Secondary Accident Rates on Los Angeles Freeways

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Abstract: There is a prevailing assumption that Freeway Service Patrol (FSP) programs improve safety for unassisted motorists by reducing the likelihood of secondary accidents. This research identifies 84,684 accident records from the California Highway Patrol's First Incident Response Services Tracking system, and subjects these data records to a sequence of filters that check for incrementally more stringent conditions consistent with secondary accidents. This paper shows that secondary accidents on Los Angeles freeways are much less frequent than suggested in the transportation engineering literature. Avoiding secondary accidents provides only a small incentive to deploy FSPs, but the expected benefits associated with reducing already low secondary accident rates may still be sufficient to justify accounting for these costs.

Introduction

The Los Angeles County Metropolitan Transportation Authority (MTA)/California Department of Transportation (Caltrans)/California Highway Patrol (CHP) Metro Freeway Service Patrol (FSP) program is the largest in the nation, operating 144 service vehicles on 40 beats covering 393 center-line miles of freeways in Los Angeles County.

Previous research has documented many of the benefits from freeway service patrols in Los Angeles and elsewhere (Skabordonis et al. 1995, 1998; Skabordonis 2000). These previous studies frequently speculate that FSP reduces the likelihood of secondary accidents, and that this effect may provide additional, measurable benefits. For example, Koenig et al. (1994) evaluated the congestion and emissions impacts of two competing incident management strategies: the freeway service patrol and alternative lane closure practices occurring on the Smart Corridor, a ten mile segment of the I-10 freeway in Los Angeles. The investigators found that roving FSP trucks' quick clearance of lane blocking incidents most often reduced congestion in the corridor, with considerable effect. The purpose of this research is to quantify estimates of secondary accident rates in the Los Angeles area.

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Defining Secondary Accidents

Raub (1997a,b) notes the problems associated with defining and measuring secondary crashes. It is usually difficult to link an initial incident and the secondary crash, and to confirm that the first incident was a contributor to the subsequent crash. Karlaftis et al. (1998) used data for the Hoosier Helper patrol service in Indiana to develop logistic regression models that examine which primary crash characteristics are likely to influence the likelihood of a secondary crash. Latoski et al. (1999) accounted for secondary crash reduction benefits and vehicle operating cost savings in addition to delay savings in an evaluation of the Hoosier Helper service.

In this research, we define secondary accidents, develop and apply a method for identifying secondary accidents that relies on special data resources, and estimate secondary accident rates on Los Angeles freeways. Our findings indicate that secondary accidents are considerably rarer events than these previous studies suggest.

Most of the research on secondary accidents defines these accidents relatively broadly, assuming that any accident sufficiently proximate to a crash location in time and space is necessarily secondary (Raub 1997b; Karlaftis et al. 1998; Latoski et al. 1999). These definitions produce counts that co-vary with the true number of secondary accidents, but can include substantial errors. For example, Karlaftis et al.'s (1998) definition excludes

1. Primary incidents that are not accidents,
2. Secondary accidents resulting from excluded primary events, and
3. Secondary accidents in the opposite direction of the flow associated with a primary accident.

Skabardonis et al. (1998) and Skabardonis (2000) observed that 1,073 of 1,154 total incidents on Los Angeles FSP Beat 8, Interstate 10, were breakdowns. Breakdowns accounted for 77 of 108 in-lane incidents. Thus breakdowns are likely a greater source of primary incidents in primary/secondary pairs than are accidents. Restricting primary incidents to crashes only, and assuming that any sufficiently proximate pair of accidents includes a secondary accident will almost certainly produce an overestimate share of secondary accidents.

We begin with the premise that a secondary accident occurs

1. At the boundary of the high density queue of traffic that forms when an initial accident or other incident causes a reduction in road capacity, or
2. Upstream from the location of the initial incident, in either direction, within the queue.

Primary incidents can consist of accidents or other events such as breakdowns, can occur on the shoulder, and can affect traffic in both directions. Primary incidents may lead to more than one secondary accident. Secondary accidents are caused by the creation and existence of the traffic queue. Incidents that do not lead to a queue cannot trigger a secondary accident.

Since traffic in the opposing direction can also be affected by a primary incident, queues routinely form in both directions following an incident, and either queue can cause secondary accidents. Secondary accidents must occur in traffic lanes and involve two or more vehicles, though we presume secondary accidents occurring within the queue will be low-speed accidents. Such minor accidents may be more quickly removed to the shoulder than primary accidents, which may involve higher speeds.

We differentiate between secondary accidents and chain reaction accidents. Chain reaction accidents occur within a few seconds of a primary incident and in immediate reaction to it. Secondary accidents occur as traffic is exposed to either the queue or to a queue boundary that forms as a result of the primary event and any associated chain reaction events. The frequency and expense of chain reaction accidents is certainly worthy of measurement and study, but the availability of FSP services can have no impact on the rates at which these chain reaction events occur. Consequently, the definition of secondary accidents used here excludes chain reaction accidents.

Identifying Secondary Accidents in Los Angeles

Prior Work

Skabardonis et al. (1998) reported that only 2.75%, or 32, of 1,154 incidents directly observed on Los Angeles FSP Beat 8, Interstate 10, consisted of accidents in traffic lanes. Nonaccident incidents in lanes were relatively more frequent, accounting for an additional 6.6% (76) of 1,154 incidents. Comparison values reported by FHWA (Lindley 1986) were considerably lower, only 0.85%. Since secondary accidents necessarily occur in lanes, the 32 accidents reported in the Skabardonis et al. sample constitute an upper bound on the number of secondary accidents.

Skabardonis et al. reported that only 6% of all accidents involved two or more vehicles. This figure includes multiple vehicle accidents on shoulders and in lanes, circumstances in which more than one vehicle is involved in a primary accident, chain reaction accidents immediately following a primary incident, and secondary accidents occurring elsewhere in the traffic queues created by a primary incident. If all multiple vehicle accidents in lanes are classified secondary accidents; then no more than five of the 81 accidents in the Skabardonis et al. sample are secondary accidents. Given the alternative number of ways multiple vehicle accidents can occur, the number of secondary accidents in the Skabardonis et al. sample may well be zero.

This Skabardonis et al. sample may not be entirely representative of the region. Skabardonis et al.'s analysis of FSP logs for the same period indicated that a larger share of the FSP-assisted incidents consisted of accidents, some 21%, but even this higher figure implied a much lower rate for secondary accidents than reported by Latoski et al. (1999).

Electronic Data Resources

Data collection efforts by the research team were reinforced by generous cooperation from MTA, the CHP, and the California Department of Transportation (Caltrans) District 7 (Los Angeles and Ventura Counties). MTA and CHP provided liberal access to their First Incident Response Services Tracking (FIRST) warehouse data, and to FIRST consultant time. Caltrans District 7 provided access to historical loop detector data archived on 4-mm tapes in their Transportation Management Center (TMC).

MTA/CHP First Incident Response Services Tracking (FIRST) System

The FIRST system was developed at MTA for installation in Los Angeles and neighboring counties to improve other agencies' access to CHP's proprietary Computer Aided Dispatch (CAD) system. FIRST is intended as both an internal management information tool for improving records management, reducing incident clearance times, and reducing costs; and as a means to better disseminate freeway incident information to the general public through TV and radio media.

The FIRST database includes all of the CHP CAD entries. Entries are coded by type. We selected the representative months of March, May, and July 1999, and the last week of December 1998 (when the FSP is not in service) for detailed examination and analysis of secondary accidents. March is a relatively wet month in Southern California, and traffic flows include commuters to the areas colleges and schools. May is a relatively dry month with lower commuter and tourist flows. July is a dry month at the height of discretionary summer travel demand. The December data provides the only window of observation when the Freeway Service Patrol is not in service.

Caltrans District 7 Historical Loop Detector Data

The density of loop detectors on Los Angeles freeway segments varies, but the freeway system is relatively well-detectorized, and on those segments where loop detectors are most densely distributed and functioning, a review of loop detector data will normally show the existence and movement of any shockwaves in the traffic stream. The freeway volume and speed data for this research consists of loop detector data downloaded from the Caltrans District 7 MODCOMP computer. The MODCOMP is a mainframe computer processing freeway loop detector data 24 hours a day, 7 days a week, providing volume and loop detector occupancy counts by detector and lane for a variety of time intervals.

Necessary and Sufficient Conditions for Secondary Accidents

Proximity in time and space are logical necessary conditions for an accident to be the secondary result of a previous incident. It is more difficult to establish sufficient conditions, i.e., to identify accidents occurring inside a traffic queue associated with a previous incident, or at the boundary of such a queue. These circumstances are most often unobserved.

The MTA/CHP FIRST system provides excellent access to the data needed to identify primary incidents and secondary accidents. The incident details, coordinates, and incident codes available from the FIRST system provide considerable information about the circumstances under which events occur, their locations on the freeway, and the nature of the incident. Further, comprehensive historical data about incidents and accidents are warehoused, and can be retrieved for subsequent analysis. We use a
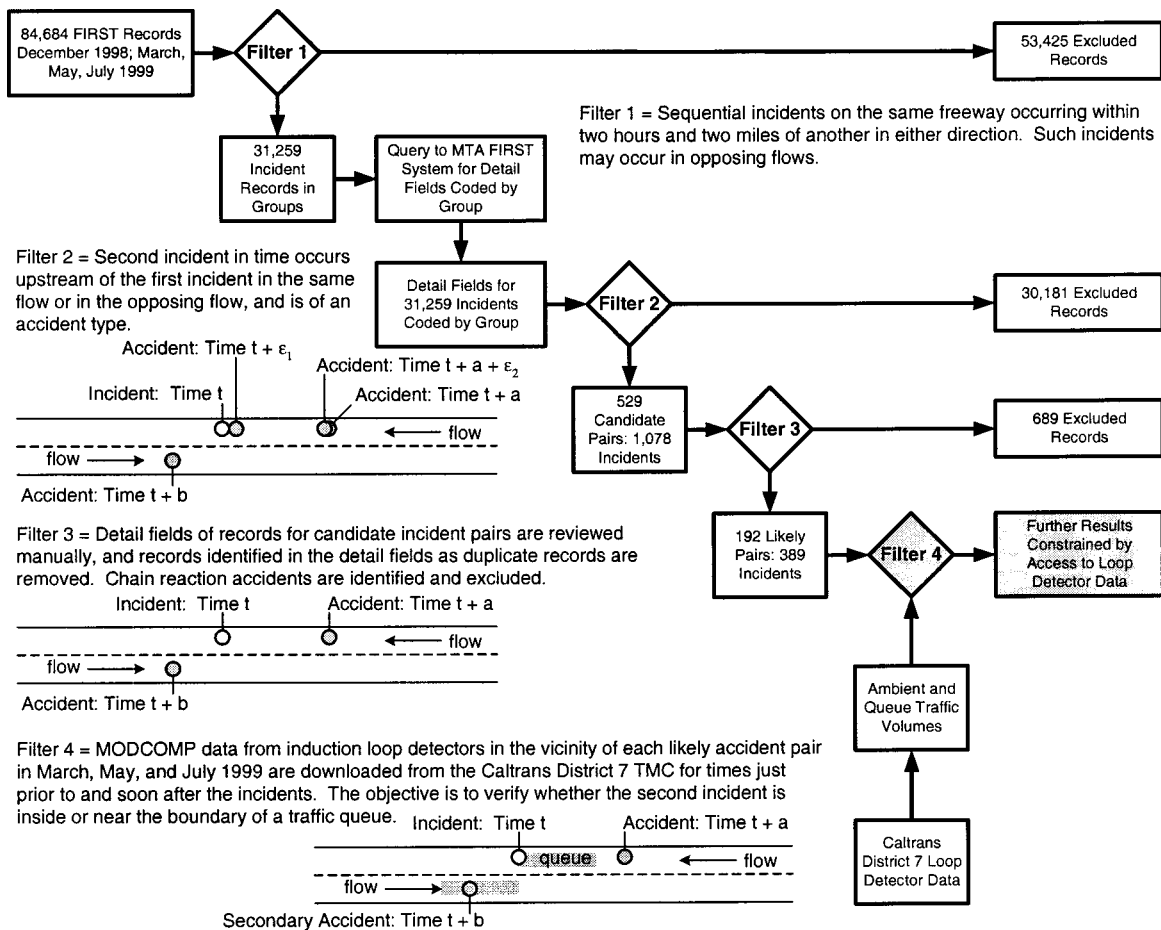
Fig. 1. Four filters used to identify primary/secondary accident pairs in the FIRST data

sequence of steps that progressively filter FIRST records to identify likely primary incident/secondary accident pairs.

The FIRST system warehouse data was used to establish a set of candidates for primary/secondary accident pairs based on the proximity definitions. FIRST accounts for almost any report of a freeway incident, and a single incident might be reported several times by any number of means. Duplicate entries are identified and eliminated by examining the record details for FIRST entries that are similar with respect to time and location. Then, loop detector data from Caltrans District 7 is used to try and verify whether apparent secondary incidents occurred in the traffic queues formed in response to apparent primary incidents. This sequence of data filters focuses ever more narrowly on establishing the sufficient conditions associated with secondary accidents. Each filter screens incident data records from analysis. The approach is summarized in Fig. 1.

A total of 84,684 FIRST records were made in the months of March, May, and July 1999; and during the last ten days of December 1998. The filters become progressively more difficult to apply because the criteria involved progress from quantitative to qualitative. The criteria applied in the first two filters are entirely rule-based, and reasonably straightforward to code into a computer program. The criteria applied in the third filter are primarily rule-based. The criteria associated with the last filter are also systematic and algorithmic, but applying these criteria requires pattern recognition that is difficult to code for completely computerized execution. The outputs of filter three provide a likely set of primary/secondary accident pairs. Filter four is intended to go

even further, and impose conditions that would conclusively eliminate all observations that are not secondary accidents from the analysis and retain only those that are.

Filter 1: Proximity in Time and Space

The first step was to identify sets of FIRST records describing events that are close together in time and space, and on the same freeway. This first filter is effectively what has been applied in all relevant empirical studies of secondary accident rates to date. In this context, a type I error occurs if a secondary accident is rejected. A type II error consists of failing to reject an event that is not a secondary accident. The objective at this initial step is to define a filter that is tolerant of type II errors, and relatively intolerant of type I errors.

The literature offers little empirical guidance on this point. Some studies (Raub 1997b) have used criteria as small as 1 mil. The most standard time criterion seems to be the duration of a primary incident plus 15 min (e.g., Raub 1997b; Latoski et al. 1999), which seems optimistic for Los Angeles freeways. Al-Deek et al. (1995) examined incidents appearing in the (Northern) California I-880 database (Skabardonis et al. 1995), and reported on incidents generating queues with maximum lengths between 2.1 and 5 mil, and durations of 42 min and 2 h and 24 min, respectively.

Based on approximately 1 month of field observations of queue lengths logged by the research team when traveling on Los Angeles freeways, Filter 1 was defined with a 2 h/2 mil standard for proximity. These field observations also verified the research
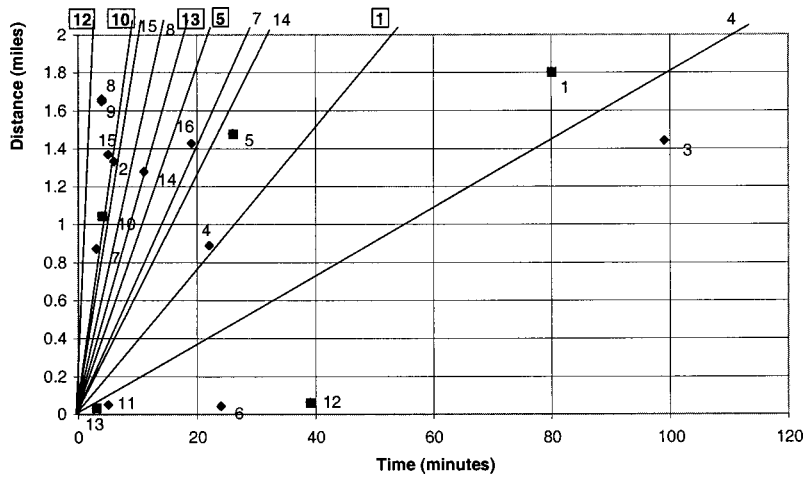
Fig. 2. Applying filter 4: Time-location coordinates and estimated shock waves for 16 likely primary/secondary pairs

team's expectation that queues routinely form in both directions following incidents. Thus Filter 1 identified groups of incidents on the same freeway, in either direction, and occurring within 2 mil and 2 h of each other. Of the 84,684 FIRST records input to Filter 1, 31,259 records (37%) met these criteria.

Filter 2: Location and Incident Type

Filter 1 does not ensure that incidents occurring subsequent to and in the same direction of a given incident are upstream from the initial incident. This is important, because an accident occurring after an incident, in the same direction as the incident, but downstream from the incident cannot be a secondary accident. Filter 2 searches the outputs of Filter 1 and excludes incidents in either direction that cannot be secondary because their locations are on the wrong side of the initial incident.

Filter 2 also identifies secondary accidents by type, location, and response details. Inspection of these details makes it possible to exclude nonaccident incidents and chain reaction accidents. Filter 2 greatly reduces the number of candidate primary/secondary pairs: of the 31,259 records input to Filter 2, just 1,078 incidents (529 pairs, 1.27% of the 84,684 original records) remained.

Filter 3: Duplicates

The detailed data associated with each FIRST record indicate whether records are duplicates; identify what other records are being duplicated; classify records by CAD type code; and, in many cases, provide additional relevant qualitative data. In Filter 3, the details for the candidate pairs from Filter 2 are reviewed. Duplicates are excluded. Cross street locations and any other relevant descriptive data are merged from the corresponding inputs to Filter 1. Filter 3 reduces the number of remaining candidate pairs by about two-thirds, providing an acceptable set of 192 likely primary/secondary pairs accounting for a total 389 incidents, or just 0.34% of the 84,684 original records.

Filter 4: Location with Respect to the Queue

Filter 4 combines data from the FIRST system with volume and loop occupancy data from Caltrans District 7's MODCOMP system. As noted above, this requires more manual attention than the previous filters. Filter 4 relies on loop detector data to identify the location of shock waves in the traffic stream building in either

direction behind a primary incident. Secondary accidents occur at this boundary in or inside the queue of high-density traffic.

The speed of the shock waves can be accurately determined from loop detector data (Al-Deek et al. 1995), making it possible to determine on which side of the wavefront a subsequent accident occurs. Each shock wave has a speed unique to the circumstance under observation. The speed of the shock wave depends on ambient flow and density upstream from the initial incident, and on the flow and density inside the region of high-density traffic that forms following the initial incident. Coordinates falling below the diagonal line occur in the high-density queue downstream from the wavefront, and are certainly secondary accidents. This determination constitutes Filter 4.

We examined the 180 likely incident groups identified by Filter 3 for the FSP months of March, May, and July 1999. The December 1998 dataset proved too small to generate a meaningful empirical estimate of secondary accident rates in the absence of FSP.

Unfortunately, loop detector data sufficient to execute Filter 4 are available for only 16 incident pairs, or about 9% of these 180 groups. Most of the pairs provided to Filter 4 could not be processed because of technical constraints on the availability of loop detector data. Nonuniform installation of induction loop detectors, lack of historical data from all detector output zones, missing and corrupted tapes of outputs, malfunctioning detectors, and field equipment communication faults collectively constrain the availability of such data.

Table 1. Results of Filter Four: Five Confirmed Secondary Accidents

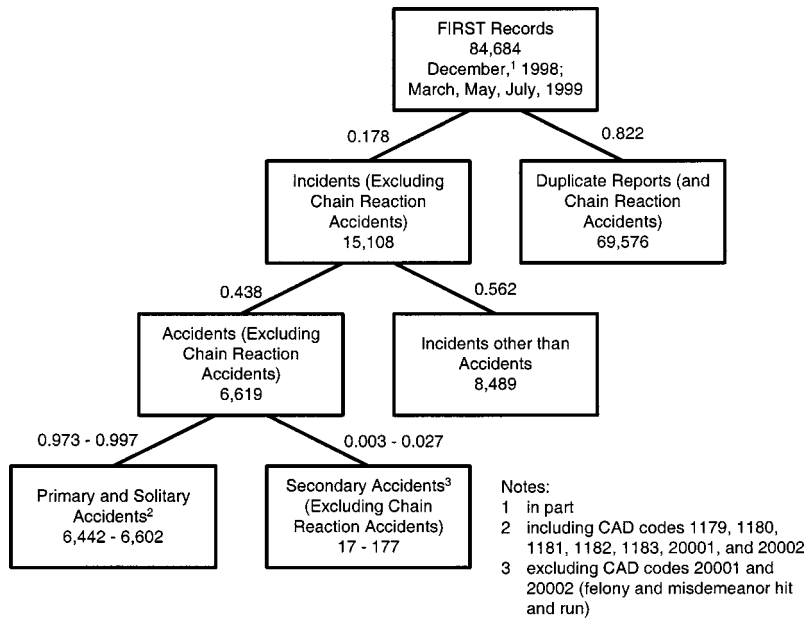| Result (1)	Incident Pair ID Numbers (2)	Count (%) (3)
Second Accident is Inside the Traffic Queue: Confirmed Secondary Accident	1, 5, 10, 12, 13	5 31.2%[a]
Second Accident is Outside the Traffic Queue: No Secondary Accident	4, 7, 8, 14, 15	5 31.2%[b]
No Shock Wave Identified: Unconfirmed Secondary Accident	2, 3, 6, 9, 11, 16	6 37.5%
Total	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15	16 100.0%

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                    ┌─────────────────────┐
                    │   FIRST Records     │
                    │      84,684         │
                    │  December,¹ 1998;   │
                    │ March, May, July, 1999│
                    └─────────────────────┘
              0.178  /                  \  0.822
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Fig. 3. Secondary accidents as a proportion of accidents and incidents

Notes:
1 in part
2 including CAD codes 1179, 1180, 1181, 1182, 1183, 20001, and 20002
3 excluding CAD codes 20001 and 20002 (felony and misdemeanor hit and run)

This lack of loop detector data does not imply that the 192 groups identified in Fig. 1 as the outputs of Filter 3 should not be classified as secondary accidents. Any of these 192 groups may include secondary accidents. The 16 pairs that could be processed by Filter 4 provide a weak estimate of how many.

The Filter 4 analysis identified a shock wave in 10 of these 16 pairs. Five of these verify that the location of a secondary accident is at the shock wave boundary or inside the queue. In the remaining six of the original 16 cases, the loop detector data showed no evidence of a shock wave in the traffic stream, and thus no opportunity for secondary accidents to occur.

Fig. 2 graphs the time-space coordinates and shock wave speeds corresponding to the 16 pairs for which loop detector data could be downloaded. These graphical representations are summarized in Table 1. Each wave speed and coordinate is indexed. The five boxed indices identify accidents verified by filter four as secondary accidents.

Analysis of Results

Establishing Upper and Lower Bounds on Secondary Accident Rates

Fig. 2 includes a very small sample, but the proportion of likely primary/secondary pairs for which secondary accidents can be verified provides the best available point estimate for the probability that any one of the pairs identified by Filter 3 includes a secondary accident. A sample of 16 is too small to comfortably assume that the observed proportion of secondary accidents is normally distributed, but if we accept the risk of doing so, an approximate 95% confidence interval for the probability that a randomly selected pair from the process generating outputs from Filter 3 includes a confirmed secondary accident is (0.0869, 0.5471). Thus as few as 17 of the 192 pairs provided by Filter 3 might include confirmable secondary accidents. The interval estimate for the probability of a confirmed or unconfirmed secondary accident is (0.4530, 0.9221). Thus up to 177 of these 192 pairs might include secondary accidents.

Computing Secondary Accident Rates

It is a straightforward matter to estimate the rate at which likely secondary accidents occur per FIRST record. However, this is a potentially misleading estimate of the relative frequency of secondary accidents because a given incident may be reported multiple times.

As noted above, records that duplicate prior incident reports are identified in each such record's details field. Detail fields were unavailable for the 84,684 FIRST records input to Filter 1. However, detail fields were available for the 31,259 records output from Filter 1. A large sample of these records reveals that slightly more than half (50.6%) of these records are duplicates. Duplicates are probably overrepresented in the outputs from Filter 1 because long incidents are more likely to be subject to multiple reports than short incidents. Thus 50.6% represents an upper bound on the share of FIRST records consisting of redundant incident reports.

The 49.4% share of the outputs from Filter 1 that consists of original (not duplicate) incident reports includes accidents and other incidents. 43.9% of the original incident reports in the outputs from Filter 1 correspond to accidents. The remaining 56.1% are incidents. These proportions can be applied to the inputs to Filter 1 to estimate the number of accident and other incident reports in the original 84,684 records.

The proportion of accidents observed in the FIRST data is considerably higher than the 4.9% share reported by Lindley (1986), or by Skabardonis et al. (1998), who reported that only 81 of 1,260 events (6.4%) on Los Angeles FSP Beat 8 consisted of accidents. The FIRST ratios are more conservative in this context than these values. The FIRST data are system-wide. Further, we have observed fewer secondary accidents than the literature suggests. If secondary accidents are rare given the FIRST shares, they would be even rarer given the values observed by Skabardonis et al.

Fig. 3 applies the FIRST proportions to the inputs to Filter 1. This makes it possible to estimate secondary accident rates in terms relative to all accidents and to all incidents, respectively. The upper bound for these rates is based on the outputs from

Filter 3, and the lower bound is based on the interval estimate of the secondary accident share that could be verified with Filter 4. We estimate that the number of secondary accidents per accident ranges from 0.015 to 0.030, and that the number of secondary accidents per incident (including accidents) ranges from 0.007 to 0.013. These rates exclude chain reaction accidents.

Conclusions

If secondary accidents are relatively frequent, then reducing the duration of primary accidents would also provide cost savings due to resulting reductions in secondary accidents. However, our analysis shows that secondary accidents distinct from chain reaction accidents are relatively infrequent events on Los Angeles freeways, and certainly less frequent than suggested in the transportation engineering literature. These data suggest that the impact of freeway service patrols on secondary accident rates must necessarily be small, and that benefits associated with reducing the frequency of secondary accidents are thus lower than generally hoped for.

The low frequency of secondary accidents does not imply that they should be ignored. Those secondary accidents that do occur are presumed to be as expensive in terms of delay and damage as any other. While avoiding secondary accidents proves only a small incentive to deploy FSP, the expected benefits associated with reducing already low secondary accident rates may be sufficient to justify accounting for these costs.

The degree to which secondary accidents block lanes is unknown. A secondary accident that occurs within the region of high density flow created by a primary incident is likely to be a low-speed event, and the drivers involved may be able to retreat to the shoulder following the accident. If so, the traffic lane would not be blocked for long. The likelihood of such low-speed, low-delay collisions varies directly with the length of queue, and thus quadratically with the duration of the primary incident.

In contrast, a secondary accident occurring at the boundary of ambient flow and a region of high-density traffic, being caused by the movement of a shock wave through the traffic stream, will not normally be a low-speed collision, and may well block the lane. If the greatest likelihood of a secondary accident is associated with the shock wave front, rather than time in the queue, then the exposure experienced by drivers is only a linear function of the duration of the primary incident.

Skabardonis et al. (1998) found that the relative frequency of accidents in lanes (29.3% of all in-lane events) was considerably higher than the relative frequency of accidents on shoulders (6.7% of all shoulder events). The fact that secondary accidents occur in lanes (by definition), and that they may be high-speed events, suggests they may well block lanes when they occur. If so,

providing access to FSP increases the likelihood that an infrequent but potentially expensive event can be avoided.

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