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Motorcycle Helmet Use and Head and Facial Injuries

Crash Outcomes in CODES-Linked Data

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16. Abstract This report examines the relationship between motorcycle helmet use and motorcycle crash outcomes in terms of injury types, hospital charges, and other variables employing data from the Crash Outcome Data Evaluation System (CODES), a program facilitated by the National Highway Traffic Safety Administration. Helmeted motorcyclists were less likely to experience facial and head injuries compared to unhelmeted motorcyclists. Helmeted motorcyclists were significantly less likely to experience a traumatic brain injury. TBIs are of particular concern in our study. TBI was associated with significantly higher hospital charges. Additionally, motorcyclists with TBI were much less likely to be discharged home and more likely to require rehabilitation or to be discharged to a long-term care facility following their hospitalization. Both of these destinations are likely to result in costs and burdens for the injured motorcyclists beyond the scope of this study's data. Finally, motorcyclists involved in alcohol- or drug-related crashes and speed-related crashes had higher odds of experiencing poor outcomes.			
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EXECUTIVE SUMMARY

This report examines the relationship between motorcycle helmet use and motorcycle crash outcomes in terms of injury types, hospital charges, and other variables employing data from the Crash Outcome Data Evaluation System (CODES), a program facilitated by the National Highway Traffic Safety Administration. States that participate in CODES perform probabilistic linkage between State crash data and medical outcome data, and use the resulting data for analyses of crash outcomes in support of highway safety.

This study represents the first time since 1996 that CODES States have submitted data for a combined analysis and the first time that as many as 18 States contributing 48 State-years of linked data have been included in such a study. The analysis was carried out under NHTSA sponsorship by the CODES Technical Resource Center established at the University of Utah.

Eighteen States in the CODES Data Network submitted the data used in this study. The combined data set contains information on 104,472 motorcyclists involved in crashes in these 18 States during the years 2003, 2004, and 2005. Advanced statistical methods such as multiple imputation were used to analyze the data.

In the data set, 57 percent of motorcyclists were helmeted at the time of the crashes and 43 percent were non-helmeted. For both groups, about 40 percent of motorcyclists were treated at hospitals or died following the crashes. However, 6.6 percent of unhelmeted motorcyclists suffered a moderate to severe head or facial injury compared to 5.1 percent of helmeted motorcyclists. Moderate to severe injuries were defined as a Maximum Abbreviated Injury Severity (MAIS) scale of level 2 or higher

Fifteen percent of hospital-treated helmeted motorcyclists suffered traumatic brain injury (TBI) compared to 21 percent of hospital-treated unhelmeted motorcyclists. TBI severity varied by helmet use. Almost 9 percent of unhelmeted and 7 percent of helmeted hospital-treated motorcyclists received minor to moderate TBI. More than 7 percent of unhelmeted and 4.7 percent of hospital-treated helmeted motorcyclists sustained severe TBI.

Median charges for hospitalized motorcyclists who survived to discharge were 13 times higher for those incurring a TBI compared to those who did not sustain a TBI ($31,979 versus $2,461). Over 85 percent of hospital-treated motorcyclists without a TBI were discharged home, compared to 56 percent of motorcyclists with severe TBI. Motorcyclists admitted to the hospital with TBI were more likely to die, be discharged to rehab, or transferred to a long-term care facility. While 17 percent of all hospital-admitted motorcyclists had TBI, they account for 54 percent of all admitted riders who did not survive.

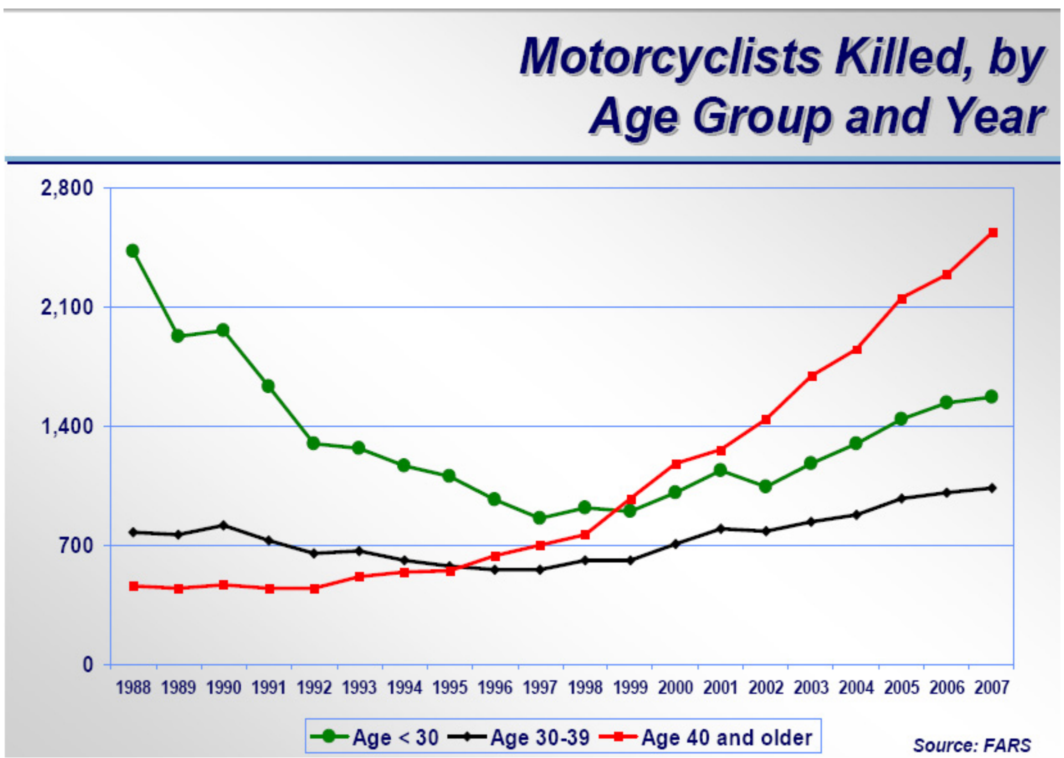
A logistic regression analysis that accounted for clustering of motorcyclists within States indicated that helmets significantly reduced the odds of sustaining head or facial injury, TBI, and dying in the hospital.

The use of standardized data submissions from multiple CODES States proved to be feasible and productive. Methods initiated for this study can be further developed for future specialized studies of crash outcomes using pooled CODES data.

BACKGROUND AND SIGNIFICANCE

During the past decade in the United States, there has been a dramatic rise in fatality rates for motorcyclists (Figure 1). Data from the National Center for Statistics and Analysis (NCSA) of the National Highway Traffic Safety Administration (NHTSA, 2008) reveal that, as of 2007, fatalities had increased for the 10th year in a row, an increase of 144 percent compared to 1997. While there has also been an increase in motorcycle registrations during this period, the rate of increase in fatalities has been greater than that of registrations (NHTSA, 2005).

Figure 1. Motorcyclist Fatalities by Age Group and Year



Source: NHTSA, NCSA, FARS, 2008.

This increase has been especially marked among riders 40 and older, who now constitute approximately half of all deaths (NHTSA, 2008). In 1997, this older group accounted for 33 percent of rider deaths, but had grown to 49 percent by 2007. Although fatalities increased in all age groups, the largest increase has been in the group of riders over the age of 49; thus the mean age of fatally injured motorcyclists has increased from 29.3 in 1990 to 37.9 in 2002. The overall percentage of older riders involved in crashes has increased. While younger people are still riding motorcycles, they now constitute a smaller proportion of fatalities.

One potential intervention for preventing injuries as a result of motorcycle crashes are motorcycle helmets. In a study of fatally injured riders, Sarkar et al. (1995) noted that 36 percent of deaths among helmeted riders were due to trunk injuries, as compared to 19 percent among the non-helmeted. Similar findings were noted in a California study of fatalities before and after a mandatory helmet law (Kraus et al., 1994). Also, according to a study conducted at the National Study Center for Trauma and Emergency medical Systems (NSC), the number of motorcycle fatalities decreased by 37 percent after enactment of the Maryland mandatory motorcycle helmet law. Additionally, helmeted motorcyclists were significantly less likely to suffer TBI than were those unhelmeted motorcyclists (Auman et al., 2002).

Despite the burden of injury associated with motorcycle crashes, at least 6 States have repealed or weakened laws that require the use of motorcycle helmets since 1995. Also, 3 States don't have a helmet law of any kind. The weakening of helmet laws in States has corresponded to a decrease in motorcycle helmet use (NHTSA, 2008). Furthermore, few comprehensive studies have been conducted to examine the types of injuries sustained by hospitalized motorcyclists; instead, most studies have focused primarily on fatalities, comparing riders with and without helmets, and trends in head injury following repeal or passage of motorcycle helmet laws. The Fatality Analysis Reporting System (FARS) data does include information on motorcyclist fatalities, but injury data is limited to the KABCO scale and only pertain to fatal crashes. The National Automotive Sampling System (NASS) General Estimates System, a large NHTSA database consisting of a sample of crashes nationwide, includes only police-observed injury information, and the NASS Crashworthiness Data System, which conducts detailed crash investigations, does not include data on motorcyclists.

Although the focus of this study is on head and facial injuries, several studies have addressed the high rates of lower-extremity, chest, and abdominal injuries following motorcycle crashes. Kraus et al. (2002), in a study of the incidence of thoracic and abdominal injuries among injured motorcyclists in California, reported that multiple intra-thoracic and intra-abdominal injuries were common, and that the number of rib fractures and whether they were bilateral was strongly associated with serious injuries to the thoracic and abdominal organs. In a British study of injured motorcyclists, Ankarath et al. (2002) showed that thoracic and abdominal trauma as well as pelvic ring fractures associated with long bone injuries were the major contributors to reduced survival following head injury.

In the original Report to Congress (1996) on the Benefits of Safety Belts and Motorcycle Helmets, data on motorcycle crashes from 7 States were compiled as part of the CODES. That study employed probabilistic linkage techniques to combine data gathered from police crash reports, emergency medical services, hospital emergency departments, and hospital discharge files to more fully describe motorcycle crash events and their outcomes. Among other findings, that report revealed (1) that hospital charges for motorcyclists who were unhelmeted were on average 8 percent higher than for those who were helmeted; and (2) that the use of a motorcycle helmet was 67 percent effective in the reduction of brain injuries. However, due to large amounts of missing data, these estimates were not adjusted for other potential predictors of injury severity.

This report further explores the relationship between helmet use and hospital outcomes. The main outcomes of interest in this study are those that motorcycle helmets could potentially prevent, namely head, facial, and traumatic brain injuries. This study further improves upon the earlier CODES analysis by expanding the number of States included in the analysis from 6 to 18. Furthermore, the use of statistical imputation to estimate missing values allows for the inclusion of all crash records into a multivariable model, thus producing estimates that have been adjusted for other crash factors.

A note on the terminology used in the report:
motorcycle rider (operator) *- the person operating or in control of the motorcycle*
motorcycle passenger *- the person seated behind the rider and not in control of the motorcycle*
motorcyclist *– a collective term used for any combined reference to the rider and passenger of the motorcycle*

METHODOLOGY

This study represents the first time since 1996 that CODES States have submitted data for a combined analysis and the first time that as many as 18 States contributing 48 State-years of linked data have been included in such a study. The analysis was carried out under NHTSA sponsorship by the CODES Technical Resource Center (TRC) established at the University of Utah and CODES Program Resource Center (PRC) established at the University of Maryland.

CODES Data Network
The CODES Data Network was used to generate data in order to perform an assessment of the medical outcomes of motorcycle crashes. The CODES Data Network consists of 19 States that work in cooperation with NHTSA to probabilistically link State motor vehicle crash data to statewide medical care systems such as EMS, emergency department admissions, and inpatient hospital discharges.

Individual States are responsible for obtaining the necessary files to participate in CODES. These include a minimum of the State motor vehicle crash and hospital inpatient discharge databases. Additionally, several States obtain emergency department and emergency medical services databases. CODES Data Network grantees are also responsible for conducting probabilistic linkages of their data using CODES 2000 software. Almost always these databases are owned by more than one State agency and the data's use is governed by the State's CODES Board of Directors, an entity created within the State that is responsible for ensuring that State data are available for linkage and developing the policies that control release of the linked data in compliance with State privacy legislation/regulations. An explanation of CODES methodologies and frequently asked questions are included in Appendices D and E.

Following approval from all 19 State boards of directors, States were requested to submit person-level linked data for all motorcyclists in police reported crashes for the years 2003 to 2005. All 19 States in the CODES Data Network were able to respond to this request. One State, Illinois, is not included due to an inordinate amount of missing data on motorcycle helmet use. Fourteen States were able to provide data for all three years, while 2 States provided data from two years, and 2 States provided a single year of data (Table 1).

Table 1. Data Years by State

State	2003	2004	2005
Connecticut	X	X	X
Delaware	X	X	X
Georgia		X	
Indiana	X	X	X
Iowa	X	X	X
Kentucky	X	X	X
Maine			X
Maryland	X	X	X
Massachusetts	X	X	X
Minnesota		X	X
Missouri	X	X	X
Nebraska	X	X	X
New York	X	X	X
Ohio	X	X	X
Rhode Island	X	X	
South Carolina	X	X	X
Utah	X	X	X
Virginia	X	X	X

Source: CODES, 2003-2005.

Combination of State Data

An inherent difficulty in combining crash data from multiple States is that police crash reports differ from State to State. To overcome differing definitions of data elements, a set of standardized variables was created (Appendix A). Each State was responsible for determining the most appropriate method of creating each standardized variable from its crash report and hospital data sets. States electronically submitted their standardized data to the CODES Technical Recourse Center at the University of Utah, which provides assistance to the CODES program under a cooperative agreement with NHTSA. Additionally, States submitted data dictionaries describing how State-specific data elements were used to create the standardized variables. CODES TRC personnel reviewed the data dictionaries and consulted with each State to ensure an accurate mapping from the State crash report.

Due to variability in State crash reports, some States were unable to create all of the standardized variables. Appendix B shows variable availability by State. While most variables were captured by all States, such as time and month of crash, some variables were much less frequently available. These variables include whether or not the motorcycle rider (operator) was licensed or had an endorsement for motorcycles and whether the crash occurred in a rural or urban location. VIN information was also sparsely captured from State to State and therefore will not be included in this report. Similarly, motorcycle licensure/endorsement is excluded from this analysis. Crash reports in the various CODES States are not detailed enough to allow a comparison of the effectiveness between different types of helmets, i.e., U.S. Department of Transportation (DOT) approved versus not DOT-approved, or face shield versus no face shield. Finally, all hospital charges have been adjusted to 2005 dollars.

Injury Severity Measures

This report makes use of several measures of injury severity. Among the foremost are KABCO and AIS. "KABCO" is an acronym for the injury severity field on most crash reports. The levels of KABCO are roughly defined as follows: K = fatal injury, A = severe or incapacitating injury, B = non-incapacitating injury, C = possible injury, O = not injured. KABCO is frequently used when analyzing motor vehicle crashes since it is available directly from the crash report and does not require a linkage to any other sources. However KABCO is considered unreliable since it is often assessed at the scene of the crash by police who are trained in public safety and not necessarily in determining injury severity (Farmer, 2003).

The Abbreviated Injury Severity Scale (AIS) is an anatomical scoring system based on hospital-collected information. AIS assigns scores on a scale from 0 to 6: 0 = no injury, 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = unsurvivable. In addition to determining the severity of an injury, AIS scores also designate the injured body region. To determine the most severe injury sustained, the Maximum AIS (MAIS) is taken to be the highest AIS score from the nine body regions (AAAM, 1990).

Ideally, AIS scores are calculated by a trained medical coder reviewing the patient chart. In CODES, however, States only have access to billing data. This data contains International Classification of Disease 9th Revision Clinical Modification (ICD-9-CM) codes that translate injuries and other diseases into a series of billing codes. For this reason, the computer program ICDMap-90 (John Hopkins University and Tri-Analytics, Inc., Baltimore, MD) was used to convert ICD-9-CM codes to AIS and MAIS values. Grantees without access to this software submitted their linked crash ICD-9-CM codes to the CODES PRC. ICDMap-90 does have some inherent weaknesses (Cryer, 2006; Meredith et al., 2002). In particular, it is possible for certain ICD-9-CM codes to map to more than one AIS code and therefore to different levels of severity. While this may lead to overestimation of injury severity in some instances, it does keep the estimates consistent from State to State. Estimated AIS and MAIS from ICD-9-CM codes were preferred over other severity scoring systems, such as Injury Severity Score (ISS) or Survivability Risk Ratios (SRR), due to AIS and MAIS being captured in other NHTSA data systems, most notably the NASS. Once the MAIS variables were generated, States were responsible for incorporating the results back into their linked State data sets.

Throughout the report we will compare injury severity as captured by KABCO and MAIS as a method of demonstrating the added value CODES-linked data can provide beyond an analysis of the crash file alone.

Given the focus of the report on motorcycle helmets, head injuries are of particular concern. One of the most severe and costly injuries a person can sustain is a traumatic brain injury. TBI may lead to a lifetime of disability and result in significant rehabilitation and long-term care costs. For this report we used the Barell Matrix definition of TBI (Barell et al., 2002). The Barell Matrix uses ICD-9-CM codes to categorize TBI into three groups, as follows:

1. Severe TBI: consists of injuries with evidence of an intracranial injury or moderate to prolonged loss of consciousness.
2. Moderate TBI: consists of injuries with no evidence of intracranial injury and loss of consciousness of less than one hour or an unknown or undocumented loss of consciousness.
3. Mild TBI: consists of head injuries with no intracranial injury and no loss of consciousness.

Additionally, we present a fourth category, "potential TBI," which was defined to be motorcyclists not already grouped into one of the other three TBI categories and having an ICD-9-CM Code of 959.01 (unspecified head injury) (NCIPC, 2003). State CODES personnel were responsible for mapping the ICD-9-CM codes in their hospital files to the Barell Matrix definitions. Individual ICD-9-CM codes were not available in the data submitted to NHTSA and the CODES TRC and are therefore not presented in this report.

Statistical Analysis

Imputation

Probabilistic linkage methodology incorporates multiple imputation to accurately account for the uncertainty associated with unavoidable missing values and sometimes inaccurately collected data inherent with large administrative data sets. The linkage process involves generating the probability distribution of matches and then sampling matches to produce multiply imputed data sets. Following probabilistic linkage, multiple imputation is used to estimate missing values for analysis. Since not all variables were available in each State, State-specific missing value imputation models were developed. Five imputed data sets were created for each State. Following imputation, all State data were combined into a single data set for analysis.

Although imputation of missing values is done at the person level, some variables describe vehicle or crash characteristics. As a result, variables that might be expected to be the same for all people on a given motorcycle or in a specific crash may differ as a result of the missing value imputation. While this is not an unexpected result of multiple imputation, it does introduce difficulties when aggregating variables to the vehicle or crash level. To correctly total the number of motorcycles and crashes in the data set, imputed values for vehicle and crash characteristics were weighted according to the number of motorcyclists for vehicle and crash level analyses. For example, consider one motorcycle with two motorcyclists and a missing value for the variable "alcohol or drug involvement." It is possible that during imputation one motorcyclist was imputed to "Yes" while the other imputed to "No." Under our weighting scheme each motorcyclist would contribute half of a count to the variable in an analysis of alcohol and drug involvement. This method was employed for all vehicle and crash level variables. Although this method potentially divides a single motorcycle or crash into more than one category, it allows us to analyze accurate counts without arbitrary decisions regarding which imputed value is most correct and thereby potentially introducing bias.

Descriptive Analysis
For this study, univariate statistics are used to describe crash, motorcycle, driver, and motorcyclist characteristics within the CODES States. Two-way associations between helmet use and hospital outcomes, such as injury severity, body area injured, receiving a TBI, and median hospital charges, are described using contingency tables and bar charts.

Multivariable Modeling
To estimate associations between motorcycle helmet use and head/facial injuries, multivariable logistic regression models are employed. Generalized estimating equations (GEE) with exchangeable correlation structures are used to account for the clustering of motorcyclists within States. The specific outcomes considered using these models are whether the motorcyclist received a facial injury; whether the motorcyclist received a head injury; whether the motorcyclist received a moderate to severe head or facial injury (defined as MAIS > 2); and whether the motorcyclist received a TBI.

Several explanatory variables were initially included in the multivariable models. These variables were: gender, age, speed limit, whether the crash was speed-related, alcohol and/or drug involvement, whether the crash was intersection-related, helmet use, motorcyclist type: rider (operator) versus passenger, single-vehicle versus multi-vehicle crash, whether the crash occurred at night (9 p.m. to 5:59 a.m.), and urban versus rural location of the crash. Interactions were considered between helmet use and each of: single vehicle, alcohol/drug involvement, and urban/rural location. Variables were selected based on their availability within the CODES Network and inclusion in the CODES Report to Congress (1996).

After initial models were analyzed, interactions between helmet use and both drug/alcohol involvement and urban/rural were removed because they were not statistically significant in any model. Urban versus rural location also failed to achieve statistical significance in any model and was removed, thus allowing the incorporation of States that were unable to calculate this variable (Iowa, Ohio, and South Carolina).

Software
All analyses were performed in SAS 9.1.3. Multivariable logistic regression GEEs were computed using PROC GENMOD; PROC MIANALYZE was used to combine results across imputations.

RESULTS

The combined data set contained information on 104,472 motorcyclists. There were 93,527 motorcycles involved in 89,086 crashes in 18 States during the years 2003-2005. The median number of riders contributed per State was 5,144. The most any State contributed to the analysis was 15,910 riders and the least was 737.

Data Set Description
The next three sections are used to provide the reader with a description of the combined CODES data set and not intended as national estimates of motorcycle crash and motorcyclist characteristics.

Crash Characteristics
Table 2 displays the characteristics of the 89,086 crashes. Over two-thirds (67.6%) of all motorcycle crashes occurred between noon and 8:59 p.m. Motorcycle crashes were more likely to occur in summer months (June, July, and August). Slightly more crashes involved multiple vehicles (56.4%) compared to just the motorcycle (43.6%). Sixty-eight percent of crashes with a known urban/rural designation occurred in an urban area and only 38 percent of crashes occurred at intersections.

Table 2. Motorcycle Crash Characteristics

Variable	Level	Count	Percent
Crash Time	0:00 – 2:59	4,460	5.0%
	3:00 – 5:59	1,771	2.0%
	6:00 – 8:59	4,663	5.2%
	9:00 – 11:59	8,433	9.5%
	12:00 – 14:59	17,287	19.4%
	15:00 – 17:59	24,248	27.2%
	18:00 – 20:59	18,717	21.0%
	21:00 – 23:59	9,507	10.7%
Crash Month	January	969	1.1%
	February	1,481	1.7%
	March	3,764	4.2%
	April	7,992	9.0%
	May	11,323	12.7%
	June	12,877	14.5%
	July	13,507	15.2%
	August	12,636	14.2%
	September	11,690	13.1%
	October	7,655	8.6%
	November	3,774	4.2%
	December	1,418	1.6%
Crash Type	Single-Vehicle	38,831	43.6%
	Multiple Vehicle	50,255	56.4%
Location	Rural	22,692	32.1%*
	Urban	48,107	67.9%*
	Unknown Location	18,287	
Intersection-Related	Not Intersection	55,043	61.8%
	Intersection-Related	34,043	38.2%

*Percentages are calculated based on crashes with known locations.

Source: CODES, 2003-2005.

Vehicle and Operator Characteristics
Characteristics of the motorcycles and drivers are displayed in Tables 3 and 4. Over 90 percent of motorcycles were full size. The most common posted speed limits for motorcyclists were ≥ 55 mph and 35 mph. Of the 93,527 motorcycle riders (operators) involved in crashes, 16.1 percent had speed-related crashes and 7.6 percent had alcohol or drug involvement.

Table 3. Motorcycle Characteristics

Variable	Level	Count	Percent
Motorcyclist Type	Full Size	78,015	93.4%*
	Not Full Size	3,925	4.7%*
	MC by VIN	1,628	1.9%*
	MC Type Unknown	9,959	
Posted Speed Limit	<= 20 mph	1,866	2.5%*
	25 mph	10,106	13.5%*
	30 mph	8,797	11.8%*
	35 mph	15,345	20.5%*
	40 mph	6,340	8.5%*
	45 mph	9,963	13.3%*
	50 mph	2,931	3.9%*
	>= 55 mph	19,387	25.9%*
	SL Unknown	18,792	
Speed-Related Crash	Not Speed-Related	78,433	83.9%*
	Speed-Related	15,094	16.1%*
Drug/Alcohol Involvement	D/A Involved	6,637	7.6%*
	D/A Not Involved	80,813	92.4%*
	D/A Unknown	6,077	

*Percentages are calculated using cases with known values.
Source: CODES, 2003-2005.

Motorcyclist Characteristics
Of the 104,472 motorcyclists in our study, the majority, 92,582 (89%), were identified as being the motorcycle rider (operator) while the remaining 11,890 (11%) were passengers (Table 4). The majority of motorcyclists were male (85%). More motorcyclists were helmeted at the time of the crash than those that were unhelmeted (57 percent versus 43%).

Table 4. Motorcyclist Characteristics

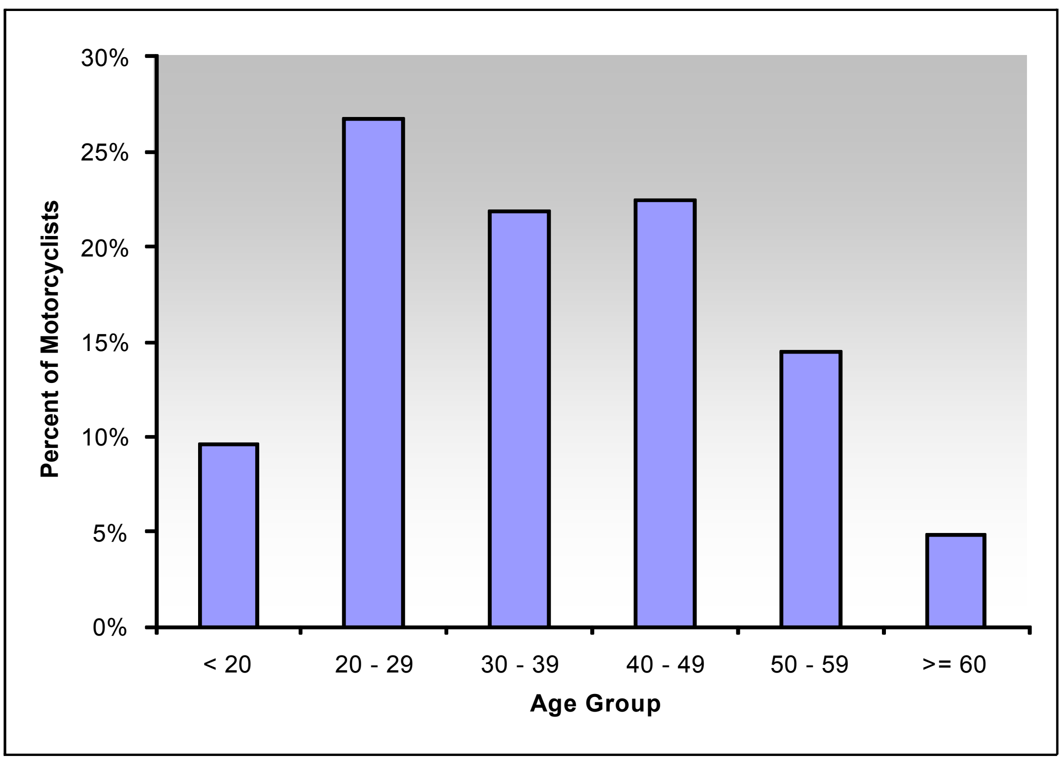
Variable	Level	Count	Percent
Motorcyclist Type	Passenger	11,890	11.4%
	Rider (Operator)*	92,582	88.6%
Gender	Male	88,267	84.5%
	Female	16,205	15.5%
Safety Equipment	Helmet Worn	59,299	56.8%
	Helmet Not Worn	45,173	43.2%

*Despite there being 93,527 motorcycles in the data set only 92,582 motorcyclists were coded as being operators. This discrepancy was present in the data submitted by States and not introduced through linkage or imputation.

Source: CODES, 2003-2005.

The age distribution of motorcyclists in our study is displayed in Figure 2. The largest age group (27%) was motorcyclists in their 20's, followed by motorcyclists between 40 to 49 years old (22%).

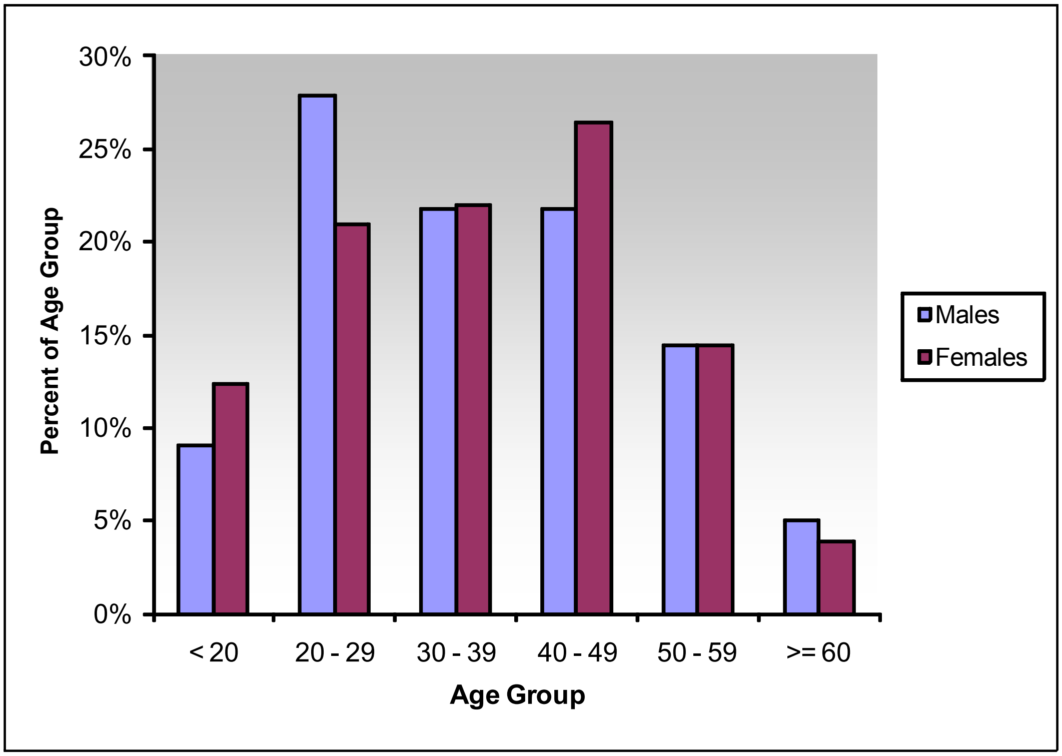
Figure 2. Motorcyclist Age Group



Source: CODES, 2003-2005.

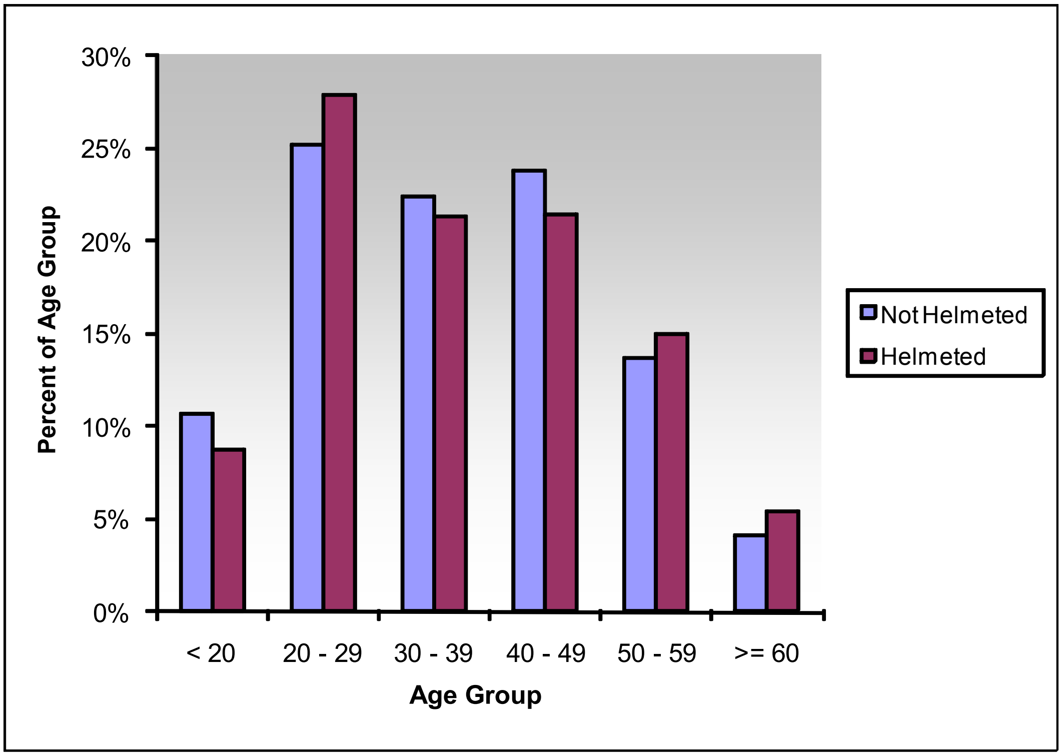
While male motorcyclists were most likely to be in their early 20's, female motorcyclists were more likely to be between 40 and 49 years old (Figure 3). Helmet use also differed by age (Figure 4). Helmeted motorcyclists were more likely to be younger compared to unhelmeted motorcyclists. The difference in helmet usage by age may be the result of age-specific helmet laws in some of the CODES States. Helmet use laws by State are shown in Appendix C.

Figure 3. Motorcyclist Age by Gender



Source: CODES, 2003-2005.

Figure 4. Motorcyclists Age by Helmet Use



Source: CODES, 2003-2005.

Injury Outcomes

Motorcyclists' injury outcomes are displayed in Table 5. Injury severity for this project was defined using both KABCO from the crash report and linkage outcomes. The KABCO scale is the traditional injury severity scale used on police crash reports and was explained above on page 14.

Based on police reports, which code an injury as fatal if the death occurs within 30 days of the crash, a total of 3,673 (4%) motorcyclists died following their crash. Only 17 percent of motorcyclists were coded as having no injuries.

The linked CODES data was used to determine the highest level of medical care that a motorcyclist received following the crash. This variable is likely related to the motorcyclist's KABCO value but is calculated based solely on the probabilistic linkage results. The results of the State linkages show that while nearly 60 percent of motorcyclists did not link to a hospital record, 27 percent linked to the emergency department, and 15 percent were admitted to the hospital. It should be noted that 3 States (Kentucky, Rhode Island, and Virginia) did not submit ED data; therefore the number of motorcyclists treated at the ED is likely an underestimate.

Table 5. Crash Outcomes

KABCO*	K	3,673	3.5%
	A	23,750	22.7%
	B	38,836	37.2%
	C	20,169	19.3%
	O	18,042	17.3%
Highest Level of Care	None	61,049	58.4%
	ED/Outpatient	28,075	26.9%
	Inpatient	15,348	14.7%

*Two motorcyclists were coded as "Died before crash" and are therefore not displayed in the KABCO portion of Table 5.

Source: CODES, 2003-2005.

As in earlier CODES reports, an aggregate injury severity variable was created based on a combination of KABCO and the highest level of care derived from the linkage. Based on these two variables motorcyclists were categorized at one of the five injury levels: Killed – as reported on the police crash report or the discharge status from the hospital file; Admitted to the hospital – crash record linked to a hospital discharge record; Treated at the ED – crash record linked to an emergency department record; Injured – KABCO value of A, B, or C but did not link to a hospital record; and Not Injured – KABCO value of O and did not link to a hospital record. The results are displayed in Table 6. Sixteen percent of all motorcyclists were not injured. Using the definition of death within 30 days of the crash, an additional 63 fatalities not coded as a "K" on the police crash report were identified based on the discharge code from a linked hospital record. While not counted as a fatality in Table 6, an additional 14 fatalities occurred in the hospital more than 30 days post-crash.

Table 6. Injury Status

Injury Status	Count	Percent
Not Injured	16,504	15.8%
Injured but Not Linked	42,060	40.3%
Treated at ED	27,375	26.2%
Hospitalized	14,796	14.1%
Killed	3,737	3.6%

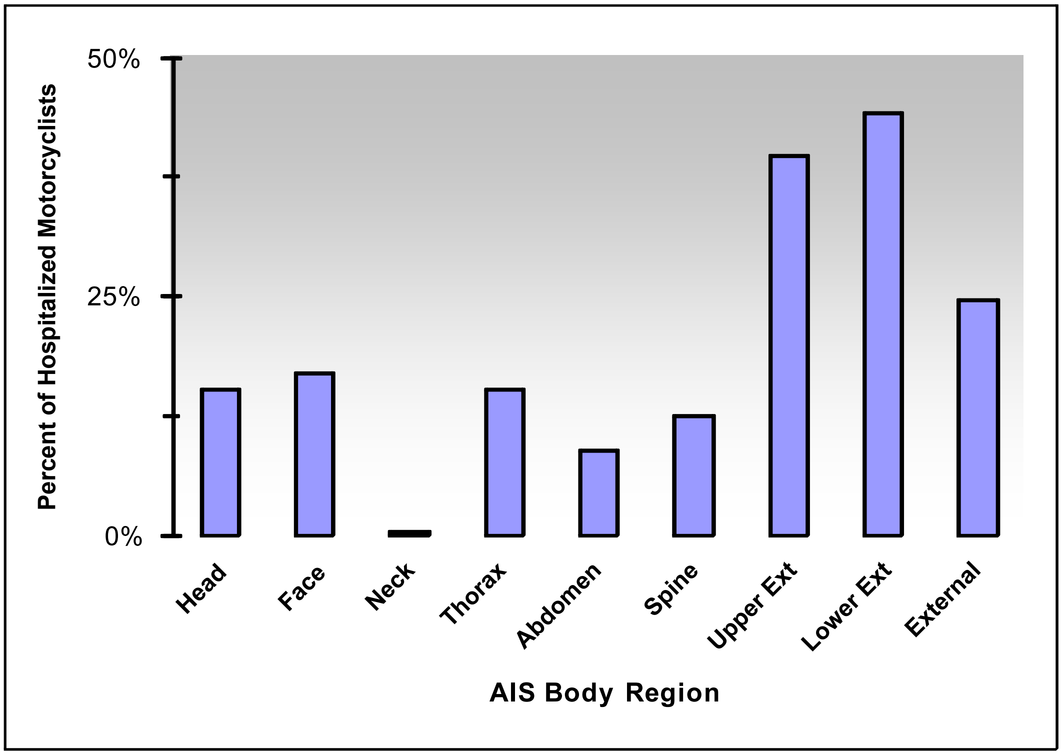
Source: CODES, 2003-2005.

Hospitalized Motorcyclists

With the linkage of crash reports to hospital records, CODES data can be used to analyze the relationship between crash factors and medical outcomes. For the remainder of this section we limit our analysis to the 43,423 motorcyclists who linked to a hospital (emergency department or inpatient) record. Motorcyclists who died at the scene and were not transported have been excluded.

Figure 5 shows the AIS body region for all hospitalized motorcyclists. Note that since motorcyclists can have multiple injuries, one motorcyclist may appear multiple times in this graph.

Figure 5. AIS Injured Body Region*



*Since a motorcyclist can injure more than one body region, the percentages in Figure 5 add up to more than 100 percent.

Source: CODES, 2003-2005.

The majority of hospitalized motorcyclists' injuries were to the upper and lower extremities. Also, more than 15 percent of motorcyclists sustained head injuries and close to 17 percent sustained facial injuries. There were a total of 100 neck injuries.

The MAIS for all hospital-treated motorcyclists is displayed in Table 7. The majority of injuries were classified as minor (18,740, 43%) or moderate (13,755, 32%). There were 31 (0.1%) motorcyclists with injuries classified as maximum and over 700 (2%) more motorcyclists suffered critical injuries.

Table 7. Maximum Abbreviated Injury Scale (MAIS)

MAIS	Count	Percent
None	2,070	4.8%
Minor	18,740	43.2%
Moderate	13,755	31.7%
Serious	6,000	13.8%
Severe	2,065	4.8%
Critical	762	1.8%
Maximum	31	0.1%

Source: CODES, 2003-2005.

Both head/face MAIS and TBI severity are displayed in Table 8. Since, the definition of TBI contains ICD-9-CM codes corresponding to the head and face MAIS body regions we have created a combined Head/Face body region and the defined the MAIS to be the maximum AIS of the head and face regions.

A total of 7,523 motorcyclists received TBI as a result of their crashes. These injuries were categorized as severe (2,522, or 34%), moderate (3,217, or 43%), minor (161, or 2.1%), and potential (1,623, or 22%). For the remainder of this section TBI categories mild and moderate will be combined, due to the relatively few cases of minor TBI.

Table 8. Head/Face and Traumatic Brain Injuries for Hospital-Treated Motorcyclists

MAIS Head/Face	None	31,960	73.6%
	Minor	5,585	12.9%
	Moderate	3,062	7.1%
	Serious	931	2.1%
	Severe	1,299	3.0%
	Critical	584	1.3%
	Maximum	2	< 0.1%
TBI Severity	None	35,900	82.7%
	Potential	1,623	3.7%
	Mild	161	0.4%
	Moderate	3,217	7.4%
	Severe	2,522	5.8%

Source: CODES, 2003-2005.

To determine the financial impact of head/facial injuries, we compared the median hospital charges for motorcyclists stratified by severity of head/facial injury and TBI (Table 9). Median hospital charges and their confidence intervals were calculated using the statistical methodology developed in Strashny (2009). Since only two motorcyclists were categorized as having a maximum head/facial injury the maximum and critical injury groups were combined. Motorcyclists who die shortly after arriving at the hospital may incur smaller charges than their injury severity would indicate, therefore the results presented in Table 9 exclude the 924 motorcyclists discharged dead from the hospital.

Table 9. Median Hospital Charges by MAIS Head/Facial and Traumatic Brain Injury Severity*

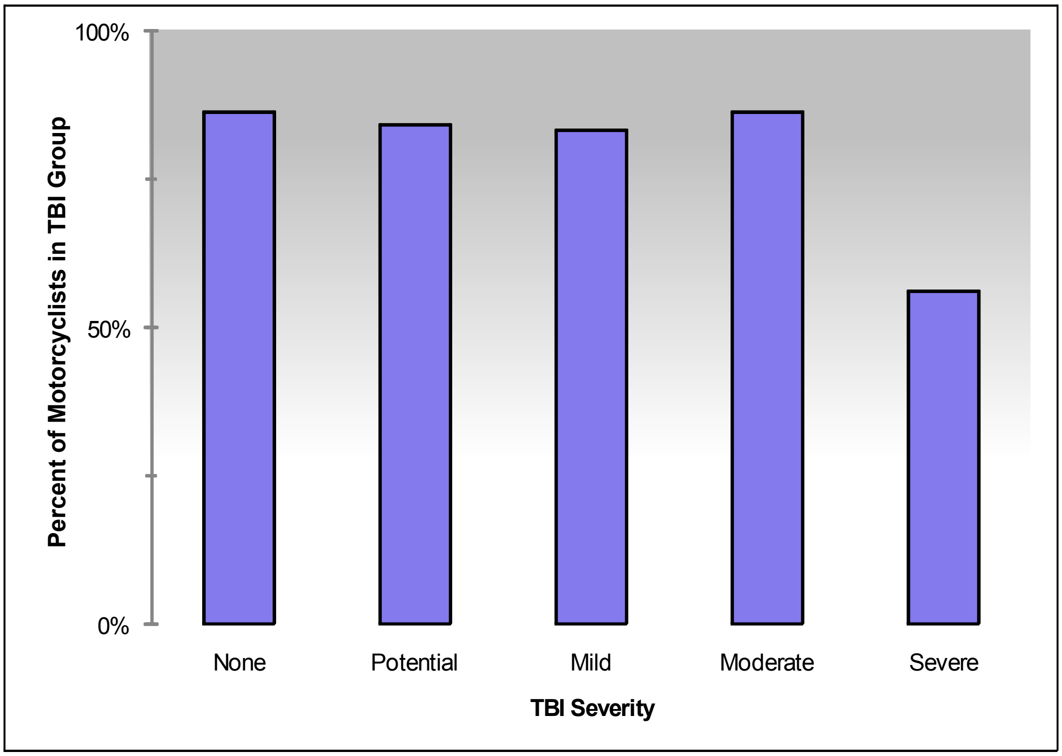
MAIS Head/Facial Injury Severity	Number of Motorcyclists	Median Hospital Charges	95% LCL	95% UCL
No Head/Facial Injury	31,543	$2,285	$2,230	$2,341
Minor	5,534	$3,786	$3,628	$3,949
Moderate	3,023	$10,205	$9,701	$10,736
Serious	906	$25,430	$23,418	$27,614
Severe	1,236	$32,954	$30,718	$35,354
Critical - Maximum	257	$73,179	$60,316	$88,784
TBI Severity	**Number of Motorcyclists**	**Median Hospital Charges**	**95% LCL**	**95% UCL**
None	35,477	$2,461	$2,406	$2,518
Potential	1,550	$3,296	$3,085	$3,522
Mild/Moderate	3,342	$9,792	$9,355	$10,249
Severe	2,130	$31,979	$30,090	$33,986

*Hospital charges have been adjusted to year 2005 dollars.
Source: CODES, 2003-2005.

As the severity of the head/facial injury increases the median of hospital charges increases 32 fold. The median of hospital charges for motorcyclists without a head or facial injury was $2,285 while a motorcyclist with an AIS head injury of 5 or 6 had median hospital charges of $73,179. Similarly, median hospital charges increase with TBI severity. Motorcyclists without TBI have a median hospital charge of $2,461 while motorcyclists with severe TBI have a median hospital charge of $31,979.

The majority of hospital-treated motorcyclists were discharged home (Figure 6). While over 80 percent of motorcyclists with no, potential, mild, and moderate TBIs were discharged home, only 56 percent of motorcyclists with severe TBI were similarly discharged.

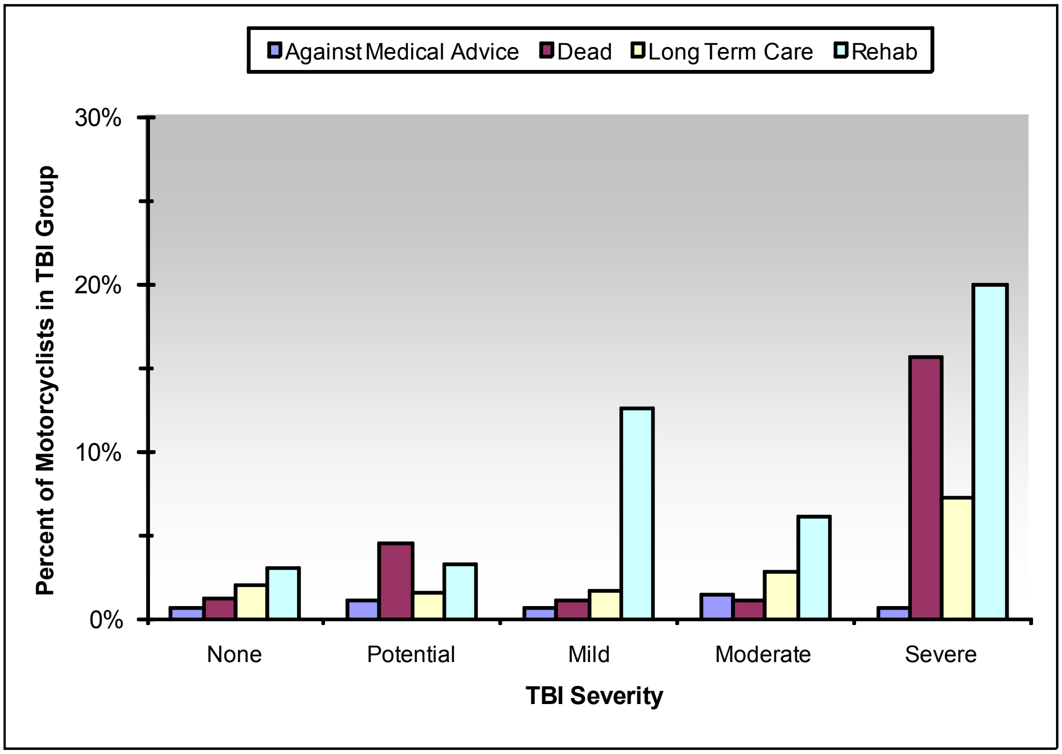
Figure 6. Percent of Motorcyclists Discharged Home by TBI Severity



Source: CODES, 2003-2005.

All remaining discharge statuses are presented in Figure 7. Motorcyclists who received a TBI were also more likely to be discharged from the hospital dead or transferred to rehab or a long-term care facility. While over 85 percent of motorcyclists without TBI were discharged home, this percent drops to 56 percent for motorcyclists with severe TBI. Additionally, while only 17 percent of all motorcyclists had TBI, motorcyclists with TBIs accounted for 54 percent of all riders discharged dead.

Figure 7. Discharge Status by TBI Severity



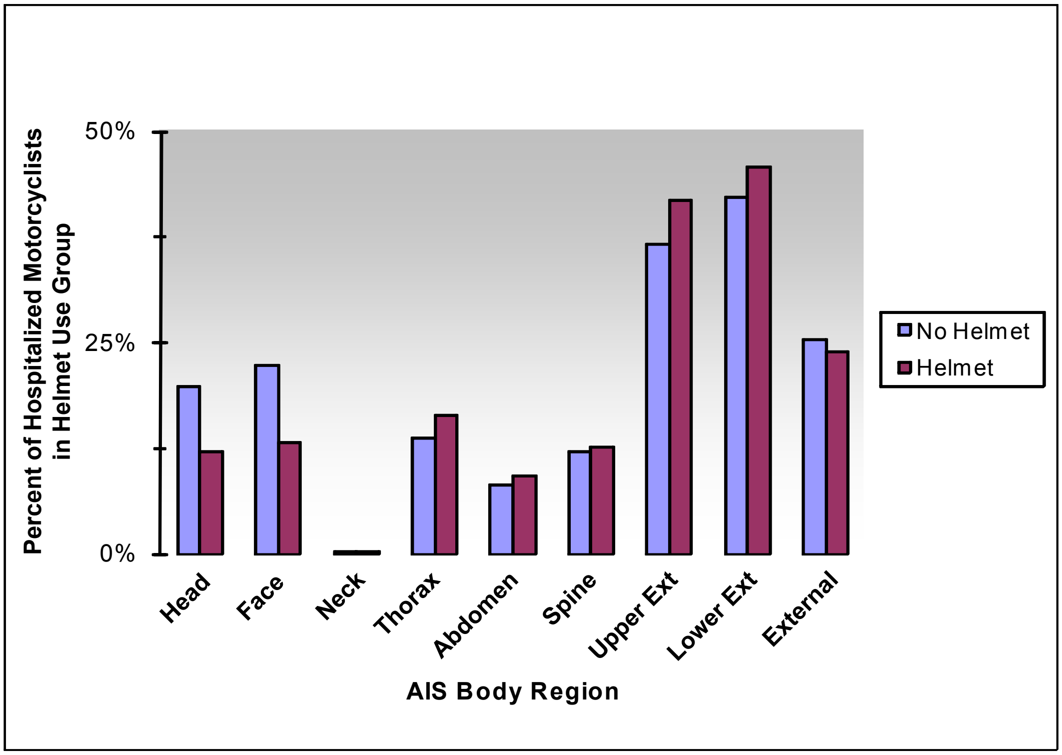
*There were a total of 14 motorcyclists in the discharged dead category whose death occurred at least 31 days following the crash.

Source: CODES, 2003-2005.

Injury Outcomes by Motorcycle Helmet Use

To determine the impact of motorcycle helmets on injury outcomes we further examined hospital outcomes by whether or not a motorcyclist was wearing a helmet at the time of the crash. Figure 8 displays the body area of injury by helmet use. Upper and lower extremities were the most commonly injured body regions for both groups of motorcyclists. However, unhelmeted motorcyclists experienced nearly twice the percentage of head and face injuries that helmeted motorcyclists did. While only 12 percent of hospital-treated helmeted motorcyclists experienced head injuries, 20 percent of hospital-treated unhelmeted motorcyclists incurred such injuries. Similarly, 13 percent of hospital-treated helmeted motorcyclists received face injuries compared to 22 percent of hospital-treated unhelmeted motorcyclists.

Figure 8. AIS Body Region by Helmet Use*



*Since a motorcyclist can injure more than one body region, the percentages in Figure 8 add up to more than 100 percent.

Source: CODES, 2003-2005.

Injury Severity by Helmet Use

Table 10 examines the MAIS severity level for the head and facial injuries. As seen in Figure 8, 20 percent of unhelmeted motorcyclists received head injuries compared to only 12 percent of helmeted motorcyclists. Additionally, head injuries to unhelmeted motorcyclists appear to be more severe than those sustained by helmeted motorcyclists. Eight and one-half (8.5) percent of unhelmeted motorcyclists sustained head MAIS of three or higher. This compares to 5.1 percent of helmeted motorcyclists.

Table 10. Helmet Use by MAIS Head/Facial Injury Severity

Head Injury Severity	Helmet Not Used	Helmet Used
No Head Injury	14,511 (80.2%)	22,266 (87.9%)
Minor	824 (4.6%)	262 (1.0%)
Moderate	1,220 (6.7%)	1,526 (6.0%)
Serious	517 (2.9%)	412 (1.6%)
Severe	693 (3.8%)	606 (2.4%)
Critical	322 (1.8%)	262 (1.0%)
Maximum	-	2 (< 0.1%)
Facial Injury Severity	**Helmet Not Used**	**Helmet Used**
No Face Injury	14,059 (77.7%)	22,014 (86.9%)
Minor	3,561 (19.7%)	2,881 (11.4%)
Moderate	464 (2.6%)	439 (1.7%)
Serious	3 (0.0%)	2 (0.0%)
Severe	-	-
Critical	-	-
Maximum	-	-

Source: CODES, 2003-2005.

There was not much difference in severity levels between unhelmeted and helmeted motorcyclists for the MAIS trunk body regions (Table 11). Additionally, there were few neck injuries in either group, 35 and 66 for unhelmeted and helmeted respectively.

Table 11. Helmet Use by MAIS Trunk Body Regions Injury Severity

Neck Injury Severity	Helmet Not Used	Helmet Used
No Neck Injury	18,051 (99.8%)	25,271 (99.7%)
Minor	28 (0.2%)	47 (0.2%)
Moderate	2 (0.0%)	4 (0.0%)
Serious	6 (0.0%)	14 (0.1%)
Severe	-	-
Critical	-	-
Maximum	-	-
Thorax Injury Severity	**Helmet Not Used**	**Helmet Used**
No Thorax Injury	15,598 (86.2%)	21,176 (83.6%)
Minor	819 (4.5%)	1,300 (5.1%)
Moderate	362 (2.0%)	601 (2.4%)
Serious	1,073 (5.9%)	1,807 (7.1%)
Severe	227 (1.3%)	434 (1.7%)
Critical	2 (0.0%)	0 (0.0%)
Maximum	6 (0.0%)	18 (0.1%)
Abdomen Injury Severity	**Helmet Not Used**	**Helmet Used**
No Abdomen Injury	16,595 (91.8%)	23,011 (90.8%)
Minor	845 (4.7%)	1,181 (4.7%)
Moderate	487 (2.7%)	796 (3.1%)
Serious	48 (0.3%)	100 (0.4%)
Severe	68 (0.4%)	143 (0.6%)
Critical	44 (0.2%)	105 (0.4%)
Maximum	-	-
Spine Injury Severity	**Helmet Not Used**	**Helmet Used**
No Spine Injury	15,899 (87.9%)	22,131 (87.4%)
Minor	1,188 (6.6%)	1,678 (6.6%)
Moderate	902 (5.0%)	1,367 (5.4%)
Serious	48 (0.3%)	90 (0.4%)
Severe	25 (0.1%)	33 (0.1%)
Critical	24 (0.1%)	33 (0.1%)
Maximum	1 (0.0%)	4 (0.0%)

Source: CODES, 2003-2005.

Extremity injury severity by helmet use is provided in Table 12. As seen in Figure 7, helmeted motorcyclists had more upper and lower extremity injuries. However, all but a few of these were categorized as minor or moderate.

Table 12. Helmet Use by MAIS Extremity Injury Severity

Upper Extremity Injury Severity	Helmet Not Used	Helmet Used
No Upper Extremity Injury	11,445 (63.3%)	14,727 (58.1%)
Minor	3,376 (18.7%)	4,839 (19.1%)
Moderate	3,039 (16.8%)	5,269 (20.8%)
Serious	227 (1.3%)	501 (2.0%)
Severe	-	-
Critical	-	-
Maximum	-	-
Lower Extremity Injury Severity	**Helmet Not Used**	**Helmet Used**
No Lower Extremity Injury	10,469 (57.9%)	13,753 (54.3%)
Minor	3,506 (19.4%)	5,401 (21.3%)
Moderate	2,762 (15.3%)	4,158 (16.4%)
Serious	1,333 (7.4%)	2,004 (7.9%)
Severe	17 (0.1%)	20 (0.1%)
Critical	-	-
Maximum	-	-

Source: CODES, 2003-2005.

No differences were noted in the number and severity level of external injuries between unhelmeted and helmeted motorcyclists (Table 13).

Table 13. Helmet Use by MAIS External Injury Severity

External Injury Severity	Helmet Not Used	Helmet Used
No External Injury	13,513 (74.7%)	19,280 (76.1%)
Minor	4,547 (25.1%)	6,021 (23.8%)
Moderate	21 (0.1%)	28 (0.1%)
Serious	6 (0.0%)	6 (0.0%)
Severe	-	-
Critical	-	1 (0.0%)
Maximum	-	-

Source: CODES, 2003-2005.

Table 14 shows that unhelmeted motorcyclists were more likely to receive TBI than helmeted riders. Over 8 percent of unhelmeted motorcyclists received mild to moderate TBI and an additional 7.3 percent received severe TBI. This compares to 7.0 percent and 4.7 percent for moderate and severe TBIs for helmeted riders.

Table 14. Helmet Use by TBI Severity

TBI Severity	Helmet Not Used	Helmet Used
No TBI	14,242 (78.7%)	21,658 (85.5%)
Potential TBI	912 (5.0%)	711 (2.8%)
Mild/Moderate TBI	1,607 (8.9%)	1,771 (7.0%)
Severe TBI	1,326 (7.3%)	1,196 (4.7%)

Source: CODES, 2003-2005.

Effectiveness of Motorcycle Helmets

The overrepresentation of facial, head, and traumatic brain injuries in the unhelmeted population led us to estimate the effectiveness of motorcycle helmets at preventing these injuries. In the following section we present both unadjusted and adjusted effectiveness estimates.

Unadjusted effectiveness estimates were generated by calculating the relative risk for a given outcome from a two-by-two table of the outcome (yes or no) versus motorcycle helmet use (yes or no). The effectiveness is then estimated to be 1 – the relative risk.

Unadjusted effectiveness estimates may be incomplete because they do not account for other variables that might be associated with the outcome, for example speed limit or alcohol and drug involvement. Therefore, logistic regression models were employed. Additionally, generalized estimating equations were incorporated to account for clustering of observations within States. The same explanatory variables were used in the logistic regression models for all outcomes. In addition to helmet use, other covariates were gender, age, whether the crash was speed-related, whether alcohol or drugs were involved in the crash, whether the crash was intersection-related, type of motorcyclist (motorcycle rider [operator] versus motorcycle passenger), number of vehicles involved in the crash (single versus multiple), whether the crash occurred at night (9 p.m. to 5:59 a.m.), and posted speed limit. A detailed explanation of variables collected for this analysis can be found in Appendix A. Additionally, as found in a prior NHTSA motorcycle study (Pickrell & Starnes, 2008), a significant interaction between helmet use and number of vehicles was included. Due to this interaction, the results of the logistic regressions are presented separately for single-vehicle and multiple-vehicle crashes. Finally, it is assumed that nonfatal and non-hospital-treated motorcyclists did not experience the outcome of interest. For motorcyclists who died at the scene and were not transported, it is unknown whether they sustained the outcome of interest and they are therefore excluded from the analysis.

Facial Injury

There were 7,350 facial injuries sustained by motorcyclists in our data (Table 15). As seen above, facial injuries were more common for unhelmeted motorcyclists compared to helmeted motorcyclists (9.2% versus 5.7%). This data provides an unadjusted estimate that motorcycle helmets are 37 percent effective at preventing facial injuries.

Table 15. Percent of Motorcyclists in Helmet Use Category by Facial Injury

	Helmet Not Used	Helmet Used
No Facial Injury	39,955 (90.8%)	54,682 (94.3%)
Facial Injury	4,028 (9.2%)	3,322 (5.7%)

Source: CODES, 2003-2005.

Table 16 shows the results of the multivariable logistic regression with facial injury as the outcome. The confidence intervals for being a male motorcyclist, type of motorcyclists, and intersection-related crash all contain 1.0. This indicates that these variables are not related to whether motorcyclists incur a facial injury. An increase of one year in age is associated with an increase of 1.01 in the odds of receiving a facial injury. By comparison an increase in age of 10 years is associated with an increase of 1.1 in the odds of receiving a facial injury. An increase in the speed limit is also associated with an increase in the odds of receiving a facial injury. An increase of 5 miles per hour, on average, increases the odds of a facial injury by 1.04. Compared to daytime crashes, motorcycle crashes that occur at night are associated with an increase of 1.1 in the odds of a facial injury, on average. Alcohol and speed involvement both had more dramatic impacts on the odds of a facial injury. Motorcyclists in alcohol- or drug-related crashes are 1.7 times more likely to receive a facial injury compared to motorcyclists in non-alcohol and non-drug-related crashes. Speed-related crashes are also associated with higher odds of a facial injury (OR = 1.3).

The interaction between helmet use and single-versus multiple-vehicle crashes is displayed in the bottom two rows of Table 16. In both single-vehicle and multiple-vehicle crashes, helmeted motorcyclists have lower odds of receiving facial injuries compared to unhelmeted motorcyclists. In single-vehicle crashes helmeted motorcyclists are half as likely to receive a facial injury compared to unhelmeted motorcyclists. Motorcyclists in multiple-vehicle crashes are 66 percent as likely to receive a facial injury as unhelmeted motorcyclists. Using the logistic model we estimate motorcycle helmets to be 48 percent effective at preventing facial injuries in single-vehicle crashes and 34 percent effective at preventing facial injuries in multiple-vehicle crashes.

Table 16. Logistic Regression Results Predicting Facial Injury

Parameter	Estimate	Odds Ratio	95% LCL	95% UCL
Intercept	-3.317			
Male	0.036	1.037	0.951	1.130
Age	**0.011**	**1.011**	**1.008**	**1.013**
Speed-Related	**0.248**	**1.281**	**1.188**	**1.381**
Alcohol/Drug Involvement	**0.536**	**1.708**	**1.552**	**1.881**
Intersection	0.016	1.016	0.948	1.089
Rider (Operator)	0.044	1.045	0.945	1.155
Nighttime	**0.112**	**1.118**	**1.044**	**1.199**
Speed Limit	**0.007**	**1.007**	**1.005**	**1.010**
Helmet AND Single Vehicle	**-0.652**	**0.521**	**0.477**	**0.569**
Helmet AND Multiple Vehicle	**-0.421**	**0.656**	**0.595**	**0.724**

Source: CODES, 2003-2005.

Head Injury

As can be seen in Table 17, a total of 6,646 motorcyclists suffered head injury as a result of their crashes. Close to double the percent of unhelmeted motorcyclists (8.1%) suffered head injury compared to the percentage of helmeted motorcyclists (5.3%) suffering a head injury. Thus, motorcycle helmets are estimated to be 35 percent effective at preventing head injuries.

Table 17. Percent of Motorcyclists in Helmet Use Category by Head Injury

	Helmet Not Used	Helmet Used
No Head Injury	40,408 (91.9%)	54,933 (94.7%)
Head Injury	3,575 (8.1%)	3,071(5.3%)

Source: CODES, 2003-2005.

Table 18 shows the results of the multivariable logistic regression with head injury as the outcome. The confidence intervals for type of motorcyclist and intersection-related crash both contain 1.0, indicating that these variables are not-related to whether motorcyclists incur a head injury. An increase of one year in age is associated with an increase of 1.01 in the odds of receiving a head injury. By comparison an increase in age of 10 years is associated with an increase of 1.1 in the odds of receiving a head injury. Higher speed limits are associated with increased odds of receiving a head injury. An increase in the speed limit of 5 miles per hour, on average, increases the odds of a head injury by 1.1. Compared to daytime crashes, motorcycle crashes that occur at night are associated with an increase of 1.1 in the odds of a head injury, on average. Motorcyclists in alcohol- or drug-related crashes are 2.0 times more likely to receive head injury compared to motorcyclists in non-alcohol and non-drug-related crashes. Speed-related crashes are also associated with higher odds of head injury (OR = 1.5).

Helmets reduced the odds of sustaining head injury in both single- and multiple-vehicle crashes. Helmeted motorcyclists in single-vehicle crashes had half the odds of receiving head injury compared to unhelmeted motorcyclists in single-vehicle crashes. In multiple-vehicle crashes, helmeted motorcyclists had 67 percent of the odds of sustaining head injury compared to unhelmeted motorcyclists. From the logistic model we estimate that helmets are 48 percent effective at preventing head injuries in single-vehicle crashes and 33 percent effective at preventing head injuries in multiple-vehicle crashes.

Table 18. Logistic Regression Results Predicting Head Injury

Parameter	Estimate	Odds Ratio	95% LCL	95% UCL
Intercept	-3.362			
Male	**0.199**	**1.220**	**1.112**	**1.338**
Age	**0.005**	**1.005**	**1.003**	**1.007**
Speed-Related	**0.426**	**1.531**	**1.419**	**1.652**
Alcohol/Drug Involvement	**0.707**	**2.028**	**1.844**	**2.231**
Intersection	0.063	1.065	0.994	1.141
Rider (Operator)	0.014	1.014	0.914	1.126
Nighttime	**0.127**	**1.135**	**1.056**	**1.221**
Speed Limit	**0.010**	**1.010**	**1.007**	**1.012**
Helmet AND Single Vehicle	**-0.657**	**0.519**	**0.473**	**0.568**
Helmet AND Multiple Vehicle	**-0.397**	**0.673**	**0.611**	**0.740**

Source: CODES, 2003-2005.

Moderate to Severe Head and Facial Injuries
In order to determine if helmets are only effective at preventing minor injuries, we furthered explored the relationship between helmet use and head and facial body regions. For this model we defined moderate to severe head or face injuries to be those having an MAIS head or face body region score of 2 or higher. There were a total of 5,878 motorcyclists that survived to hospital admission and suffered a moderate to severe head or facial injury (Table 19). Table 19 provides an unadjusted estimate that helmets are 22 percent effective at preventing moderate to severe head and facial injuries.

Table 19. Percent of Motorcyclists in Helmet Use Group by Moderate to Severe Head/Facial Injury

	Helmet Not Used	Helmet Used
No Moderate to Severe Head/Face Injury	41,079 (93.4%)	55,030 (94.9%)
Moderate to Severe Head/Face Injury	2,904 (6.6%)	2,974 (5.1%)

Source: CODES, 2003-2005.

As in the head and facial injury models above, both alcohol and drug involvement and speed-related crashes are more likely to be associated with moderate to severe head or facial injuries (Table 20). Also, as before, helmets reduce the odds of moderate to severe head or facial injuries in single-vehicle crashes (OR = 0.61) and multiple-vehicle crashes (OR = 0.78). Thus we estimate from our model that helmets are 40 percent effective at preventing moderate to severe head or facial injuries in single-vehicle crashes and 22 percent effective at preventing moderate to severe head or facial injuries in multiple-vehicle crashes.

Table 20. Logistic Regression Results Predicting Moderate to Severe Head or Facial Injury

Parameter	Estimate	Odds Ratio	95% LCL	95% UCL
Intercept	-3.550			
Male	**0.212**	**1.236**	**1.117**	**1.366**
Age	**0.005**	**1.005**	**1.003**	**1.007**
Speed-Related	**0.466**	**1.594**	**1.469**	**1.730**
Alcohol/Drug Involvement	**0.767**	**2.153**	**1.940**	**2.388**
Intersection	0.053	1.054	0.980	1.134
Rider (Operator)	-0.007	0.994	0.888	1.112
Nighttime	**0.113**	**1.119**	**1.038**	**1.207**
Speed Limit	**0.009**	**1.009**	**1.006**	**1.011**
Helmet AND Single Vehicle	**-0.503**	**0.605**	**0.550**	**0.664**
Helmet AND Multiple Vehicle	**-0.248**	**0.780**	**0.709**	**0.858**

Source: CODES, 2003-2005.

Traumatic Brain Injury

In order estimate the effectiveness of helmets at preventing potential and unequivocal TBI, we grouped motorcyclists having any severity of TBI as well as those with potential TBI into the TBI = “yes” group. All other motorcyclists were coded as TBI = “no”. The results are displayed in Table 21.

Table 21. TBI Status by Helmet Use Group

	Helmet Not Used	Helmet Used
No TBI	40,138 (91.3%)	54,326 (93.7%)
TBI	3,845 (8.7%)	3,678 (6.3%)

Source: CODES, 2003-2005.

Table 21 shows that the probability of receiving a TBI following a motorcycle crash is 0.087 for unhelmeted motorcyclists compared to only 0.063 for helmeted motorcyclists. These two estimates provide a risk ratio of 0.73, indicating that motorcycle helmets are 27 percent effective at preventing traumatic brain injury.

Table 22 shows that confidence intervals of the odds ratios for age, type of motorcyclist, and intersection-related crash contain the value of 1.0. This indicates that these variables are not related to whether motorcyclists incur TBI. An increase of 5 miles per hour, on average, increases the odds of TBI by 1.04. Compared to daytime crashes, motorcycle crashes that occur at night are associated with an increase of 1.1 in the odds of TBI, on average. Motorcyclists in alcohol or drug-related crashes are 2.0 times more likely to receive a TBI compared to motorcyclists in non-alcohol and non-drug-related crashes. Speed-related crashes are also associated with higher odds of TBI (OR = 1.5).

Helmets significantly reduced the odds of TBI in both single-and multiple-vehicle crashes. In single-vehicle crashes, helmeted motorcyclists had just under 60 percent of the odds of TBI compared to unhelmeted motorcyclists. For multiple-vehicle crashes, helmeted motorcyclists had 76 percent of the odds of unhelmeted motorcyclists for sustaining TBI. Using the logistic model we can estimate the effectiveness of motorcycle helmets at preventing TBI to be 41 percent for single-vehicle crashes and 25 percent for multiple-vehicle crashes.

Table 22. Logistic Regression Results Predicting Traumatic Brain Injury

Parameter	Estimate	Odds Ratio	95% LCL	95% UCL
Intercept	-3.116			
Male	**0.128**	**1.136**	**1.038**	**1.244**
Age	0.002	1.002	1.000	1.004
Speed-Related	**0.387**	**1.473**	**1.370**	**1.585**
Alcohol/Drug Involvement	**0.711**	**2.037**	**1.854**	**2.238**
Intersection	0.044	1.045	0.979	1.115
Rider (Operator)	0.049	1.051	0.945	1.168
Nighttime	**0.099**	**1.105**	**1.030**	**1.184**
Speed Limit	**0.008**	**1.008**	**1.006**	**1.010**
Helmet AND Single Vehicle	**-0.528**	**0.590**	**0.541**	**0.642**
Helmet AND Multiple Vehicle	**-0.281**	**0.755**	**0.691**	**0.825**

Source: CODES, 2003-2005.

CONCLUSIONS

This report examines factors associated with motorcycle crash outcomes using CODES data supplied by 18 States. Of particular interest to this report were injuries that may have been preventable by motorcycle helmet use. These outcomes include head/facial injuries and traumatic brain injuries. CODES data consists of Statewide crash databases probabilistically linked to Statewide emergency department and hospital admission data. These properties make CODES data particularly ideal for identifying specific medical injuries through the use of ICD-9-CM codes and AIS mapping.

Helmeted motorcyclists were less likely to experience facial and head injuries compared to unhelmeted motorcyclists. Helmeted motorcyclists were significantly less likely to experience TBI. TBIs are of particular concern in our study. TBI was associated with significantly higher hospital charges. Additionally, motorcyclists with TBI were much less likely to be discharged home and more likely to require rehab or to be discharged to long-term care facilities following their hospitalizations. Both destinations are likely to result in costs and burdens for the injured motorcyclists beyond the scope of this study's data. Finally, motorcyclists involved in alcohol- or drug-related crashes and speed-related crashes had higher odds of experiencing poor outcomes.

It is important to note that the State crash databases used in the CODES combined analysis did not identify whether the individual motorcycle helmets involved in fatal crashes comply with DOT regulations. The National Occupant Protection Use Survey (NOPUS), a national probability-based sample survey, estimated that 48 percent of motorcyclists wore a DOT-compliant helmet in 2005.

Although CODES data from 18 States cannot be considered a representative sample of all motorcycle crashes in the United States for generating national counts or estimates, as a census of 48 State-years of reported motorcycle crashes, this data provides very large numbers of helmeted and unhelmeted motorcyclists for which it is possible to make useful comparisons and study rare outcomes. This study also provides a useful demonstration of how data from multiple States can be combined for research purposes. Methods initiated for this study can be further developed for future specialized studies of crash outcomes using pooled CODES data.

APPENDIX A

Specifications for the standardized CODES motorcycle data submission

Data Element	*Values*	*Definitions*
Dataset name: Inclusion criteria: riders (operators) and passengers of vehicles denoted as motored cycles (SEE ADDENDUM 1 FOR DEFINITIONS)		
GENERIC VARIABLES	Apply to all observations	
State	State identifier	2-character State abbreviation for your State
Year of Linked Data		4-digit year
Imputation Number	1-5	Imputation data set identifier 1-5
CRASH LEVEL VARIABLES	Assign these crash characteristics to all MC operators and riders in the crash.	
Crash ID Number	As provided or generated	Unique ID number for the crash. For added confidentiality this number should be generated by CODES personnel rather than drawn from State crash data ID. It should uniquely identify a crash within the data set.
Crash Time	The three-hour time block in which crash occurred	00:00-02:59, 03:00-05:59, 06:00-8:59, 09:00-11:59, 12:00-14:59 15:00-17:59, 18:00-20:59, 21:00-23:59
Crash Month	The month in which the crash occurred	Jan-Dec
Crash Type	Single vehicle versus multiple vehicle	As reported on the crash report. A multiple-vehicle crash includes collisions of multiple motor vehicles in transport. For motorcycle model, the other vehicle does not have to be another motorcycle. A single-vehicle crash includes all other types of crashes.
Rural/Urban Crash Location	Rural/Urban	Rural: FHWA Highway Performance Monitoring System (HPMS) definition of rural (excludes small local roads); rural defined as <5,000 population. Urban: All other not defined as HPMS rural including HPMS large central metro, large fringe metro, small metro
Intersection-Related	Intersection-Related versus Not Intersection-Related	Location of the crash next to an intersection and results from an action related to the movement of traffic units through the intersection. On-ramps and off-ramps should not be treated as intersections.
Posted Speed Limit	As reported	Missing values will be imputed as continuous variable

VEHICLE LEVEL VARIABLES	Assign these vehicle or driver characteristics to all MC operators and riders on the cycle.	
Vehicle Number	As provided or generated	ID number for uniquely identifying vehicles within a crash. For added confidentiality this number may be generated by CODES personnel rather than drawn from State crash data ID.
PAR-Reported Motorcycle Body Type	Full size/Not full size	(SEE ADDENDUM 1 FOR DEFINITIONS
Operator Impaired	Operator Impaired versus Operator Not Impaired	The “impaired operator” indicator is “yes” if the MC operator was suspected of being under the influence/using alcohol or drugs as documented on the crash record under Driver Condition, Driver Contributing Factor, BAC level, etc. Does not include operators who are only impaired by fatigue or other non-alcohol, non-drug factors. For riders, this indicator refers to the operator, not the rider.
Operator Licensed for Motorcycle	Operator licensed for motorcycle versus Operator not licensed for motorcycle	Derive from available variables for license type and endorsement.
Speeding	Vehicle was speeding versus Not speeding	Driver contributing factor or presence from State crash data: Use Speed-Related, Too Fast for Conditions, or similar PAR-reported attribute. Code by vehicle for each occupant.

PERSON-LEVEL VARIABLES	Apply specifically to each operator or rider.	
Person Number	As provided or generated	ID number for uniquely identifying persons within a vehicle. For added confidentiality this number may be generated by CODES personnel rather than drawn from State crash data ID.
Driver (Operator)	Operator versus Not Operator	Indicates whether or not this person was the operator of the cycle vehicle at the time of crash
Age	In whole years as reported	Age of the person (operator or rider) who is the subject of the observation.
Gender	Male or Female	Gender of the person (operator or rider) who is the subject of the observation.
Helmet Use	Helmet used or not used	Helmet use at time of crash, as reported.
Police-reported Injury Severity	Killed, Incapacitating, Non-Incapacitating, Possible, None, Injury severity unknown, Died before crash	K, A, B, C, O, U, D (based on State PAR, using attributes available) Note: "U" indicates an injury occurred but severity is unknown. Use if available on State PAR. If injury status recorded as unknown, leave missing.
Highest Level of Care	None/Unlinked Outpatient ED Inpatient	None/Unlinked: Assign unlinked crash records to this category. Outpatient: occupants or riders on crash records that linked to a hospital record for observation only (0-23 hours) and/or outpatient services such as ambulatory surgery or outpatient procedures (such as x-rays, cat-scans, physical therapy referred from doctor's office, clinic, or hospital), but which do not include any other higher level of care such as treatment in the emergency department nor prior or subsequent hospital inpatient admission ED: occupants or riders on crash records that linked to either an EMS record indicating transport to a hospital or a hospital record for emergency department treatment and discharge without admission for inpatient treatment. Includes persons who died in the emergency department. Inpatient: occupants or riders on crash records that linked to a hospital record for inpatient treatment, with or without emergency department treatment. Includes all hospital inpatients, including those treated first in the emergency department prior to hospital admission.
Maximum AIS by body region	MAIS1-9 for Head, Face, Neck, Thorax, Abdomen, Spine, Upper Extremity, Lower Extrem, External	MAIS score ranging from 1 (minor) to 6 (maximum) or 0 for no injury to each of 9 body regions. If not included in your data, you should arrange to have it added by CODES PRC in MD using ICDMAP90. For unlinked set to 0.
MAIS score	Maximum AIS score for the person over all body regions: 0-6, or 7 for injury with severity unknown	Maximum AIS score over all body regions. If not included in your data, you should arrange to have it added by CODES PRC in MD using ICDMAP90. For persons who were admitted but have no injury information, use 7. For unlinked set to 0.
TBI Injury	Severity levels	1- severe, 2- moderate, 3- mild, 4- potential (SEE ADDENDUM 2 FOR DEFINITIONS)
Payer	N/A Public Private Self/Uninsured Other	Use N/A for unlinked crash records. Public payers include Medicaid, Medicare, other government sources. Private payers include the commercial insurers, workers compensation. Self and uninsured includes self and other payers without insurance. Other includes all others not included above.
Discharge Status	N/A AMA Died LTC Rehab Home	Disposition of the patient after discharge obtained from the discharge record of the final hospital admission. Discharge records for patients transferred to another acute care facility should be combined to obtain the final discharge status. Use N/A for unlinked records. For linked records, SEE ADDENDUM 3 FOR DEF'S.
Charges	As Reported	Hospital charges in dollars. For those with sequential linked admissions, use total charges. For unlinked crash records, set to zero.
Length of Stay	Length of hospital stay in days.	For those with sequential linked admissions, use total days. For unlinked crash records, set to zero.

Addendum 1 – Motorcycle body types

If PAR body type (FARS equivalent) is:	THEN, code PARTYPE as:
Body type = 80, Motorcycle	**PARTYPE= 1 (full-size)**
Body type = 81 - Moped (*motorized bicycle*) 82 - Three-Wheel Motorcycle/Moped - Not All-Terrain Vehicle 83 - Off-Road Motorcycle *(2-wheel)* 88 - Other Motored Cycle Type *(mini-bikes, motor scooters)* 89 - Unknown Motored Cycle Type Note that the FARS motorcycle equivalents do **not** include the following FARS categories: 90 - ATV *(All-Terrain Vehicle; includes 3 or 4 wheels)* 91 - Snowmobile 92 - Farm Equipment Other Than Trucks 93 - Construction Equipment Other Than Trucks *(includes graders)* 94 - Motorized Wheel Chair *(since 1997)* 97 - Other V. Type (includes go-cart, fork-lift, city street sweeper, dune/swamp buggy, golf cart)	**PARTYPE= 2 (not full-size)**

Addendum 2: Traumatic Brain Injury Definitions

	CODES MOTORCYCLE MODEL Revised Definition of Severity Levels for TBI Injuries				
	Instructions: For each patient, assign all of the patient's codes that match a code in group 1 a "1", all of the codes that match a code in group 2 a "2", etc. If a patient has only one TBI code, assign the TBI severity to match the level for that code. When a patient has multiple TBI codes – for example a 3, 1, and 2,-- then the patient would be assigned to the level of the most severe TBI code, which in this case is level 1.				
Description	ICD Category	Group 1-Severe	Group 2-Moderate	Group 3-Mild	Group 4-Potential
Fracture of Vault of Skull	800	800.1-800.4 800.6-800.9 800.03-800.05 800.53-800.55	800.00 800.02 800.06 800.09 800.50 800.52 800.56 800.59	800.01 800.51	
Fracture of Base of Skull	801	801.1-801.4 801.6-801.9 801.03-801.05 801.53-801.55	801.00 801.02 801.06 801.09 801.50 801.52 801.56 801.59	801.01 801.51	
Other and Unqualified Skull Fractures	803	803.1-803.4 803.6-803.9 803.03-803.05 803.53-803.55	803.00 803.02 803.06 803.09 803.50 803.52 803.56 803.59	803.01 803.51	
Multiple Fractures involving Skull or Face with Other Bones	804	804.1-804.4 804.6-804.9 804.03-804.05 804.53-804.55	804.00 804.02 804.06 804.09 804.50 804.52 804.56 804.59	804.01 804.51	
Concussion	850	850.2-850.4	850.0 850.1 850.5 850.9		
Cerebral Laceration and Contusion	851	851			

Subarachnoid, Subdural, and Extradural Hemorrhage Following Injury	852	852			
Other and Unspecified Intracranial Hemorrhage Following Injury	853	853			
Intracranial Injury of Other and Unspecified Nature	854	854			
Injury to Optic Nerve and Pathways	950	950.1-950.3			
Head Injury, Unspecified	959				959.01 without other TBI codes
Shaken Baby Syndrom	995	995.55			

Addendum 3: Discharge Status Definitions

Discharge Status: **Disposition of the patient after hospital discharge as obtained from the discharge record of the final hospital admission. Discharge records for patients transferred to another acute care facility should be combined to obtain the final discharge status.**		
AMA	07	Left hospital against medical advice
HOME – Discharged home with or without home health services. Home could be a shelter.		
	01	Discharged to Home or Self care
	06	Discharged/transferred to Home Under Care of Organized home Health Service Organization in Anticipation of Covered Skill care
	08	Discharged/transferred to home under care of a Home IV provider
	50	Hospice-Home
	71	Discharged/transferred/referred to another institution for outpatient (as per plan of care)
	72	Discharged/transferred to this institution for outpatient services(as per plan of care)
LONG-TERM CARE (LTC) - Discharged to long-term care such as nursing home (skilled or intermediate care), *Rest home, Hospice Medical Facility, etc.*		
	03	Discharged/transferred to Skilled Nursing Facility (SNF) with Medicare Certification in Anticipation of Covered Skilled Care
	04	Discharged/transferred to an Intermediate Care Facility (ICF)
	51	Hospice-Medical Facility Providing Hospice Level of Care
	61	Discharged/transferred to a Hospital-Based Medicare Approved Swing Bed
	63	Discharged/transferred to a Medicare Certified Long-Term Care Hospital (LTCH)
	64	Discharged/transferred to a Nursing Facility Certified under Medicaid but not Certified under Medicare
DIED - Died in the hospital as an inpatient Note: Codes 40-42 apply when State law permits only physicians to declare death. Thus, some patients who die outside of a hospital and not in the presence of a physician must be transported to a hospital where physicians are available to “declare” the death.		
	20	Expired
	40	Expired at Home
	41	Expired at Medical Facility
	42	Expired Unknown Place

REHAB - Discharged to an inpatient rehab facility, or Discharged or transferred to another short term general hospital for inpatient rehab care, or Discharge/transferred to another type of institution for inpatient care or referred for outpatient services.		
	10	Medicaid discharge to psychiatric
	62	Discharged/transferred to an Inpatient Rehabilitation Facility (IRF) including Rehabilitation Distinct Part Units of a Hospital
	65	Discharged/transferred to a Psychiatric Hospital or Psychiatric Distinct Part Unit of a hospital
When a patient has not been discharged at the time the database was created, then efforts should be made to locate that patient in the subsequent data year to obtain the final diagnosis before defaulting to the use of “missing.”		
	30	Still Patient
The following codes are used for transfers to other acute care facilities and thus are not the final discharge for the crash event. Efforts should be made to link to these hospitals to obtain the final diagnosis before defaulting to the use of “missing.”		
	02	Discharged/transferred to a Short-Term General Hospital for Inpatient Care
	05	Discharged/transferred to another Type of Health Care institution not Defined Elsewhere in this Code
Some specialized acute care facilities may not contribute data to the Statewide hospital discharge database. Efforts should be made to link patients transferred to these hospitals if they are included in the State hospital discharge data before defaulting to the use of “missing.”		
	43	Discharged/transferred to a Federal Health Care Facility
	66	Discharged/transferred to a Critical Access Hospital
When an inpatient record includes an admission code, then efforts should be made to locate the record with the final discharge diagnosis code before defaulting to the use of “missing.”		
	09	Medicare outpatient admitted as inpatient

APPENDIX B

Variable Availability by State

Variable	CT	DE	GA	IN	IA	KY	ME	MD	MA
Time	X	X	X	X	X	X	X	X	X
Month	X	X	X	X	X	X	X	X	X
Crash Type	X	X	X	X	X	X	X	X	X
Location	X	X	X	X		X	X	X	X
Intersection	X	X	X	X	X	X	X	X	X
MC Type	X	X	X		X	X	X	X	X
Alcohol/drug involvement	X	X	X	X	X	X	X	X	
Licensed for MC	X		X	X	X	X		X	X
Posted Speed Limit	X		X	X	X	X	X	X	X
Speed-Related		X	X	X	X	X	X	X	X
Gender	X	X	X	X	X	X	X	X	X
Age	X	X	X	X	X	X	X	X	X
Rider	X	X	X	X	X	X	X	X	X
Helmet	X	X	X	X	X	X	X	X	X
KABCO	X	X	X	X	X	X	X	X	X
Level of Care	X	X	X	X	X	X	X	X	X
MAIS 1-9	X	X	X	X	X	X	X	X	X
TBI	X	X	X	X	X	X	X	X	X
Payer	X	X	X	X	X	X	X	X	X
Discharge	X	X	X	X	X	X	X	X	X
Total Charges	X	X	X	X	X	X	X	X	X
Length of Stay	X	X	X	X	X	X	X	X	X
ED data available	X	X	X	X	X		X	X	X

Variable	MN	MO	NE	NY	OH	RI	SC	UT	VA
Time	X	X	X	X	X	X	X	X	X
Month	X	X	X	X	X	X	X	X	X
Crash Type	X	X	X	X	X	X	X	X	X
Location	X	X	X	X		X		X	X
Intersection	X	X	X	X	X	X	X	X	X
MC Type	X	X	X	X	X		X	X	X
Alcohol/drug involvement	X	X	X	X	X	X	X	X	X
Licensed for MC	X	X	X					X	X
Posted Speed Limit	X	X	X		X	X	X	X	X
Speed-Related	X	X	X	X	X		X	X	X
Gender	X	X	X	X	X	X	X	X	X
Age	X	X	X	X	X	X	X	X	X
Rider	X	X	X	X	X	X	X	X	X
Helmet	X	X	X	X	X	X	X	X	X
KABCO	X	X	X	X	X	X	X	X	X
Level of Care	X	X	X	X	X	X	X	X	X
MAIS 1-9	X	X	X	X	X	X	X	X	X
TBI	X	X	X	X	X	X	X	X	X
Payer	X	X	X	X	X	X	X	X	X
Discharge	X	X	X	X	X	X	X	X	X
Total Charges	X	X	X	X	X	X	X	X	X
Length of Stay	X	X	X	X	X	X	X	X	X
ED data available	X	X	X	X	X		X	X	

Source: CODES, 2003-2005.

APPENDIX C

Helmet Law by State

State	No Law	Partial Law	Universal Law
Connecticut		Motorcyclists <= 17 years	
Delaware		Motorcyclists <= 18 years	
Georgia			X
Indiana		Motorcyclists <= 17 years	
Iowa	X		
Kentucky		Motorcyclists <= 20 years	
Maine		Motorcyclists <= 14 years	
Maryland			X
Massachusetts			X
Minnesota		Motorcyclists <= 17 years	
Missouri			X
Nebraska			X
New York			X
Ohio		Motorcyclists <= 17 years	
Rhode Island		Motorcyclists <= 20 years	
South Carolina		Motorcyclists <= 20 years	
Utah		Motorcyclists <= 17 years	
Virginia			X

Source: Insurance Institute for Highway Safety, http://www.iihs.org/laws/helmet_history.html.

APPENDIX D

Frequently Asked Questions Regarding CODES

1. What s the Crash Outcome Data Evaluation System?

CODES, a program facilitated by NHTSA, provides software and technical assistance to States to study the population of all occupants in police-reported crashes and to use the results to improve traffic safety. Crashes not meeting the State's police reporting threshold or out-of-State crashes involving victims treated in-State are excluded. CODES evolved from a congressional mandate and has become institutionalized in many States, producing data analyses on crash outcomes in terms of mortality, morbidity, injury severity, and health care costs. To date, NHTSA has funded 30 States to implement CODES.

Police-reported crash data is the major source of population-based information about crashes Statewide. Thus, it is crucial for traffic safety decision-making. However, because the impact of the crashes on the occupants of the vehicles involved is not usually known at the scene, crash data does not include the injury outcome information traffic safety needs to evaluate effectiveness in terms of decreased mortality, morbidity, injury severity, and hospital costs. As with all routinely collected State data used for administrative purposes, it also is limited by the reporting threshold and by missing and inaccurate data. Additional information is needed to identify which specific characteristics of the person, vehicle, and/or event are likely to result in death, or to prevent death but result in severe injury, or prevent severe injury but result in long-term disability, or allow the victim of a crash to walk away with a minor injury or unharmed.

In contrast, the injury data files are created for public health purposes. They include medical details about the type and severity of the injury and the subsequent costs (billed charges) for all persons treated for an injury, regardless of the cause of that injury. Injury data describe the injury outcome at the location of treatment, either at the scene or en route, at the emergency department or after admission as an inpatient. Different entities manage and control access to these data. Unfortunately, documentation of the cause as a motor vehicle crash may be missing from the injury record. When the crash is documented, minimal information is included about the vehicle and type of crash and no information is collected about the severity of the crash or its location, e.g., out-of-State. Thus traffic safety cannot use the injury data alone to obtain the outcome information it needs to target State resources.

CODES solves the problem by linking person-specific motor vehicle crash and injury State data to obtain the crash injury outcome information needed to improve traffic safety. In addition, the linkage techniques enable the inclusion of other traffic safety State data, such as vehicle registration, driver licensing and citation data, which expand the comprehensiveness of the crash outcome information generated.

2. What does CODES provide that other crash data sets cannot?

CODES-linked crash outcome data is a unique resource because it identifies crash characteristics for both the injured and the non-injured. Analyses are less likely to be biased when data includes characteristics of people involved in crashes who have unexpected outcomes: people who are injured in spite of using safety equipment and people who are not injured in spite of not using safety equipment.

CODES enhances the existing State data without the expense of additional data collection. The crash outcome linkage provides EMS and hospitals with time of the crash that is earlier than time of the call and needed to calculate the total time to the hospital, a measure of the responsiveness of the trauma system. Roadway inventories are enhanced with the inclusion of injury type and severity by location. Licensing data are enhanced when driver information is linked to the injury severity and health care costs caused by driving under the influence, aggressive driving, or speeding.

CODES promotes collaboration between the traffic safety and health communities. Owners of the crash and injury data are required to serve as members of the board of directors. The board is responsible for ensuring that State data is available for linkage and for developing the policies that control release of the linked data in compliance with State privacy legislation/regulations. The success of these proactive partnerships spills over into other areas of traffic safety, which also depend upon a collaborative approach to improve crash outcome. This collaborative approach is consistent with the NHTSA's Program Guidelines and the Data Improvement Grants. CODES States found they met the guidelines for traffic records assessments and had already established much of the structure required for Data Improvement funding.

CODES is useful to promote safety legislation. Because the CODES crash-outcome data is State-specific, it is more likely to convince State legislators about the value of supporting primary belt laws or the cost of repealing helmet use legislation. The ability to compare State-specific results to national estimates provides further clarification about the need for immediate action.

3. How does CODES generate the linked crash outcome data?

Each State links person-specific crash records to the Statewide ambulance run reports (EMS), hospital emergency department and inpatient records, and death certificate records, all of which are also person-specific. Few States include in the State data unique identifiers such as social security numbers. Instead, indirect identifiers that discriminate among the events and the people involved are matched. Some States augment the person-specific crash outcome data with driver-specific data from the State licensing files, vehicle-specific data from the State registration data files, and roadway-specific data from the roadway inventory data files to facilitate the linkages.

The linkage is a sophisticated process. In the real world, we cannot know for certain which crash and injury records are true matches. The lack of unique identifiers, weak indirect identifiers, records (crash or injury) missing for occupants known to have been injured, in addition to the expected problems of missing, and/or inaccurate data, all contribute uncertainty. After evaluating the quality of the State data, CODES grantees implement advanced methods of linkage using CODES2000 software, which estimates the probability that a possible record pair is a valid match.

4. How does CODES handle missing links?

Not all valid matches have high probabilities. This occurs when either the crash or injury record is missing or when the identifiers are unable to discriminate among the crashes and the persons involved or are weakened because of missing, inaccurate or inconsistent values. Conclusions based only on high-probability linked pairs cannot be presented as representative of the population. Linked pairs, excluded because of low probabilities caused by weak identifiers or incomplete data, may in fact be valid. To compensate for the imperfect data, CODES constructs ("imputes") multiple sets of data that can be used to statistically summarize estimates about the crash population. These estimates are representative of the population from which they were derived, just as a scientifically selected survey sample is representative of the population from which it was drawn.

5. How are imputed datasets analyzed?

Once the missing links have been identified, standard techniques for handling missing values are used to analyze the linked datasets. In SAS, the procedures used are PROC MI and PROC MIANALYZE. These techniques provide confidence intervals that accurately reflect uncertainty caused by missing data.

APPENDIX E

Probabilistic Linkage Using Multiple Imputation

The CODES links crash reports to injury outcome records such as ambulance run reports (EMS), and emergency department or hospital discharge records in order to evaluate injuries and medical charges associated with crashes. In addition, other traffic safety datasets including roadway inventory, vehicle registration, driver licensing and citations, and insurance claims may also be linked to provide a more comprehensive picture. Most CODES datasets do not have common unique identifiers. Consequently, CODES applies a statistical methodology to link the datasets. The probability that two records are a true link is determined by comparing all event characteristics (e.g., date and place) and all person characteristics such as age and sex that are common to both records. These characteristics are called *quasi-identifiers*.

Probabilistic Linkage

CODES record linkage is conducted using CODES2000, commercially available software that implements an extension of Fellegi and Sunter's statistical theory of record linkage (Fellegi & Sunter, 1969; McGlincy, 2004 and 2006). CODES2000 determines the posterior odds for a true link by applying Bayes' rule for odds (Gelman et al., 2004, p. 9), "the posterior odds are equal to the prior odds multiplied by the likelihood ratio." Parameters of the linkage model are determined using Markov Chain Monte Carlo data augmentation (Schafer, 1997, p. 72). CODES linkage concepts are summarized in Table A-2-1.

Table A-2-1. CODES Linkage Concepts (Pr X Means Probability of X)		
Concept	**Definition**	**Calculation**
Probabilistic Record Linkage	Bayes' Rule for Odds applied to record linkage: Posterior odds for a true match equal the prior odds multiplied by the likelihood ratio	Posterior Odds = (M / U) X (m / u)
Prior Odds for a True Match	Odds for a true match estimated from prior information. Posterior odds after comparing one match field become prior odds for next.	M / U = Estimated # of Matched Pairs / Estimated # of Unmatched Pairs
m Probability	Conditional probability for a comparison result (agreement, disagreement, or missing) for true matched pairs	m Agreement = Pr(Reported) X Pr(Correct) X Pr(Field has Given Value for Matched Population) …
u Probability	Conditional probability for a comparison result (agreement, disagreement, or missing) for true unmatched pairs	u Agreement = Pr(Reported) X Pr(Correct) X Pr(Field has Given Value for Crash Population) X Pr(Field has Given Value for Hospital Population) …
Likelihood Ratio for a True Match	Likelihood for comparison result for true matched pairs / Likelihood for comparison result for true unmatched pairs	Likelihood Ratio Agreement = (m Agreement / Pr(Agreement)) / (u Agreement / Pr(Agreement)) = m Agreement / u Agreement …

Imputation of Missing Links and Missing Values

Missing values and reporting errors in the data collection processes may lead to low probabilities being assigned to many true matches. If only high-probability links are selected then low-probability false negatives can make selected links unrepresentative of the total population of true linked pairs. To be able to include these low-probability matches in outcome studies, CODES2000 completes five linkage imputations; that is, missing links are determined five times resulting in five complete datasets. (Note that multiple imputation does not attempt to identify each missing link but instead constructs samples representative of the distribution of low to high probability links. As a result, analyses yield valid statistical inferences that reflect the uncertainty associated with having low-probability true links.) Standard statistical analyses are performed on each of the five datasets and then combined to produce final results using procedures in SAS.

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