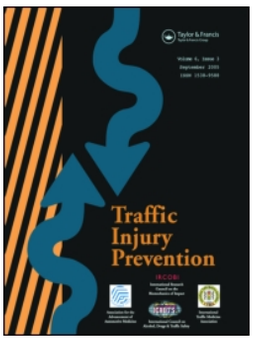

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Factors Associated with Higher Levels of Injury Severity in Occupants of Motor Vehicles That Were Severely Damaged in Traffic Crashes in Kentucky, 2000–2001

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Objectives: *The majority of motor vehicle occupants who were killed or hospitalized in crashes in Kentucky in 2000–2001 occupied vehicles that were severely damaged in the crash. Even so, overall only a small percentage of all severely damaged vehicle occupants were killed or hospitalized. The purpose was to identify occupant, vehicle, crash, and roadway/environmental factors that were associated with increased risk of severe injury in crashes where the occupant's vehicle was severely damaged.*
Methods: *This study probabilistically linked Kentucky's statewide motor vehicle crash and inpatient hospital discharge data files for 2000 and 2001, and selected cases representing occupants of vehicles that were reported by police as having either "severe" or "very severe" damage. For occupants who were identified through data linkage as having been hospitalized, the Injury Severity Score (ISS) was calculated using ICDMAP-90^{TM} software, and the scores were stratified into the following categories: critical (>24), severe (15–24), moderate (9–14), and mild (<9). We then created an outcome variable, injury severity level, with five levels: killed; hospitalized with at least moderate injuries (ISS = critical, severe, or moderate); hospitalized with mild injuries (ISS = mild); injured according to the police report but not hospitalized; and no apparent injury according to the police report. We performed a stepwise, ordinal logistic regression of injury severity, using independent variables identified from the existing crash literature.*
Results: *Occupant risk factors for higher levels of injury severity selected by the regression were age (risk increased with age, other factors being equal), female gender, restraint non-use, ejection from the vehicle, and driver impairment (by alcohol and/or drugs). Crash risk factors included head-on collision, collision with a fixed object, vehicle rollover, and vehicle fire. Roadway/environmental factors were federal- or state-maintained roadway and posted speed limit 89 kph (55 mph) or greater.*
Conclusions: *Many of the identified risk factors are explicitly or implicitly mentioned in the strategic plans of key organizations involved in highway safety and injury prevention in Kentucky. Our analysis provides additional evidence of their importance, and confirms that their mitigation will reduce injury severity in crashes involving severe vehicle damage. Additionally, older occupants and female occupants showed increased risks of serious injury, but to our knowledge these factors are not currently addressed in any state plans. An opportunity exists to clarify the nature of these risks through further studies, which might lead to the identification of countermeasures specific to these populations.*

Keywords Severe Vehicle Damage; Data Linkage; Motor Vehicle Crash; Injury Severity; Ordinal Logistic Regression; Risk Factors

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Linked motor vehicle crash (MVC) report and hospital discharge files for Kentucky from 2000 and 2001 indicate that the majority of persons who were killed or hospitalized in MVCs occupied vehicles that were at least severely damaged in the

Table I Number and percentage of crash-involved vehicle occupants by extent of vehicle damage and injury severity level

	Extent of vehicle damage							
	Severe or very severe		Less than severe		Unknown		Total	
Injury severity level	#	%	#	%	#	%	#	%
Killed	1,281	90.9	127	9.0	2	0.1	1,410	100.0
Hospitalized, moderate-to critical injuries	1,955	84.2	361	15.5	6	0.3	2,322	100.0
Hospitalized, mild injuries	2,443	63.8	1,367	35.7	19	0.5	3,829	100.0
Injured* but not hospitalized	39,410	44.3	48,741	54.8	858	1.0	89,009	100.0
No apparent injuries*	41,005	8.0	462,344	90.6	7,037	1.4	510,386	100.0
Unknown	1,808	8.2	19,158	86.5	1,173	5.3	22,139	100.0
Total	87,902	—	532,098	—	9,095	1.4	629,905	—

*According to the MVC report.

crash (SDVs). There were 629,905 occupants involved in crashes in Kentucky in those years. Table I presents the number and percentage of vehicle occupants by vehicle damage and injury severity levels.

Only 14% of all crash-involved occupants were in SDVs. However, that relatively small group of occupants includes 91% of those who were killed, 84% of those who were hospitalized with moderate-to-critical injuries, 64% of those hospitalized with mild injuries, and 45% of those who were injured but neither killed nor hospitalized. By contrast, only 8% of all uninjured vehicle occupants were in SDVs.

Table II, however, illustrates that most occupants of even severely damaged vehicles (91%) either had no apparent injuries, or experienced injuries that did not result in hospitalization or death. The objective of this study was to identify factors associated with more severe levels of injury among occupants of SDVs. The results of this analysis were also compared with the stated highway safety and injury prevention goals and objectives of several state agencies, in order to assess the similarities and differences between the two.

METHODS

Kentucky MVC Database

In Kentucky, crash reporting is mandated for crashes involving an injury or property damage in the amount of $500 or more. Persons reported as killed in this database include those who died on the scene or within 30 days after the crash date. The MVC database includes occupant, vehicle, crash, and environmental information related to each reported incident. Occupant information includes demographics, seating position, restraint use, whether the driver was suspected of driving under the influence of drugs and/or alcohol, driver licensing restrictions, ejection status, contributing human factors to the crash, and police-reported injury status. Vehicle information includes vehicle make, model, year, and registration number; vehicle information number, extent of damage, whether the vehicle overturned or caught fire, pre-collision vehicle action, type of fixed object struck, and contributing vehicular factors to the crash. Crash information includes incident date, time, county, and location; manner of collision, and location of the first collision event. Environmental information includes traffic controls, weather and light conditions, posted speed limit, contributing environmental factors to the crash, and the roadway's type, condition, and number of lanes.

Kentucky Inpatient Hospital Discharge Database (HDD)

Hospital discharge reports are required for all inpatients discharged from licensed Kentucky hospitals. Selected outpatient procedures are reported to this database as well. For this study we selected inpatient discharges only. The HDD dataset contains personal and medical information including patient admit and

Table II Number and percentage of crash-involved vehicle occupants by extent of vehicle damage and injury severity level

	Extent of vehicle damage					
	Severe or very severe		Less than severe		Unknown	
Injury severity level	#	%	#	%	#	%
Killed	1,281	1.5	127	0.0	2	0.022
Hospitalized, moderate-to critical injuries	1,955	2.2	361	0.1	6	0.066
Hospitalized, mild injuries	2,443	2.8	1,367	0.3	19	0.2089
Injured* but not hospitalized	39,410	44.8	48,741	9.2	858	9.4338
No apparent injuries*	41,005	46.6	462,344	86.9	7,037	77.372
Unknown	1,808	2.1	19,158	3.6	1,173	12.897
Total	87,902	100.0	532,098	100.0	9,095	100.0

*According to the MVC report.

discharge dates, demographics, diagnoses, procedures, hospital charges billed, and patient disposition. As a crude check of system sensitivity, our 2001 HDD inpatient file contained 38,833 cases having a first-listed diagnosis 800-999 according to the—a rate of 957 per 100,000 Kentucky residents. By comparison, the "1999 National Hospital Discharge Survey" (Popovic and Hall, 2001) reported a rate of 931 per 100,000 U.S. residents.

Data Linkage and Case Selection

The MVC and HDD files for the years 2000 and 2001 were linked using probabilistic methods that have been described in detail in the literature (Jaro, 1989). Probabilistic data linkage (PDL) matches observations on administratively unrelated data sets by comparing the values of common data elements, and calculating the probability that pairs of observations represent the same individual. Occupants whose crash records linked to a hospital inpatient record with a probability of at least 90% were considered for the purposes of this study to have been hospitalized. We linked the MVC and HDD files based on the following common variables: occupant age, gender, date of birth, injury status, position in the vehicle (driver or passenger), incident date and time, hospital code, vehicle type (car, truck, or motorcycle), and type of object first struck (fixed object or other motor vehicle). Limitations of PDL in the context of this study are discussed in the final section.

On Kentucky's crash report form, the extent of damage to a crash-involved vehicle is recorded as one of the following: no damage, very minor, minor, minor/moderate, moderate, moderate/severe, severe, very severe, other property, or unknown. The Kentucky Uniform Police Traffic Collision Reporting Manual states that, "Severe damage refers to a disabled vehicle which must be towed and is totally damaged. This includes vehicles which could be driven but would be further damaged by doing so." The manual also indicates that "Very severe damage refers to damage to the entire vehicle [with] no possibility of repair (totaled)," or to extreme damage due to water immersion, fire, explosion, and so on. We selected crash cases representing occupants of vehicles that were reported as having either "severe damage" or "very severe damage" as our population for study ($N = 87{,}902$). Of these observations, 13.6% were excluded from the analysis due to missing values on either the outcome variable or one or more of the covariates. Table III shows the distribution of missing values in our study dataset.

We used ICDMAP-90^{TM} (Johns Hopkins University and Tri-Analytics, Inc., Baltimore, MD) to assign injury severity scores IS to hospitalized occupants. IS scores range from 1 (least severe) to 75, and we grouped them, after the National Foundation for Trauma Care's Trauma Resource Network (Bishop + Associates, 1999), into the following categories: critical (>24), severe (15–24), moderate (9–14), and mild (<9). We then created an outcome variable (injury severity level) with five levels: killed; hospitalized with at least moderate injuries (ISS of critical, severe, or moderate); hospitalized with mild injuries (ISS of mild); injured according to the police report but not hospitalized; and no apparent injury according to the police report.

Table III Observations excluded due to missing values

	Total		Included		Excluded	
Injury severity level	#	%	#	%	#	%
Killed	1,281	1.5	1,228	1.6	53	0.4
Hospitalized	4,398	5.0	4,141	5.5	257	2.1
Injured* but not hospitalized	39,410	44.8	36,881	48.6	2,529	21.1
No apparent injuries*	41,005	46.6	33,650	44.3	7,355	61.3
Unknown	1,808	2.1	—	—	1,808	15.1
Total observations	87,902	100.0	75,900	100.0	12,002	100.0

*According to the MVC report.

Data Analysis

All analyses were conducted using SAS version 8.2. Ordinal logistic regression with stepwise selection was used to analyze the relationship between the injury severity level and occupant, crash, vehicle, and environmental characteristics. Covariates considered were age, gender, person type (driver or passenger), seating position, restraint use, driver suspected of DUI, ejection from vehicle (partial or complete ejection vs. no ejection), vehicle overturned, type of first impact (fixed object vs. other), collision type (head-on vs. other), fire, vehicle type, number of vehicles involved in the collision (single vs. multiple), vehicle year, collision time, roadway type, number of lanes on roadway, light condition on roadway, rural or urban crash location, and posted speed limit. These were selected based on existing crash literature (Kim et al., 1995; Johnson et al., 1996; Bedard et al., 2002).

RESULTS

The results of ordinal logistic regression with stepwise selection are summarized in Table IV. We grouped the selected factors into four categories representing characteristics of the occupant, vehicle, crash, and roadway or environment.

Occupant Risk Factors

Several occupant characteristics were associated with increased odds of a higher injury severity level when involved in a SDV crash.

Age

For every one-year increase in an SDV occupant's age, the odds of more severe injury increased by 1.013. From this we can determine that, for example, after controlling for other factors a 60-year old SDV occupant was 1.65 times as likely as a 20-year-old SDV occupant to experience a higher injury severity level.

Table IV Results of multivariate ordinal logistic regression of injury severity level ($N = 75{,}900$)

Variable	Adjusted OR	99% CI	p-value
Occupant age	1.01	1.012–1.014	<0.0001
Occupant gender			
Male	1.00	1.00–1.00	—
Female	1.62	1.56–1.68	<0.0001
Restraint use			
Restrained	1.00	1.00–1.00	—
Unrestrained	3.38	3.20–3.55	<0.0001
Driver suspected DUI			
No	1.00	1.00–1.00	—
Yes	1.43	1.31–1.55	<0.0001
Vehicle fire			
No	1.00	1.00–1.00	—
Yes	2.85	2.13–3.80	<0.0001
Occupant ejected			
No	1.00	1.00–1.00	—
Yes	6.50	5.68–7.43	<0.0001
Head-on collision			
No	1.00	1.00–1.00	—
Yes	1.93	1.82–2.05	<0.0001
Vehicle overturned			
No	1.00	1.00–1.00	—
Yes	1.45	1.33–1.57	<0.0001
Collision with fixed object			
No	1.00	1.00–1.00	—
Yes	1.35	1.29–1.41	<0.0001
Posted speed limit (kph)			
< 89	1.00	1.00–1.00	—
>=89	1.36	1.30–1.41	<0.0001
Roadway type			
State or federal	1.26	1.21–1.31	<0.0001
Other	1.00	1.00–1.00	—

Gender

Female SDV occupants were 1.6 times as likely as male SDV occupants to be more severely injured.

Restraint Use

Unrestrained SDV occupants were 3.4 times as likely as restrained SDV occupants to experience a higher injury severity level.

Ejected from Vehicle

Occupants who were ejected from their vehicles were 6.5 times as likely as those who were not ejected to be more severely injured in a SDV crash.

Driver Suspected of DUI

Occupants of SDVs with drivers who were suspected of DUI were 1.4 times as likely as other SDV occupants to be more severely injured.

Vehicle Risk Factors

Rollover

The risk of more severe injury for occupants in rollover SDV crashes was 1.4 times greater than the risk for non-rollover SDV occupants.

Fire

The risk of more severe injury for occupants of SDVs that caught fire was 2.9 times greater than the risk for other SDV occupants.

Crash Risk Factors

Head-on Collision

For SDV occupants in head-on collisions, the risk of more severe injury was 1.9 times higher than for other SDV occupants.

Collision with Fixed Object

For SDV occupants in collisions with fixed objects, the risk of more severe injury was 1.4 times higher than for other SDV occupants.

Roadway/Environmental Risk Factors

Federal/State Roadway

Occupants in SDV crashes on federal- or state-maintained roadways were 1.3 times more likely to be more severely injured than SDV occupants in crashes on other types of roadways.

Posted Speed Limit (PSL)

When the roadway's PSL was 89 kilometers per hour (kph; 55 miles per hour) or higher, the risk of more severe injury in an SDV crash was 1.4 times greater than at PSLs less than 89 kph. Considering PSL as a proxy for the actual vehicle speed, this result indicates that, other factors being equal, higher speeds produce more severe injuries.

DISCUSSION

The increased risks of death and injury associated with being unrestrained, impaired driving, and high speeds are well-documented in the crash literature. To cite some recent studies, Valent et al. (2002) reported that driver injury was strongly associated with lack of seat belt use. Smith et al. (2003) found that police-reported alcohol use doubled the odds of death or hospitalization. In an analysis of single-vehicle collisions with fixed objects taken from the Fatality Analysis Reporting System,

Table V Number and percentage of SDV occupants ejected, by injury severity level

Injury severity level	Number	Total	Percent
Killed	335	1,281	26.2
Hospitalized, moderate-to-critical injuries	224	1,955	11.5
Hospitalized, mild injuries	137	2,443	5.6
Injured* but not hospitalized	830	39,410	2.1
No apparent injuries*	46	41,005	0.1
Unknown	3	1,808	0.2
Total	1,575	87,902	1.8

*According to the MVC report.

Bedard et al. (2002) reported that the fatality odds at speeds of 111 kph (69 mph) or higher prior to or at impact were 2.64 times higher (99% CI = 1.82–3.83) than at speeds of less than 56 kph (35 mph). This study's results were in agreement with these findings.

Occupant Risk Factors

Ejection from Vehicle

Table V shows the number and percentage of SDV occupants who were ejected from their vehicles. Among the 1,281 SDV occupants in this study who were killed, 26% were ejected. The percentage ejected decreases steadily with injury severity level: among those who experienced no apparent injuries, only 0.1% were ejected.

Furthermore, there is a clear relationship between ejection and restraint use. In our sample, complete ejection happened to one in every 16 occupants of SDVs who were reported by police as unbelted, and partial ejection to one in every 65. By comparison, one in every 530 SDV occupants reported to be wearing a lap/shoulder belt was completely ejected, and the same number again were partially ejected. Or, to view it in another way, 88.7% (297 out of 335) of fatally injured, and 86% (1,345 out of 1,557) of all, complete or partially ejected occupants of SDV were unrestrained. This accords with a national study that reported the percentage unrestrained among fatally injured, ejected occupants to be 88.5% (Malliaris et al., 1996).

Interestingly, however, Malliaris also found that the considerable increase in restraint usage rates from 1982 to 1992 produced little change in ejection rates. Apparently, the occupants who contributed to the rise in the belt use rate over their study period included relatively few of those occupants involved in crashes leading to ejections. This finding, if it has continued to hold over the past decade, has implications for strategies to prevent ejections.

Older Occupants

Bedard et al. (2002) reported increased odds of death for crash-involved drivers aged 80 and older compared with those aged 40–49 years. Li et al., (2003) estimated the role of fragility (susceptibility to injury) versus excessive crash involvement in the increased fatality risk of older drivers per vehicle mile of travel, and reported that fragility appeared to be of greater importance. Morris et al. (2002) reported that the chest is the older driver body region most prone to injury in both frontal and side-impact crashes. Wang (1998), using data from the Crash Injury Research and Engineering Network (CIREN) and the National Automotive Sampling System (NASS), found that occupants aged 60 or greater were at increased risk of chest region injuries, particularly rib fractures.

Female Gender

Several studies (Bedard et al., 2002; Broyles et al., 2003; Kim, 1995; Evans, 1991) have reported an increased risk of severe injury in females as compared to males. Differences in physiology between males and females are commonly offered as one explanation. It seems also worth investigating whether gender differences in average height may expose females to more severe insults within the vehicle. Shorter drivers, for example, must sit closer to the steering wheel and air bag. In Kentucky, female occupants have lower rates of crash *involvement* than males (Qin & Singleton, 2003). However, our results as well the general literature, suggest that, other factors being equal, they are at greater risk of death or hospitalization than males when involved in certain kinds of crashes.

Vehicle Risk Factors

We found that occupants of overturned vehicles were 1.45 times more likely to be have a higher injury severity level in SDV crashes than were other occupants. Table VI shows the number and percentage of SDV occupants in rollover crashes, by injury severity level. Among uninjured SDV occupants, 3.8% were involved in rollover crashes, compared to nearly 14% of those who were killed. Ejection from the vehicle is a significant factor in deaths and hospitalizations resulting from rollover crashes. In Kentucky in 2000–2001, of the 178 occupants killed in rollover crashes, nearly 52% were completely ejected and 14% were partially ejected. Of the 347 occupants hospitalized in rollovers, 24% were completely ejected and 3% were partially ejected.

Vehicle fires were rare, occurring to only 0.5% of all SDV occupants, and 1.9% of those who were killed. Our analysis

Table VI Number and percentage of SDV occupants in overturned vehicles, by injury severity level

Injury severity level	Number	Total	Percent
Killed	178	1,281	13.9
Hospitalized, moderate-to-critical injuries	166	1,955	8.5
Hospitalized, mild-injuries	181	2,443	7.4
Injured* but not hospitalized	2,809	39,410	7.1
No apparent injuries*	1,538	41,005	3.8
Unknown	57	1,808	3.2
Total	4,929	87,902	5.6

*According to the MVC report.

Table VII Number and percentage of SDV occupants in vehicles that caught fire, by injury severity level

Injury severity level	Number	Total	Percent
Killed	24	1,281	1.9
Hospitalized, moderate-to-critical injuries	6	1,955	0.3
Hospitalized, mild injuries	6	2,443	0.2
Injured* but not hospitalized	77	39,410	0.2
No apparent injuries*	339	41,005	0.8
Unknown	15	1,808	0.8
Total	467	87,902	0.5

*According to the MVC report.

Table IX Number and percentage of SDV occupants in fixed object collisions, by injury severity level

Injury severity level	Number	Total	Percent
Killed	524	1,281	40.9
Hospitalized, moderate-to-critical injuries	771	1,955	39.4
Hospitalized, mild injuries	947	2,443	38.8
Injured* but not hospitalized	11,729	39,410	29.8
No apparent injuries*	8,733	41,005	21.3
Unknown	449	1,808	24.8
Total	23,153	87,902	26.3

*According to the MVC report.

determined that SDV occupants in vehicles that caught fire were 2.9 times more likely than other SDV occupants to have a higher injury severity level. Table VII shows the number and percentage of SDV occupants in vehicles that caught fire, by injury severity level.

Crash Risk Factors

Table VIII shows the number and percentage of SDV occupants in head-on collisions with another motor vehicle, by injury severity level. Head-on collisions were relatively uncommon among uninjured SDV occupants, occurring in only 8.4% of cases. Among the injured their incidence increased: 23% of those killed and 20% of those hospitalized were involved in head-on collisions.

Table IX shows the number and percentage of SDV occupants in fixed object collisions, by injury severity level. Among SDV occupants, fixed object collisions were more than twice as common as head-on collisions. Approximately one in five uninjured SDV occupants were involved in fixed object collisions, but the percentage nearly doubled among those killed or hospitalized. That is, nearly 41% of SDV occupants who were hospitalized or killed were involved in fixed object collisions.

Roadway and Environmental Risk Factors

Table X shows the number and percentage of SDV occupants that crashed on a state- or federally maintained roadway, by injury severity level. Nearly seven out of every ten SDV occupants crashed on such a roadway. These roads often have only two lanes, a narrow or non-existent shoulder, and/or hazards such as trees and utility poles located near the roadside. It seems clear that injury prevention and traffic safety programs in Kentucky need to focus on mitigating, and increasing occupants' awareness of, the risks of driving on these roadways.

Comparison with State Strategic Plans and Programs

Many of the risk factors identified by this analysis are explicitly (restraint use, DUI, head-on collisions, and speeding) or implicitly (ejection, rollover crashes, and fixed object crashes) addressed in the strategic plans, and targeted by the safety programs, of state organizations involved in highway safety and injury prevention in Kentucky (Kentucky Cabinet for Health Services, 2000; Kentucky State Police, 2003; Kentucky Transportation Cabinet, 2002). This study provides additional evidence for their importance, and confirms that their mitigation will reduce not only fatalities but also hospitalizations, of which there were at least four for every fatality in Kentucky in 2000 (Qin & Singleton, 2000). (Utah's Crash Outcome Data Evaluation System (CODES) reported a similar hospitalization-to-fatality ratio for MVC's in the "2001 Utah Crash Summary" (Utah CODES, 2002)). As well, increased risks were identified for older occupants and female occupants that, to our knowledge, are not currently addressed in any state plans or programs. An opportunity exists to clarify the nature of these risks through further studies, which might lead to the identification of countermeasures specific to these populations. Finally, in-depth analyses based on these results may provide insights into effective ways to address all of the identified risk factors.

Table VIII Number and percent of SDV occupants in head-on collisions, by injury severity level

Injury severity level	Number	Total	Percent
Killed	299	1,281	23.3
Hospitalized, moderate-to-critical injuries	426	1,955	21.8
Hospitalized, mild injuries	465	2,443	19.0
Injured* but not hospitalized	5,312	39,410	13.5
No apparent injuries*	3,455	41,005	8.4
Unknown	169	1,808	9.3
Total	10,126	87,902	11.5

*According to the MVC report.

Table X Number and percentage of SDV occupants in crashes on state- or federally maintained roadways, by injury severity level

Injury severity level	Number	Total	Percent
Killed	996	1,281	77.8
Hospitalized, moderate-to-critical injuries	1,470	1,955	75.2
Hospitalized, mild injuries	1,826	2,443	74.7
Injured* but not hospitalized	28,052	39,410	71.2
No apparent injuries*	27,090	41,005	66.1
Unknown	1,085	1,808	60.0
Total	60,519	87,902	68.8

*According to the MVC report.

Limitations

Misclassification of Seat Belt Use

Police-reported restraint use for the front seat occupants selected for this study was approximately 90%. However, the 2000 Safety Belt Usage Survey in Kentucky, an observational study conducted by the Kentucky Transportation Center (KTC), reported a rate of 60% for front seat occupants (KTC, 2001). Overstatement of restraint usage on collision reports would result in an underestimate of the protective effect of wearing a restraint.

Missing Data

Nearly 14% of crash observations representing SDV occupants were excluded from the regression due to missing values on either the outcome variable or one or more of the covariates. This could bias the adjusted odds ratios.

Data Linkage

Probabilistic data linkage is subject to both Type I (matching pairs that are not, in fact, matches) and Type II (failing to match pairs that are, in fact, matches). The Type I error can be controlled by specifying a cutoff probability for accepting matches, which was set at 90% for this study. The Type II error is more difficult to estimate with confidence. It is known that occupant date of birth, a key linkage variable, is not recorded for passengers thought by police to be uninjured. As a result, if in fact such persons were later hospitalized, their MVC and HDD records are less likely to be matched by data linkage than those for occupants who were reported by police as injured. Also, in some areas of the state, an unknown percentage of severely injured crash-involved occupants are transported to trauma centers outside the state for treatment. Such persons will not be accounted for in Kentucky's HDD files. The result is that these occupants will be misclassified in the linkage process as non-hospitalized when they were, in fact, hospitalized.

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