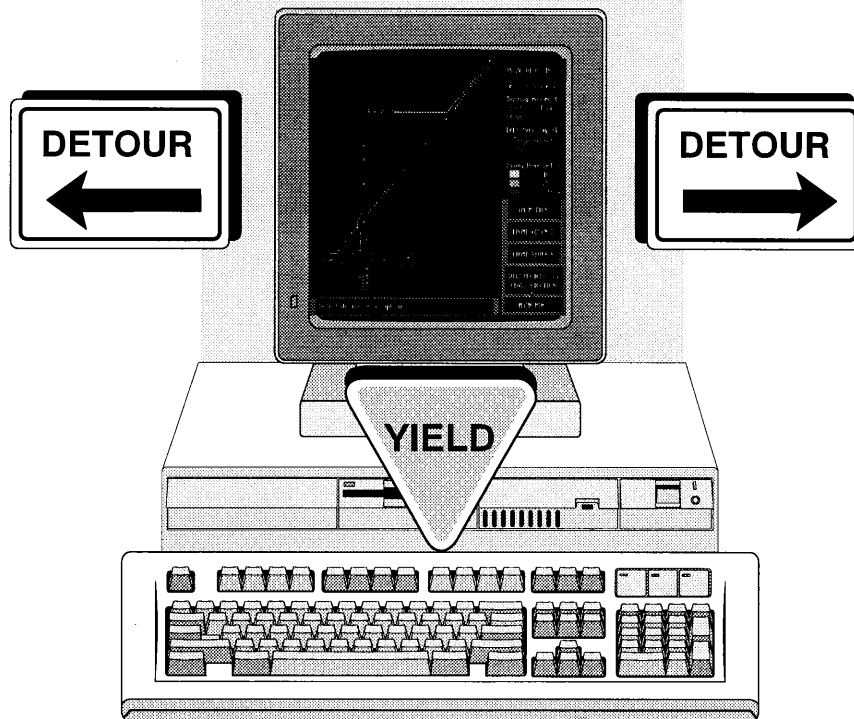


FINAL REPORT

**SIMULATION ANALYSIS OF
ROUTE DIVERSION STRATEGIES
FOR FREEWAY INCIDENT
MANAGEMENT**



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16. Abstract <p>Freeway incident management has become an important issue in departments of transportation nationwide. With many of the nation's roadways operating very close to capacity under the best of conditions, the need to reduce the impact of incident-related congestion has become critical. One way to achieve this reduction is to improve the management of traffic after an incident has occurred, including the use of traffic diversion strategies. Very often, however, diversion strategies are employed without proper consideration given to the effect of such a strategy on the alternate route, which in many cases is congested prior to the addition of diverted traffic. Careful analysis of diversion strategies, which includes examinations of the operational characteristics of both the freeway and alternate routes, can lead to much more efficient and effective strategies.</p> <p>This project establishes a methodology for analyzing diversion strategies using CORSIM, a microscopic simulation model developed by the Federal Highway Administration capable of simultaneously analyzing freeway and arterial roadways. The model process for incident specification and simulation was tested and applied to several case studies. The results of the study show that the model is a valuable tool in analyzing diversion strategies; the critical freeway volume at which diversion becomes advantageous can be determined, as can bottleneck locations on the alternate routes. Signal timing adjustments can be tested and fine-tuned to achieve the ideal maximum flow along the diversion route.</p>			
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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Freeway incident management has become an important issue in departments of transportation nationwide. With many of the nation's roadways operating very close to capacity under the best of conditions, the need to reduce the impact of incident-related congestion has become critical. One way to achieve this reduction is to improve the management of traffic after an incident has occurred, including the use of traffic diversion strategies. Very often, however, diversion strategies are employed without proper consideration given to the effect of such a strategy on the alternate route, which in many cases is congested prior to the addition of diverted traffic. Careful analysis of diversion strategies, which includes examination of the operational characteristics of both the freeway and alternate routes, can lead to much more efficient and effective strategies.

This project establishes a methodology for analyzing diversion strategies using CORSIM, a microscopic simulation model developed by the Federal Highway Administration capable of simultaneously analyzing freeway and arterial roadways. The model process for incident specification and simulation was tested and applied to several case studies. The results of the study show that the model is a valuable tool in analyzing diversion strategies; the critical freeway volume at which diversion becomes advantageous can be determined, as can bottleneck locations on the alternate routes. Signal timing adjustments can be tested and fine-tuned to achieve the ideal maximum flow along the diversion route.

SIMULATION ANALYSIS OF ROUTE DIVERSION STRATEGIES FOR FREEWAY INCIDENT MANAGEMENT

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INTRODUCTION

Congestion on urban freeways has grown significantly in recent years. In 1975, approximately 40% of urban interstate peak hour traffic flowed at an average speed of less than 56 kph (35 mph). By 1990, this percentage had risen to almost 70%. It has been estimated that by the year 2005, urban congestion costs could be as high as 8 billion vehicle-hours and \$88 billion.¹ Traffic volumes have grown by approximately 5% per year in recent years, which indicates that congestion will only worsen unless steps are taken to alleviate it.² The answer to congestion problems has traditionally been to provide additional capacity by building more roadways. This is no longer a viable alternative. Beyond the obvious funding problems, there are problems associated with the availability of land, environmental impacts, and the fact that any excess capacity provided will be quickly absorbed and congestion will return. Transportation professionals have, therefore, begun to look for new ways to address congestion.

It is estimated that 60% of all congestion-induced delay is caused by incidents.³⁻⁵ A report by the California Department of Transportation placed the cost of incident-related congestion at approximately \$1 million per day.⁶ These costs are particularly significant when one considers the fact that incident-related congestion is considered by some to be “one of the least understood and most disruptive phenomenon facing traffic flow management.”⁴ It is important to realize that although major incidents do cause severe traffic flow disruptions, minor incidents, including breakdowns, cause a substantial portion of the total delay attributable to incidents. A report by the Federal Highway Administration (FHWA) stated that minor incidents are responsible for 65% of all incident delay, with major incidents accounting for the remaining 35%.⁶

The duration of an incident is not dependent on any one factor but rather is the result of many factors working together. A rear-end collision that blocks one lane of traffic on a weekday during rush hour will more than likely not have the same duration as a similar incident occurring on a weekend night. A study conducted at the University of California, Irvine, found that the average duration of an incident is 37 min, with a standard deviation of 30 min. This high standard deviation is a result of the wide variation in incident duration, attributable to differing conditions. For example, the study determined that the average duration of a night-time

disablement involving a lane closure was 14 min, whereas the average duration of a daytime injury accident involving lane closures was 66 min.⁷

The process of managing an incident has four distinct stages.² In the first stage, the incident is detected; in the second stage, the proper response is sent to the scene; in the third, the debris created by the incident, including the vehicles and any other objects, is removed from the roadway; and in the fourth, with full capacity restored, the queues dissipate and traffic flow returns to preincident conditions. During recovery, the fourth stage, throughput increases as the vehicles queued during the incident attempt to clear the area. This increased flow level is termed the *getaway flow* and is constrained by the physical capacity of the roadway. During peak periods, the normal demand flow very often approaches this capacity, and therefore it takes a significant amount of time for queues to dissipate and flow to return to normal. This is known as the *time to normal flow*.

PROBLEM STATEMENT

Incident management programs have been established in urban areas nationwide to help reduce the magnitude of incident-induced congestion. The weakest element of these programs is the recovery stage, particularly the utilization of traffic diversion strategies. Although such strategies are used in many areas, they have not been fully evaluated to determine their impact on the local transportation system. In most cases, in fact, only the impact on the freeway has been considered. For example, although the Northern Virginia area does have the advantage of a traffic management system (TMS), the diversion strategies developed have not been evaluated to determine their effect on the arterial street network. Further, diversion is used only in extreme cases. The incident management handbook developed for the FHWA states that "In general, when two or more lanes of a freeway are expected to be shut down for two or more hours, institution of the alternate route plan should be considered."⁸ If delay on the network as a whole is to be minimized, incident management programs need to incorporate comprehensive traffic management strategies and decision aids for defining strategies to be used in the recovery stage need to be developed.

PURPOSE AND SCOPE

The purpose of this project was to investigate whether simulation models could be used as decision aids for defining traffic diversion strategies for effective incident management. A methodology was developed for using such a model to determine the effects of various incident types on freeway traffic flow and of diversion of freeway traffic on the arterial network. The combined freeway/arterial roadway system was considered so that strategies that provide the lowest overall delay could be established, rather than having the problem shift from one location to another. This approach is significant because it addresses the often-held belief that congestion

on one roadway can be alleviated by diverting traffic to another roadway when in fact the other roadway might not have the capacity to accommodate diverted traffic.

CORSIM, a microscopic simulation model developed by the FHWA, was chosen as the model for this study. Since the program is still undergoing testing, some effort was directed toward evaluating the software and determining its potential for application in the analysis of incidents. This process included analysis of the model's ability to simulate incidents and the delay that results. Once the process was established, it was applied to two sites in Northern Virginia for which diversion strategies had been specified in the incident management plan. Alternative diversion strategies were analyzed to determine their effectiveness in reducing incident-induced congestion during the peak period.

METHODOLOGY

Model Selection

Several simulation models are available to conduct analyses of arterials or freeways, but few have the ability to do both simultaneously, taking into consideration the effects of one on the other. The TRAF family of models includes NETSIM and FRESIM, two microscopic models widely regarded as the most promising for use with arterials and freeways, respectively. A new model, CORSIM, combines these two models, allowing for a systemwide analysis of the freeway and surrounding arterial network. The fact that this model can perform such an analysis, in addition to it being an FHWA product and, therefore, public domain software, made it the logical choice to be used in this study.

In order to measure performance in a network, it is important to look at the system as a whole, rather than as a sum of its parts. In studying freeway incident management, this means considering the arterial routes surrounding the affected portion of freeway as well as the mainline itself. Within CORSIM, vehicles enter the network through either a freeway or an arterial entry node and proceed through the network. If a vehicle enters the network on an arterial link and wishes to enter the freeway, it does so through what is termed an *interface node*. Interface nodes represent points at which vehicles exit one subnetwork and enter another. In the case of CORSIM, interface nodes occur on the ramps carrying vehicles between the arterial and freeway networks.

The characteristics of vehicles and drivers (e.g., acceleration and deceleration rates and passive or aggressive tendencies) are carried through from one subnetwork to the next to provide a more accurate analysis of conditions. For example, a driver/vehicle combination designated as an aggressive driver in a high-performance sports car in one subnetwork will retain the same characteristics in the other subnetwork. In addition, queuing on ramps due to saturated conditions on the mainline are reflected in the arterial network as additional vehicles try to enter the ramp. Likewise, vehicles trying to exit the freeway onto a congested arterial will be forced to

wait on the ramp or possibly even queue onto the mainline freeway until it is physically possible for them to proceed. The interaction of vehicles at the freeway/arterial interface is an important feature when analyzing urban areas since peak period congestion affects both the freeway and the major arterials.

Modeling Incidents with CORSIM

CORSIM has the capability to model incidents on both the freeway and arterial streets in the coded network. Since this study is focused on the effects of freeway incidents, the discussion here is limited to the manner in which freeway incidents are modeled. Incidents may take the form of complete lane blockages or merely slowdowns resulting from incidents or other activities taking place on the shoulder.

The data required to specify the occurrence of an incident within a CORSIM dataset include the following:

- the link on which the incident occurs
- the effect the incident has on each lane on the link, including any auxiliary lanes
- the location of the incident along the link
- the length of roadway affected by the incident
- the time the incident occurs and how long it lasts
- the rubberneck factor
- the location of any signs warning of blockages.

In addition to the effects of the blockage on traffic flow, CORSIM models the rubbernecking phenomenon. The term *rubbernecking* refers to the tendency of drivers of vehicles in adjacent lanes to slow down as they pass an incident in order to see what is happening. This reduction in speed results in lower throughput, and therefore lower capacity. This factor is what explains the additional capacity reduction, beyond that corresponding to the physical loss, that occurs when one lane of a three-lane facility is blocked by an incident. Studies have shown that capacity reductions for such occurrences are approximately 50%, rather than the 33% reduction one would expect from the 33% loss in physical capacity.^{3,6,9} Later discussion focuses on precisely how this phenomenon is modeled by CORSIM.

The *FRESIM User Guide* suggests that a reasonable estimate of the length of the blockage is the length of the number of vehicles involved plus one.¹⁰ Since the program uses an estimate of

6.1 m (20 ft) per vehicle, an incident involving two vehicles would be reasonably represented by a blockage of 18.3 m (60 ft). In addition to this incident specification, the manual suggests that a secondary incident consisting of only rubbernecking be placed at the upstream end of the primary incident. This secondary incident should be the same length as the primary incident and have the same duration. This would take into account the drivers beginning to respond to an incident when they first see it, rather than waiting until they reached the physical location.

The specification of an incident consisting of only rubbernecking can also be used to simulate the effects of an incident on the shoulder. In this case, no lanes on the freeway would be blocked by the incident, but capacity would be reduced due to the reduction in speed of drivers passing the incident. Rubbernecking could also be used to model the effects of work zones on traffic characteristics. Drivers very often slow through work zones to see what is being done or to adjust for the restricted geometric conditions. Under these circumstances, drivers would be notified in advance of any lane closures and would have the opportunity to change lanes before reaching the point of closure.

Lanes may be designated as blocked at the point of the incident, having a capacity reduction caused by rubbernecking at the point of the incident, or flowing under normal conditions. For most lane-blocking incidents, the lanes not blocked by the incident will have some loss of capacity, as discussed earlier. This is modeled in CORSIM through the use of the rubberneck factor, which increases the distance at which vehicles follow each other.

Model Analysis

Rubberneck Factor

The first step in the analysis of the model's ability to simulate the effects of incidents was to determine the effect of the value of the rubberneck factor. This was accomplished by establishing a hypothetical network consisting only of a mainline freeway section. The freeway was coded as a three-lane, one-directional section with a free flow speed of 96.6 kph (60 mph) and an hourly volume of 2,000 vehicles per hour per lane (vphpl). One lane of the three was coded as being completely blocked, and the remaining two were coded as having capacity reductions due to rubbernecking. Rubberneck factors of 10%, 15%, 20%, and 25% were input. These factors were chosen primarily because the *FRESIM User Guide* suggested a factor of 10%. When the theoretical value of the reduced capacity was calculated, however, it was lower than the reduction found to occur under incident conditions quoted in the literature. To get a calculated 50% reduction, the factor had to be increased to 25%. The range for testing was therefore chosen as 10% to 25%. The resulting capacity reductions were measured by comparing the 15-min period before the onset of the incident to the 15-min period during which the lane was blocked. An output of the simulation model is the number of trips that have been made on the link over a period of time, and these numbers were the basis of the comparisons.

Once the reductions for each factor value were determined, they were compared to the theoretical value of the reduction derived from the definition of the factor as given in the *FRESIM User Guide*. The guide states that the capacity reduction is simulated by increasing the distance at which vehicles follow one another. According to the guide, this should result in a capacity reduction in the specified lane equal to the percentage entered for the rubberneck factor. In other words, if a value of 10% was entered for a lane with a capacity of 2,000 vph, the reduced capacity would be approximately 1,800 vph. In terms of link capacity, if one lane of three was completely blocked and the remaining two were influenced by a rubberneck factor of 10%, the capacity of the link would be reduced as shown in the following equation

$$RC = (100\%) \left(\frac{1}{3} \right) + (10\%) \left(\frac{1}{3} \right) + (10\%) \left(\frac{1}{3} \right)$$

$$RC = 40 \%$$

where 1/3 indicates the portion of volume normally carried in each lane and the percentages indicate the capacity reduction in that lane during the incident. In this example, the capacity would be reduced by 40%. It should be noted that FRESIM distributes vehicles equally across all lanes; therefore, one third of the total volume traveling on a three-lane section can be assumed to be in each lane.

Incident Duration

A series of runs were conducted to determine the effect incident duration has on overall system performance. The same network as described previously was used with a rubberneck factor of 15%. Incidents of varying durations (10, 15, 20, 25, and 30 min) were simulated with input volumes of 6,000 vph. The time to normal flow was estimated for each of these cases, as was the overall delay experienced in the network. The time to normal flow was determined by requesting output from the model at 5-min intervals and comparing the speed and throughput over each interval. Output provided by the model is cumulative, gathered since the beginning of the simulation period, and although intermediate output may be requested, speeds are calculated by the program from the vehicle miles traveled on the link divided by the vehicle minutes spent on the link. Both of these values are cumulative for the entire simulation period and therefore result in an average speed for the simulation period. In order to determine the speed over a specific 5-min period, the number of vehicle miles traveled during that period was divided by the number of vehicle minutes of travel occurring in the same 5 min. When both speed and throughput returned to preincident conditions, the freeway was assumed to have returned to normal flow.

Case Studies

Several case studies were undertaken to test the application of the model to specific situations. These applications focused on the ability of the method to provide a measure of the operational characteristics of a particular system in absolute terms as well as a comparative measure among several diversion strategies.

Both of the sites analyzed are in Arlington County in Northern Virginia on westbound I-66, inside the I-495 Capital Beltway. The first is in the area of Lee Highway, and the second is in the area of Glebe Road. Diversion strategies have been developed for I-66 as part of the Northern Virginia Incident Management Plan, and these plans provided the network for analysis in this portion of the project. The section of westbound I-66 analyzed is designated as an exclusive HOV facility from 4:00 to 6:30 p.m. Only vehicles carrying three or more people are allowed to use the facility during this period, and therefore traffic volumes resulting from these restrictions are considerably lower than those prior to, and immediately following, the restricted period. In fact, automatic traffic counters used for monitoring purposes by the TMS indicate that the volumes on I-66 during the HOV period are approximately half the average volumes for the hour before and after the HOV period. For this reason, the analysis period was chosen as 3 p.m. to 4 p.m., the hour prior to the HOV restricted period for the westbound direction. Examination of the traffic counts taken on the arterial streets indicated that this hour is, if not a peak period, a relatively high-volume hour for all intersections included in the analysis. Thus, it was decided that this hour represented an overall network peak at both locations.

Data for both case study locations were obtained from several sources. Arlington County has the distinction of being one of only two counties in Virginia that maintains its own roads. Since the responsibility also includes maintenance of any traffic control devices, the Arlington County Department of Public Works was contacted to obtain information regarding traffic volumes and signal timings. It was found that signal timing and phasing information was readily available, but information regarding current traffic volumes was not. The Northern Virginia District Office of the Virginia Department of Transportation (VDOT) was asked to conduct counts and did so from the middle of August through early September 1993. Intersection geometrics were also recorded at the time of the counts and verified by the researchers at a later date. Traffic volumes on I-66 were obtained from the automatic vehicle counters mentioned previously.

Site 1: Westbound Lee Highway

The first site, shown in Figure 1, is located on I-66 westbound, just west of the Theodore Roosevelt Bridge. According to the incident management plan, if an incident occurs on westbound I-66 between the ramp to westbound Lee Highway and the ramp from westbound Lee Highway, traffic is to be diverted onto Lee Highway and brought back to the freeway past the incident. In order to analyze this strategy, the network was coded to include the section of

LEE HIGHWAY CASE STUDY

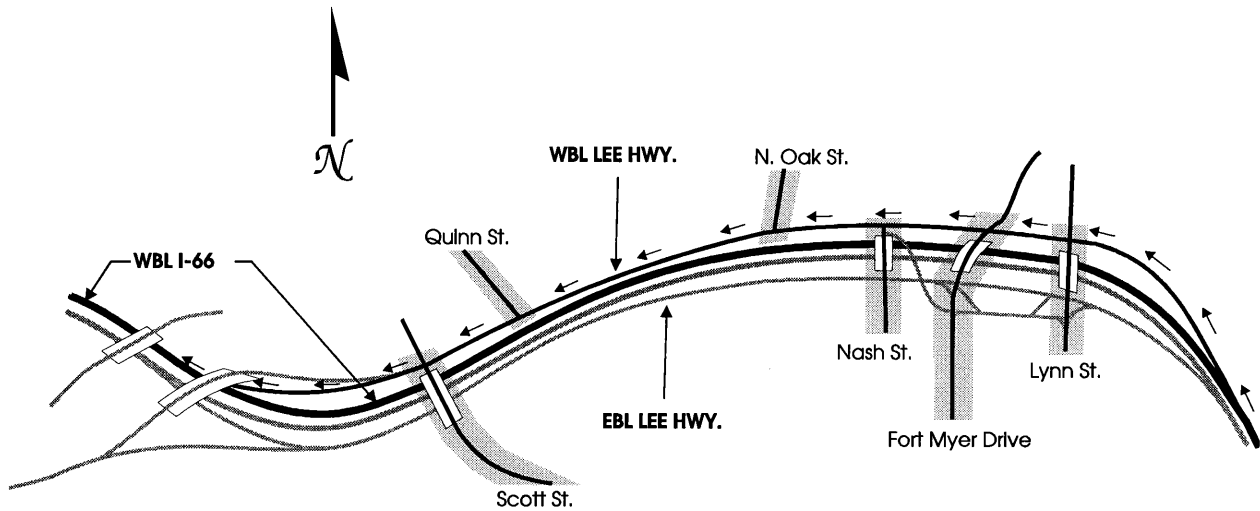


Figure 1

westbound I-66 between the exit and entry ramps as well as a portion of roadway on either end to capture the effects of weaving.

The portion of Lee Highway from I-66 to just west of the ramp to WB I-66 made up the arterial portion of the network. It should be noted that Lee Highway is divided in this area, with the east- and westbound lanes acting as separate one-way facilities. The intersections along Lee Highway of Lynn Street, Fort Myer Drive, Nash Street, Oak Street, Quinn Street, and Scott Street were included in the network. Lynn Street provides flow only in the southbound direction, and Fort Myer Drive only in the northbound direction. All of these intersections are controlled by pretimed signals.

Analysis of this site began with coding the base case, which included both the freeway and arterial. Geometric details such as turn pocket lengths were measured from as-built plans and checked with intersection diagrams gathered during site visits. The traffic volumes collected for the intersections along Lee Highway were used, along with mainline and ramp volumes for I-66. The output from this file was checked to ensure the model was accurately representing the area under study.

Once the base case was established and verified, several program runs were conducted with incidents to test the capabilities of the program. The first run included an incident blocking one lane for 45 min. Subsequent runs were conducted with volumes increased on I-66 by 500 and 1,000 vph. Diversion was then implemented for the run with an additional 1,000 vph. In addition to these runs, a file was created that specified an incident that blocked both lanes. The duration of this incident was also 45 min, and diversion was tested for this case. In all cases in-

GLEBE ROAD CASE STUDY

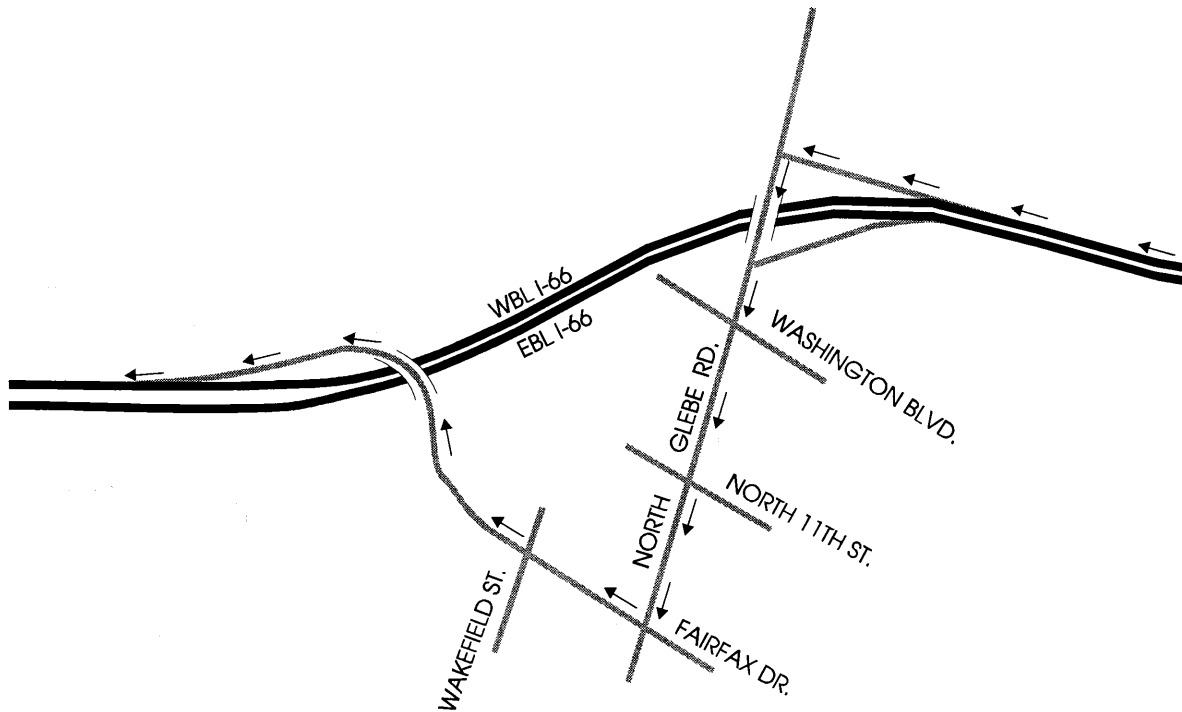


Figure 2

volving diversion, signal timings were modified to obtain the best possible flow for the diverted traffic stream.

Site 2: Glebe Road/Fairfax Drive

The second site is located approximately 6.4 km (4 mi) from Washington, D.C. As shown in Figure 2, the freeway section of the network extends from just east of the Glebe Road exit to just west of the on-ramp from Fairfax Drive. The alternate route specified for this area calls for vehicles to exit at Glebe Road, travel southbound on Glebe to the intersection with Fairfax Drive, and then reenter the freeway at Fairfax Drive. Along the route, diverted vehicles must travel through the signalized intersections of Glebe Road at Washington Boulevard, 11th Street, and Fairfax Drive and Wakefield Street at Fairfax Drive.

A base case for this site was coded to include the mainline I-66 and the portions of Glebe Road and Fairfax Drive that are specified as the alternate route. The volumes for the intersections were determined from the traffic counts, and volumes for I-66 and the ramps were determined from printouts of detector data supplied by the TMS. The base case was run, and the

output was checked to ensure the model was providing an accurate representation of flow through the network. Once this was accomplished, an incident was introduced that blocked one lane for 45 min. Diversion was added to this file, and several subsequent runs were conducted with differing levels of diversion.

RESULTS

Model Analysis

Rubberneck Factor

As stated previously, a sample dataset was created to test the sensitivity of the model to changes in the rubberneck factor. Table 1 presents the results of the runs. The through volume is the number of vehicles that were able to exit the link during the period of time when one lane of the three-lane roadway was blocked. The percent reduction is the difference between the through volume and the 1,500 vehicles that traveled the link in the 15 min prior to the incident. The theoretical reduction is based on the definition of the rubberneck factor as given in the *FRESIM User Guide*. As Table 1 shows, the simulated values resulted in higher percent reductions in capacity than the theoretical values. The high volume used for this run could explain the discrepancy. As volumes increase, the reaction of the traffic stream to the change in density becomes more pronounced. At 2,000 vphpl, it is possible the network was operating close to capacity. The reduction in capacity due to the rubberneck factor, therefore, had a greater impact than it would for conditions operating at lower flow levels. Running the same network again with input volumes of 1,800 vphpl rather than 2,000 vphpl resulted in lower reductions in capacity. These values are also shown in Table 1.

Table 1					
CAPACITY REDUCTION DUE TO RUBBERNECK FACTOR					
Rubberneck Factor (%)	Throughput (6,000 vph)	% Reduction	Throughput (5,400 vph)	% Reduction	Theoretical Reduction (%)
10	837	44	890	34	40
15	766	49	845	38	43
20	738	51	829	40	46
25	705	53	775	43	50

The goal of this effort was to determine the factor required to produce the capacity reduction found to occur for most incidents. The literature states that for an incident blocking one lane of a three-lane facility, capacity at the site of the incident is reduced an average of 50%.^{3,6,7} Due to the fact that this study focused on incidents that occur on high-volume roadways, it was felt that a rubbernecking factor of 15% would be the most appropriate to obtain the desired capacity reduction in the case studies conducted as it results in a 49% reduction (see Table 1). More data on traffic flow characteristics during incidents would be required to determine the relationship between volume and the effect of the rubberneck factor in CORSIM.

Incident Duration

A series of runs was conducted to determine the effect incident duration has on overall system performance. It was anticipated that the time to normal flow would increase significantly with incident duration. The results of the runs shown in Table 2 revealed that this was not strictly the case, however. Although the increase in duration from 10 to 15 min caused an increase in recovery time of 5 min, and the increase in duration from 15 to 20 min caused an increase in recovery time of 10 min, there was no increase in recovery time from the 20- to 25-min durations. Examination of the output produced by the model showed an increase in the volume of vehicles flowing past the incident location immediately following the clearance of the incident. This phenomenon, the getaway flow, is seen in observations of actual incidents. Volumes will increase to the physical capacity of the roadway to clear the queue as quickly as possible. CORSIM, however, may overestimate the capacity of the roadway and therefore provide an overly optimistic representation of the recovery phase of an incident actually occurring on the roadway.

Studies have shown that the relationship between the duration of an incident and the delay resulting from the incident is not one to one. In fact, one study suggested that delays increase geometrically with increases in incident duration.⁶ In other words, an incident lasting 30 min

Table 2		
EFFECT OF INCIDENT DURATION ON TIME TO NORMAL FLOW		
Duration (min)	Total Time (min)	Recovery Time (min)
10	65	40
15	75	45
20	90	55
25	95	55
30	130	85

would have a delay 4 times as high as the same incident lasting only 15 min. The delay values for the various incident durations discussed are shown in Table 3. Using the example from the literature regarding the geometric relationship between incident duration and delay, the incident lasting 15 min resulted in 325 vehicle-hours of delay and the incident lasting 30 min resulted in 1,115 vehicle-hours of delay. Although the latter case is not quite 4 times higher than the former one ($325 \times 4 = 1,300$), it does follow the trend. Once again, the fact that the delay was somewhat lower than might have been projected from observed patterns could be due to the optimistic capacities assumed in the program.

The results of the procedural tests indicated that the model is capable of reflecting the impacts of incidents on traffic flow. The delay experienced in the network increases with increases in incident duration, as does the time to normal flow. In addition, a rubberneck factor of 15% was chosen to simulate the effects of incidents on the unblocked lanes for high-volume freeways.

Table 3 RELATIONSHIP BETWEEN INCIDENT DURATION AND DELAY	
Incident Duration (min)	Delay (veh-hr)
10	170
15	325
20	580
25	855
30	1115

Site 1: Lee Highway

The analysis of this site began with coding the base case. This file included all the geometric and operational information, but it did not include the specification of an incident. The results were checked to ensure that the simulation was accurately representing the conditions in the area. The queue lengths and delay times at all signalized intersections along Lee Highway were examined and compared to those observed in the field. In addition, speeds on I-66 were checked for reasonableness. Tables 4 and 5 present the results of the base case run for the arterial and freeway, respectively. The total delay was 97.0 vehicle-hours. The majority of this

Table 4 DELAY AND LEVEL OF SERVICE: LEE HIGHWAY BASE CASE		
Intersection	Delay (sec/veh)	Level of Service
Lee Hwy/Lynn Street	13.6	B
Lee Hwy/Ft. Myer Drive	10.4	B
Lee Hwy/Nash Street	4.5	A
Lee Hwy/Oak Street	1.6	A
Lee Hwy/Quinn Street	0.1	A
Lee Hwy/Scott Street	3.8	A

Table 5 FREEWAY SEGMENT DELAY AND SPEED: LEE HIGHWAY BASE CASE		
Segment	Delay (sec/veh)	Speed (kph)
Entry point to Lee Hwy exit	0.08	83.0
Lee Hwy exit to midpoint	0.03	86.0
Midpoint to Lee Hwy entrance	0.03	85.7
Fairfax entrance to exit point	0.11	81.0

delay was experienced on Lee Highway, not on I-66. The delay values for the NETSIM and FRESIM subnetworks were 84.3 vehicle-hours and 12.7 vehicle-hours, respectively.

The first incident file run for this case placed a lane-blocking incident approximately 1,219 m (4,000 ft) downstream of the westbound Lee Highway off-ramp. The incident was coded to have a duration of 45 min, with a rubberneck factor of 15% specified for the adjoining lane. As expected, this resulted in an increase in the delay on the freeway. Total delay on I-66 increased from the 12.7 vehicle-hours in the base case to 15.8 vehicle-hours. The arterial remained relatively unchanged since no diversion was implemented. The average speed of vehicles remained relatively high, with a low of 64.4 kph (40 mph) during the incident. Figure 3 shows the variation in speed over the simulation period. The incident began 15 min into the simulation and ended 1 hour into the simulation. As the graph illustrates, the flow returned to

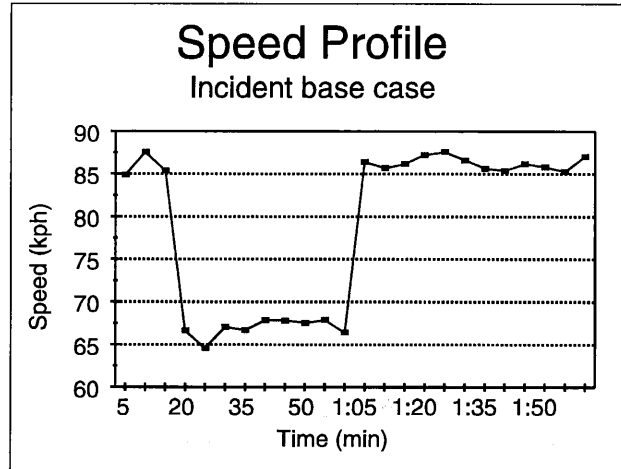


Figure 3

normal quickly after the incident was cleared, and the overall impact was relatively minor. Therefore, diversion of traffic would not be recommended in this case.

To determine the volume conditions on I-66 under which diversion would be beneficial, several more runs were made with higher volumes on I-66 to determine the effects of the same 45-min incident. In the first run, the volume was increased by 500 vph, for a total of 2,852 vph entering the network on the freeway. The total delay for vehicles traveling on this network was 103.4 vehicle-hours, and the delay attributable to the freeway portion almost doubled from the base case to 21.7 vehicle-hours. The speed through the affected area still remained relatively high, and the network seemed to return to normal quickly (see Figure 4). Accordingly, diversion would most probably still not be advantageous.

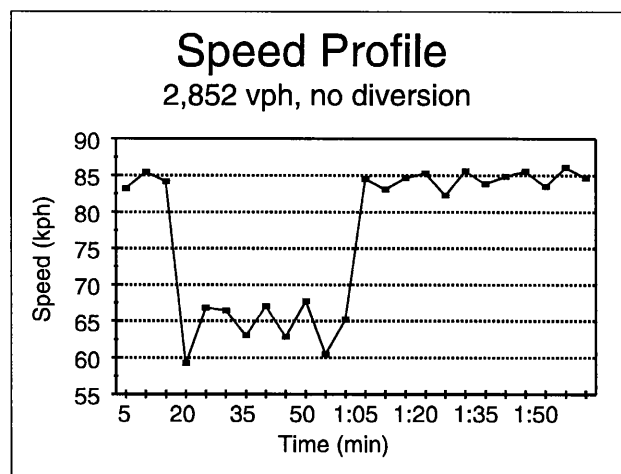


Figure 4

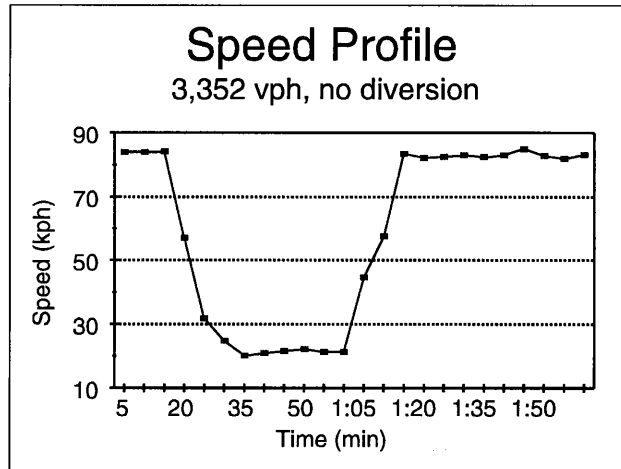


Figure 5

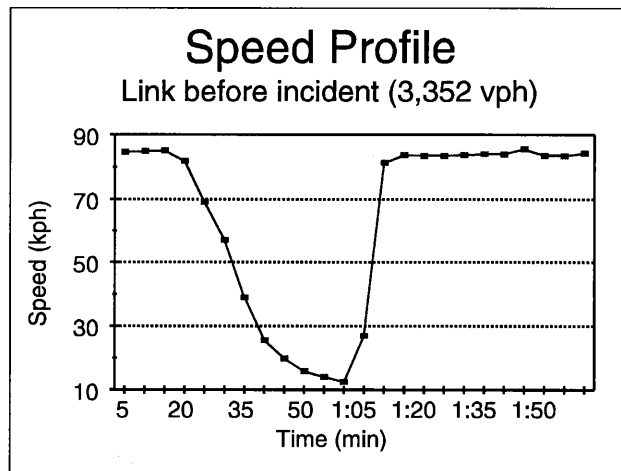


Figure 6

The next run increased the freeway volume to 3,352 vph. The speeds resulting from this case are shown in Figure 5. As the figure illustrates, there was a substantial reduction in speed as a result of the incident under this volume condition. The total delay in the network increased to 186.9 vehicle-hours of delay, with the freeway component of this delay at 105 vehicle-hours. In addition, the disruption of flow propagated backward to the preceding link in the network. A speed profile for this link is shown in Figure 6. By the time the incident was cleared, a queue formed that was approximately 1.6 km (1 mi) long. Due to the fact that the incident affected an extended section of the freeway, diversion was considered for this case. Diversion was assumed to begin approximately 10 min after the onset of the incident.

A time of 10 min was chosen because of a limitation of the program. All diversion within CORSIM is done manually by altering the destination of vehicles as they enter the network. Once

a vehicle is in the network, its destination cannot be changed. In the case of the incident simulation, what this means is that once vehicles join the queue caused by the incident, there is no way to cause them to divert. If a large enough number of vehicles join the queue such that it extends beyond the entrance to the ramp used in the diversion, that ramp will be effectively blocked and no vehicles will be able to divert. To overcome this problem, the time between the onset of the incident and the beginning of diversion was kept short so that the queue would not extend past the diversion ramp entrance. In actuality, vehicles in queue would begin to divert in response to the delay caused by the incident, thereby clearing a path for vehicles further back in the queue.

Vehicles were directed to divert from the freeway at the ramp to westbound Lee Highway and return to the freeway approximately 1.2 km (0.75 mi) downstream. The input file was altered to reflect a new origin-destination matrix for vehicles entering the network during the incident, and the turning volumes at the intersections along Lee Highway were altered to reflect the higher volumes and altered turning percentages. This was done by dividing the simulation into time periods and specifying different turning percentages at the ramps and each intersection along the arterial route. In this case, the diverted vehicles traveled through each intersection until they reached the ramp back to I-66 so the through volume at each intersection would be increased by the number of diverted vehicles. These changes were coded to be in effect until the end of the incident, and then the system was to return to its preincident condition. Fifty percent of the traffic on I-66 was assumed to divert for this case.

Due to the excellent levels of service at all the intersections along the diversion route under the base conditions, the diversion of 50% of the freeway traffic did not cause much additional delay on the arterial network. In fact, the total arterial delay for the 2-hr simulation increased by only 6 vehicle-hours, from 84.3 vehicle-hours in the base case to 90.9 vehicle-hours in this case. The delay on the freeway was significantly decreased by diverting traffic, from 105 vehicle-hours in the case without diversion to 37.8 vehicle-hours. An additional run was conducted specifying the level of diversion to be 60% rather than 50% to see if the system performance could be further improved. It was found that the additional vehicles attempting to exit caused too much turbulence in the freeway traffic flow and the delay experienced by vehicles on the freeway actually increased.

The effect of an incident blocking both lanes of the freeway was also examined. An incident was specified at the same location as in the previous cases, but this time both lanes were coded as being blocked for the duration of the incident. As expected, this resulted in a substantially greater delay for vehicles traveling on the freeway. In fact, the run was not completed because there were too many vehicles queued behind the incident and the program automatically terminated the run. When the run was terminated, the queue was in excess of 8 km (5 mi) long. In this case, diversion was definitely warranted. Once again, diversion was assumed to begin 10 min after the onset of the incident. All vehicles entering the network were instructed to exit at the ramp to westbound Lee Highway. The first run did not result in the correct number of vehicles reaching the NETSIM subnetwork. Further investigation revealed that exiting vehicles

were being delayed by the signal at Lynn Street and the flow of diverted vehicles was therefore being impeded. The signal timings were altered by a trial and error process at Lynn Street to allow more green time for the westbound movement, and the correct exiting volume was achieved. Originally, the signal timings were returned to normal as soon as the diversion ended, but it was found that if the altered timings were left in place for the hour after the clearance of the incident, delay in the overall network could be further reduced.

Table 6 presents the system delay for the three diversion strategies tested as well as the base case for comparison purposes. Although all three of the diversion strategies still resulted in an overall system delay far greater than the base case with no incident, the improved signal timings did have a significant impact on reducing delay in the system. It should be noted that the level of service was checked for all intersections on the alternate route, and all were found to operate at an acceptable level of service for each of the diversion strategies.

<p align="center">Table 6 DELAY COMPARISON FOR DIVERSION STRATEGIES (Incident blocking 2 lanes)</p>			
Condition	NETSIM Subnetwork Delay (veh-hr)	FRESIM Subnetwork Delay (veh-hr)	Total System Delay (veh-hr)
Base case	12.7	84.3	97
No change in timings	60.5	563.2	623.7
Altered timings	51.4	386.4	437.8
Continuous altered timings	58.0	337.1	395.1

Site 2: Glebe Road

The base case for the Glebe Road site was prepared and executed in the same manner as that for the Lee Highway site. The run was verified for conformity with conditions observed in the field: the queue lengths, delays, and travel times on Glebe Road and the speeds and delays on I-66. The only link with a significant average queue was the northbound approach to the intersection of Glebe Road at Fairfax Drive. The left-turn movement at this intersection is heavy, and all turns are made from one 45.7-m (150 ft) left-turn bay. The demand is often not completely served during the green phase, and the queue extends beyond the capacity of the turn bay much of the time. This spillover effect was observed in the field and was replicated by the model. The levels of service for each intersection in the NETSIM subnetwork are presented in Table 7. The average speeds and delay time for the individual freeway segments are shown in Table 8. The total systemwide delay for this case was 337.9 vehicle-hours. The reduction in speeds on the

Table 7		
DELAY AND LEVEL OF SERVICE: GLEBE ROAD BASE CASE		
Intersection	Delay (sec/veh)	Level of Service
Glebe Road/I-66 Ramp	6.96	B
Glebe Rd/Washington Blvd	14.18	B
Glebe Road/11th Street	2.74	A
Glebe Road/Fairfax Drive	34.27	D
Fairfax Drive/Wakefield	3.11	A

Table 8		
FREEWAY SEGMENT DELAY AND SPEED: GLEBE ROAD BASE CASE		
Segment	Delay (sec/veh)	Speed (kph)
Entry point to Glebe Exit	1.7	91.6
Glebe exit to midpoint	2.6	90.0
Midpoint to Fairfax entrance	6.1	81.3
Fairfax entrance to exit point	3.6	87.3

link approaching the entrance ramp from Fairfax Drive can be attributed to the increased weaving in this section. Vehicles are entering the freeway at speeds lower than those of the vehicles already on the freeway, and this causes turbulence in the flow.

The first incident specified for this case had a duration of 45 min and blocked one lane completely, with rubbernecking reducing the capacity in the lane that remained open. The incident was placed approximately 305 m (1,000 ft) downstream from the Glebe Road off-ramp. The overall system delay increased to 1,039 vehicle-hours, with 859.7 vehicle-hours of delay experienced by motorists on the freeway. The average speed on the link on which the incident occurred as well as the preceding link dropped dramatically. The speed profile for the link is shown in Figure 7. FRESIM does not report queue lengths directly, but by looking at the vehicle content of individual links under normal (preincident) conditions and after the occurrence of the incident, one can estimate a queue length. Link 1-2, the link preceding the incident link, had an occupancy of 250 vehicles per lane prior to the incident. Forty-five minutes later, just as the incident was cleared, the occupancy had increased to 750 vehicles in the left lane and 510 vehicles in the right lane. This indicates that the queue of slower moving vehicles caused by the

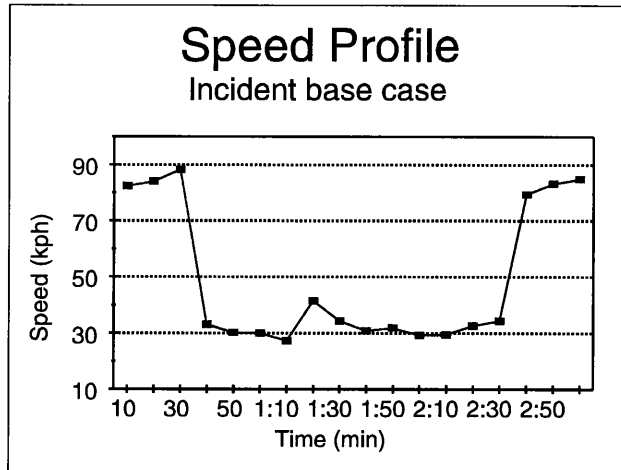


Figure 7

incident was at least 250 vehicles long. The higher occupancy in the left lane was due to the fact that the lane was the unblocked lane on the next link, making it the preferred lane for travel. It would be a conservative estimate to assume that the queue was at least 1.6 km (1 mi) long and probably closer to 3.2 km (2 mi) at this time. Diversion was considered for this case.

The first diversion strategy tested was a complete diversion. All vehicles entering the network were assigned to exit at Glebe Road and re-enter at Fairfax Drive. A problem was encountered regarding the ability of vehicles to maneuver physically through the diversion. The logic in FRESIM is such that if a vehicle is unable to execute the lane changes necessary to exit at its assigned destination, a message is reported to the user that the “vehicle missed destination” and it is removed from the network.

It was originally thought that if a vehicle was unable to exit, it would simply continue on the freeway. In the case of incident diversion, this would account for those vehicles that refused to divert. Unfortunately, a vehicle trace revealed that this is not the case. When the movement of individual vehicles is traced at 1-sec increments over a period of time, the “disappearance” of these vehicles can be observed. At a location just prior to the exit, the vehicle will be reported on the link, and in the trace for the next second, it will not be found on either the exit link, the freeway link feeding the exit, or the subsequent freeway link. This phenomenon can result in substantial loss of volume. The reasons vehicles miss their assigned exits are unclear, although it does tend to happen more often under high-volume conditions. The *User Guide* states that it is due to vehicles being unable to find an acceptable gap in the traffic stream to merge. Further evaluation of the vehicle trace showed that often a vehicle that missed an exit was following a vehicle that waited until the last minute before merging into the auxiliary lane and the following vehicle could not react in time. To compound this problem, the trace also showed that this often

triggers a chain reaction in which the vehicle following the first vehicle to miss the exit also misses, as does the vehicle behind it, etc.

When 100% of the freeway volume was instructed to divert to the arterial, more than 500 vehicles missed the exit, which represents approximately 30% of the vehicles destined to divert during the 35-min diversion period. This was considered unacceptable due to the fact that the vehicles disappeared, causing an incorrect number of vehicles in the network and, therefore, inaccurate results. Consequently, the run was not analyzed further.

In an attempt to determine what percentage of vehicles could divert successfully, a number of runs were conducted with decreasing percentages. For a diversion strategy with only 40% of the freeway volume attempting to divert, there were still approximately 125 vehicles, 16% of the 760 vehicles instructed to divert, who were unable to exit successfully. Under actual incident conditions, vehicles could be forced to exit by police or fire officials on the scene. It was therefore decided to look more carefully at the effects of the diversion on the arterial and assume that the vehicles were able to exit.

In order to simulate the correct volume on the surface street and yet still model the freeway section, a dummy link was introduced to feed vehicles onto the Glebe Road exit ramp (within the NETSIM subnetwork). During the time diversion would take place, the freeway volume was reduced to reflect the diverted volume and these vehicles were reassigned to the dummy entry point. By doing this, the proper number of vehicles were placed on the arterial and the effects of the increased volume could be accurately measured. To test the strategy, 50% of the freeway volume was assumed to divert.

To allow for reasonable flow along Glebe Road, the minimum green times for the side streets at each intersection were reduced. This time was then added to the minimum green specified for the Glebe Road approach. As might be expected, this resulted in a significant increase in the delay experienced by vehicles on the side street approaches. With additional volumes attempting to travel southbound on Glebe Road, the delay on those approaches also increased, even with the increased green time at the signals. Unfortunately, due to a limitation of the program that prohibits actuated signal specifications from being changed during the course of a simulation, the altered timings for the signals had to be in place for the entire simulation period. In addition, the large number of right-turning vehicles at the intersection of Glebe Road and Fairfax Drive caused significant problems. This intersection is designed with a channelized right-turn lane that begins approximately 46 m (150 ft) prior to the intersection, and all right turns are made from this lane. In order to service all the right-turning vehicles involved in the diversion, however, these vehicles must be allowed to discharge from two lanes. This could be accomplished in the field by placing an officer at the scene to instruct drivers.

The level of service for each intersection during the diversion period is presented in Table 9, along with the average delay for the intersection. As the table shows, the intersection of Glebe Road and Fairfax Drive is at LOS F during the diversion, the junction of the ramp with Glebe

Table 9 DELAY AND LEVEL OF SERVICE: GLEBE ROAD DIVERSION		
Intersection	Delay (sec/veh)	Level of Service
Glebe Road/I-66 Ramp	54.98	E
Glebe Rd/Washington Blvd	25.44	D
Glebe Road/11th Street	36.37	D
Glebe Road/Fairfax Drive	72.14	F
Fairfax Drive/Wakefield	5.49	B

Road is operating at LOS E, and the intersections of Washington Boulevard and 11th Street with Glebe Road are both operating at LOS D. In addition, the program reported numerous spillback messages, indicating that the queuing capacity of a link had been exceeded.

Despite the deteriorated level of service on the arterial, the overall system delay under this condition was approximately 500 vehicle-hours less than in the case with no diversion. The systemwide delay for this case was 794.4 vehicle-hours. The delay to the arterial system went up from 277.3 vehicle-hours with no diversion to 456.1 vehicle-hours with 50% of the vehicles diverting.

CONCLUSIONS

1. CORSIM is a valuable tool in evaluating the effects of incidents on systemwide traffic flow. Although the program cannot model every situation explicitly, an estimate of the amount of additional traffic the alternate route can accommodate can be determined.
2. For incidents where only one lane is closed, there is often an optimum diversion percentage beyond which freeway delays increase due to friction caused by the weaving of vehicles attempting to exit.
3. The physical capacity of the ramps and weaving sections to accommodate the diverted traffic is critical for successful diversion. If diverted vehicles cannot maneuver the weaving section, excessive queuing on the mainline will result.

RECOMMENDATIONS

1. The FHWA should continue its efforts in refining and updating the logic of the CORSIM program. The following suggestions for improvements in the model are offered.
 - Provide additional documentation of the effects of the rubberneck factor. This effort would require substantial data collection of incident traffic flow characteristics.
 - Add a feature that allows for the forced exiting of vehicles. At this time, vehicles unable to execute the lane changes required to exit are simply removed from the network, resulting in inaccurate network volumes.
 - Within intermediate output, provide intermediate, rather than cumulative, speeds for each link.
 - Provide a means for altering signal timings at actuated signals for a specific time period within the simulation period. Currently, actuated signal parameters must remain constant.
2. When development of the program is complete, VDOT staff should apply the CORSIM model to all potential diversion strategies to ensure their effectiveness, identify any bottleneck locations, and determine modifications to signal timings along the route that are necessary for optimum system performance. This work should be the responsibility of the district traffic engineering staff in cooperation with staff from traffic management centers (TMCs) where applicable.
3. When the model is fully developed, training in its use should be made available for traffic engineering staff so that personnel will be qualified to conduct the types of analyses referred to in Recommendation 2. Although it is likely that the FHWA will sponsor training courses, it is also likely that they will not be developed until some time after the official release of the program. The Virginia Transportation Research Council is prepared to provide technical assistance as an adjunct to that formal training to ensure that VDOT staff can apply the model correctly.

FURTHER STUDY NEEDS

Additional work in the area of traffic flow during incidents is needed to define motorist response to incidents more clearly. This research assumed that no motorists would divert unless instructed to do so and that a specific percentage of drivers could be forced to divert by some means. Investigation of the number of motorists that divert as a response to the delay and queuing without any information as to the cause of the delay would be useful, as would the number of motorists who divert with such information and the number who divert when told to

do so. Such information would be valuable to the engineer who must make the decision of when to divert traffic from a freeway. If a particular diversion route has been found to have the capacity to handle a 30% freeway diversion and studies have shown that 25% of the motorists divert without instruction, formal diversion should not be implemented. However, signal timing changes and turn restriction changes as discussed in this report should be implemented.

The results of this study indicate that simulation models in general, and CORSIM specifically, hold great promise for use in the analysis of the effects of incidents and the effectiveness of incident diversion strategies. Further work is needed, however, to improve the deficiencies of the model discussed in this report. Once this has been completed, further analysis of incident diversion plans should be undertaken by VDOT staff to develop a database of operationally sound diversion strategies for specific incident characteristics. This database could then be incorporated into an expert system for use in the TMCs. Such a system would greatly aid operators of the TMC when they are faced with incident situations requiring traffic management.

REFERENCES

1. Institute of Transportation Engineers. 1992. *Mobility Facts*. Washington, D.C.
2. Roper, D. H. 1990. *Freeway Incident Management*. NCHRP 156. Washington, D.C.: Transportation Research Board.
3. Cambridge Systematics, Inc. 1990. *Incident Management*. Prepared for Trucking Research Institute, ATA Foundation, Inc.
4. Garrison, D., and Mannering, F. 1990. Assessing the Traffic Impacts of Freeway Incidents and Driver Information. *ITE Journal*, 60 (8): 19-23.
5. Shepard, F. D. 1991. *Incident Management in Virginia: A State of the Practice Report*. VTRC Report No. 92-R6. Charlottesville: Virginia Transportation Research Council.
6. Reiss, R.A., and Dunn, W.M., Jr. 1991. *Freeway Incident Management Handbook*. Report No. FHWA-SA-91-056. Washington, D.C.: Federal Highway Administration.
7. Guiliano, G. 1988. *Incident Characteristics, Frequency, and Duration of a High Volume Urban Freeway*. Report No. UCI-ITS-WP-88-11. University of California, Irvine: Institute of Transportation Studies.
8. Virginia Department of Transportation. 1990. *Northern Virginia Freeway Management Team: Operating Manual*. Richmond.

9. Lari, A.P.E.; Christianson, D.; and Porter, S. 1982. *I-35W Incident Management and Impact of Incidents on Freeway Operations*. St. Paul: Minnesota Department of Transportation, Office of Traffic Engineering.
10. U.S. Department of Transportation. 1993. *FRESIM User Guide: Beta Version 3.1*. Washington, D.C.