SCOOT and Incidents

Performance Evaluation in Simulated Environment

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SCOOT is a widely used adaptive signal control system. There have been many evaluations of SCOOT during normal traffic conditions. It is hypothesized that SCOOT's ability to adapt to varying traffic during incidents provides an added benefit over its normal congestion-relieving capability. Through an interface between CORSIM and an actual SCOOT system, this study evaluates, in a simulated environment, SCOOT's performance during incidents to quantify these additional benefits. The evaluation is made over a range of volumes and incident durations. A theoretical test network and two real-world networks are simulated. Network and intersection delay, travel time, and queue length are used as measures of effectiveness (MOEs) throughout the comparison to quantify total and marginal benefits. During a 45-min incident within the Salt Lake City downtown area network, SCOOT reduced network delay, travel time, intersection delay, and queue length by 28.3%, 22.8%, 30.7%, and 24.2%, respectively, relative to the optimized plan-based control. Similar results were observed on the other real-world network. Although adaptive control has benefits above plan-based signal control, the findings indicate that during incidents, SCOOT provides an additional increase in benefits. The findings indicate that average SCOOT MOEs improve by 7% for a 15-min incident, by 12% for a 30-min incident, and by 18% for a 45-min incident depending on congestion level. The additional benefits that SCOOT adaptive control provides during incidents are quantified through the system's inherent ability to respond to traffic conditions in real time.

Congestion is one of the most pressing traffic problems in urban areas. Incidents are expected to contribute to more than 70% of the total congestion at a cost of $48 billion by 2005 (*1*). According to NHTSA statistics for 2000 (*2*), 43.9% of the annual incidents in the United States are urban intersection related.

When incidents occur on urban arterials, delay depends on the incident type and location (*3*). Incident congestion results in long queues, environmental pollution, longer travel times, and lower throughput. Several traffic control strategies such as metering, signal modification, communication through in-vehicle devices, and changeable message signs are used to minimize the effects of congestion during incidents (*4*). The most popular optimization objectives of incident management are overall travel time reduction, throughput maximization, and queue minimization (*5*).

Signal modification is an effective strategy for handling surface street incident congestion. Signal modification strategy provides benefits by reducing delay and queue lengths (*6*). Signal modification strategies include longer or shorter cycle time, phase changes to reflect current demand, and changes in the green splits and offsets to balance queues for conflicting movements. These signal modification strategies require a signal control system that is responsive to changing traffic demand. Most signal control systems in the United States are plan based (PB) and therefore are less flexible during incidents. Some of these signal control systems allow for minor traffic timing adjustments but fail to accommodate the large fluctuations created during incidents. These PB signal control systems do not respond to real-time traffic conditions but implement signal timings with limited flexibility. Thus the PB system's inefficiency leads to high congestion and longer recovery times during incidents. Adaptive traffic control systems (ATCS) were developed to react to the inherent traffic variations occurring from cycle to cycle, and therefore they operate more efficiently. ATCS is a computerized traffic management system that calculates cycle lengths, splits, and offsets on the basis of real-time traffic detection. Since the philosophy of the ATCS is based on real-time traffic detection and response, these systems perform better than PB signal control during normal operations and should provide more efficiency during incidents. It should be noted that once a network reaches saturation, congestion is inevitable. ATCS delays the onset of congestion and recovers from congestion more quickly by changing signal timings to more efficiently use the available capacity.

LITERATURE REVIEW

Background information related to this research is provided and an attempt is made to familiarize the reader with commonly used terms.

Incidents

An incident is a complex scenario defined by a number of variables (*7*):

- Number of lanes blocked,
- Duration for which the lanes were blocked,
- Incident location—impacts of a midblock incident are different from those of intersection incidents, and
- Length of road blocked.

The impacts of incidents are dependent on the time of day, geometry, intersection control, and existing traffic demand flow level (*8*). If the traffic flow levels are high, incidents can cause gridlock (*9*).

ATCS and Incidents

Limited research has been done in evaluating the performance of ATCS during incidents. Taylor and Narupiti conducted research to

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evaluate the performance of the coordinated adaptive traffic system (SCATS) in Sydney, Australia, during congestion (*10*). They reported that SCATS is not very efficient in accommodating incidents. However, Taylor and Abdel-Rahim reported that SCATS control does respond to certain incidents by extending or shortening the duration of the green time at adjacent intersections (*11*).

SCOOT (split, cycle, and offset optimization technique) was developed in 1973 at the Transport and Road Research Laboratory, in the United Kingdom (*12*). Traffic control and coordination in SCOOT are achieved by varying the split, cycle, and offset to minimize a network objective function. This objective is expressed as a performance index (PI) and is a composite measure of queues, delay, and stops (*13*).

SCOOT identifies congestion using upstream detectors. When the queue backs up to the upstream detector, the detector occupancy increases. SCOOT uses these data to identify exit blockage at an intersection and thereby identify possible incident locations. SCOOT also has an optional module called integrated incident detection (INGRID) to detect the incidents in urban areas controlled by SCOOT. The automatic SCOOT traffic information database (ASTRID) is another optional database module in SCOOT that automatically monitors and records the traffic conditions for later retrieval and analysis. INGRID uses the traffic data from ASTRID as a reference against current detector data to identify the incidents.

The benefits of SCOOT over PB signal control during an incident were evaluated in Coventry, United Kingdom, during a complete arterial closure. This single event was a complete closure at undersaturated conditions for 3 h, and the evaluation showed a 21% reduction in delay at the network level and a 28% reduction in delay per vehicle on the diverted route (*14*). Further, a comprehensive understanding of SCOOT's performance during incidents is possible by examining SCOOT performance during various incident scenarios, incident durations, and traffic congestion levels. This evaluation is most feasible in the simulated environment.

METHODOLOGY

The performance of SCOOT during incidents is evaluated here for an incident scenario of one-lane closure for 15, 30, and 45 min and six different network traffic congestion levels. The network congestion is measured on the basis of volume-to-capacity (v/c) ratios: 0.80, 0.85, 0.90, 0.95, 1.0, and 1.05.

SCOOT's performance is compared with that of Synchro (*15*) optimized PB control. The measures of effectiveness (MOEs) are network delay, average vehicle travel time, average intersection delay, and average queue length. Incidents are simulated under peak-hour optimized PB control and SCOOT control for different congestion levels, and the MOEs are measured.

According to National Transportation Statistics (NTS) (*3*), an average incident lasts 30 min with a standard deviation of 15 min (*16*). Therefore, incident durations between 15 and 45 min represent 68% of all incidents. According to NTS, 75% to 80% of the incidents result in one-lane closure (*3*). From the NTS information, incident scenarios of one-lane closure with durations of 15, 30, and 45 min are reported since they represent the most common incidents.

The incidents studied are defined by the following variables:

- Midblock location;
- One-lane closure;
- Incident durations of 15, 30, and 45 min; and
- Congestion levels of 0.80, 0.85, 0.90, 0.95, 1.00, and 1.05.

Figure 1 explains the problem statement.

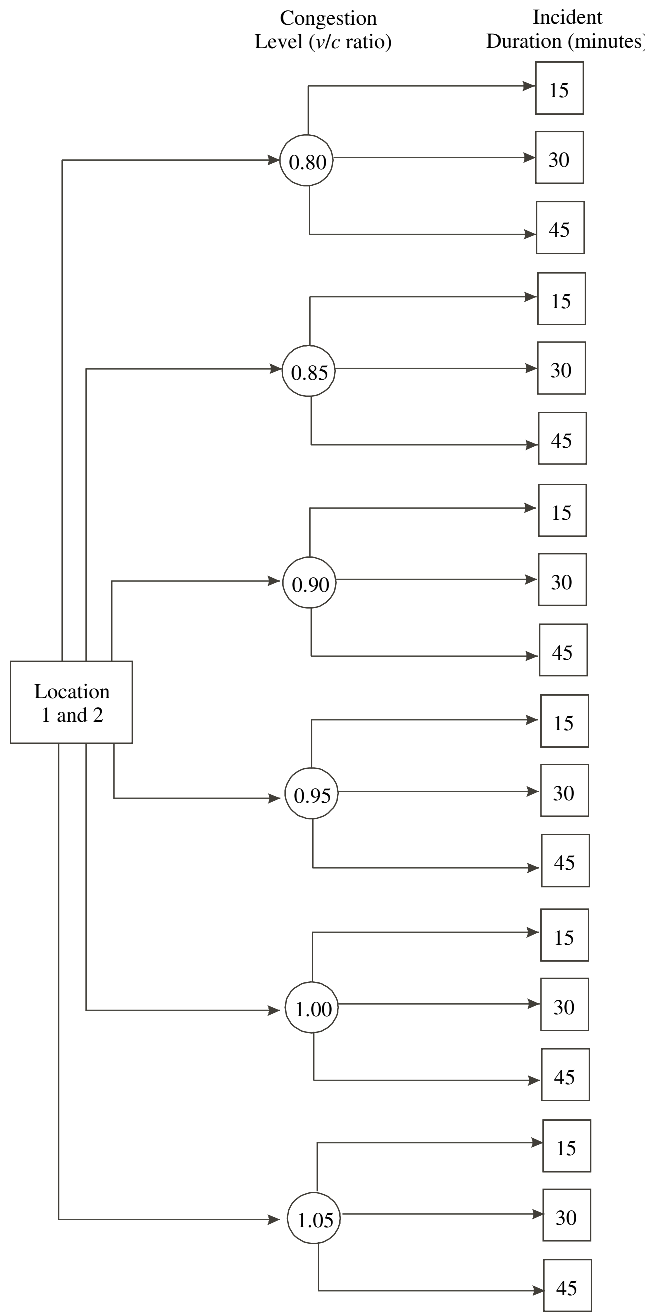

FIGURE 1 Scope of research.

SCOOT-CORSIM INTERFACE

In a typical field installation, the SCOOT computer communicates directly with another computer, which acts as an interface between the SCOOT computer and the field signal controller unit. Since investigating a range of accident scenarios is not a feasible field-based study, an interface to a simulation model is needed. SCOOT was connected to the FHWA microsimulator CORSIM (*17*). The SCOOT-CORSIM interface was developed at the University of Utah (*18*). An actual SCOOT kernel on a DEC-ALPHA hardware platform with a VMS operating system is interfaced with a personal computer with CORSIM. In this way, SCOOT is not emulated but is actually controlling the CORSIM simulation. Just as detector information is communicated to SCOOT in an actual field installation through the controller interface computer, real-time detector information from CORSIM-simulated detectors was sent to SCOOT through this interface program. SCOOT then computed optimal signal timings for the detected flow. These updated signal timings were then sent back to CORSIM, which implemented the timings in real time. The CORSIM simulation creates an output file of MOEs for the simulation. A postprocessor called ACCUSIM (*19*) is used to analyze the output file.

NETWORK MODELING

The performance of SCOOT is evaluated first on a theoretical test network and then on two real-world networks. A test network is important to develop the relationships between traffic flow and incident duration with an MOE on a simple grid network with uniform geometry, signal timing, flows, and incident characteristics. This test network quantifies the idealized and unbiased result to establish a benchmark. Two real-world networks are simulated with field geometry and observed traffic flows, and the performance of SCOOT and PB signal systems is evaluated with incidents of varying duration. The benefits in MOE reduction on the real-world networks are then compared with the results obtained from the theoretical network. This comparison validates the results obtained on the test network. Thus the methodology of starting with a test network and validating its results with real-world networks is valuable in quantifying the benefits of SCOOT during incidents.

Test Network

A 16-intersection grid network as shown in Figure 2 is chosen with the assumption that it represents the incident-affected area for durations of 15, 30, and 45 min. Moreover, the 16-intersection network has at least one interior intersection that is not affected by random flows at the cordons and therefore has defined platoon arrival. Two internal locations were tested on the test network in the preliminary modeling and were found to be link insensitive. Therefore, the incident location was selected randomly from the available internal links. All the intersections operate with eight-phase coordinated signal timing plans with protected-permitted left-turn signal phasing.

Twenty-four sets of 5-min turning movement volumes were generated using the Monte Carlo simulation method (*20*) for each congestion level. The 2-h flow profile is not simply a uniform distribution of traffic but is based on the typical growth and subsidence of traffic during a peak period. The peak-hour flows are used from each simulated flow profile in Synchro to obtain optimized PB signal timing plans. The incidents are simulated on the test network operating with the traffic flows generated from the Monte Carlo simulation. Figure 3 shows the incidents' occurrence relative to the generated flow profiles.

Real-World Networks

For the two real-world networks, the traffic data were collected in 5-min intervals during the p.m. peak periods. The geometry of the network was obtained from field observations. The PB signal timings for the real-world networks were reoptimized using the collected real-world traffic flows and geometry to provide the most optimized PB condition.

Salt Lake City Downtown Network

The downtown Salt Lake City network is a rectangular grid network as shown in Figure 4. The network extends eight blocks east to west

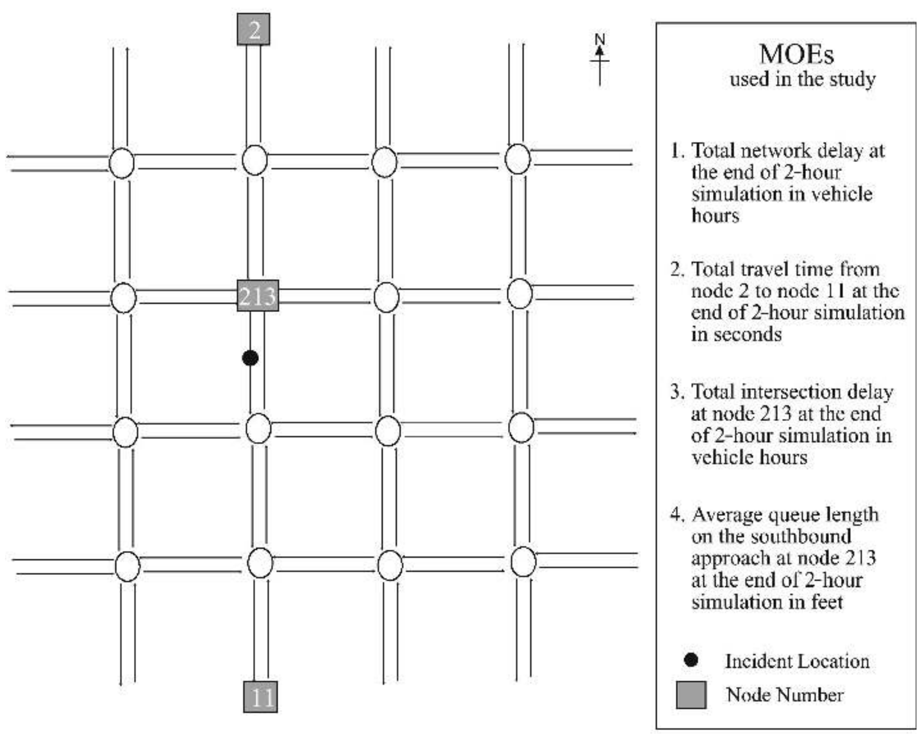

FIGURE 2 Test network and MOEs.

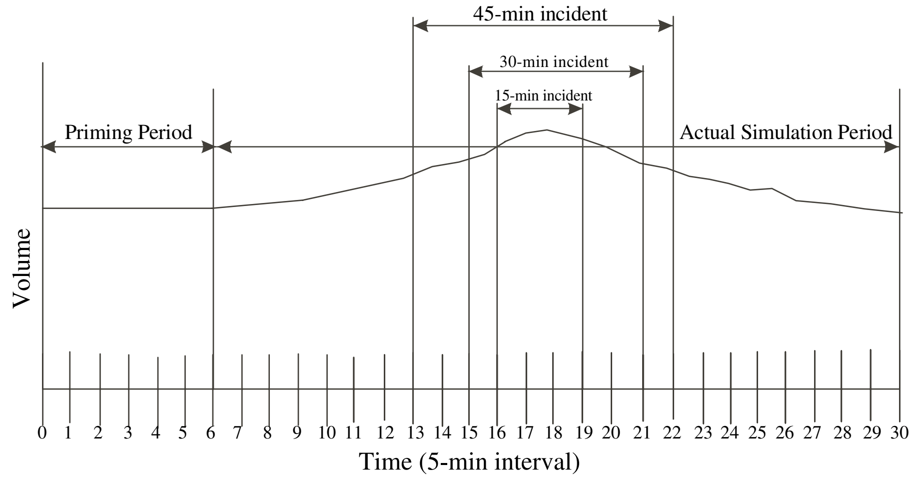

FIGURE 3 Timing of incidents.

and five blocks north to south. This network contains four high-volume arterials: State Street, 700 East, 400 South, and 600 South. The annual average daily traffic (AADT) for these arterials ranges from 12,000 to 40,000 (*21*). This network has 28 signalized intersections, which operate with two-, four-, and eight-phase signal timings. All major arterials are seven-lane facilities; the other arterials are five-lane facilities. All approaches have right-turn and left-turn pockets at the intersections.

Fort Union Area Network

The Fort Union network is triangular with converging arterials as shown in Figure 5. The AADT on the arterials ranges from 9,500 to 63,000 (*21*). The network has 15 signalized intersections, operating with two-, four-, and eight-phase signals. All major arterials are seven-lane facilities and the other arterials are five-lane facilities.

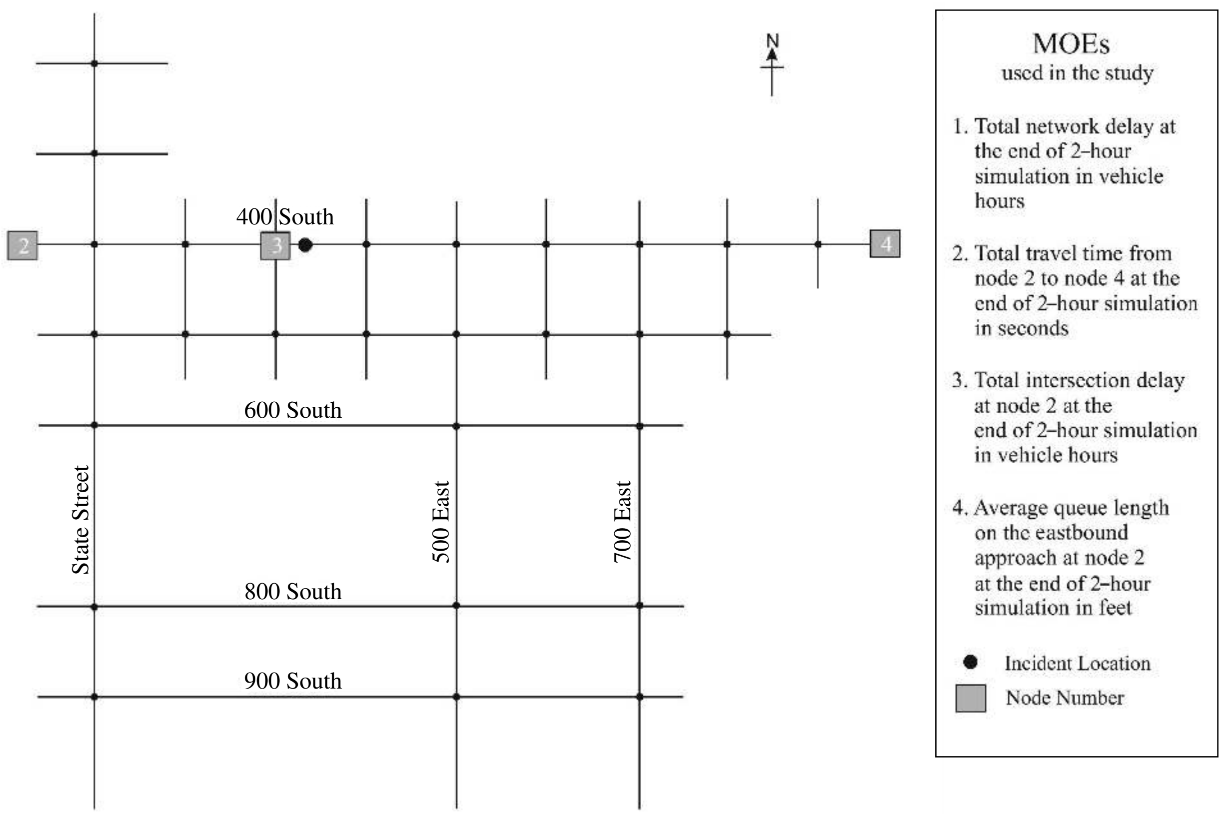

FIGURE 4 Salt Lake City downtown area network and MOEs.

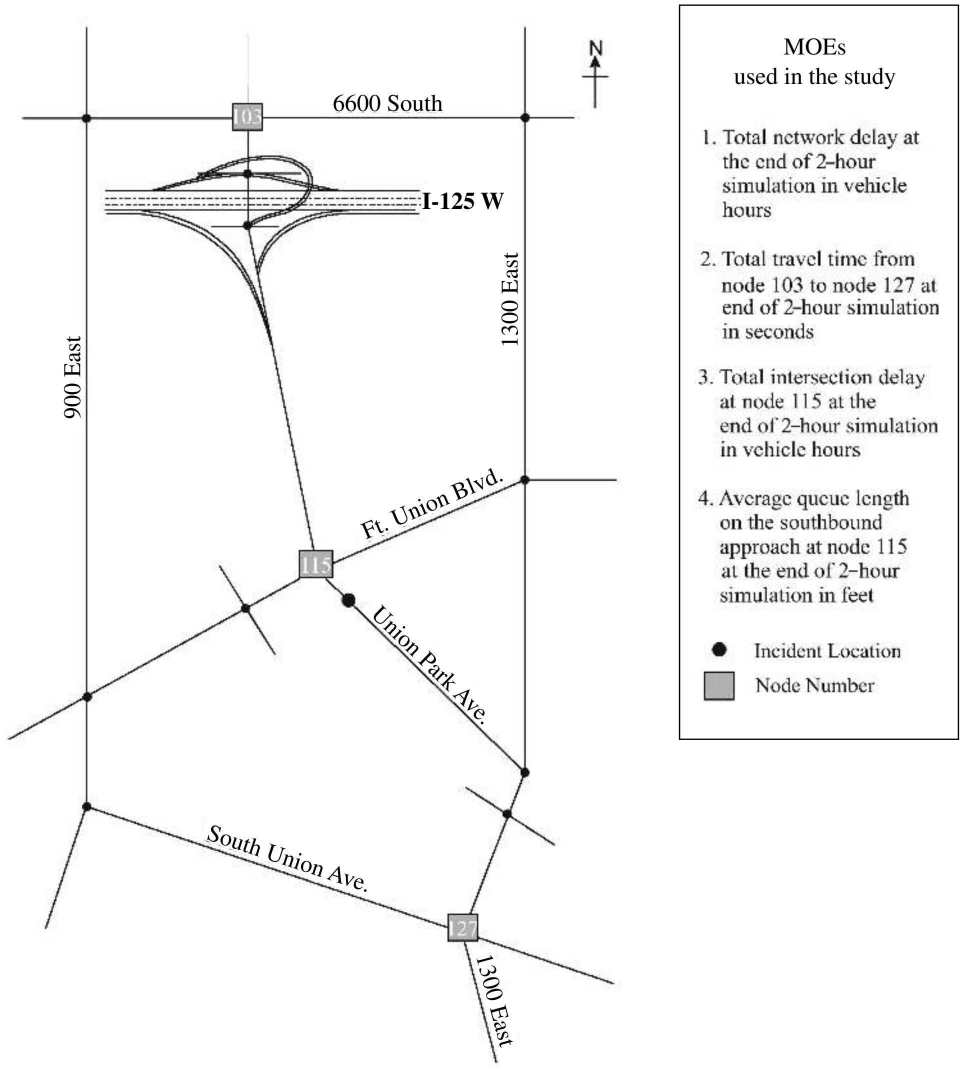

FIGURE 5 Fort Union area network and MOEs.

RESULTS

The MOEs for the different signal controls are compared relative to the *v*/*c* ratio. It is important to note that the *v*/*c* ratio is a general measure of network traffic level and does not specifically represent the congestion at each intersection or approach. Similarly, the corridor *v*/*c* ratio represents the average *v*/*c* ratio of the intersections in the study corridor. These ratios are important since they define the congestion level of the network and hence are used as a measure for defining network congestion characteristics. Since the same random-seed-generated CORSIM file is used for all signal control simulations, the performance of SCOOT and PB signal systems can be compared for the same conditions.

Although the benefits of adaptive control over PB have already been identified, the value of this research is in quantifying the marginal benefits that adaptive control provides in addition to the base condition, without an incident. This incremental or marginal benefit is the additional benefit that adaptive control provides during an incident because of its reactive nature.

Figure 6 shows how the network delay benefits of SCOOT increase with increasing incident duration for the test network. The marginal benefits occurred from a *v*/*c* ratio range of 0.8 to 1.0 with a maximum at 0.9. The benefits of SCOOT in network delay reduction could not be evaluated for 15- and 30-min incidents with a congestion level of 1.05 and for a 45-min incident with congestion levels of 1.0 and 1.05 because of gridlock formation. CORSIM does not dissipate gridlock irrespective of simulation duration, and therefore the benefits could not be quantified.

The Salt Lake City downtown area network operates at a *v*/*c* ratio of 0.82. The benefits of network delay reduction during SCOOT control on the Salt Lake City downtown area network vary between 24.7% and 28.3%. The Fort Union area network operates at a *v*/*c* ratio of 0.80. The benefits of network delay reduction during SCOOT control on the Fort Union area network show that the benefits vary between 26.5% and 35.2%. However, the corresponding benefits on the test network varied between 16% and 18%. The discrepancy between expected and modeled results is likely because of the uniformity of the test network, unlike the real-world networks. For this

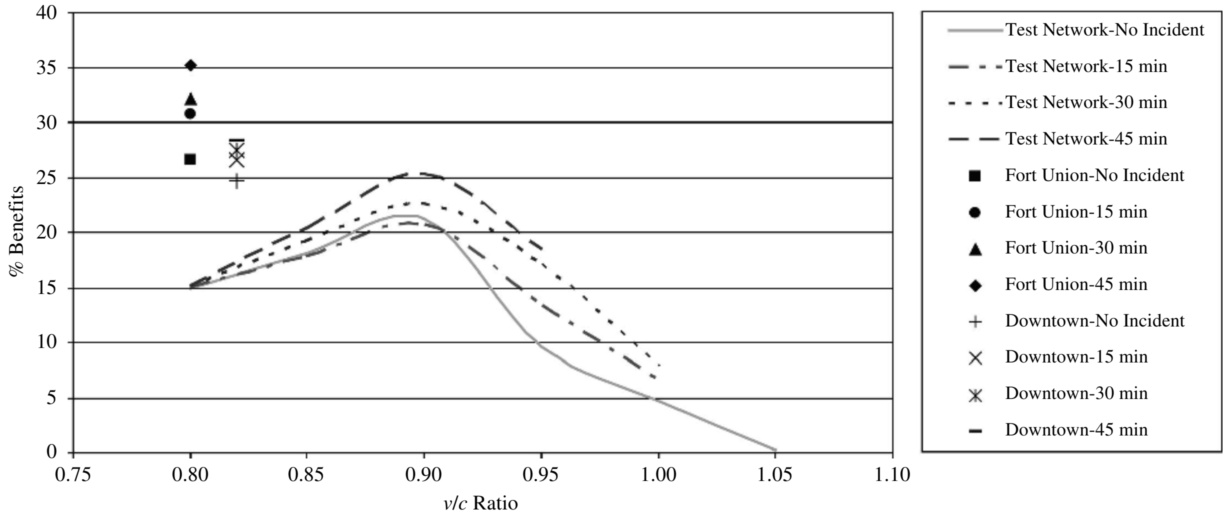

FIGURE 6 Network delay benefits of SCOOT over those of Synchro-optimized PB signal system.

example, when the test network operates at a *v*/*c* ratio of 0.8, all the intersections operate at *v*/*c* ratios close to 0.8. In the case of real-world networks, even when the network operates at 0.8, many intersections actually operate at ratios higher than 0.8. From these findings, it appears that benefits are related to the specific network characteristics, and therefore a general statement regarding expected benefits is difficult to identify from the test network modeling.

Figure 7 shows that the travel time benefits of SCOOT increased with increasing incident duration. The benefits in travel time reduction during SCOOT control are substantially higher than those during PB signal control since SCOOT is able not only to allocate extra green time to regularly flush the queues formed but also to change offsets and recoordinate in real time. SCOOT also uses upstream detection to avoid creation of gridlock by backing queues into the upstream intersection. The benefits of travel time reduction are not quantified at *v*/*c* ratios of 1.0 and 1.05, since the PB signal control resulted in gridlock formation at high *v*/*c* ratios.

The study corridor in the Salt Lake City downtown area network operates at a *v*/*c* ratio of 0.85. The benefits of travel time reduction during SCOOT control on the Salt Lake City downtown area network vary between 16.6% and 22.8%. The corresponding benefits on the test network varied between 15.5% and 19.1%. The results on the test network and those on the Salt Lake City downtown area network correspond well. The likely reason is that all the intersections in both the test and the Salt Lake City network operate at similar *v*/*c* ratios.

The study corridor in the Fort Union area network operates at a *v*/*c* ratio of 0.95. The travel time benefits during SCOOT control vary between 8.9% and 20.3%. The corresponding expected results from the test network range between 14.3% and 18.2%. The discrepancy for the 15-minute incident is again attributed to the varying *v*/*c* ratios that occur in real-world networks.

The intersection delay calculation uses the intersection upstream of the incident. Figure 8 shows the intersection delay benefits on the test network. Since SCOOT responds to the real-time traffic condition and flushes queues regularly in the incident-affected direction, it is natural to expect high intersection benefits. However, it is important to note that the extra green time given to the incident-affected

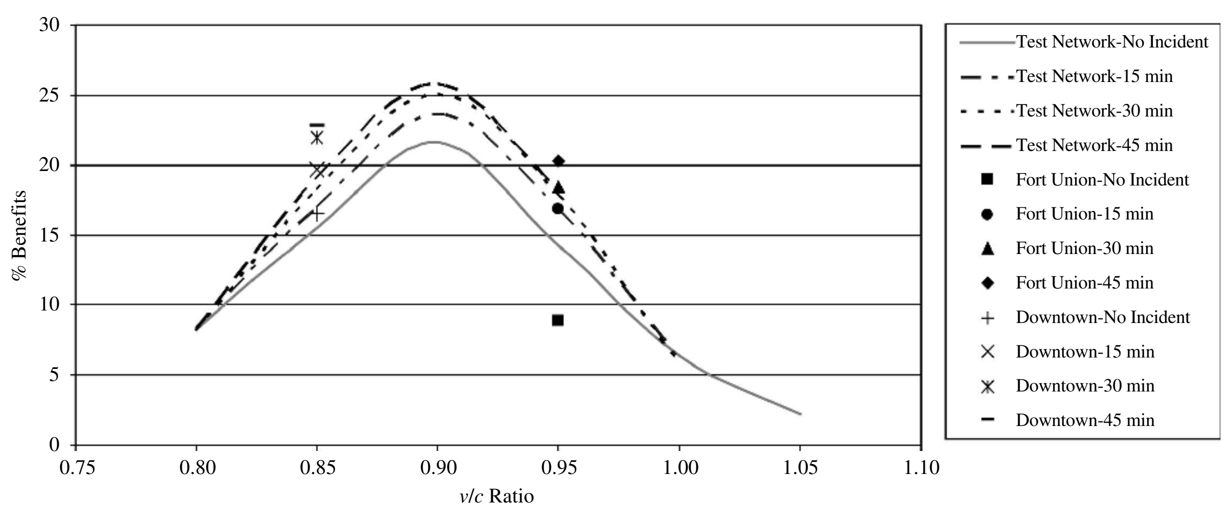

FIGURE 7 Travel time benefits of SCOOT over those of Synchro-optimized PB signal system.

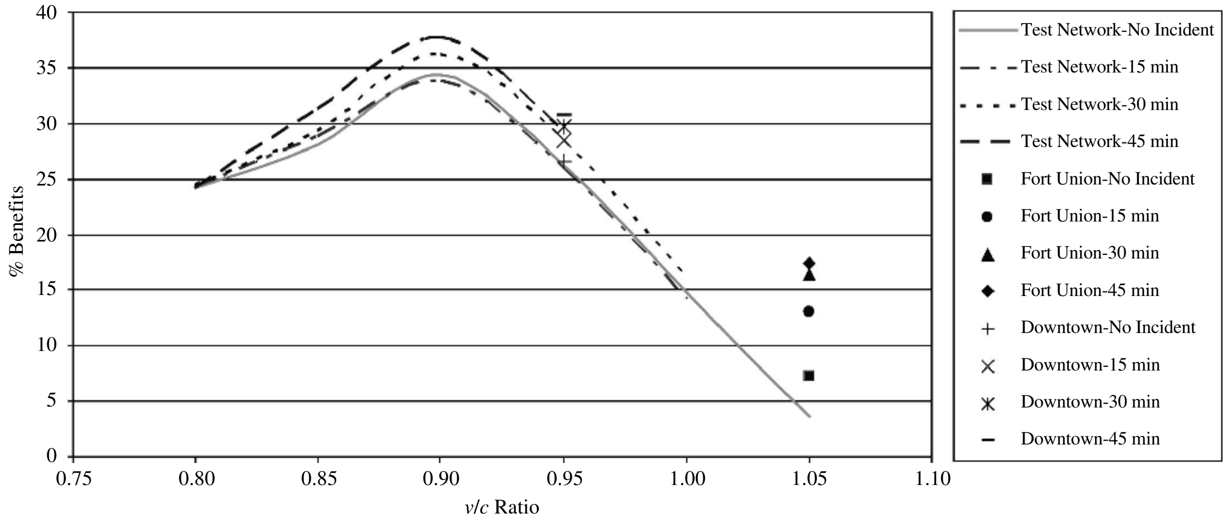

FIGURE 8 Intersection delay benefits of SCOOT over those of Synchro-optimized PB signal system.

direction means reduced time for the no-incident direction, causing additional delay. The SCOOT PI calculation attempts to minimize the system impact, and therefore moving the incident-affected direction with a flushing approach is only valuable when opposing flows are also not spilling into the upstream intersection.

The study intersection in Salt Lake City downtown area network operates at a *v/c* ratio of 0.95. The intersection delay benefits during SCOOT control vary between 26.6% and 30.7%. The corresponding results on the test network indicated an expected benefit between 26.3% and 29.3%. The study intersection in the Fort Union area network operates at a *v/c* ratio of 1.05. The intersection delay benefits with SCOOT control are between 7.3% and 17.4% with an expected test network result of 3.7%. Moreover, gridlock formation is observed on the test network operating at a *v/c* ratio of 1.05 during PB control. However, no such gridlock is observed during SCOOT control on the Fort Union area network for any incident duration.

Figure 9 shows the queue length benefits on the test network for 15-min, 30-min, and 45-min incidents. The benefits of queue length reduction during SCOOT control on the Salt Lake City downtown area network vary between 15.4% and 24.2%. The corresponding results on the test network vary between 12.2% and 20.2%. This comparison shows that incidents have a substantial effect on queue length at the intersection. The queue lengths on all the approaches are balanced by giving extra green time along the incident-affected direction. Since extra green time results in extra delays to the other directions, and since delay is an important parameter of the PI, the extent of green time given to the incident direction is constrained. The benefits of queue length reduction during SCOOT control on the Fort Union area network vary between 3.8% and 23.2%. The corresponding result on the test network during the no-incident scenario is 0.9%.

DISCUSSION OF RESULTS

SCOOT control provides a benefit over PB control in relation to travel time, delay, and queue length. This benefit is expected since SCOOT reacts to changing traffic demand by using upstream detection instead of by assuming uniform flows. Additional benefits exist with SCOOT

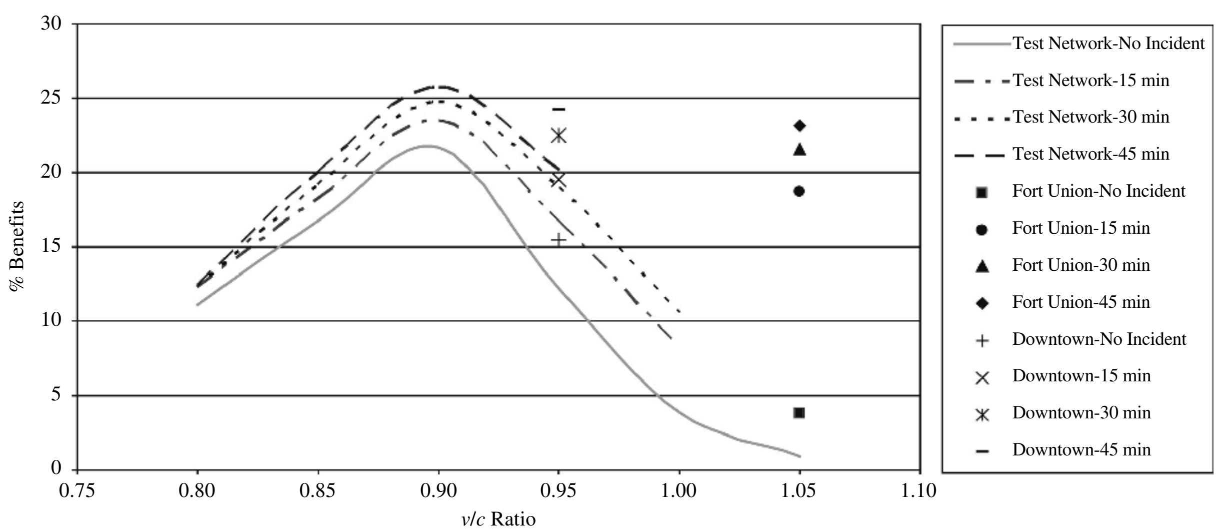

FIGURE 9 Queue length benefits of SCOOT over those of Synchro-optimized PB signal system.

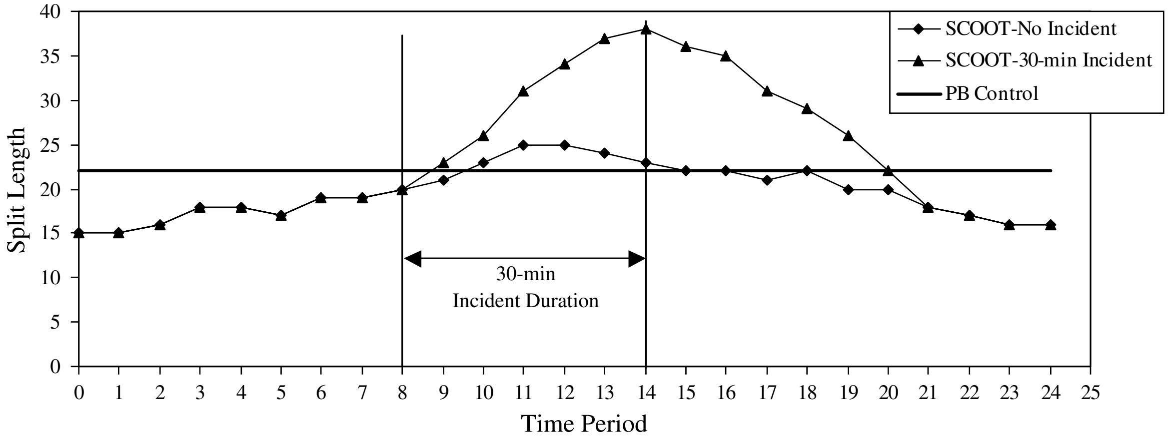

FIGURE 10 Split length variation for 30-min incident on network operating at *v/c* ratio of 0.9.

control during incident conditions simply because of its ability to react to the changing traffic conditions. Once incidents are detected, SCOOT can accommodate them by providing more time to the incident-affected direction. SCOOT dynamically changed signal timings to maintain optimal operation of the intersections. It was observed that, under normal conditions, the cycle length fluctuated between 75 and 90 s in the test network operating at a *v*/*c* ratio of 0.90. However, during a 30-min incident on the same network, the cycle length fluctuated between 75 s and 120 s. Figure 10 shows the split length variation for the incident-affected direction during the 30-min incident.

Figure 10 also shows that PB control consistently gave 22 s of green time to the incident-affected movement irrespective of the traffic condition. SCOOT control changed the split from 15 s to 25 s, depending on the real-time flow condition during normal conditions. However, when incidents occur, SCOOT, with its upstream detection, recognized the reduction in road capacity and gave more time to the incident-affected direction. SCOOT control increased the split length by approximately 165% to accommodate the congestion in the incident-affected direction. Figure 10 shows that SCOOT effectively manages the congestion during incidents by changing signal timings according to the real-time traffic flow. Table 1 shows the incremental benefits of SCOOT during incidents of different durations for a *v*/*c* ratio of 0.9. This *v*/*c* ratio provided maximum benefits in reduced delay, travel time, and queue length for the test network.

PB signal control lacks the ability to identify an incident and respond. The result is long queues, delays, and travel times. Since SCOOT responds to real-time traffic conditions, it provides additional benefits during incidents. The results indicate that the average SCOOT MOEs for the 0.9 *v*/*c* ratio improve by 7% for a 15-min incident, 12% for a 30-min incident, and 18% for a 45-min incident, depending on congestion level. Table 1 shows that the test network with SCOOT control experienced reduced network delay, travel time, intersection delay, and queue length by approximately 21%, 22%, 34%, and 22% under normal conditions. However, during a 45-minute incident, SCOOT reduced various MOEs by as much as 25%, 26%, 39%, and 26%. Therefore, the marginal benefits of SCOOT during incidents increased by approximately 19% (for example, an increase from 21% to 25% above the PB condition results in an increase in the marginal benefits of network delay reduction by 19% (25% − 21%)/21% = 19%).

CONCLUSIONS

Additional advantages that adaptive control provides during incidents were identified. Although it has been well documented that adaptive control systems provide a benefit during normal traffic operations, this study quantified and examined the additional benefits of

TABLE 1 Incremental Benefits of SCOOT During Incidents

v/c Ratio of 0.9		Network Delay	Travel Time	Intersection Delay	Queue Length
PB - Normal Condition		-	-	-	-
SCOOT - Normal Condition		21%	22%	34%	22%
Incident with SCOOT	15 min	21%	24%	37%	24%
	30 min	23%	25%	38%	25%
	45 min	25%	26%	39%	26%
Percentage Increase in Marginal Benefits of SCOOT During 15–min Incident		0%	9%	9%	9%
Percentage Increase in Marginal Benefits of SCOOT During 30–min Incident		10%	14%	12%	14%
Percentage Increase in Marginal Benefits of SCOOT During 45–min Incident		19%	18%	15%	18%

SCOOT during various incident durations and congestion levels. The performance of SCOOT on the test network was compared with the results obtained on two real-world networks. Conclusions from the analysis of the study are as follows:

- SCOOT benefits increased relative to those of PB control with increasing incident duration for all congestion levels.
- The marginal benefits of SCOOT during incidents are quantified for a range of *v/c* ratios from 0.8 to 1.0. PB control resulted in gridlock formation during incidents at ratios of 1.0 and higher. Under the same conditions, SCOOT control prevented gridlock. Although the marginal benefits could not be quantified, the benefits in delay, travel time, and queue reduction are substantial.
- SCOOT benefits maximize at a *v/c* ratio of 0.9. The marginal benefits of SCOOT also follow the same trend for all incident durations.
- The marginal benefits of SCOOT during incidents for the 0.9 *v/c* ratio improve SCOOT performance by an average of 7% for a 15-min incident, 12% for a 30-min incident, and 18% for a 45-min incident relative to the performance of PB signal control.

This study represents primary research in understanding the benefits of ATCS during incidents. A signal system that detects and responds to incidents through signal timing adjustments provides a distinct advantage in managing and clearing incident-related congestion. SCOOT relieves incident congestion by identifying an incident and then responding by reallocating green time on the incident-affected link while continuing to maintain coordination. Marginal benefits that adaptive control provides during incidents were quantified.

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