Evaluation of Emergency Vehicle Signal Preemption on the Route 7 Virginia Corridor

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Research, Development & Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This study was conducted by ITT Systems, McLean, VA, under Federal Highway Administration (FHWA) contract no. DTFH61-97-C-00055.

This report is a valuable resource for those who use – or are considering using – traffic signal preemption to give the right-of-way to emergency vehicles as they navigate through a signalized network. It quantifies the impact of traffic signal preemption on a heavily traveled signalized arterial in Loudoun County, Virginia. It will also be of interest to those interested in traffic simulation and the "hardware-in-the-loop" concept.

Copies of this report will be available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the RD&T Report Center, HRTS, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706.

Michael F. Trentacoste
Director, Office of
Operations Research and
Development

NOTICE

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16. Abstract

This study analyzed the impact of emergency vehicle traffic signal preemption across three coordinated intersections on Route 7 (Leesburg Pike near Landsdowne) in Virginia. FHWA's Traffic Software Integrated System (TSIS) package, which includes the CORSIM simulation model and the vehicle animator, TRAFVU, was used for this study. Using FHWA's Traffic Research Laboratory (TReL) as a test bed, ITT Systems utilized the Controller Interface Device (CID) to interface a modified version of the CORSIM simulation with Type 170 controllers programmed with the identical signal plans to those existing at the Route 7 intersections, with minor modifications to allow signal preemption. In this carefully controlled hardware-in-the-loop environment, CORSIM provided the microscopic simulation and tabulation of measures of effectiveness, but instead of CORSIM emulating controller features, the simulation package sent detector information to the physical controllers and read-back phase indicators. Since CORSIM tabulates performance measures of effectiveness (MOE's), quantitative results with and without preemption measurements were obtained.

Results showed that for the geometric and operational conditions studies, the impact of emergency signal preemption on the signal coordination of the corridor was minor. Although several of the preemption cases had "statistically significant means" when compared to the base case (no preemption), the magnitude of the 1.6-percent increase in average travel time was considered minor. Relatively long spacing between intersections, platoon dispersion over long distances, and very long cycle lengths were judged to be some of the reasons for this increase.

The information contained in this report will be of assistance to public agencies considering the installation of emergency signal preemption systems and to Intelligent Transportation Systems engineers.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Executive Summary

This study analyzed the impact of emergency vehicle traffic signal preemption across three coordinated intersections on Route 7 (Leesburg Pike near Landsdowne) in Virginia. Emergency vehicle signal preemption is a preferential treatment technique used to ensure continuous green phases to emergency vehicles (i.e., ambulances) at successive signalized intersections on arterials. It may reduce the time necessary for ambulances to reach a victim or emergency facility, providing faster, life-saving 911 response. However, the impact of signal preemption on the time-based coordination (i.e., synchronization) of an arterial is not well documented.

The motivation for this study was the construction of a new hospital, which opened near the study area. Emergency response personnel expressed an interest in deploying a preemption system that would aid ambulances in quickly and safely reaching the hospital. The Virginia Department of Transportation (VDOT) was interested in quantifying the effects that signal preemption would have on Route 7 traffic, particularly during the morning rush hour (8:00 a.m.) when inbound traffic towards Washington, D.C. is quite heavy. This information could then be used to make an informed decision regarding the deployment of an emergency vehicle preemption system.

The Federal Highway Administration's (FHWA's) Traffic Software Integrated System (TSIS) package, which includes the CORSIM simulation model and the vehicle animator, TRAFVU, was used for this study. TSIS, developed for FHWA by ITT Systems, also integrates several other analysis tools used extensively in the scope of this project. CORSIM (CORridor SIMulation) is a microscopic traffic simulation model of network and freeway traffic operations. Developed by FHWA and maintained by ITT Systems, this computer program is part of the TRAF family of simulation models. CORSIM integrates two TRAF models, NETSIM (Network Simulation) and FRESIM (Freeway Simulation), which are used to simulate urban streets and freeway segments, respectively.

Using FHWA's Traffic Research Laboratory (TReL) as a test bed, ITT Systems utilized the Controller Interface Device (CID) to interface a modified version of the CORSIM simulation model with Type 170 controllers supplied by VDOT. The Type 170 controllers were programmed with the identical signal plans that exist at the study intersections, with minor modifications to allow signal preemption. In this carefully controlled hardware-in-the-loop environment, CORSIM provided the microscopic simulation and tabulation of measures of effectiveness (MOE's), but instead of CORSIM emulating controller features, the simulation package sent detector information to the physical controllers and read-back phase indicators. Since CORSIM tabulates performance MOE's, quantitative results with and without preemption measurements were obtained. Several ambulance routes, each with multiple runs, were analyzed. The results were aggregated and interpreted.

Although several of the preemption cases had "statistically significant means" when compared to the base case (no preemption), the magnitude of the 1.6-percent increase in average travel time was considered minor. This was a somewhat surprising result because

preemption is typically considered to cause significant disruptions in traffic. Some possible explanations for this relatively modest impact might include:

- Relatively long spacing between intersections. Platoon dispersion over long distances tends to decrease the benefits of maintaining coordination.
- Modest traffic demand that does not lead to terribly oversaturated conditions during and after preemption.
- Emergency vehicle detection that is quite close to the intersection (152 m [500 ft]). This results in a relatively short-duration preemption that holds the right of way for the emergency vehicle, but may not provide sufficient green time to clear the approach the emergency vehicle is arriving on.
- The signalized corridor appears to have a very long cycle length. This may be causing significant delay on the side streets that masks the impact preemption may have on side streets.

The results showed that *for the geometric and operational conditions studied*, the impact of emergency signal preemption on the signal coordination of the corridor was minor. These results do not warrant the application of an adaptive control system (ACS) to assess the impact of emergency vehicle preemption on this corridor. A follow-up study, at an alternate location, may be needed for that purpose.

The researchers also artificially increased traffic volumes in order to have an understanding of the impact of preemption by analyzing pertinent MOE's. As expected, the increased volumes (with the original timing plans) resulted in a dramatic increase in average travel time and side-street delay.

In summary, this study effectively quantified the effect of emergency vehicle signal preemption on the coordination of a signal system for the conditions studied. The information contained in this report may be of assistance to public agencies considering the installation of emergency signal preemption systems and to Intelligent Transportation Systems engineers.

Introduction and Background

Emergency vehicle signal preemption is a preferential treatment technique used to ensure continuous green phases to emergency vehicles (i.e., ambulances) at successive signalized intersections on arterials. It may reduce the time necessary for ambulances to reach a victim or emergency facility, providing faster, life-saving 911 response. However, the impact of signal preemption on the time-based coordination (i.e., synchronization) of an arterial is not well documented.

This study analyzed the impact of emergency vehicle traffic signal preemption across three coordinated intersections on Route 7 (Leesburg Pike near Landsdowne) in Virginia (Figure 1). The motivation for this study was the construction of a new hospital, which opened near the study area. Emergency response personnel expressed an interest in deploying a preemption system that would aid ambulances in quickly and safely reaching the hospital. The Virginia Department of Transportation (VDOT) was interested in quantifying the effect that signal preemption would have on Route 7 traffic, particularly during the morning rush hour (8:00 a.m.) when inbound traffic towards Washington, D.C. is quite heavy. This information could then be used to make an informed decision regarding the deployment of an emergency vehicle preemption system.

Results from this study will also assist traffic researchers to understand the benefits of adaptive traffic control. If signal preemption causes a significant degradation of the operational performance of the corridor, an adaptive control system (ACS) may be evaluated as a possible solution to the problem.

This study did not attempt to evaluate commercial preemption systems; therefore, the results documented in this report are independent of any preemption system.

Technical Approach

The Federal Highway Administration's (FHWA's) Traffic Software Integrated System (TSIS) package, which includes the CORSIM simulation model and the vehicle animator, TRAFVU, was used for this study. TSIS, developed for FHWA by ITT Systems, also integrates several other analysis tools used extensively in the scope of this project. CORSIM (CORridor SIMulation) is a microscopic traffic simulation model of network and freeway traffic operations. Developed by FHWA and maintained by ITT Systems, this computer program is part of the TRAF family of simulation models. CORSIM integrates two TRAF models, NETSIM (Network Simulation) and FRESIM (Freeway Simulation), which are used to simulate urban streets and freeway segments, respectively.

Using FHWA's Traffic Research Laboratory (TReL) as a test bed, ITT Systems utilized the Controller Interface Device (CID) to interface a modified version of the CORSIM simulation with Type 170 controllers supplied by VDOT. The Type 170 controllers were programmed with the identical signal plans existing at the Route 7 intersections, with minor modifications to allow signal preemption. In this carefully controlled hardware-in-the-loop environment, CORSIM provided the microscopic simulation and tabulation of measures of effectiveness (MOE's), but instead of CORSIM emulating controller features, the simulation package sent detector information to the physical controllers and read-back phase indicators. Since CORSIM tabulates performance MOE's, quantitative results with and without preemption measurements were obtained.

Several ambulance routes, each with multiple runs, were analyzed. The results were aggregated and interpreted. This report presents those results.

The purpose of this analysis is twofold:

- To provide VDOT a basis on which to evaluate the level of service resulting from emergency vehicle signal preemption.
- To demonstrate the capabilities of the TReL and the "hardware-in-the-loop" concept in a real-world application.

Study Area

The area for the study was located on Route 7 (Leesburg Pike), between Sterling and Leesburg, Virginia, near an area called Landsdowne, named because of its proximity to the Landsdowne Resort. This segment of Route 7 is located approximately 24 km (15 mi) northwest of the Washington, D.C., Capital Beltway and is considered a suburban arterial for the purpose of this study (figures 1 and 2).

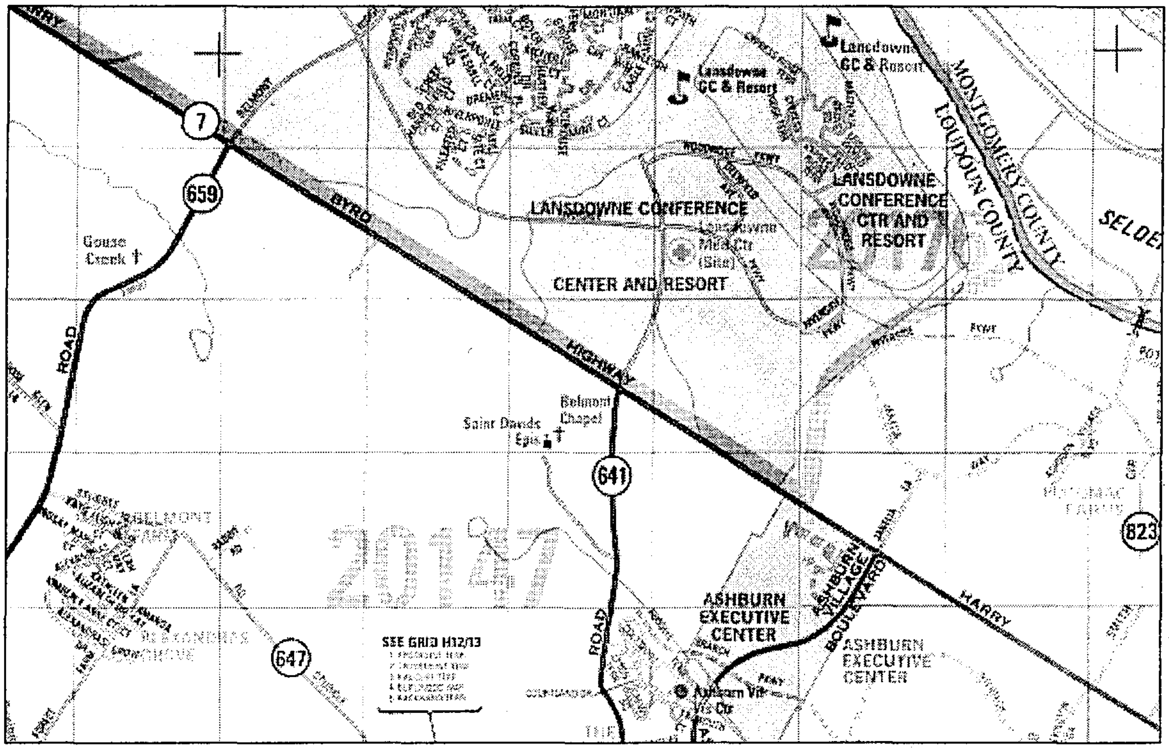


Figure 1. Map identifying study area.

Figure 2. Map overlaid on aerial photograph of study area.

This portion of Route 7 is a major commuter route for commuters traveling to/from the Tysons Corner area and Washington, D.C. It carries heavy eastbound volumes during the morning peak period and heavy westbound volumes during the afternoon peak period.

The opening of a new hospital in this corridor stimulated interest by emergency service providers in deploying emergency vehicle preemtion. However, VDOT wanted to quantify the impact of emergency signal preemption on the time-based coordination of the signalized intersections of this corridor ***before*** making any deployment decisions. The capabilities available in the TReL made this possible.

This study was constrained to the three consecutive signalized intersections directly adjacent to the new hospital on Route 7 (figure 3).

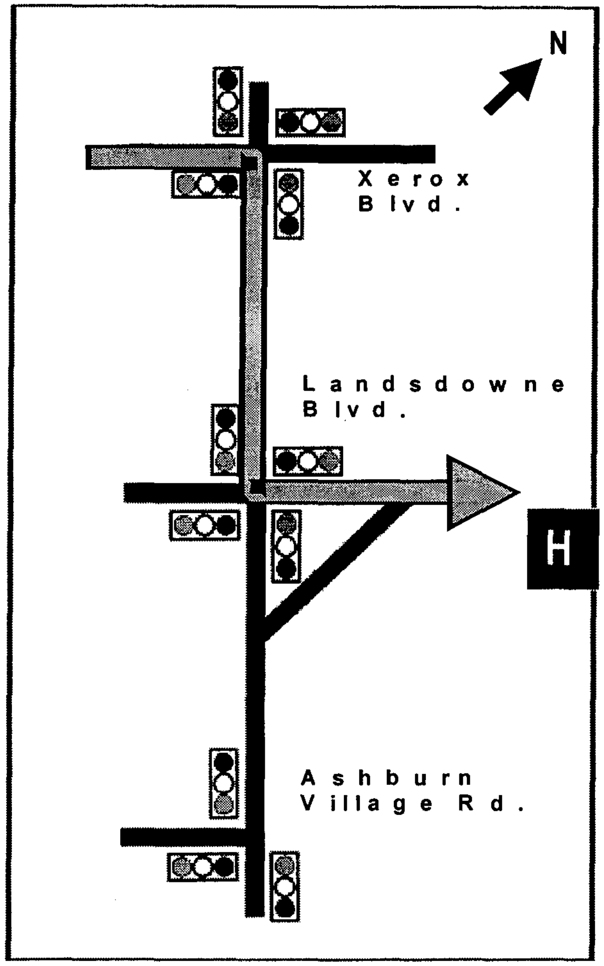


Figure 3. Study intersections and sample emergency vehicle path.

The geometric and operational characteristics of these three intersections were obtained through both field visits and data provided by VDOT, as depicted on the following figures:

- Node 5: Intersection of Route 7 with Belmont Road/Xerox Boulevard (figure 4).
- Node 4: Intersection of Route 7 with Ashburn Road/Landsdowne Boulevard (figure 5).
- Node 3: Intersection of Route 7 with Ashburn Village Road (figure 6).

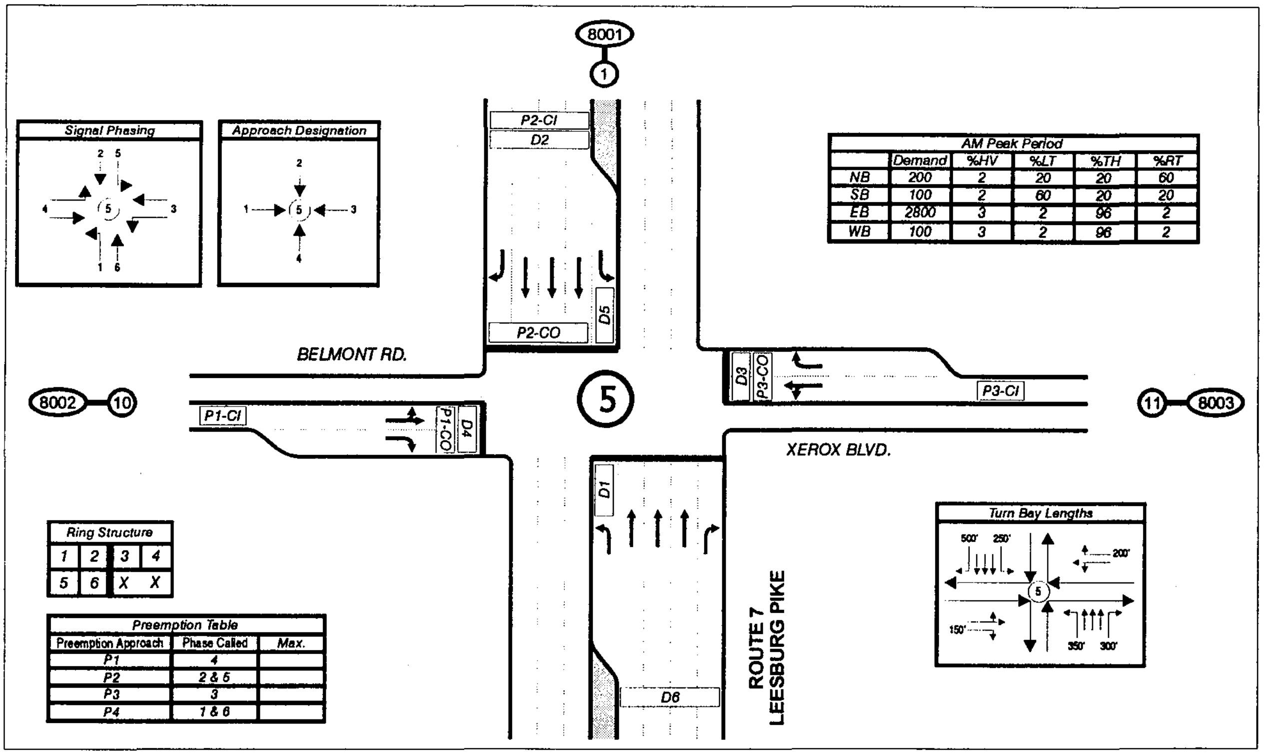


Figure 4. Geometry and intersection layout for Route 7 at Belmont Rd./Xerox Blvd. (Node 5).

This intersection is a typical four-legged intersection. Notice that protected left-turn bays from the minor street are not present.

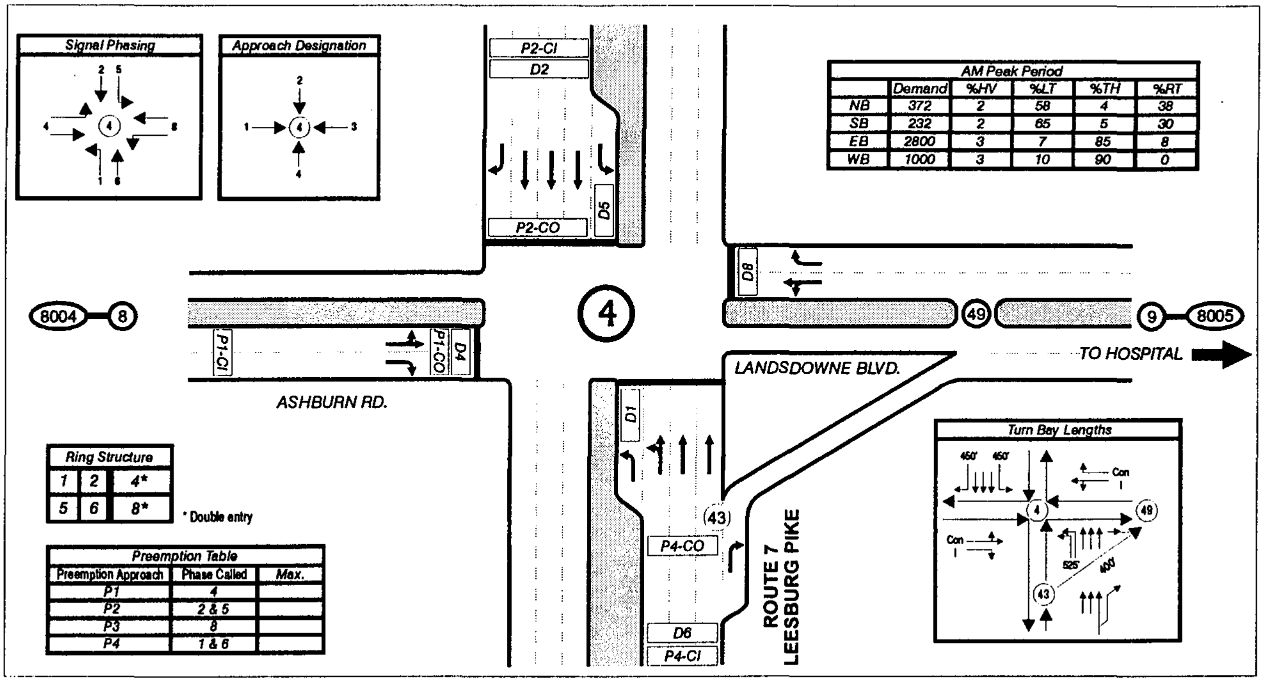


Figure 5. Geometry and intersection layout for Route 7 at Ashburn Rd./Landsdowne Blvd. (Node 4).

Notice that Westbound Route 7 traffic wishing to exit into Northbound Landsdowne Boulevard has a dedicated exit ramp for this purpose. Protected left-turn bays from the minor streets are not provided.

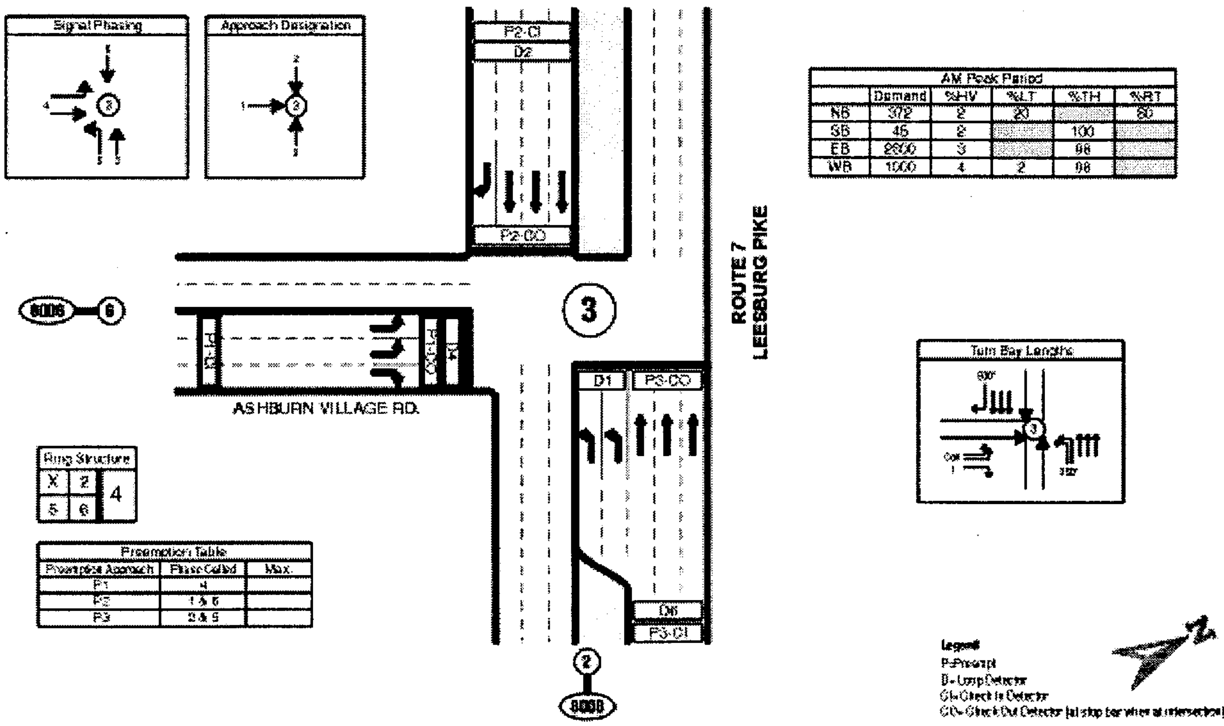


Figure 6. Geometry and intersection layout for Route 7 at Ashburn Village Rd. (Node 3).

This is a typical T-intersection with dedicated double left-turn lanes from the minor street.

Evaluation Procedure and Equipment

As stated in the Technical Approach section of this document, the TSIS analysis package was used as the software component for this study. Several other hardware components were also used to perform this evaluation. The most critical of these hardware components was the Controller Interface Device (CID), also discussed in the Technical Approach section.

The CID can be thought of as a computer-controlled suitcase tester. The "loop detector switches" on the CID are closed every time a vehicle passes over a loop detector specified in the CORSIM network (e.g., Loop D1 in figure 6). Similarly, since the CID has input modules monitoring the phase outputs, the simulation can read back the state of each Type 170 controller. The phase states (red, amber, and green) are used by the simulation model to determine which vehicles should be moving and which vehicle should be queuing. Since this environment allows the simulation to directly consider how real hardware is performing, the impact of features can be directly incorporated into the simulation.

For example, if a preemption call comes in on channel 1 at intersection 3 (figure 6) and stays there for 140 seconds, the controller would dwell in phase 4 for 140 seconds. The CORSIM simulation would:

- Directly consider the impact of a red indication on phases 2, 5, and 6 for that duration.
- Directly consider the effect on the network as the controller came out of preemption and attempted to get back in step. "Getting back in step" typically requires either shortening or lengthening phases.

Another important hardware component used in this evaluation was the 232 VDOT cabinet itself. Three cabinets, identical to those found in the field throughout Northern Virginia, housed the Type 170 controllers in addition to the vehicle detectors and phase load switches. Each CID was wired to one cabinet and allowed virtually all aspects of the actual intersection to be simulated.

In order to quantify the impact of emergency vehicle preemption, it was essential that a carefully controlled set of experiments be conducted with real traffic signal control equipment. In designing the experiments, several issues were considered, for example:

- Time period(s) to be analyzed.
- Number of iterations needed to obtain statistically meaningful results.
- Number of preemptions during study periods.
- Worst-case recovery time for signals to return to coordination.
- Route(s) of emergency vehicles preempting signals.
- Procedure for generating emergency vehicles (fixed or random headways).
- Location of vehicle when preemption sequence is initiated.
- Timing plan in effect (cycle length, coordination plan).

- Duration of simulation.
- MOE's used to quantify performance.

The following process was followed:

Step 1. Code CORSIM

Utilizing the ITRAF input processor, also packaged under TSIS, the geometric and operational characteristics of the three-intersection network were coded. This involved converting the network (figure 2) to the link-node diagram required by CORSIM (figure 7).

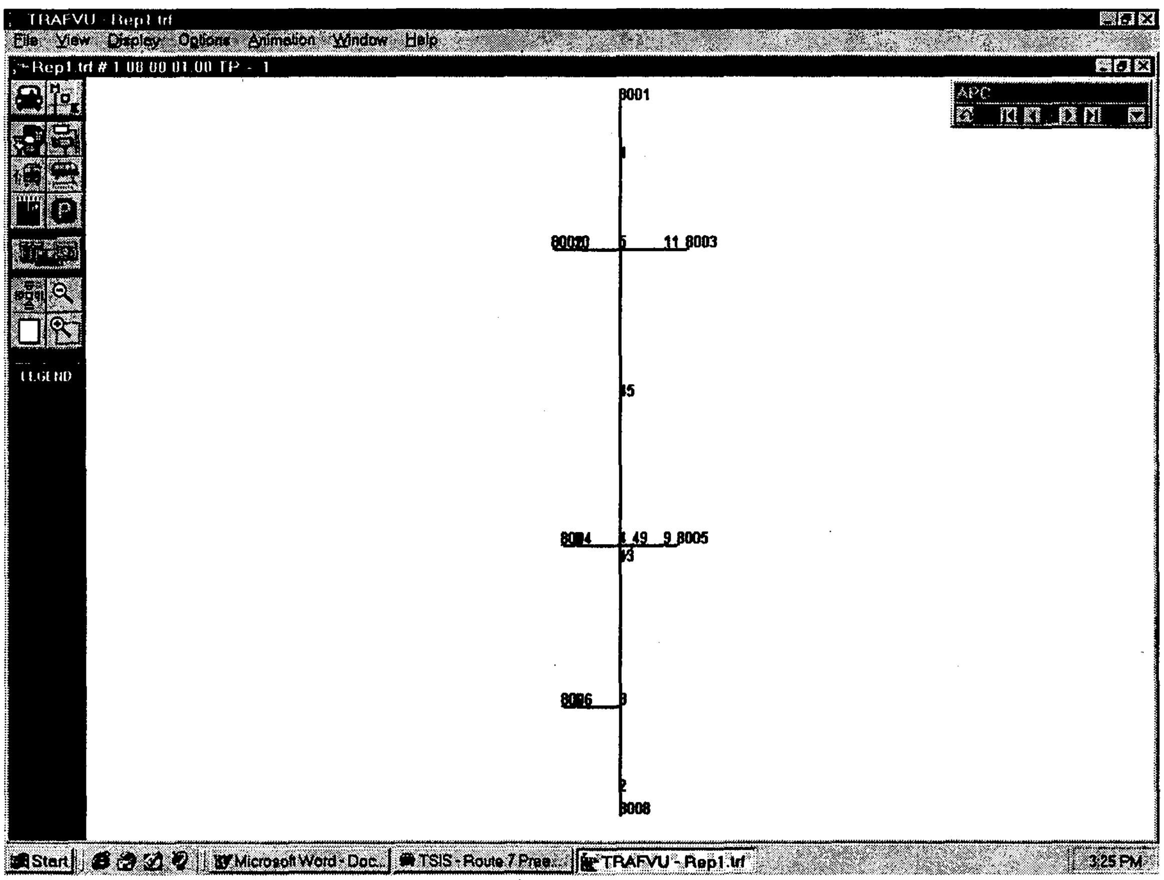


Figure 7. Link-node diagram.

It is important to note that a special (custom) version of the CORSIM model was used in order to simulate emergency vehicle preemptions. The release version of CORSIM does not possess the logic necessary to simulate ambulances and preemption logic. Therefore, a special version of CORSIM was created by ITT Systems for this purpose, where the "ambulance" was coded as a passenger car with a very aggressive driver for the purpose of vehicle performance and driver behavior. However, some of the behavior characteristics of an ambulance and the resulting traffic impact created (i.e., use of shoulder, vehicles moving out of the way, etc.) cannot be simulated by CORSIM. This limitation must be kept in mind when reviewing the results.

Step 2. Equipment Setup

Figure 8 illustrates the simulation architecture used for this study. The following steps were followed:

- Type 170 software (BiTran) on all three controllers was obtained and loaded.
- A system diagram sketch (SDS) showing the network orientation, turn pockets, detectors, and phase assignments was prepared.
- Cabinet load switches to be monitored were identified and documented on the SDS.
- Detector inputs (cabinet pins and rack positions) to be used were identified and documented on the SDS, including the mode (pulse or presence) of the detectors.
- MS-DOS computers and monitors were connected to each of the Type 170 cabinets in order to observe the state of the controllers, set date and time, and force the controllers into specified plans using the BiTran software. This reliably allowed the determination of the state of the system without keying-in individual hexadecimal codes on each of the Type 170 controllers. A diagram of this equipment is shown in figure 8.

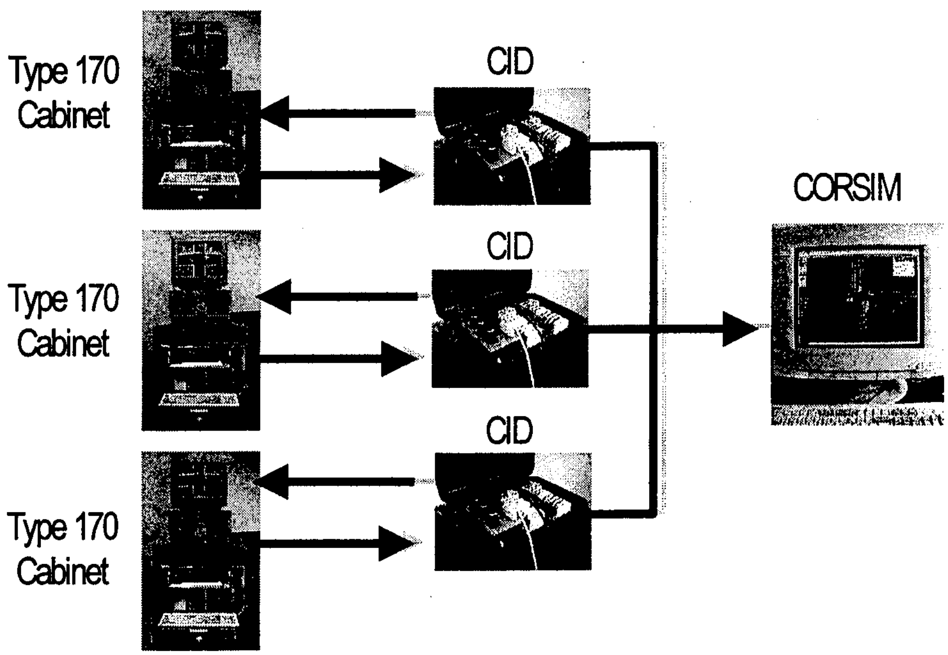


Figure 8. Diagram illustrating simulation architecture used for evaluating preemption impact.

Figure 9 illustrates the equipment setup used in the study.

Figure 9. Equipment used in simulation.

Step 3. Determine and Code Study Cases

For the purpose of this study, a "case" is the combination of the ambulance's path to the hospital, its creation time during the simulation, and the number of preemptions simulated. Nine cases were studied. Figure 10 shows the nine study cases along with the random number seeds[1] used for each of the 20 iterations. The figure also shows the phases preempted for each of the intersections affected.

Notice that Case 0 is the base case, or the no-preemption case, used as a baseline for comparison purposes. The rightmost column graphically shows the ambulance's path.

Cases 7 through 9 are identical to cases 1, 2, and 4, respectively, except that they have two preemptions each, at 5 minutes (300 seconds) and at 5 minutes plus one cycle length (210 seconds) or 520 seconds. The purpose of these three cases was to assess the impact of multiple preemptions on recovery time.

[1] Random number seeds are used by CORSIM to achieve variability, within a normal distribution, from iteration to iteration.

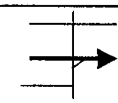
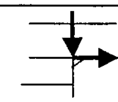
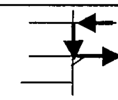
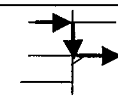
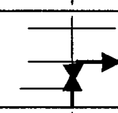
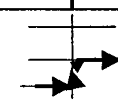
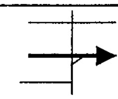
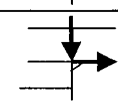
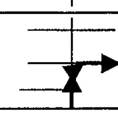
Case	Number of Replications	Record Type 2, Entry 4 Random Number Seed	Record Type 2, Entry 17 Random Number Seed	Record Type 2, Entry 18 Random Number Seed	Node & Phases Preempted	Ambulance Creation Time (sec.)	Ambulance Path	
0	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	Base case - No Preemptions H			
1	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	4 (ϕ4)	300H	8004-8-4-49-9-8005	
2	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (ϕ2 &ϕ5) 4 (ϕ2 & ϕ5)	H 300 H	8001-1-5-45-4-49-9-8005	
3	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (ϕ3) 4 (ϕ2 & ϕ5)	300H	8003-11-5-45-4-49-9-8005	
4	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (ϕ4) 4 (ϕ2 & ϕ5)	H 300 H	8002-10-5-45-4-49-9-8005	
5	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (Not preempted) 3 (ϕ2 & ϕ5)	300H	8008-2-3-43-49-9-8005	
6	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	4 (Not preempted) 3 (ϕ4)	H 300	8006-6-3-43-49-9-8005	
7	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	4 (ϕ4)	300, 520	8004-8-4-49-9-8005	
8	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (ϕ2 &ϕ5) 4 (ϕ2 & ϕ5)	300, 520	8001-1-5-45-4-49-9-8005	
9	20	1023, 5151, 3271, 8323, 8753, 1581, 9821, 1919, 1277, 3957, 3557, 8327, 1613, 9483, 3981, 6257, 3397, 6897, 4299, 7673	2387, 1949, 7887, 4271, 8143, 2919, 3769, 2493, 7683, 3079, 4957, 1141, 8147, 7057, 7869, 8481, 4389, 8627, 9537, 1623	8661, 5243, 6361, 1277, 8631, 9107, 5397, 1281, 9291, 9217, 1571, 1537, 6169, 9951, 5577, 4313, 5417, 9481, 3143, 1351	5 (Not preempted) 3 (ϕ2 & ϕ5)	300, 520	8008-2-3-43-49-9-8005	

Figure 10. Study Cases and Random Number Seeds.

Also, to evaluate the effect that increased volumes would have on the network, two cases (4 and 7) were run at three increased volume levels (a, b, and c), as shown in table 1. These increased volume rates were chosen to provide insight into the impact of preemption during saturated or near saturated conditions.

Table 1. Entry volumes* used in study.

Entry Link	**Actual Volumes* (vph)**	**"a" Volumes (vph) (Halfway Between Actual & Saturation)**	**"b" Volumes (vph) (Saturation)**	**"c" Volumes (vph) (10% Over Saturation)**
8001-1	2,800	4,700	6,600	7,260
8002-10	200	200	200	200
8003-11	100	100	100	100
8004-8	372	372	372	372
8005-9	232	232	232	232
8006-6	372	372	372	372
8008-2	1,000	3,800	6,600	7,260

*Note: These entry volumes resulted in intersection counts (left, right, and through) as observed and reported by VDOT. Percentage of heavy vehicles (i.e., trucks) used was 3 percent for Route 7 and 2 percent for the side streets.

Step 4. Run the Simulations

Twenty (n=20) iteration runs for each of the 10 cases, or 200 simulation runs, were executed utilizing the actual volumes reported by VDOT and three sets (a, b, and c) of artificially increased volumes (see table 1). This sample size would provide sufficient variability within the runs to generate statistically valid results.

The duration of each of the simulation runs was 33 minutes, running in real time.[2] This simulation duration was based on the worst-case short-way transition time that the Type 170 controllers were using for coordination. It should be pointed out that these parameters have a profound impact on how the controller recovers from preemption (and, therefore, on the system's MOE's) and there is absolutely no guidance in the literature regarding how these parameters should be set.

Based on the transition parameters, a worst-case time for an intersection to return to coordination was estimated. This recovery time was important in deciding how long the simulations should run, to avoid cutting off the transition effects (which continue for a couple of cycles after the controller returns to coordination). Also, it was important to avoid excessively long simulation runs that would average-out (dilute) the impact of the emergency vehicle preemption.

The time period analyzed was then 8:00 a.m. to 8:33 a.m.

The scripting feature in CORSIM was used to automate the runs.

Step 5. Analyze Results

CORSIM produces two types of output files: (1) the .OUT file, which contains tabular MOE information, and (2) the .TSD file, which contains the animation file that TRAFVU can display graphically. Both files were studied:

Output file (.OUT) data

From the .OUT files, the following MOE's were of interest:

- Corridor Travel Time for Through Movement Through All Three Intersections.
- Average Side-Street Delay.
- Cumulative Number of Stops for Through Movements Through All Three Intersections.

The CORSIM results for these MOE's are tabulated in tables 2 and 3.

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[2] For the purpose of this report, "real time" is equal to wall clock (or 1 second of simulation for each second of processing) time.

Table 2. Tabulation of MOE's for actual Route 7 volumes. (Top number is the mean value, bottom number is the standard deviation.)

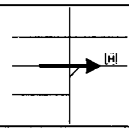
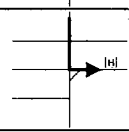
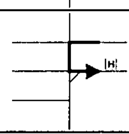
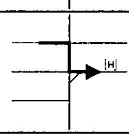
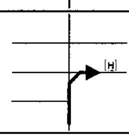
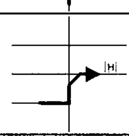
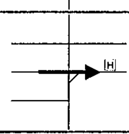
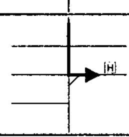
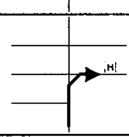
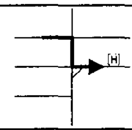
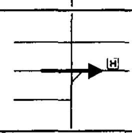
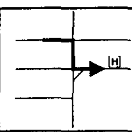
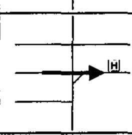
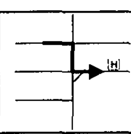
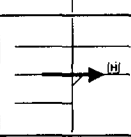
1 Case Number	2 Intersections & Phases (ϕ) Preempted	3 Ambulance Entry Time (sec.)	4 Ambulance Path	5 Corridor Travel Time (and Standard Deviation) for Through Movement Through All Three Intersections (sec.)		6 Average Side-Street Delay (and Standard Deviation) (sec.)	7 Cumulative Number of Stops (and Standard Deviation) for Through Movements Through All Three Intersections	
				Westbound	Eastbound		Westbound	Eastbound
0 (n=20)	Base case, no preemptions			197.3 2.3	208.6 4.9	60.1 3.2	464 30.6	1251 88.1
1 (n=20)	4 (ϕ4)	300		198.1 3.4	212.1 3.6	60.5 3.8	474 21.9	1310 53.6
2 (n=14)	5(ϕ2 & ϕ5), 4(ϕ2 & ϕ5)	300		197.5 3.7	213.1 7.8	61.8 6.5	472 33.4	1292 84.9
3 (n=20)	5(ϕ3), 4(ϕ2 & ϕ5)	300		197.3 5.1	215.9 10.1	57.3 5.8	450 58.2	1294 136.2
4 (n=19)	5(ϕ4), 4(ϕ2 & ϕ5)	300		196.4 5.3	212.2 8.1	60.9 8.3	439 61.7	1213 124.0
5 (n=20)	4(not preempted), 3(ϕ2 & ϕ5)	300		195.6 2.0	206.7 4.2	60.1 3.5	453 30.6	1203 92.5
6 (n=20)	4(not preempted) 3(ϕ4)	300		194.8 2.6	207.6 5.2	59.7 3.3	434 24.3	1204 118.6
7 (n=20)	4(ϕ4)	300, 520		199.8 4.8	213.7 4.9	57.1 6.2	466 34.4	1301 113.4
8 (n=20)	5(ϕ2 & ϕ5) 4(ϕ2 & ϕ5)	300, 520		199.9 9.0	212.0 6.1	68.1 8.2	480 51.6	1291 61.5
9 (n=20)	4(not preempted), 3(ϕ2 & ϕ5)	300, 520		194.7 2.7	207.1 3.7	60.6 3.5	451 36.5	1222 75.0

Table 3. Tabulation of MOE's for increased volumes a, b, and c for Cases 4 and 7. (Top number is the mean value, bottom number is the standard deviation.)

1 Case Number	2 Intersections & Phases (ϕ) Preempted	3 Ambulance Entry Time (sec.)	4 Ambulance Path	5 Corridor Travel Time (and Standard Deviation) for Through Movement Through All Three Intersections (sec.) Westbound	 Eastbound	6 Average Side-Street Delay (and Standard Deviation) (sec.)	7 Cumulative Number of Stops (and Standard Deviation) for Through Movements Through All Three Intersections Westbound	 Eastbound
a (n=20) base volumes	Base case, no preemptions			495.0 32.2	425.6 61.9	144.5 15.7	4060 257.0	2488 173.7
4 (n=20) a volumes	5(ϕ4), 4(ϕ2 & ϕ5)	300		487.3 28.1	455.6 58.0	145.3 13.7	4225 191.8	2746 199.3
7 (n=17) a volumes	4(ϕ4)	300, 520		532.6 58.7	424.8 55.9	147.0 19.1	4163 772.7	2548 575.4
b (n=20) base volumes	Base case, no preemptions			547.7 32.1	629.6 61.1	150.1 17.4	4390 256.6	3826 175.4
4 (n=20) b volumes	5(ϕ4), 4(ϕ2 & ϕ5)	300		526.5 47.5	672.3 48.4	144.7 15.5	4290 798.8	3943 270.5
7 (n=20) b volumes	4(ϕ4)	300, 520		573.6 68.3	669.8 47.8	144.0 16.4	4551 296.2	3948 203.9
c (n=20) base volumes	Base case, no preemptions			540.8 40.0	638.4 41.4	149.7 17.7	4338 245.4	3862 150.0
4 (n=20) c volumes	5(ϕ4), 4(ϕ2 & ϕ5)	300		536.6 38.6	666.9 47.2	145.6 14.3	4384 286.2	4008 274.2
7 (n=14) c volumes	4(ϕ4)	300, 520		550.9 53.5	657.8 83.7	145.8 13.8	4251 825.9	3712 801.0

Animation file (.TSD) data

Since TSIS does not currently provide a tool to extract or filter the signal-state data, manually viewing the animation through TRAFVU was necessary. This process, although tedious and time-consuming, gave a clear picture of how the transition algorithm[3] works, shortening some cycles and lengthening others until the desired (programmed) cycle length is achieved. By reviewing the animation file, it was observed that the average preemption time ranged from 16 seconds on the south approach to Intersection 5 for Case 4 to 34 seconds on the west approach to Intersection 4. In most cases, it took four to five cycles before the controllers were observed to be back in coordination. Since the only known point in the cycle is the end of phases 2 and 6, the number of cycles reported for the controller to get back into coordination may be less (by up to one cycle). This can be verified with TRAFVU once every cycle if it is in coordination.

[3] For consistency purposes, the BiTran default algorithm was used.

Figure 11 shows a typical TRAFVU display. The flagged vehicle indicates the ambulance as it travels through the network.

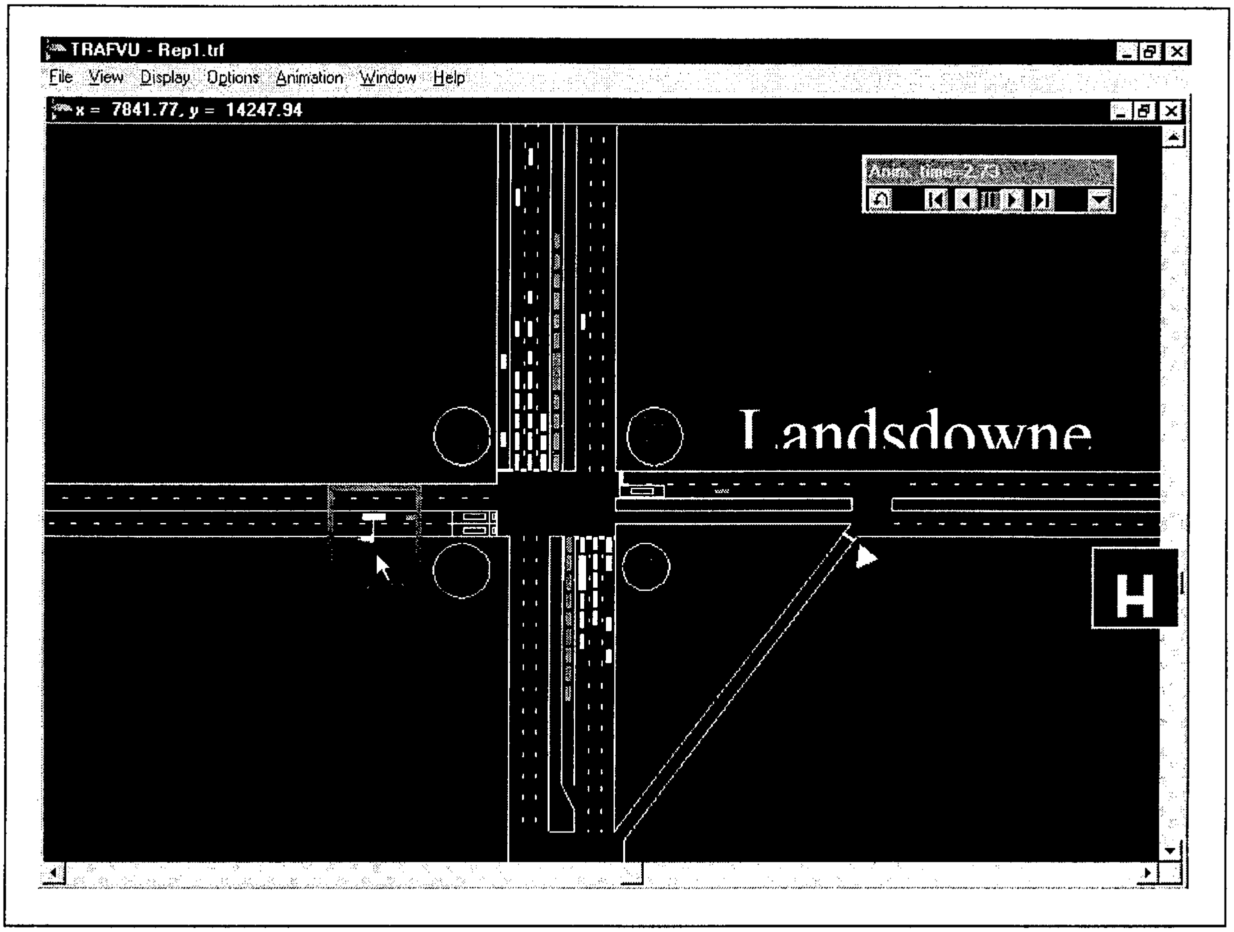


Figure 11. Sample TRAFVU animation display.

Step 6. Results

Previously summarized in table 1 were the various demand volumes applied to the network. Table 2 summarizes these experiments as performed with actual volumes and the average corridor travel time for each of the preemption scenarios. Column 1 lists the "case number" and the number of simulation runs performed. The intersections (and phases) preempted are shown in column 2. The time(s) the emergency vehicle (ambulance) was introduced into the simulation is shown in column 3, and its path is shown schematically in column 4. Column 5 tabulates the corridor travel time (westbound and eastbound, respectively), column 6 averages side-street delays, and column 7 provides a cumulative number of stops (westbound and eastbound, respectively). The smaller number below each of the larger numbers is the standard deviation[4] to give the reader a feel for the observed statistical variance.

Although several of the preemption cases have "statistically significant means" (EB Case 7 vs. EB Case 0, t=3.29) when compared to the base case, the magnitude of the 2.4-percent increase in average travel time was not considered very serious (not outside the bounds of normal traffic fluctuations). This was a somewhat surprising result because preemption is typically considered to cause significant disruptions in traffic. Some possible explanations for this relatively modest impact might include:

- Relatively long spacing between intersections. Platoon dispersion over long distances tends to decrease the benefits of maintaining coordination.
- Modest traffic demand that does not lead to terribly oversaturated conditions during and after preemption.
- Emergency vehicle detection that is quite close to the intersection (152 m [500 ft]). This results in a relatively short-duration preemption that holds the right of way for the emergency vehicle, but may not provide sufficient green time to clear the approach the emergency vehicle is arriving on.
- The signalized corridor appears to have a very long cycle length. This may be causing significant delay on the side streets that masks the impact preemption may have on side streets.

To get a feel for the sensitivity of the network to preemption under higher volumes, demand volumes a, b, and c were applied to the network (see table 1) and run for three cases – no preemption, Case 4, and Case 7. The results of these runs are tabulated in table 3. The first thing the reader should notice is the dramatic increase in average travel time and side-street delay in comparison to table 2. This can be attributed to the dramatic increase in the volumes on the Route 7 entry links (8001-1 and 8008-2). It should be pointed out that the network was not re-timed for these new volumes.

As you can see from the data tabulated in table 3, there is a more pronounced impact for some, but not all, of the preemption scenarios. For example, in demand volume a (Base Case, column 5 vs. Case 7, column 5), Case 7 increases average westbound travel time from 495.0 to 532.6 seconds. This reflects an approximate 7.6-percent increase in travel time. Even with the large standard deviations, this increase has a t-statistic of 2.36, which suggests that there is a statistically significant difference in the mean (Base Case, no preemption vs. Case 7) at a 95-percent confidence interval. Other cases are less clear. For example, looking at table 3, compare Base Case a, column 5 to Case 4, column 5. Notice that in the eastbound direction, the travel time increases from 425.6 to 455.6 seconds. In this example, the standard deviations are large, but the t-statistic is a relatively modest 1.58. As a result, even though the mean increased by 7 percent, there is no statistical evidence (at the 95-percent confidence interval) to suggest that the means are different.

[4] The standard deviation formula was computed using the STDEV function in Excel 97.

In summary, for the original volumes, signal timings, and preemption specification provided by VDOT, emergency vehicle preemption did have a statistically significant negative impact on the network for some preemption scenarios. However, this impact was judged by the authors to be relatively minor.

When higher (hypothetical) volumes were applied to the same network, some volume and preemption scenarios resulted in a statistically significant negative impact on the network. The impact of preemption with these elevated volumes was much more pronounced.

Conclusion

Using FHWA's Traffic Research Laboratory (TReL) as a test bed, this study demonstrated the use and capabilities of the CORSIM simulation model within the "hardware-in-the-loop" concept, in a real-world application.

The study effectively quantified the effect of emergency vehicle signal preemption on the coordination of the existing signal system on the Route 7 Virginia corridor. The simulation allowed researchers to evaluate existing and artificial traffic volumes to assess and quantify the impact of preemption by analyzing pertinent MOE's, *before* any field deployment took place.

The results showed that *for the geometric and operational conditions studied*, the impact of signal preemption on the signal coordination of the corridor was minor. These results do not warrant the application of an adaptive control system (ACS) to assess the impact of emergency vehicle preemption on this corridor. A follow-up study at an alternate location may be needed for that purpose.

The information contained in this report may be of assistance to public agencies considering the installation of emergency signal preemption systems and to Intelligent Transportation Systems engineers.