Estimating Incident Impacts in Real Time

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Abstract

During an incident, responders may need to balance the intensity of their response approach against potential congestion delays. Often, these decisions must be made in real time using available data. As one example, a responder may decide to push a crashed truck to the shoulder and risk damaging the cargo. Based on discussions with first responders, this study identified data needs to support cost-benefit decisions made by on-scene incident managers. Procedures for estimating the impacts associated with an ongoing incident are described, considering capacity reductions, queuing, economic losses from congestion, and risks of secondary crashes. These procedures could be encoded in a spreadsheet for dispatch use or as a web site or smart phone application for use at the incident scene.

Keywords: Incident management, cost-benefit analysis

Introduction

Traffic congestion and safety receive significant and continued attention from transportation professionals. The financial cost of congestion in the United States in 2014 was estimated at $160 billion, or $960 per commuter (*1*), with traffic incidents accounting for approximately 25 percent of total congestion (*2*). Incidents cause congestion by reducing a road's capacity, as even an incident that is confined to the road shoulder reduces the capacity of a two-lane freeway by 19 percent (*3*). One strategy to reduce incident-based congestion is to quickly clear existing incidents by moving vehicles and debris from the roadway to the shoulder, and from the shoulder to a tow lot, as soon as reasonably possible.

Several states have dedicated incident management programs that utilize wreckers, accelerated crash investigation technologies, safety service patrols, and incentive-based towing programs to reduce incident clearance time (*4*, *5*). As part of a broader study, the Virginia Department of Transportation (VDOT) conducted interviews with incident responders such as police, fire, rescue, and safety service patrol, regarding the challenges they face when attempting to clear an incident (*4*). Many responders expressed a need to estimate the future impacts of an ongoing incident. Four specific use cases for real-time incident impact estimates were identified.

In one use case, incident scene responders noted that there was a financial component to the decision to clear some incidents, particularly when deciding to push cargo to the shoulder. Commercial vehicle operators may want to delay pushing truck crashes to the shoulder in order to avoid damaging the cargo.

If incident responders could estimate the congestion costs to motorists from a delay in pushing to the shoulder, responders could then weigh these costs against the cost of potential damages to cargo when deciding how best to clear an incident.

A different use case was developed from discussions with the Virginia Chief Medical Examiner's Office. In a fatal crash, a coroner must arrive on the scene to confirm a fatality before the body may be moved and the scene cleared. In some situations, however, the coroner may allow on-scene responders to move the body before the coroner's arrival if they are able to identify the body themselves. The decision to allow responders to move the body is partly a factor of the congestion generated by the incident and the time required for the coroner, who could be delayed by the same queue, to travel to the scene. If a coroner could estimate the anticipated incident queue at their expected time of arrival, the coroner might allow responders to move the body and clear the incident prior to arrival. In some crashes, this could reduce clearance time by several hours.

Another use case involves first responder training. In many training classes, there is a high-level discussion of the risk of additional crashes that are directly or partly due to the congestion caused from the primary incident. These secondary crashes are related to the primary incident and are more likely to occur during longer primary incidents and during severe congestion. Although current training covers the factors leading to secondary crashes, the discussion is very high level and relies on out-of-date and generalized metrics. A tool to estimate the secondary crash probability of a specific incident and a specific location and time could provide responders with a better understanding of the relationship between secondary crashes and quick incident clearance. This would provide an additional incentive to responders to clear an incident quicker to improve public safety and reduce the responders' own time on-scene.

A final use case came from discussions with VDOT incident managers. When managing major incidents, VDOT uses contractors to provide traffic control and advanced warning for motorists. In some incidents, traffic may be diverted onto alternate routes. Both situations could benefit from queue length estimates based on current and expected conditions so that contractors could position warnings at appropriate locations and prepare diversions at relevant off-ramps.

Based on the identified needs of incident responders, procedures were developed for estimating the anticipated cost of delay, queue length, and risk of secondary crash from an ongoing incident in real time. This paper describes procedures for estimating these values with minimal user input, requiring only number of lanes, number of lanes blocked, interstate number and direction (e.g. I-66 East), interstate mile marker, day of the week, month, and time of day. These procedures can be integrated into a spreadsheet for use as a decision support tool for management or dispatch, or it can be integrated into a web site or smart phone application for use by incident responders in the field.

Estimating queue length

Estimating incident queue length involves the comparison of the volume of traffic on the roadway (demand) and the volume that can pass the incident (capacity). Incidents reduce road capacity, and the 2010 *Highway Capacity Manual* (*6*) provides estimates for the remaining capacities that are due to incidents, re-created in Table 1.

Table 1. Proportion of freeway capacity remaining during an incident (*6*)

Number of Lanes (One Direction)	Shoulder Disablement	Shoulder Accident	One Lane Blocked	Two Lanes Blocked	Three Lanes Blocked
2	0.95	0.81	0.35	0.00	N/A
3	0.99	0.83	0.49	0.17	0.00
4	0.99	0.85	0.58	0.25	0.13
5	0.99	0.87	0.65	0.40	0.20
6	0.99	0.89	0.71	0.50	0.26
7	0.99	0.91	0.75	0.57	0.36
8	0.99	0.93	0.78	0.63	0.41

Using a default freeway capacity of 2200 vehicles per hour per lane, and multiplying by the appropriate factor in Table 1, the expected capacity of the roadway during an incident can be determined. Further, by multiplying the freeway segment's AADT by the correct adjustment factor to account for seasonal, daily, and hourly fluctuations in demand, the demand at the incident location and time can be estimated. The queue length calculation assumes that any demand that cannot be served by the current capacity will add to the queue length and that any situations in which capacity exceeds demand will subtract from the queue length. From guidance in the 2010 *Highway Capacity Manual* (*6*), passenger vehicles are assumed to require 20 feet of roadway per lane when queued and trucks are assumed to require 75 feet. For example, when demand exceeds capacity by 200 vehicles per hour on a three-lane interstate with 5 percent trucks, the queue length grows at the following rate:

$$\frac{[200(.05)(75) + 200(1 - .05)(20)]}{5280 \text{ x } 3} = 0.287 \text{ mi/hr}$$

If capacity were instead to exceed demand by 200 vehicles per hour, the queue length would decrease at the same rate. The following equation shows the change in queue length per hour:

$$QL_h = \frac{(v_h - c_a)[P_T \times 75 + (1 - P_T) \times 20]}{5280 \times N_{original}}$$

where

QL_h = queue length change (mi) for hour h

v_h = demand volume in hour h (vph)

c_a = adjusted incident capacity (vph)

P_T = percentage of trucks

$N_{original}$ = base number of lanes before the lane closure. In the case of a work zone, the total number of lanes available before the incident should be used.

Estimating incident delay costs to motorists in US dollars

In order to provide responders with financial justification for quickly clearing an incident, a methodology was developed to estimate the delay costs of an incident for a traveler. Average costs per hour of delay were obtained from the 2015 Urban Mobility Scorecard (*7*), which used $17.67 per hour for passenger vehicles and $94.04 per hour for commercial vehicles. AADT and truck percentages can be obtained from most state departments of transportation. The delay was calculated using the following equation:

$$D = \frac{(v_h - c_a)\frac{T^2}{2}}{v_h}$$

where

D = total delay due to excess demand for analysis period T (hr)

v_h = demand volume in hour h (veh/hr)

c_a = adjusted incident capacity (veh/hr)

T = duration of analysis period (hr).

The cost of delay was then calculated by multiplying the portion of traffic in each vehicle class by its respective delay cost and then summing the costs. The cost of delay can be calculated using the following equation:

$$Cost_T = D \times [P_T \times \$94.04 + (1 - P_T) \times \$17.60]$$

where

$Cost_T$ = delay cost over analysis period T ($)

P_T = truck portion of vehicle demand.

Estimating secondary crash risk

A crash that occurs as a result of this primary incident is referred to as a secondary crash. The Federal Highway Administration has acknowledged this phenomenon and defines a secondary crash as: "A crash occurring within an accident scene or within the queue, including the opposite direction, resulting from an original incident" (*8*).

Several transportation agencies have attempted to reduce the number of secondary crashes. The Minnesota Department of Transportation recently installed a queue warning system to alert drivers of unexpected upcoming congestion. In the first three months after installation, they experienced a 22 percent reduction in crashes and a 54 percent reduction in near crashes. Most states focus efforts on quickly clearing primary incidents to reduce incident duration and associated queuing. The Virginia Transportation Research Council has documented many of the strategies and initiatives to minimize incident duration and the associated secondary crashes (*4*).

There are two types of secondary crashes: those that occur within the primary incident scene and those that occur outside of the primary incident but within a queue caused by the primary incident. Secondary crashes that occur near the primary incident are referred to as proximity crashes while those that occur within a queue caused by the primary incident are referred to as queue crashes.

Several studies have attempted to measure the rate and characteristics of secondary crashes. The studies differ on how they define and classify secondary crashes, with most focusing on deterministic spatial and temporal boundaries around a primary incident (*9–12*), or focusing on crashes within a deterministic queue (*13–15*).

The secondary crash risk estimates used in this study were developed by Goodall (*16*) as part of the VDOT incident management study (*4*). At the time of its development, it was the first study to investigate the prevalence of secondary crashes considering both empirical queues and incident duration, and was also the first study to investigate the relationship between empirical demand and secondary crash rate. Using this methodology, a 2016 study found that 13.8 percent of all crashes on I-66 in Virginia were secondary to another incident, and 9.2 percent were secondary to a crash-specifically (*16*).

In the methodology proposed by Goodall (*16*), private sector speed data is collected, and any speeds less than 30 percent below historical speeds are considered non-recurring congestion. For a crash to be considered a queue crash, it must have occurred either upstream or downstream such that a straight line connecting the secondary crash to the primary incident through space and time is 90 percent within congested periods. Figure 1 demonstrates a primary-secondary incident relationship.

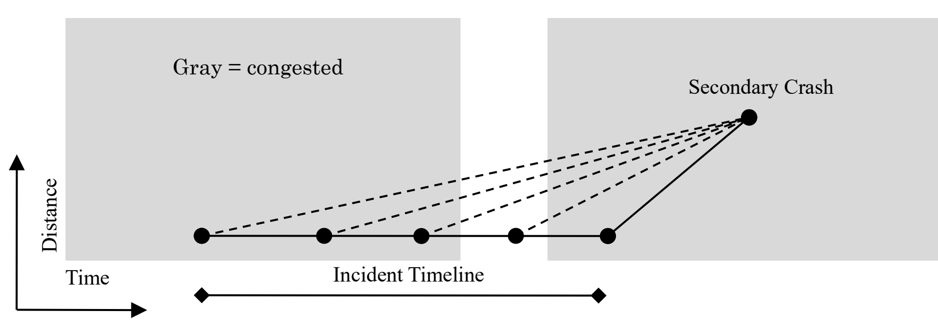

Figure 1. Identifying secondary crashes from multiple points along the primary incident timeline

Some secondary crashes occur in the immediate proximity of the primary incident, even in the absence of congestion as drivers are distracted by the incident. For this study, the definition of proximity crash is any crash occurring within 0.5 miles and within the duration of the primary incident (*16*).

As vehicles upstream approach an unexpected queue, sudden braking behaviors may increase the crash risk for distracted drivers. With each driver that encounters this queue, the risk for a secondary crash may increase slightly. Several studies of secondary crash occurrence have investigated the effect of traffic volume, but used surrogate measures for volume such as time of day (*14*) or unadjusted average annual daily traffic (AADT) (*11*, *15*).

In keeping with previous work (*16*), the procedure developed as part of this effort requires AADT volumes and adjustment factors for all roads in order to estimate hourly volumes at the desired segment. Other sources of volume data can be substituted when available. The secondary crash risk model requires as inputs the duration of the incident, the demand volume encountering the incident or queue, and whether the traffic at the incident scene has become congested (*16*). The model then outputs the probability that a secondary crash has occurred by that time. The model is shown in the following equations:

$$P(s) = \frac{e^{Y}}{1 + e^{y}}$$

where *P(s)* is the probability of a secondary crash occurring, and Y is defined as:

$$\text{For } \begin{cases} C = 0; Y = -4.459 + 0.006985t + 0.000162d \\ C = 1; Y = -2.836 + 0.006985t + 0.000162d \end{cases}$$

and where $C = 1$ indicates congestion, t is incident duration in minutes, and d is the number of vehicles estimated to have encountered the incident since the beginning of the incident. Congestion is defined as any period in which estimated demand is greater than or equal to estimated capacity, using the values of v_h and c_a from the queue length calculations.

An example probability of secondary crash occurrence for a road with a demand of way with an estimated demand of 2,000 vehicles per hour is shown in Figure 2.

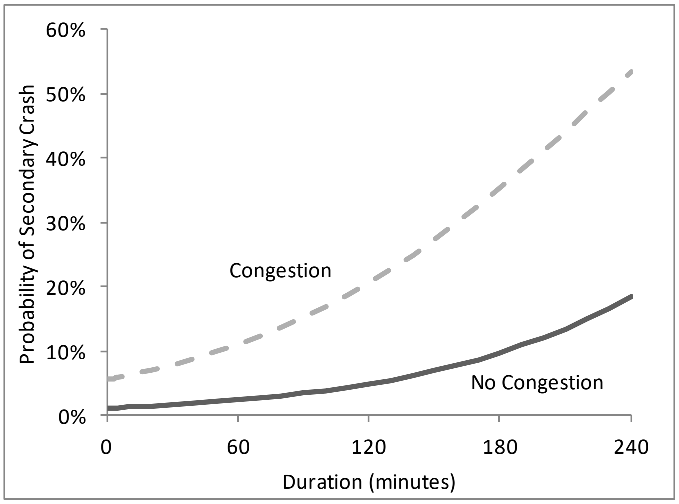

Figure 2. Estimated probability of a secondary crash at 2000 vehicle per hour demand

Additional challenges

Several lessons were learned when determining incident data needs and developing estimation procedures. First, factors such as weather effects, holiday effects, availability of detour routes in the vicinity of incidents, and operational improvements (such as adjusted signal timing) to detour routes are desirable features to be included in the methodology but are not yet supported by models in the literature. Finally, the accuracy of the models must be field tested with the help of responder feedback.

Conclusions

In interviews, incident responders in Virginia expressed a need for real-time estimates of costs, delays, queue lengths, and secondary crash risks from incidents than can be calculated and accessed in real time, preferably from the incident scene (*4*). This study developed procedures to calculate these data using widely available inputs (e.g. AADT, adjustment factors, and truck percentages), established delay and queuing models, and realistic cost assumptions. Future work should refine the models to support irregular traffic demands from holidays and adverse weather. These procedures should be developed into a usable software tool, accessible either via spreadsheet, web interface, or smartphone application to further support its objective as a decision support tool for incident responders.

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