Research Report
KTC-11-06/SPR402-10-1F

KENTUCKY TRANSPORTATION CENTER

IDENTIFICATION OF SECONDARY CRASHES AND RECOMMENDED COUNTERMEASURES

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IDENTIFICATION OF SECONDARY CRASHES AND RECOMMENDED COUNTERMEASURES

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16. Abstract

The objective of this study was to identify and analyze the occurrence of secondary crashes on roadways in Kentucky and recommend countermeasures to reduce their frequency and severity.

Results show a small percentage of crashes coded as a "Secondary Collision" were confirmed to be a secondary crash based on the definition and requirement of "*a crash occurring as a result of a previous crash*". It appeared that many of those miscoded as a "Secondary Collision" were the result of misinterpretation of what constituted a secondary crash versus a secondary event. Adoption of the definition used in this analysis, along with more training and data input quality control was recommended.

A review of 9,330 crashes coded as a "Secondary Collision" confirmed 362 or 3.88 percent as secondary crashes, and matching collision reports for the previous crash were located for only 236 crashes. An alternative analysis involved a query of the CRASH database to determine the time and distance relationships between the primary and subsequent-related crashes. The algorithm was able to identify 87 percent of the secondary crashes that were previously identified with the extensive manual search and review of crash reports.

Based on analysis of the severity associated with secondary collisions (362) identified in the 18-month period of 2009-2010, the overall costs were estimated to be $11,228,100 when considering "Economic Cost" and $33,636,100 when considering "Comprehensive Cost."

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EXECUTIVE SUMMARY

It has been assumed that the probability of a secondary crash increases when an incident occurs, and the risks remain high until the incident is cleared. Studies have attempted to quantify secondary crashes as one of the peripheral effects of an incident and have had limited success due to the complexity of identifying such a crash. The objective of this study was to identify and analyze the occurrence of secondary crashes on roadways in Kentucky and recommend countermeasures to reduce their frequency and severity.

Results from the literature review indicated that most previous studies reported a wide range of secondary incident frequency based on analysis procedures. It was found that relatively high percentages of total crashes were determined to be associated with secondary crashes in these studies as compared to the results from analysis of Kentucky data.

Review and analysis of crash data forms included the 18-month period between January 2009 and June 2010, with 9,330 crashes coded as secondary. Based on interpretations and opinions of reviewers, 362 or 3.88 percent were secondary crashes. Further analysis of collision reports resulted in 236 (2.53 percent) of the 362 crashes being identified as secondary based on identification of a correlating or matching crash report. Whether the number is 362 or 236 crashes, this represents a very small percentage (approximately 0.10 to 0.15 percent) of total annual crashes confirmed to be secondary crashes.

Results show a small percentage of crashes coded as a "Secondary Collision" were confirmed to be a secondary crash based on the definition and requirement of "*a crash occurring as a result of a previous crash*". It appeared that many of those miscoded as a "Secondary Collision" were the result of misinterpretation of what constituted a secondary crash versus a secondary event. Adoption of the definition used in this analysis, along with more training and data input quality control was recommended.

An alternative procedure was used to identify secondary crashes, with analysis of time and distance from the primary crash as the parameters. The analysis involved a query of the CRASH database to determine the time and distance relationships between the primary and subsequent-related crashes. The algorithm was able to identify 87 percent of the secondary crashes that were previously identified with the extensive manual search and review of crash reports. This simplified method was recommended for application on annual basis to determine the magnitude of the secondary crash problem. It was also recommended that the frequency of secondary crashes could be addressed with increased attention to the safety of motorists within the immediate area of a collision. Prompt initiation of emergency traffic control should provide advance warning to approaching motorists and reduce the probability of a secondary collision.

Based on analysis of the severity associated with secondary collisions (362) identified in the 18-month period of 2009-2010, the overall costs were estimated to be $11,228,100 when considering "Economic Cost" and $33,636,100 when considering "Comprehensive Cost."

1.0 BACKGROUND

For all roadway users, the probability of a secondary crash increases immediately when an incident occurs, and the risks remain high until the incident is cleared. In some instances, the severity of secondary crashes is greater than the initial incident. Secondary crashes have frequently been discussed as a type of crash that needs to be better understood and quantified. Previous studies have attempted to quantify this type of crash as one of the peripheral effects of an incident and have had limited success due to the complexity of identifying such a crash. The documentation of secondary crashes in Kentucky has been addressed to some degree with recent (2008) implementation of a separate code on the Uniform Police Traffic Collision Report for noting whether the crash involved a "secondary collision". Subjectivity associated with coding the occurrence of a secondary crash is a factor that should be addressed through education and training of investigating officers relative to what constitutes a secondary crash. One definition of secondary crashes offered by FHWA's Office of Safety is as follows:

Unplanned incidents (starting at the time of detection) for which a response or intervention is taken, where a collision occurs either; a) within the incident scene, or b) within the queue (which could include the opposite direction) resulting from the original incident.

Kentucky's Highway Incident Management Task Force crafted a definition for use with the CRASH form as follows:

A secondary crash is a crash that has occurred due to non-recurring traffic congestion. The congestion should be a result of an earlier documented crash.

The objective of this study was to identify and analyze the occurrence of secondary crashes on roadways in Kentucky and recommend countermeasures to reduce their frequency and severity. It is anticipated that improved identification and understanding of secondary crashes could lead to implementation of countermeasures that will impact crash frequency and overall highway safety.

2.0 LITERATURE REVIEW

Research into the occurrence of secondary incidents has been very limited, and a review of literature over the past two decades has revealed nine key articles. Each of these articles is examined below in order to investigate: 1) the definition or methods employed in order to identify secondary incidents; 2) the independent variables which can influence the rate and severity of incidents; and 3) methods which can be utilized in order to mitigate the occurrence of such incidents.

TABLE 1 Definition and Identification of Parameters for Classification of Secondary Incidents

Definition	Khattack et al (2009)	Zhan et al (2009)	Hirunyanitiwattana and Mattingly (2006)	Karlaftis et al (1999)	Raub (1997)	Sun and Chilukuri (2007)	Moore et al (2004)	Zhan et al (2008)	Chilukuri and Sun (2006)
Result from queuing and congestion	√	√				√	√		
Caused at least in part by another incident	√	√	√			√	√		
Fixed temporal/ spatial parameter	√	√	√	√	√		√	√	
Dynamic temporal/ spatial parameter						√			√
Cumulative arrival and departure curve		√							
Same direction within 60 min. and 2 miles/3.218 kilometers			√						
0.497 miles/0.8km upstream and clearance period plus 15 min.				√					
1.119 miles/1.8km plus 15 min.					√				
Upstream in either direction							√		
2 mile/3.218 kilometer duration plus 15 min.								√	
Lane blockages only								√	

The most commonly accepted definition for a secondary incident is an incident caused at least in part by another incident (2, 4, 5, 7, 8). Integral to this definition is the recognition that secondary incidents result from the congestion and queuing initiated by the primary incident (4, 5, 7, 8).

The majority of investigations have utilized fixed spatial and temporal parameters in order to identify secondary incidents (2, 3, 4, 5, 6, 8, 9). These fixed parameters vary among investigations, and range from incidents incurring in the same direction as the primary incident, with a range of 2 miles upstream and within 60 minutes (2), to incidents occurring in both directions (5), and a popular time framework as the clearance time of the initial incident plus 15 minutes (3, 6, 9).

Dynamic spatial and temporal parameters have also been utilized (1, 7). The dynamic spatial and temporal parameter is an attempt by Sun and Chilukuri to account for the changeable nature of traffic congestion associated with the initial incident. The incident has a congestion level with a rising limb, and a peak, followed by a receding limb, represented by the incident progression curve. The following steps were identified in developing the incident progression curve: 1) processing of intranet incident reports; 2) filling in incomplete incident reports; 3) non-linear regression of incident progression curves; 4) merging of progression curves into a master curve (1, 7).

The cumulative arrival and departure curve employed by Zhan et al (8) is a deterministic model used to estimate traffic delays and queue lengths. The maximum queue length associated with a lane blockage incident is identified as the reference or standard length for determining possible secondary incidents (8). One last definition, taken account of by Zhan et al (9) is that secondary incidents are considered to be those incidents, which result in lane blockages.

The following table highlights the independent variables or influencing factors outlined by four of the authors when examining the occurrence or prevalence of secondary incidents. Each of these factors will be discussed below.

TABLE 2 Independent Variables and Factors Influencing the Occurrence of Secondary Incidents

	Khattak et al (2009)	Zhan et al (2009)	Karlaftis et al (1999)	Zhan et al (2008)
Time/duration	√	√	√	√
No. of lanes	√			√
Weekdays	√		√	
Peak period	√	√		√
Speeding	√	√		
Rollover	√	√		√
Environmental		√		
Lane closure		√		
Injury		√		
Vehicle type	√	√	√	
Location/traffic		√	√	
Season	√		√	
No. of Vehicles				√

The most obvious and understandable of factors (upon which each of the authors agree) is that the rate of secondary incidents is heavily influenced by the duration of the incident, or incident clearance time. There is a positive correlation in all their results; between the length of time it takes to clear the scene and the number of, or potential for secondary incidents to occur (3, 4, 9, 8). The number of lanes also has an impact on the likelihood of secondary incidents. According to Khattak et al (4), the more lanes there are at the incident site the greater the probability of a secondary incident. Zhan et al (9) on the other hand state that if there are more than two lanes blocked then this will significantly increase the possibility of a secondary incident. Weekdays and peak period can be taken account of together. All four authors (3, 4, 9, 8) agree that one or both of these factors is an important attribute in determining the probability of a secondary incident. Both factors take account of the same principle, the busier the roadway, and the more traffic present (i.e. during peak periods, such as rush hour on weekdays) the greater the chances of a secondary incident occurring.

Speeding and rollover are two factors also generally considered simultaneously. According to Zhan et al (9) when all other factors remain equal, a primary incident, which results in vehicle rollover, increases the likelihood of secondary incidents taking place. Khattak et al (4) also recognize a positive correlation between vehicle speeding and rollover with secondary crash occurrence.

Zhan et al (8) also list environmental condition factors as a potential independent variable when predicting the probability of a secondary incident occurring. Examples listed include pavement, precipitation, wind, visibility and illumination, which can collectively determine the conditions on scene. Tied into this reasoning is season, as illustrated by both Karlaftis et al (3) and Khattak et al (4). Khattak et al (4) base their assumption that there are less secondary incidents in winter upon the findings in Karlaftis et al (3) report. Karlaftis et al (3) are in agreement with Zhan et al (8) in so far as they state that environmental conditions can severely impact visibility at a scene. However, their findings are somewhat counter-intuitive to the extent that there is a reduced probability of a secondary incident occurring during the winter months. Karlaftis et al (3) speculate that this may be due to the fact that drivers are naturally more cautious when driving over winter, and travel at a reduced speed.

According to Zhan et al (8) both lane closure and injury are fundamental aspects of the primary incident that influence the likelihood of secondary incidents. Although other authors neglect these factors, they are implicit to incident clearance time and duration of incident. Essentially, injury and lane closures are indicators as to the severity of the primary incident, which may increase the time spent on scene.

Each report mentions either vehicle type or number of vehicles involved in the primary incident as being a contributory factor to secondary incident rate (3, 4, 9, 8). Zhan et al (8) investigate the issue of vehicle type. This category of vehicle type is further subdivided to incorporate the number of vehicles involved, whether or not a commercial vehicle is present, and the type of vehicle (car, van, tractor, truck etc.) Karlaftis et al (3) have a similar subdivision of vehicle type, based on the premise that larger vehicles take longer to clear from the roadway, and thus impact incident clearance and duration, the primary factor determining secondary incidents.

Karlaftis et al (3) utilize vehicle location as a proxy for vehicle speed. The rational implied in this concept, is that vehicles move faster in the left lane, as opposed to the right lane, and much faster when compared to entry/exit ramps. The operating speed of a vehicle influences the ability of the vehicle to stop in time to avoid a secondary incident. Zhan et al (8), take this assessment one step further to include the corridor considered (the particular roadway), and the volume/capacity ratio of the particular roadway on which the secondary incident occurs.

The third aspect of the literature review examines methods that can be applied in order to mitigate secondary incidents. Again four authors examined this aspect of incident management within their reports (4, 2, 3, 6). Table 3 below is an overview of each of these methodologies. The following section will examine each facet of these mitigation examples in detail.

TABLE 3 Methodologies for Mitigation of Secondary Incidents

	Khattak et al (2009)	Hirunyanitiwattana and Mattingly (2006)	Karlaftis et al (1999)	Raub (1997)
Duration	√			√
Incident management-clarify roles	√			√
Aggressive clearance strategies	√	√		√
Patrol vehicles at high frequency segments	√	√		
Notification upstream		√	√	
In-vehicle transmitter			√	
CCTV			√	

Incident clearance time and duration is noted as being one of the primary factors influencing the likelihood of secondary incident occurrence. It is intuitive then that this is listed as a mitigation effort, which can be put in place in order to reduce secondary incidents (4, 6). By implementing stringent incident management on the primary incident, this can help lessen the likelihood of secondary incidents, by clearing the incident scene as soon as possible. Integral to rigorous incident management is the need to clarify the role of each responding agency at an incident scene. Inherent within each of the roles being played is a hierarchy of who is in charge, and under what circumstances. This hierarchy needs to be clearly defined and adhered to by each actor on scene (4, 6). An aggressive clearance strategy again plays into the role of incident management and incident duration (2, 4, 6).

Placing patrol vehicles at high incident frequency segments has the effect of slowing traffic through places noted for incidence occurrence (2, 4). This practice can reduce the number of primary incidents occurring and thereby negate the possibility of secondary incidents. Notification upstream of the primary incident can allow drivers sufficient time to either reduce their speed or divert around the primary incident, and again lower the number of secondary incidents occurring (2, 3). Hirunyanitiwattana and Mattingly (2) note that the rate and severity of secondary incidents vary between urban and rural locations. Incident rate in urban locations was much higher, with the probability of a secondary incident higher than the probability of a primary incident. Despite a lower incident rate in rural areas, the probability of a fatality was much higher. Karlaftis et al (3) describe in-vehicle transmitters as an option for decreasing secondary incidents. This system would allow the first responder to create and send highway advisory radio messages and variable message sign messages from their vehicle at the incident scene. Provided these types of message boards are available this would improve motorist notification upstream of an incident.

Closed circuit television is the final mitigation effort described by Karlaftis et al (3). CCTV is noted as a means to again monitor traffic characteristics upstream of an incident, and develop an early warning system, which will notify first responders when there is an increased likelihood of secondary incidents.

A very recent report by Khattak et al (3), found that secondary incidents account for nearly 2.0 percent of recorded incidents in the Hampton Roads area of Virginia in 2006. Of all the accidents (crashes), 7.5 percent had associated secondary incidents, 1.5 percent of disabled vehicles had secondary incidents, and 0.9 percent of abandoned vehicles had secondary incidents. It was also found that secondary incidents in the area of study were 18 minutes, which was 4 minutes longer than the mean duration of other (independent) incidents, indicating that secondary incidents were not necessarily minor incidents. A corresponding result was that a 10-minute increase in the primary incident duration was associated with 15 percent higher odds of secondary incidents. Cost-benefit analysis showed that reducing the number of secondary incidents by 25 percent resulted in incident delay benefits estimated at $1.11to $1.23 million per year, dependent upon the methodology used.

3.0 ANALYSIS AND PROCEDURES

3.1 CRASH Database

The analysis procedure focused on review of crash data records from Kentucky's CRASH database which contains coded information, as well as the actual content of the Uniform Police Traffic Collision Reports. An attempt was made to identify and analyze all crashes coded as secondary for the purpose of summarizing generalized and specific characteristics. Attention was given to defining secondary crashes in order to capture accurate data for this analysis. The definition was simplified to include only those crashes that met the criteria of being "*a crash occurring as a result of a previous crash*". This more concise definition was used after preliminary analysis indicated that the definition adopted by the Kentucky's Highway Incident Management Task Force for use with the CRASH form was either not being considered when decisions were made regarding secondary crashes, or it was not sufficiently clear to produce accurate records. The definition included with the CRASH form as supplemental information is as follows:

A secondary crash is a crash that has occurred due to non-recurring traffic congestion. The congestion should be a result of an earlier documented crash. This definition supplemented a code for "Secondary Collision" that was added to the Kentucky Uniform Police Traffic Collision Report form in 2007.

A query of the CRASH database for the years 2007 through 2010, with results tabulated in Table 4 below, demonstrates the frequency with which investigation officers have used the "Secondary Collision" code:

TABLE 4 Summary of Crashes Coded as "Secondary Collisions"

Year	Crashes Coded as Secondary Collision	Total Annual Crashes	Percent Coded as Secondary
2007	1,314	150,213	0.87
2008	7,252	145,166	5.00
2009	6,528	147,760	4.42
2010	6,016	150,513	4.00

This summary shows that the "Secondary Collision" code was used infrequently when the change was made in 2007 (or possibly only a partial year of data was captured); however, the use of the code increased dramatically in 2008. The frequency with which the code was used, as a percentage of total annual crashes, decreased from 2008 (5.0 percent) to 2009 (4.42 percent) and then again from 2009 to 2010 (4.0 percent). This appears to be an indication that the code is being used somewhat more selectively by investigating officers.

3.2 Secondary Crash Collision Reports

A more detailed review of those crashes coded as secondary collisions was performed for the 18-month time period of January 2009 through June 2010. This analysis involved review of each collision report where the code for "Secondary Collision" was noted. Reviewers were instructed to consider the crash as secondary only if it was determined to be "*a crash occurring as a result of a previous crash*". Table 5 is an overview summary of frequency of secondary crashes being coded and those verified to be secondary crashes based on the specified definition. For the 18-month period, there were 9,330 crashes coded as secondary. Based on interpretations and opinions of reviewers, 362 or 3.88 percent were secondary crashes. For the 147,760 crashes that occurred in 2009, the 237 secondary collisions represent 0.16 percent of the all crashes. Further analysis of collision reports resulted in 236 of the 362 crashes being identified as "secondary" based on identification of a correlating or matching crash report. This represents 2.53 percent of the 9,330 crashes coded as secondary. Using this analysis approach for the 2009 year of data, only 164 (0.11 percent) of 147,760 crashes were confirmed to be secondary crashes

Results from this analysis show a small percentage of crashes coded as a "Secondary Collision" were confirmed to be a secondary crash based on the definition and requirement of "*a crash occurring as a result of a previous crash*". It appeared that many of those miscoded as a "Secondary Collision" were the result of misinterpretation of what constituted a secondary crash versus a secondary event. A high number of crashes were most likely secondary events. Examples were crashes involving another object after an initial impact, such as car to car and then impact with a tree. Another frequently coded "Secondary Collision" that was a secondary event involved a vehicle leaving the roadway (interpreted as the first event) and then impact with a tree, ditch, embankment or other fixed object of some type.

TABLE 5 Summary of Crashes Coded, Reviewed, and Verified as "Secondary Collisions"

Month	Coded Secondary	Secondary Crashes (Based on Review and Opinion)		Secondary Crashes (Correlating Report Found)	
		Number	Percent	Number	Percent
January	587	15	2.56	9	1.53
February	471	8	1.70	2	0.42
March	508	22	4.33	10	1.97
April	573	24	4.19	18	3.14
May	581	22	3.79	14	2.41
June	513	20	3.90	15	2.92
July	519	24	4.62	17	3.28
August	485	13	2.68	10	2.06
September	567	31	5.47	25	4.41
October	625	24	3.84	21	3.36
November	480	12	2.50	7	1.46
December	571	22	3.85	16	2.80
Total 2009	6480	237	3.66	164	2.53
January	542	16	2.95	8	1.48
February	474	18	3.80	5	1.05
March	425	22	5.18	14	3.29
April	478	36	7.53	18	3.77
May	457	13	2.84	10	2.19
June	474	20	4.22	17	3.59
Total 2010	2850	125	4.39	72	2.53
Total 2009- 2010	9330	362	3.88	236	2.53

In order to expand the understanding of the types of crashes being coded as “Secondary Collisions” by investigating officers, each of the crashes verified as secondary was categorized as follows:

CRASH TYPE	DEFINITION
Avoidance Failure	Avoiding a collision and involved in another collision
Collision in Traffic	Collision in traffic resulting from another collision
Observational Collision	Operator(s) were out of vehicle when collision occurred
Debris/Spillage in Roadway	Debris in roadway from first collision or spillage
ERV/Wrecker	Emergency response vehicles on scene and involved
Other	Any other type of secondary collision

Of those crashes coded as “Secondary Collisions” that could be categorized by one of the crash types described above, their frequency of occurrence indicates approximately 44 percent of the secondary collisions were categorized as “Avoidance Failure” (158 of 362) and another 20 (72 of 362) percent were “Collision in Traffic”. These are similar and together represent nearly 64 percent of all the crashes that were identified as secondary collisions and analyzed in more detail. These two types of crashes indicate drivers were unable to avoid a vehicle that was apparently in or near the roadway as a result of another crash. With the prerequisite of another crash occurring prior to the secondary collision, the time and distance spacing between the initial event and secondary event are critical to the identification of these crashes and the potential to reduce their occurrence. Avoidance opportunities would be limited when there is a very short time between the first crash and the secondary crash.

3.3 Secondary Crashes Identified by Time and Distance

An alternative procedure was used to identify secondary crashes, with analysis of time and distance from the primary crash as the representative parameters. This analysis involved a query of the CRASH database to determine the time and distance relationships between the primary and subsequent-related crashes. Those 236 crashes previously identified as a secondary collision (crashes where a correlating or matching report could be found) were analyzed to determine a usable time (rounded to approximately 80 minutes) and distance (rounded to approximately 6,000 feet or 1828.8 meters) in relation to the previous crash. For secondary collisions not occurring on the same route as the initial crash, the length parameter was decreased to 1,000 feet/304.8 meters in an effort to capture side street or intersection crashes but to avoid capturing completely unrelated crashes. These parameters were then run against the entire crash database for 2009 to determine the number of crashes which would be identified based on pre-selected parameters of time and distance, without regard to the use of the “Secondary Collision” code. The pre-selection process involved a subjective decision to not include outlier parameters, but rather those that were most likely represented in the range of time and distance to capture secondary collisions.

A Visual Basic.Net program was developed to search the 2009 crash database for crashes meeting the parameters previously discussed. The 2009 database (containing 148,010 crash records) was sorted by collision data and time. Only crashes with a date, time, GPS coordinates and a RT_Unique (unique county and route identifier) were used in the search. A crash was identified as a primary crash if another crash was found to be within the time and space parameters, with a smaller spatial search radius used for crashes on a different route.

The program returned 5,265 crashes with one or more matching crashes. The total number of matching crashes was counted for each primary crash. As expected some matching crashes were already identified as a matching or primary crash. Matching duplicates were removed if they were identified prior to the occurrence of the primary crash. It was determined that in 885 of the total 5,265, there were zero matching crashes after duplicates were removed. In many of these cases the primary and its secondary crashes were all secondary crashes to a previously occurring primary. In some rare cases (such as Master File Number 70708266), three of the identified secondary crashes were previously identified; however, one of the secondary crashes was not. In this case, the number of matched crashes changed from four to one. Several of the primary crashes with more than four matching crashes (after duplicates were removed) were examined. In many cases they represented interstate crashes with several crash reports associated with a primary crash. In other cases they represented an environmental condition such as an icy road. The following table shows the frequency of secondary crashes after application of the duplicate removal process.

TABLE 6 Frequency Distribution of Matched Crashes Before and After Removal of Duplicates

Number of Matched Crashes	Original Count	Duplicates Removed
0	0	885
1	4,749	4037
2	412	296
3	56	30
4	27	10
5	9	3
6	3	2
7	9	2

It was also possible for a primary crash to have been previously identified as a matching crash. There were 1,076 matching crashes that were also flagged as primary. There were 522 primary crashes that were also associated with another primary crash as a result of both crashes being coded as occurring at precisely the same time. This caused the software to capture both.

There were 5,294 unique matching crashes identified in 2009 after all duplicates were removed, regardless of the primary crash. In theory, these crashes could be secondary crashes in that they occurred after a previous crash within the time and space parameters. A total of 431

(8.1%) of these crashes were coded as secondary. However, 109 of these crashes did not have data for the secondary crash indicator, likely because they were paper reports. This slightly increased the percentage to 8.3% since the unknown data should be removed.

Several of the secondary crashes identified by the program were reviewed and a high percentage of parking lot crashes were being identified either as the primary or matching crash (18%). The model still identifies 3,966 crashes that were coded as not being a secondary crashe (this excludes any without this data). Based on a manual review of some of these crashes, it is still likely that some were not identified as a secondary crash by the officer, but a large majority are not secondary crashes. Therefore the model is still largely oversampling the number of secondary crashes even when parking lot crashes are excluded. However, compared to the number of crashes identified solely by police officers in 2009 (6,440), the model, with parking lots excluded, identified fewer crashes (4,481). Of those crashes identified, 3% (136 or 4,481) were true secondary crashes as determined by the manual review process described in Section 3.2 compared to 2.5% (164 of 6,440) of the crashes identified as secondary on the police report form.

A total of 136 (or 83%) of the model results (excluding parking lot crashes) were previously identified as a true secondary crash when compared to the 164 crashes identified in the manual search process for 2009. A small number (8 crashes) of the true secondary crashes were identified by the model as the primary crash, however, including all primary crashes identified by the model would greatly increase the number of incorrectly identified secondary crashes. Based on data from 2009, the model identified 30% fewer potential secondary crashes as compared to crashed flagged by the police officer and still identified a majority (82%) of the true secondary crashes. It should be noted that this analysis did not investigate true secondary crashes that were not identified by a police officer. Furthermore, most of the true secondary crashes that were not identified by the model were matched to primary crashes that spanned over very long distances or time. Future research may lead to ways to increase the identification of such crashes.

3.4 Crash Costs

An analysis was performed to determine the overall costs associated with secondary collisions. This involved accessing the CRASH database and summarizing the severity for each of the 362 crashes identified in the 18-month period of 2009-2010. Listed below are National Safety Council (NSC) estimated costs for "economic cost" ("comprehensive cost" shown in parenthesis) (11).

- Fatalities - $1,290,000 ($4,300,000)
- Incapacitating Injuries - $67,800 ($216,800)
- Non-Incapacitating Injuries - $21,900 ($55,300)
- Possible Injuries - $12,400 ($26,300)
- Property Damage Only - $2,400 ($2,400)

Using these costs, crashes in the 18-month period were analyzed to determine severity and appropriate costs were assigned. It was found that 5 fatalities occurred during the study period. Injuries by type included 30 incapacitating, 59 non-incapacitating, and 66 possible. The remainder of crashes (264) was reported as property damage only (PDO). Results indicate the overall costs were $11,228,100 when considering "Economic Cost" and $33,636,100 when considering "Comprehensive Cost". For the secondary crashes identified during the 18-month period, the average cost would be $31,017 when using "Economic Cost" values, and $92,917 when using the "Comprehensive Cost' values. A summary of the secondary crash costs for the period between January 1, 2009 and June 30, 2010 is presented in Table 7 below.

TABLE 7 Secondary Crash Costs – January 2009 through June 2010 (18 Months)

Crash Injury Severity	Severity Frequency	Economic Cost - NSC	Secondary – Economic Cost	Comprehensive Cost - NSC	Secondary – Comprehensive Cost
Fatalities	5	$1,290,000	$6,450,000	$4,300,000	$21,500,000
Incap. Inj.	30	$67,800	$2,034,000	$216,000	$6,504,000
Non. Incap.	59	$21,900	$1,292,100	$55,300	$3,262,700
Possible	66	$12,400	$818,400	$26,300	$1,735,800
PDO	264	$2,400	$633,600	$2,400	$633,600
TOTALS			$11,228,100		$33,636,100

4.0 SUMMARY OF RESULTS

Primary findings from the analysis of secondary crashes are as follows:

1. It was determined from the literature review that the most commonly accepted definition for a secondary incident was an incident caused at least in part by another incident.

2. Results from the literature review also indicated that most previous studies reported a wide range of secondary incident frequency based on analysis procedures. It was found that relatively high percentages of total crashes were determined to be associated with "secondary crashes" as compared to the results from analysis of Kentucky data.

3. A supplemental code for "Secondary Collision" was added to the Kentucky Uniform Police Traffic Collision Report form in 2007, with the definition as follows:
   A secondary crash is a crash that has occurred due to non-recurring traffic congestion. The congestion should be a result of an earlier documented crash.
   The frequency with which the code was used, as a percentage of total annual crashes, decreased from 5.0 percent (7,252) in 2008 to 4.0 percent (6,016) in 2010. This appears to be an indication that the code is being used somewhat more selectively by investigating officers.

4. The definition of secondary collision for this study was simplified to include only those crashes that met the criteria of being "*a crash occurring as a result of a previous crash*".

5. Review and analysis of crash data forms included the 18-month period between January 2009 and June 2010, with 9,330 crashes coded as secondary. Based on interpretations and opinions of reviewers, 362 or 3.88 percent were secondary crashes. Further analysis of collision reports resulted in 236 of the 362 crashes being identified as secondary based on identification of a correlating or matching crash report. This represents 2.53 percent of the 9,330 crashes coded as secondary. Whether the number is 362 or 236 crashes, this represents a very small percentage (approximately 0.10 to 0.15 percent) of total annual crashes confirmed to be secondary crashes.

6. Results show a small percentage of crashes coded as a "Secondary Collision" were confirmed to be a secondary crash based on the definition and requirement of "*a crash occurring as a result of a previous crash*". It appeared that many of those miscoded as a "Secondary Collision" were the result of misinterpretation of what constituted a secondary crash versus a secondary event.

7. A summary of crash types indicated approximately 44 percent of the secondary collision" were categorized as "Avoidance Failure" (158 of 362) and another 20 (72 of 362) percent were "Collision in Traffic". These are similar and together represent nearly two-thirds of all the crashes that were identified as secondary collisions and analyzed in more detail. These two types of crashes indicate drivers were unable to avoid a vehicle that was apparently in or near the roadway as a result of another crash.

8. An alternative procedure was used to identify secondary crashes, with analysis of time and distance from the primary crash as the representative parameters. This analysis involved a query of the CRASH database to determine the time and distance relationships between the primary and subsequent-related crashes. The algorithm was able to identify 82 percent of the secondary crashes that were previously identified with the extensive manual search and review of crash reports. The model identified 30% fewer potential secondary crashes than the secondary crash code on the police report.

9. Based on analysis of the severity associated with secondary collisions (362) identified in the 18-month period of 2009-2010, the overall costs were estimated to be $11,228,100 when considering "Economic Cost" and $33,636,100 when considering "Comprehensive Cost".

5.0 RECOMMENDATIONS

It is recommended that a more specific definition of secondary crashes be provided to investigating officers. The definition presently included with the CRASH form as supplemental information is as follows: *A secondary crash is a crash that has occurred due to non-recurring traffic congestion. The congestion should be a result of an earlier documented crash.* This definition supplemented a code for "Secondary Collision" that was added to the Kentucky Uniform Police Traffic Collision Report form in 2007. Based on analyses performed as part of

this research effort, a more simplified definition was adopted as follows: "*a crash occurring as a result of a previous crash*". This definition is being recommended to replace the current definition included with the collision report form, along with a query to the data provider which prompts them to verify if the crash was the result of a previous crash. In addition, it is recommended that additional emphasis be placed on this issue when training is provided to officers expected to complete the crash collision form.

As an alternative means of identifying secondary crashes, it is recommended that the time and distance parameters developed from analysis of actual crashes be applied to the CRASH database annually to determine their frequency. In addition, an analysis to assign total costs associated with these types of crashes should be performed to assess the degree of the problem, with appropriate actions as necessary. It should be noted that the overall frequency was found to be small and therefore countermeasure actions should be commensurate with the problem.

Increased attention should be given to the safety of motorists within the immediate area of a collision. Prompt initiation of emergency traffic control should provide advance warning to approaching motorists and therefore reduce the probability of a secondary collision.

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