HRGC is equipped with a flashing-light signal system and is located within 200 feet of an intersection controlled by a traffic control signal. If the signalized intersection is located farther than 200 feet from the HRGC, coordination with the flashing-light signal system, queue detection, or other alternatives should be considered. Most traffic signal control manuals and guidebooks follow this MUTCD guidance for preemption operation. More guidelines about preemption operation are introduced in the Results section of this report.

Preemption Studies

Preemption operations at HRGCs promote safety by giving the right of way to trains, but such operations can increase the delay on the highway by interrupting normal traffic operations. Some studies attempted to address this problem. Zhang et al. [5] developed the signal optimization under rail crossing safety constraints (SOURCAO) model for optimizing traffic network signals at HRGCs. This model used an inference engine to choose a preemption phase sequence that promoted grade crossing safety. A neural network and sequential quadratic programming (SQP) algorithm were used to find the optimized phase length to minimize the total delay. The SOURCAO model decreased the average network delay by 13.8% and improved safety. However, in its calculation of safety improvement, the study used a problematic measure of unsafe time: the proportion of time during which the queued vehicles were on the link from the intersection to the grade crossing while the crossing was closed for railroad traffic. This time could be an unsafe situation if the queue is extended across a nearby rail crossing. This study also considered only the fixed-time traffic signal control. Cho and Rilett [6] developed an improved transition preemption strategy (ITPS) algorithm to overcome the limitations of standard preemption (SP) and the transition preemption strategy (TPS), such as not considering pedestrian and driver safety or the impact made on intersection operational efficiency by having only one detector with limited prediction capability. The ITPS algorithm provided more time to the blocked phases during the preemption mode than phases served during the preemption mode, thus improving the intersection performance and reducing truncations of the pedestrian clearance phase at the onset of preemption. This algorithm improved the safety with zero truncation of the pedestrian clearance phase. The delay also decreased by 5.4% compared to the delay for both the SP and TPS algorithms.

Bullock et al. [7] investigated track clearance performance measures from fixed 15-second, fixed 20-second, and extensible track clearance green times at railroad-preempted intersections. This study measured the preemption trap performance by counting how often a track clearance green phase failed to completely clear the link between the tracks and the intersection during a preemption event. The number of opportunities for a preemption trap to occur was reduced from 33 to 3 when the fixed track clearance interval was increased from 15 to 20 seconds. The opportunities for a preemption trap to occur were 0 when the extensible track clearance interval was used. However, this study did not consider the traffic delay, though the delay increased as the track clearance interval increased. This study also measured a preemption trap performance that counted how often track clearance green phases failed to completely clear all queued vehicles between the intersection and track during a preemption event. Bullock et al. [8] also introduced a methodology to prioritize un-preempted signalized intersections near HRGCs for interconnecting with a railroad. This methodology used the queue margin from clear storage distance and the estimated queue length. The methodology recommended railroad preemption for high-ranked intersections. However, the study used only one value for vehicle length to estimate the queue length, and it assumed the estimated queue length depended only on cycle length.

Genetic Algorithm

Genetic algorithms (GA) are widely used to solve various transportation problems such as traffic signal optimization, routing, and scheduling. Kim et al. [9] used a GA to determine optimal sensor locations for the accurate estimation of travel time on a freeway. The study used a GA with VISSIM, a microscopic simulation model, to estimate travel time from selected sensor locations. This approach estimated average travel time with errors within 10% and performed better than the conventional approach that used fixed-point sensors. Stevanovic et al. [10] presented a VISSIM-based GA Optimization of Signal Timings (VISGAOST) model. The VISGAOST model was tested to optimize four basic signal timing parameters on two VISSIM networks. Timing plans optimized by the GA reduced delays and stops by at least 5% compared to the best Synchro plans. Yang and Benekohal [11] considered both vehicle and pedestrian delays at an isolated intersection and developed a GA optimization procedure to optimize signal timings by minimizing the total user time. The GA found suitable signal plans and generated contour diagrams to determine appropriate pedestrian crossing phases. However, this study did not consider pedestrian safety.

Though most preemption studies aim to decrease delay and improve safety, they often focus on reducing delay without taking appropriate measures to improve safety. The drawback of this state of the practice is that optimal plans are determined without taking the preemption operation into account. This may lead to non-optimal performance as the operations of these optimized plans will be distorted by preemption. During the current study, the preemption is taken into account during the optimization process itself by embedding the preempted operation into the objective function calculations using GA-based signal optimization.

This report is organized as follows: The objectives and approach of this study are presented in the next section. The GA-based signal optimization approach is explained in the Methodology section, including selection of the study site, construction of the VISSIM network, and parameters selection for the GA. The improvements in delay and safety resulting from GA-based optimal preemption signal plans are evaluated and compared to signal timing plans optimized with Vistro, which is a state-of-the-art model to optimize the signal timing plan.

STUDY APPROACH

This study has two objectives: 1) Promote HRGC safety and 2) Reduce highway traffic delay. The methodological approach for addressing these objectives comprises two steps. The first step (safety) is to find preemption phase sequences for the study area that prevent the queue from backing on to the HRGC. The second step (delay) is to develop a GA framework to find the optimized signal phase lengths for reducing highway traffic delay.

Microscopic traffic simulation models are widely used in the transportation field because they can simulate real-world conditions such as delays, speeds, travel times, queues, and flows. This study used the VISSIM model to represent preemption control and to evaluate the impact of preemption control on the highway network. VISSIM can model actuated signal control with any types of special features such as transit priority or railroad or emergency vehicle preemption [12]. VISSIM is a useful tool for evaluating various alternatives for new project based on transportation engineering and planning measures of effectiveness. It can also analyze traffic and transit operations under such constraints as lane configuration, traffic composition, traffic signals, and transit stops. The GA is used to optimize the lengths of each signal phase.

Signal timing optimization models such as Vistro, PASSER, Synchro, and TRANSYT-7F are widely used to improve the performance of a signal. These programs can optimize various variables for the signal timing plan, including the cycle length, offsets, phase lengths, and sequences, usually to minimize delay. VISSIM can use these optimal signal timing plans for normal operations. However, current traffic signal timing optimization models do not optimize preemption control. This study uses the GA to optimize the preemption phase sequence and lengths to simultaneously improve delay and safety. The GA approach was developed to solve both constrained and unconstrained optimization problems, and it has been used to solve various complex transportation problems. For this study, maximum green times for each signal phase are optimized to minimize the impact of preemption on highway traffic congestion.

METHODOLGY

Selection of the Study Area

The study team reviewed HRGCs in cities in Virginia to choose the study area. HRGC inventory and crash data, including the number of crashes, fatalities, injuries, and vehicle property damage, were collected from HRGC inventory and crash and incident reports by the Federal Railroad

Administration (FRA) [13]. The FRA Web Accident Prediction System (WBAPS) was also used to rank or identify potential high-crash crossings [14]. WBAPS uses two independent factors to evaluate the hazardousness of crossings: 1) The physical/operating characteristics of the crossing and 2) Five years of accident history data at the crossing. One HRGC on Broad Rock Boulevard in the city of Richmond was selected as the study site (see Figure 2). As of April 2012, Richmond had the greatest number (523) of HRGCs among cities in Virginia. WBAPS ranked the selected HRGC, and 10 crashes have occurred at this site since 1990 (see Table 1). Also, this intersection is not currently preempted with the crossing.

Table 1: Accident History of the Study Site

Crossing ID No.	Number of Accidents	Date	Number of Killed Persons	Number of Injured Persons	Vehicle Property Damage ($)
623668M	10	08/05/11	0	1	2,498
		08/23/09	0	0	10,000
		05/10/09	0	0	3,000
		06/28/08	0	0	5,000
		04/28/07	0	0	600
		10/12/05	0	0	6,500
		09/10/05	0	0	6,500
		10/11/03	0	0	0
		01/15/00	0	0	3,000
		11/18/94	1	0	1,500

Figure 2: Study area

Constructing the VISSIM Network

VISSIM requires various types of input data: geometric data (number of lanes, lengths), demand data (entry, turning, and train volumes), and control data (signal control, signs). The geometric data were obtained from Google Earth (Figure 2), and entry volumes for peak time were estimated from the 2012 average daily traffic volumes reported by the Virginia Department of Transportation [15]. The research team also collected turning volumes and control data from intersection-turning movement counts and traffic plan reports by the City of Richmond. The annual WBAPS report for 2012 [14] provides train data, including volumes and speed. The VISSIM network was created using existing input data and signal plans, including a designed preemption control plan that was coded into the Ring Barrier Controller (RBC).

Initializing the GA

Starting the GA requires the initial population of maximum green times to determine the lengths of each signal phase under preemption control. Each signal phase has lower and upper bounds for maximum green time, and the initial population was randomly generated at one-second intervals within both bounds. The total number of individual chromosomes equals the given number of populations in the GA.

Updating the Signal Controller

VISSIM users can create signal timing plans for both normal and preemption operations in RBC. The network is operated with normal operation, and then preemption operation is initiated once a train is identified at a check-in detector. The initial, randomly generated chromosomes are imported to RBC via MATLAB script. The RBC file for an individual chromosome is updated and saved to run on VISSIM. All individuals for maximum green time in newly populated generations are also imported to update the signal controller, as shown in Figure 3.

Running VISSIM through VISSIM COM Interface

Each updated signal controller is used to run VISSIM to evaluate each individual solution. This study used the component object model (COM) interface from MATLAB script to control the VISSIM model, such as when running, changing parameters, and exporting simulation outputs. Transportation projects can have manifold scenarios and must be analyzed through a comprehensive process. Many researchers are using programming environments such as Visual C++, VBA, or MATLAB to handle large data and to apply external algorithms. It is also possible to connect VISSIM with the external programming environment through the COM interface [16].

Evaluating Results

Both network delay and average queue length on the link between the intersection and the HRGC were used to evaluate each individual solution at every GA generation (solution iteration) as the object function in GA. The network delay during one peak hour was estimated from the network performance evaluation in VISSIM. Queue lengths were measured by queue counters in

VISSIM at the arrival of every train at the HRGC. It was assumed that three trains passed through the study area during the peak hour. The maximum queue length was also used to count the number of crashes, which is the measure of improvement of HRGC safety. The "number of crashes" term in this study refers to the number of instances when the maximum queue length was greater than 300 feet (i.e., the distance between the intersection and crossing used to store queued vehicles).

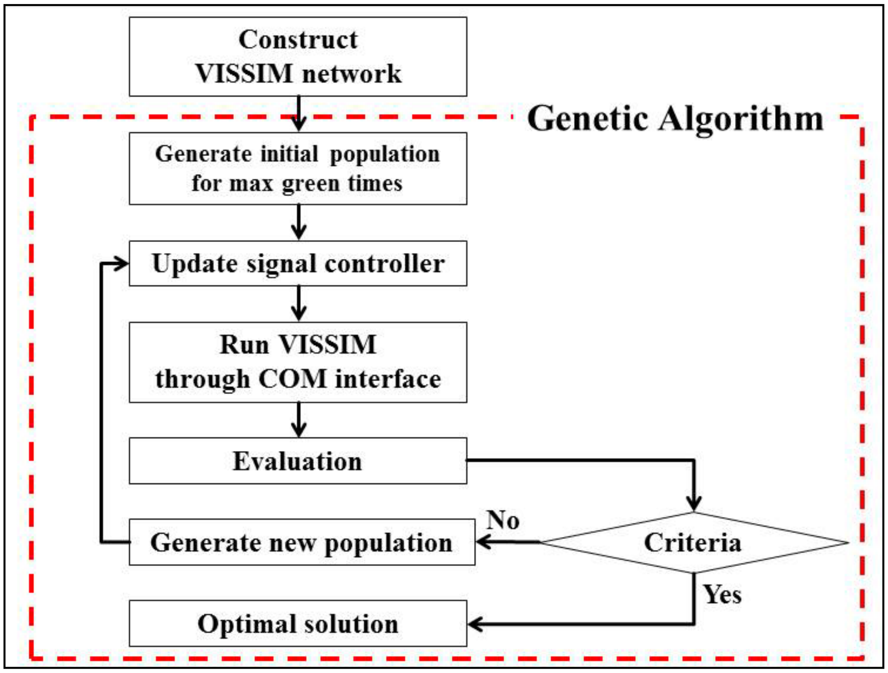


Figure 3: Study flow chart

Termination Criteria

The GA in this study can be terminated by two independent criteria. The first criterion is that the GA runs until the cumulative change in the objective function for 20 consecutive generations is less than 1%. The second criterion is that the number of generations reaches a given maximum.

Generation of New Population

If, after evaluation, the termination criteria are not satisfied, the GA generates a new population for the next generation according to three rules. The first rule is elitism: The best individual from the previous generation is preserved without change and carried over to the next generation. This study preserved the two best individuals from the previous generation. By the elitism rule, the current best individual will be the optimal solution if the population of this generation is satisfied with the above termination criteria. This study used the uniform crossover and 10% of the mutation rate to make a new population for the next generation as the second rule. The final rule is the mutation and it is used to avoid becoming trapped in a local optimum solution.

RESULTS

Preemption Phase Sequence

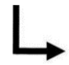
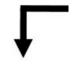
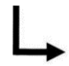
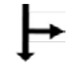
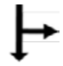
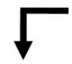
The preemption phase sequence comprises five steps: a) Entry into preemption, b) Termination of the current phases, c) Track clearance phase, d) Preemption hold phase, and e) Return to normal operation [17]. The signal control enters into preemption control once the approaching train is identified by the check-in detector. The current phases should be terminated by the start of preemption control if they conflict with the track clearance phase. They will be extended if the current phase is the same as the track clearance phase. Minimum green and pedestrian clearance times can be truncated to quickly terminate the current phases. However, the right-of-way transfer time is required to terminate the current conflicted phases by providing required clearance intervals under normal operation, such as the yellow and all-red intervals.

The track clearance phase is served once the current phases are terminated to clear queues on the link between the intersection and the HRGC. The length of the track clearance phase is determined by the geometric condition of the site (i.e., the distance [clear storage distance] of the link between the intersection and the HRGC and the minimum track clearance distance with the design vehicle clearance distance [18]). MUTCD defines this phase length as the time required for the design vehicle of maximum length stopped just inside the minimum track clearance distance to start moving through and clear the entire minimum track clearance distance [2]. Some studies have used the maximum number of queued vehicles or queue lengths to calculate track clearance phase length. This study used the geometric condition to control safety, though using the maximum queue lengths to calculate the track clearance phase length can reduce the preemption impact on congestion when the queue length is small and does not reach the HRGC.

Following the track clearance phase is the hold phase during which the train is near or in the HRGC. The hold phase allows traffic movement that does not conflict with train movement. Finally, the exit phase is served to return to normal operation after the train has passed the crossing.

Table 2 represents signal phase sequences for normal and preemption operations. As stated, the intersection of this study area is not preempted, and it currently uses a normal signal phase sequence when the train passes the crossing (Table 2). The only traffic control features at the crossing are the typical gates and flashers, and they do not interconnect with the intersection. The research team found two cases for preemption phase sequences for the study area, which has a three-way intersection. As shown in Table 2, a northbound through phase must be selected for the track clearance phase to clear queues on the link between the intersection and the HRGC. An eastbound, left-turn phase was selected for the hold phase because this is the only phase that does not conflict with train movement. Two alternative phases exist for the exit phase, and each alternative was selected for each case under preemption control.

Table 2: Signal Phase Sequences for Normal and Preemption Operations

Operation	Scenario	Phases*		
Preemption		Track clearance phase	Hold phase	Exit phase
	Case 1			
	Case 2			
Normal		1	2	3
				

* All phases permit right turn on red (RTOR).

Optimization of Signal Phase Length

After the preemption phase sequences are decided, the next step is to optimize the signal phase lengths. The GA optimizes the maximum green times for all phases to find the optimal signal phase lengths. The maximum green times are applied to both normal and preemption operations as these operations use the same maximum green times in the RBC. There are a total of five scenarios in this report. The first scenario is “No preemption Vistro,” which uses the optimal signal timing plan from Vistro for each traffic demand in Table 3 and is not preempted with the crossing. The “No preemption Vistro” scenario is used to verify that preemption operation can improve safety. The next two scenarios are “Cases 1 and 2 Vistro” that use the same signal timing plan as the “No preemption Vistro scenario” and are preempted with the crossing. The final two scenarios—“Cases 1 and 2 GASOPS”—use the optimal signal timing plan from the proposed approach for each demand and random seed of VISSIM. The “Cases 1 and 2 GASOPS” scenarios are also preempted with the crossing. Vistro is used to create the optimal signal timing plans for three different traffic demands. Vistro is a state-of-the-art model developed by PTV (a company developed VISSM) to optimize the signal timing plan of normal operation [19]. Vistro was selected to optimize the signal timing plan of a three-way intersection for the normal operation (the most ideal approach for optimizing signal plans given the conditions) and was evaluated using VISSIM.

Each of the five scenarios in Table 4 was evaluated using three different traffic demands to investigate the impact of preemption on highway congestion. Most studies have used a proportion of traffic demand change as low as 10% or 20%. However, this study considered high proportions of demand change because this study is determining the future need for preemption given an anticipated significant increase in traffic. The intersection is not currently preempted because of low traffic, as shown in Table 4. The delays of all scenarios with Demand 1 are also too low in Table 4. The resulting delay of just 10 to 12 seconds per vehicle means this intersection is operating at level of service (LOS) B (i.e., stable flow with slight delays), according to the LOS criteria for signalized intersections found in the *Highway Capacity Manual* (HCM) [20].

Table 3: Entry Volumes of Traffic Volume Demand

Demand	**Entry Volume (veh./hr.)**		
	Southbound	**Westbound**	**Northbound**
Demand 1	838	300	691
Demand 2	1257	450	1037
Demand 3	1676	600	1382

Table 4 represents the objective functions of the average network delay and queue length from the optimal solutions produced by the GA for each scenario. Results show that preemption operation improves safety because queue lengths in all "Cases 1 and 2 Vistro" scenarios are less than the "No preemption Vistro" scenario. All queue lengths in the "Cases 1 and 2 Vistro" scenarios are 0, even when the demand is doubled. All queued vehicles on the link are cleared during the track clearance phase of preemption operation. All "Cases 1 and 2 GASOPS" scenarios also have no queue lengths because of the operating preemption signal in RBC. By contrast, the possibility of collision between trains and queued vehicles in the "No preemption Vistro" scenario continuously increases with increasing demand. In the "No preemption Vistro" scenario, the maximum queue length increases from 35 to 101 feet. A crash can occur if the maximum queue length is more than 300 feet (i.e., the distance between the intersection and the crossing that can store queued vehicles).

Table 4: Delay and Safety Objective Functions of Scenarios

Demand	**Sequence**	**Model**	**Delay (sec./veh.)**		**Safety**
			Mean	**SD**	**Queue length (ft.)**
Demand 1	No preemption	Vistro	11.5	0.22	3.9 (35*)
	Case 1	Vistro	11.6	0.23	0
		GASOPS	10.3	0.07	0
	Case 2	Vistro	11.6	0.06	0
		GASOPS	10.3	0.13	0
Demand 2	No preemption	Vistro	15.3	0.15	21.8 (101*)
	Case 1	Vistro	15.9	0.56	0
		GASOPS	13.2	0.49	0
	Case 2	Vistro	15.4	0.21	0
		GASOPS	13.1	0.30	0
Demand 3	No preemption	Vistro	22.0	1.30	36.3 (99*)
	Case 1	Vistro	23.0	0.70	0
		GASOPS	20.4	0.25	0
	Case 2	Vistro	22.5	0.92	0
		GASOPS	20.3	0.61	0

* Maximum queue lengths when the train arrives at the HRGC.

Results also indicate that the GASOPS model reduces delay for the preempted signal, despite the conventional preemption operation showing increased delays under preemption operation. As shown in Figure 4, all delays in the “Cases 1 and 2 Vistro” scenarios are greater than those experienced in the “No preemption Vistro” scenario. This is because preemption operation interrupts normal operation. Preemption operation increases delay, although it improves safety. However, Figure 4 also illustrates that all delays experienced in the “Cases 1 and 2 GASOPS” scenarios are lower than those of the “No preemption Vistro” scenario and improve safety. The GASOPS model, therefore, is more efficient for minimizing the delay for preempted signals. Vistro and other existing optimization models can ideally optimize normal operation, but the GASOPS model simultaneously optimizes both normal and preemption operations.

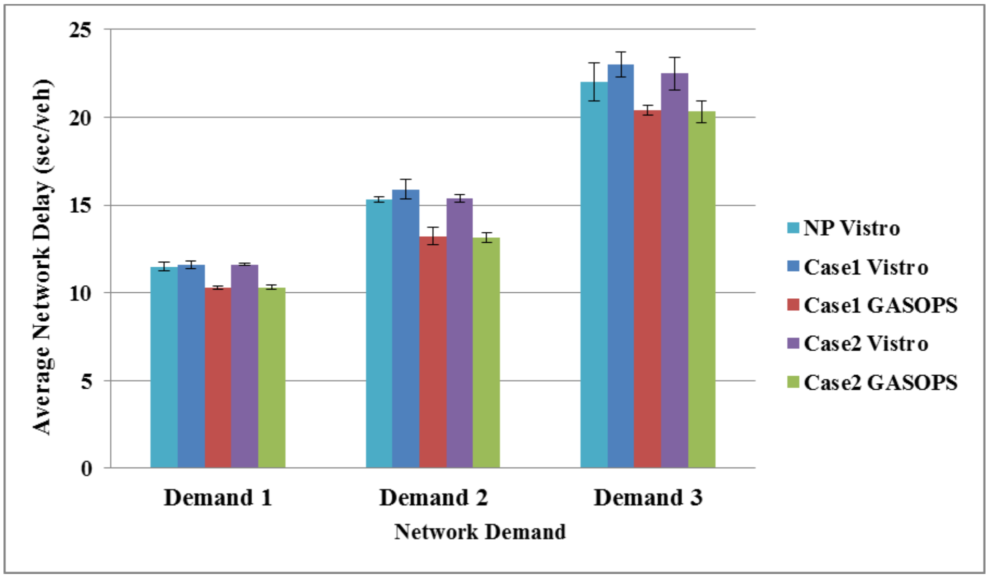


Figure 4: Comparison of average network delay with standard deviation

All delays occurring across all demand conditions in the “Cases 1 and 2 GASOPS” scenarios are lower than those of the “Cases 1 and 2 Vistro” scenarios, as shown in Figure 4. In Demand 1, delays experienced in the “Cases 1 and 2 GASOPS” scenarios are all 11.2% less than delays in the “Cases 1 and 2 Vistro” scenarios. In Demand 2, the GASOPS scenarios are more efficient than Vistro (i.e., delays in the “Cases 1 and 2 GASOPS” scenarios are 17.0% and 14.9% lower than delays in the Vistro scenarios, respectively). In Demand 3, delays in the “Cases 1 and 2 GASOPS” scenarios are lower than delays in the Vistro scenarios by 11.3% and 9.8%, respectively. Most standard deviations of GASOPS scenarios are lower than those of Vistro in all demand cases because GASOPS scenarios use the individual optimized phase lengths for each scenario with different random seeds. However, all Vistro scenarios used one set of signal timing plans for different random seeds. It is difficult to conclude which preemption phase sequence used between Case 1 and Case 2 is more efficient because both GASOPS cases have similar delays. The preemption phase sequence used in Case 2 for Vistro is more efficient than Case 1.

Figure 5 shows the GA-based optimization convergences for all scenarios in Demand 2 and random seed 92. Each Vistro scenario has only one value because its signal timing plan is optimized by Vistro, not GA. The objective function in this study is the sum of the delay and average queue length computed in VISSIM. However, the objective function of all scenarios is the delay because the average queue lengths of all scenarios are 0, as shown in Table 4. When comparing each scenario, only the delay is used. The objective functions of the "Cases 1 and 2 Vistro" are 15.9 and 15.4, respectively. As stated, the GA preserves the two best individuals from the previous generation and uses them in the next generation. Figure 5 plots the best individual at every generation. The "Cases 1 and 2 GASOPS" scenarios converge into the minimum objective function through 40 generations. The delay for the "Case 1 GASOPS" scenario begins at 15 seconds per vehicle and converges at 13.5 seconds per vehicle at the 20th generation. The delay for the "Case 2 GASOPS" scenario begins at 13.8 seconds per vehicle and converges at 13.1 seconds per vehicle at the 23rd generation. The "Case 2 GASOPS" scenario has the least network delay in the Demand 2 condition, as shown in Figure 4.

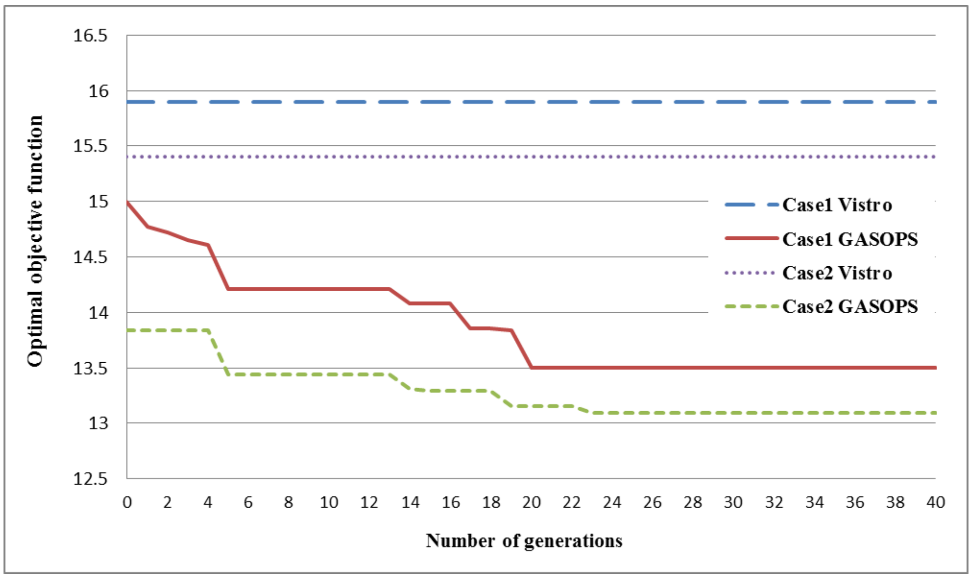


Figure 5: GA-based optimization convergences with Demand 2 and random seed 92

Contour plots are usually used to identify the optimal values of two parameters [21]. VISSIM computes objective functions for each pair of the best solution candidates from each generation, and it charts them in a contour plot to identify the value pairs that produce the smallest objective function. Figure 6 shows an example contour plot from the preemption phase sequence in Case 1, although the GASOPS model optimizes four phases. The hold and exit phases in the preemption operation are optimized, although the length of the track clearance phase is fixed, as stated. The best optimal solution of Case 1 GASOPS with Demand 2 and random seed 92 is when the hold and exit phase lengths are 8 and 11 seconds, respectively. The plot shows that the exit phase length is a more significant factor because the objective functions are small when the exit phase length is between 10 and 12 seconds.

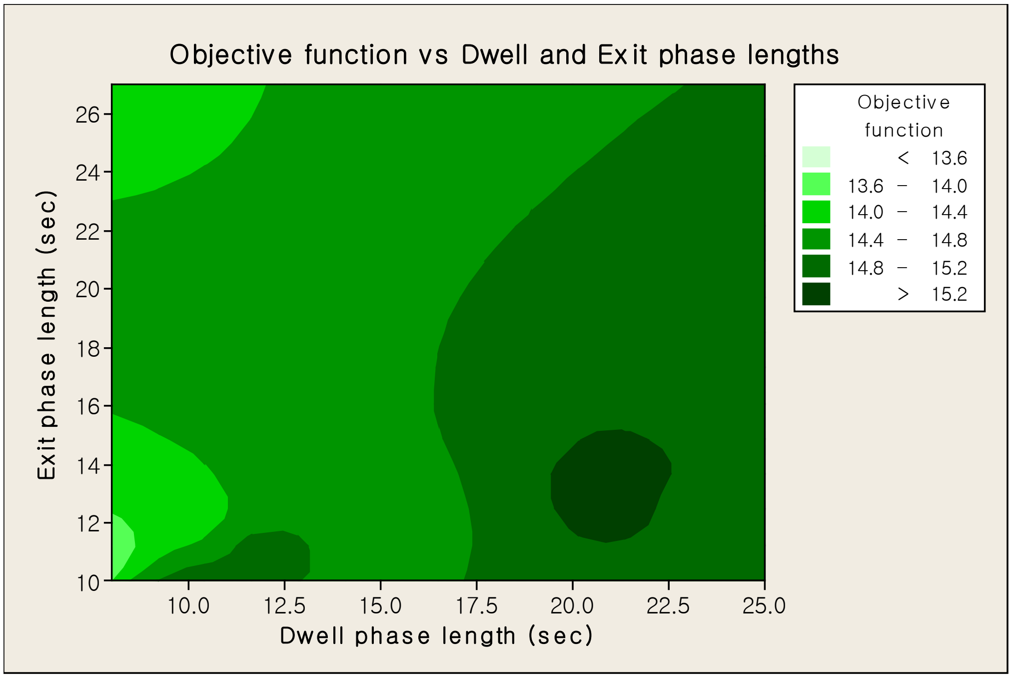


Figure 6: Contour plot of Case 1 GASOPS with Demand 2 and random seed 92

CONCLUSIONS

This report presents a GASOPS model to improve safety and reduce highway traffic delay for preempted signal operations at HRGCs. After finding preemption phase sequences for the study area, a GA was developed to determine the optimized signal phase lengths for reducing highway traffic delay and preventing the queue from backing on to the HRGC. Results show that the GASOPS model is more efficient for minimizing delay for preempted signals than normal optimal plans. This optimization approach reduces the delay by a maximum of 17%. The GASOPS model simultaneously optimizes signal timing plans for both normal and preempted operations; current signal optimization models can optimize for only normal operations. The GASOPS model also improves safety as all queue lengths in the GASOPS scenarios are 0, even during high traffic demand due to the preemption operation. This approach will be useful when designing and improving preemption operations for signalized intersections near HRGCs.

Future research should consider a four-way intersection because there are more combinations of preemption phase sequences available than at the three-way intersection used during this study. Future research should also consider flexible or extensible track clearance phases, which can increase operational efficiency by providing the minimum track clearance phase length according to the current queue length when a train is approaching. The pedestrian clearance interval should also be considered during future research endeavors.

ACKNOWLEDGMENT

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APPENDICES

Appendix A: HRGC Accident/Incident Report

DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION (FRA)

HIGHWAY-RAIL GRADE CROSSING ACCIDENT/INCIDENT REPORT

OMB Approval No. 2130-0500

1. Name of Reporting Railroad: CSX Transportation [CSX]	1a. Alphabetic Code: CSX	1b. Railroad Accident/Incident No.: 000092581
2. Name of Other Railroad or Other Entity Filing for Equipment Involved in Train Accident/Incident	2a. Alphabetic Code	2b. Railroad Accident/Incident No.
3. Name of Railroad or Other Entity Responsible for Track Maintenance (single entry): CSX Transportation [CSX]	3a. Alphabetic Code: CSX	3b. Railroad Accident/Incident No.: 000092581
4. U.S. DOT Grade Crossing ID No.: 623668M	5. Date of Accident/Incident (month / day / year): 0 8 / 0 5 / 2011	6. Time of Accident/Incident: 7:55 AM ☐ PM ☑
7. Nearest Railroad Station: MEADOW; 8. Subdivision: NORTH END	9. County: RICHMOND	10. State Abbr.: VA; Code: 51
11. City (if in a city): RICHMOND	12. Highway Name or No.: BROAD ROCK RD	Public ☑ Private ☐

Highway User Involved / **Rail Equipment Involved**

		Code
13. Type	A. Auto B. Truck C. Truck-trailer D. Pick-up truck E. Van F. Bus G. School Bus H. Motorcycle J. Other Motor Vehicle K. Pedestrian M. Other (specify)	H
14. Vehicle Speed (est. mph at impact)		0
15. Direction (geographical)	1. North 2. South 3. East 4. West	4
16. Position	1. Stalled or stuck on crossing 2. Stopped on Crossing 3. Moving over crossing 4. Trapped on crossing by traffic 5. Blocked on crossing by gates	2
17. Equipment	1. Train (units pulling) 2. Train (units pushing) 3. Train (standing) 4. Car(s) (moving) 5. Car(s) (standing) 6. Light loco(s) (moving) 7. Light loco(s) (standing) 8. Other (specify) A. Train pulling- RCL B. Train pushing- RCL C. Train standing- RCL D. EMU Locomotive(s) E. DMU Locomotive(s)	1
18. Position of Car Unit in Train		1
19. Circumstance	1. Rail equipment struck highway user 2. Rail equipment struck by highway user	1
20a. Was the highway user and/or rail equipment involved in the impact transporting hazardous materials?	1. Highway User 2. Rail Equipment 3. Both 4. Neither	4
20b. Was there a hazardous materials release by	1. Highway User 2. Rail Equipment 3. Both 4. Neither	4
20c. State here the name and quantity of the hazardous material released, if any		
21. Temperature (specify if minus)		79 °F
22. Visibility (single entry)	1. Dawn 2. Day 3. Dusk 4. Dark	4
23. Weather (single entry)	1. Clear 2. Cloudy 3. Rain 4. Fog 5. Sleet 6. Snow	1
24. Type of Equipment Consist (single entry)	1. Freight Train 2. Passenger Train-Pulling 3. Commuter Train-Pulling 4. Work Train 5. Single Car 6. Cut of cars 7. Yard/Switching 8. Light loco(s) 9. Maint./inspect. car A. Spec. MoW Equip. B. Passenger Train-Pushing C. Commuter Train-Pushing D. EMU E. DMU	1
25. Track Type Used by Rail Equipment Involved	1. Main 2. Yard 3. Siding 4. Industry	1
26. Track Number or Name		#1 MAIN
27. FRA Track Class (1-9,X)		4
28. Number of Locomotive Units		2
29. Number of Cars		24
30. Consist Speed (Recorded speed if available)	R. Recorded E. Estimated	21 mph; E
31. Time Table Direction	1. North 2. South 3. East 4. West	2
32. Type of Crossing Warning	1. Gates 2. Cantilever FLS 3. Standard FLS 4. Wig wags 5. Hwy. traffic signals 6. Audible 7. Crossbucks 8. Stop signs 9. Watchman 10. Flagged by crew 11. Other (specify) 12. None	Code(s): 01, 02, 03, 06, 07, 11
33. Signaled Crossing Warning	(See reverse side for instructions and codes)	1
34. Roadway Conditions	A. Dry B. Wet C. Snow/Slush D. Ice E. Sand, Mud, Dirt, Oil, Gravel F. Water (Standing, Moving)	A
35. Location of Warning	1. Both Sides 2. Side of Vehicle Approach 3. Opposite Side of Vehicle Approach	1
36. Crossing Warning Interconnected with Highway Signals	1. Yes 2. No 3. Unknown	2
37. Crossing Illuminated by Street Lights or Special Lights	1. Yes 2. No 3. Unknown	1
38. Highway User's Age		38
39. Highway User's Gender	1. Male 2. Female	1
40. Highway User Went Behind or in Front of Train and Struck or was Struck by Second Train	1. Yes 2. No 3. Unknown	2
41. Highway User	1. Went around the gate 2. Stopped and then proceeded 3. Did not stop 4. Stopped on crossing 5. Other (specify) 6. Went around/thru temporary barricade (if yes, see instructions) 7. Went thru the gate 8. Suicide/Attempted suicide	5
42. Driver Passed Standing Highway Vehicle	1. Yes 2. No 3. Unknown	2
43. View of Track Obscured by (primary obstruction)	1. Permanent Structure 2. Standing railroad equipment 3. Passing Train 4. Topography 5. Vegetation 6. Highway Vehicles 7. Other (specify) 8. Not Obstructed	8
44. Driver was	1. Killed 2. Injured 3. Uninjured	2
45. Was Driver in the Vehicle?	1. Yes 2. No	1

Casualties to:	Killed	Injured
46. Highway-Rail Crossing Users	0	1
49. Railroad Employees	0	0
52. Passengers on Train	0	0

47. Highway Vehicle Property Damage (est. dollar damage)	$2,498
48. Total Number of Vehicle Occupants (including driver)	1
50. Total Number of People on Train (include passengers and train crew)	2
51. Is a Rail Equipment Accident / Incident Report Being Filed 1. Yes 2. No	Code: 2
53a. Special Study Block	Video Taken? ☑ Yes ☐ No; Video Used? ☑ Yes ☐ No
53b. Special Study Block	

54. Narrative Description (Be specific, and continue on separate sheet if necessary)
Q78304 ON NUMBER 1 MAIN STRUCK THE DRIVER OF A MOPED THAT WENT AROUND GATES AND HIT THE EDGE OF THE RIGHT CROSS ARM CAUSING HIM TO SPIN AROUND AND FALL TO THE GROUND IN FRONT OF THE SOUTHBOUND TRAIN. PROTECTION ALSO AT CROSSING: PAVEMENT MARKINGS (STOP LINES & RR XING SYMBOLS). .

55. Typed Name and Title	56. Signature	57. Date

NOTE: This report is part of the reporting railroad's accident report pursuant to the accident reports statute and, as such shall not "be admitted as evidence or used for any purpose in any suit or action for damages growing out of any matter mentioned in said report...." 49 U.S.C. 20903. See 49 C.F.R. 225.7 (b).

FORM FRA F 6180.57 (Rev. 08/10) * NOTE THAT ALL CASUALTIES MUST BE REPORTED ON FORM FRA F 6180.55A

OMB approval expires 02/28/2014

Appendix B: Ranked HRGCs by WBAPS

*PUBLIC HIGHWAY-RAIL CROSSINGS RANKED BY PREDICTED ACCIDENTS PER YEAR AS OF 12/31/2012**

*Num of Collisions: Most recent year is partial year (data is not for the complete calendar year) unless Accidents per Year is 'AS OF DECEMBER 31'.

RANK	PRED COLLS.	CROSSING	RR	STATE	COUNTY	CITY	ROAD	NUM OF COLLISIONS 12*	11	10	09	08	DATE CHG	WD	TOT TRN	TOT TRK	TTBL SPD	HWY PVD	HWY LNS	AADT
1	0.262672	623668M	CSX	VA	RICHMOND (C	RICHMOND	BROAD ROCK RD	0	1	0	2	1		GT	29	2	79	YES	4	19,000
2	0.083357	857678R	VPAX	VA	NORFOLK	NORFOLK	HAMPTON BLVD	1	0	0	0	0		HS	8	1	10	YES	6	30,000
3	0.064134	623530L	CSX	VA	RICHMOND (C	RICHMOND	HOSPITAL ST	0	0	1	0	0		GT	24	2	20	YES	2	6,400
4	0.054075	623670N	CSX	VA	RICHMOND (C	RICHMOND	TERMINAL AVE	0	1	0	0	0		GT	29	2	79	YES	2	810
5	0.047777	224281G	CSX	VA	HENRICO	RICHMOND	POPLAR SPRINGS	0	0	0	0	1		GT	20	1	70	YES	2	1,500
6	0.045711	860437F	CSX	VA	HENRICO	RICHMOND	HUNGARY RD	0	0	0	0	0		GT	38	2	70	YES	4	15,360
7	0.037587	623640W	CSX	VA	RICHMOND (C	RICHMOND	BELLS RD	0	0	0	0	0		GT	34	1	10	YES	4	11,000
8	0.036613	623635A	CSX	VA	RICHMOND (C	RICHMOND	HOPKINS RD	0	0	0	0	0		GT	34	3	10	YES	4	9,200
9	0.035353	857676C	VPAX	VA	NORFOLK	NORFOLK	RUTHVEN RD	0	0	0	0	1		GT	8	2	10	YES	4	250
10	0.034554	623663D	CSX	VA	RICHMOND (C	RICHMOND	JAHNKE RD	0	0	0	0	0		GT	30	2	79	YES	2	12,000
11	0.030971	623518E	CSX	VA	RICHMOND (C	RICHMOND	HERMITAGE RD	0	0	0	0	0		GT	15	2	20	YES	4	10,000
12	0.030030	860435S	CSX	VA	HENRICO	RICHMOND	HERMITAGE RD	0	0	0	0	0		GT	38	2	70	YES	2	3,900
13	0.029645	623672C	CSX	VA	RICHMOND (C	RICHMOND	WALMSLEY BLVD	0	0	0	0	0		GT	29	3	50	YES	2	5,700
14	0.029107	623522U	CSX	VA	RICHMOND (C	RICHMOND	BROOK RD	0	0	0	0	0		GT	19	2	30	YES	4	7,361
15	0.027153	860441V	CSX	VA	HENRICO	RICHMOND	MILL RD	0	0	0	0	0		GT	38	2	70	YES	2	2,400
16	0.025252	623636G	CSX	VA	RICHMOND (C	RICHMOND	COFER ST	0	0	0	0	0		GT	34	2	10	YES	2	3,800
17	0.023793	623637N	CSX	VA	RICHMOND (C	RICHMOND	TERMINAL AVE	0	0	0	0	0		GT	34	1	10	YES	2	3,000
18	0.023600	623678T	CSX	VA	CHESTERFIELD	RICHMOND	KINGSLAND RD	0	0	0	0	0		GT	28	2	79	YES	2	2,100
19	0.023567	735343N	BCR	VA	NORFOLK	NORFOLK	AZALEA GARDEN	0	0	0	0	0	09/12	GT	2	1	10	YES	5	17,435
20	0.022274	623664K	CSX	VA	RICHMOND (C	RICHMOND	BASSETT AVE	0	0	0	0	0		GT	31	2	79	YES	2	1,372
21	0.021721	735340T	BCR	VA	NORFOLK	NORFOLK	MILITARY HWY	0	0	0	0	0		GT	2	1	10	YES	4	45,000
22	0.021400	623548W	CSX	VA	RICHMOND (C	RICHMOND	BELLS RD	0	0	0	0	0		GT	8	2	25	YES	4	9,100
23	0.021078	224554Y	CSX	VA	LYNCHBURG	LYNCHBURG	GARNET ST	0	0	0	0	0		GT	18	3	35	YES	2	3,360
24	0.021023	224289L	CSX	VA	HENRICO	RICHMOND	CHARLES CITY RD	0	0	0	0	0		GT	26	2	79	YES	2	2,300
25	0.019983	623527D	CSX	VA	RICHMOND (C	RICHMOND	VALLEY RD	0	0	0	0	0		GT	24	3	20	YES	2	2,438
26	0.019079	224286R	CSX	VA	HENRICO	RICHMOND	BEULAH RD	0	0	0	0	0		GT	21	2	79	YES	2	1,879
27	0.017959	224551D	CSX	VA	LYNCHBURG	LYNCHBURG	CONCORD TPKE	0	0	0	0	0		GT	18	3	35	YES	2	1,700
28	0.017497	224298K	CSX	VA	HENRICO	RICHMOND	MILLER RD	0	0	0	0	0		GT	24	3	79	YES	2	1,144
29	0.017332	224557U	CSX	VA	LYNCHBURG	LYNCHBURG	WASHINGTON ST	0	0	0	0	0		GT	17	3	35	YES	2	1,700
30	0.017207	224559H	CSX	VA	LYNCHBURG	LYNCHBURG	7TH/ADAMS STRE	0	0	0	0	0		GT	17	3	25	YES	2	1,650
31	0.017024	465206K	BCR	VA	NORFOLK	NORFOLK	INGLESIDE RD	0	0	0	0	0		GT	2	3	10	YES	4	16,000
32	0.016629	917275U	CSX	VA	RICHMOND (C	RICHMOND	DEEPWATER TERM	0	0	0	0	0		NO	5	1	10	YES	2	3,202
33	0.016629	642687T	CSX	VA	RICHMOND (C	RICHMOND	DEEPWATER TERM	0	0	0	0	0		XB	5	1	10	YES	2	3,202